PONTIFICIAE ACADEMIAE SCIENTIARVM SCRIPTA VARIA

46

SEMAINE D'ETUDE

SUR LE THÈME

HUMANITE ET ENERGIE
BESOINS - RESSOURCES - ESPOIRS

November 10-15, 1980

ÉDITÉ PAR

ANDRÉ BLANC-LAPIERRE

PONTIFICIA
ACADEMIA
SCIENTIARVM

EX AEDIBVS ACADEMICIS IN CIVITATE VATICANA

MCMLXXXI

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STUDY WEEK

ON

MANKIND AND ENERGY: NEEDS - RESOURCES - HOPES

November 10-15, 1980

EDITED BY

ANDRÉ BLANC-LAPIERRE

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INDEX

SCIENTIFIC PAPERS (*)

(*) The number of interventions made impossible to reproduce them in all details. Some of them have been grouped and summarized. The most synthetic of them have however been kept almost completely. We hope that the essentials of the ideas developed have been accurately respected.

MANAGEMENT AND BASIC RESOURCES CONTENT OF ENERGY

NUCLEAR ENERGY

ENERGY AND ENVIRONMENT

SOLAR ENERGY

ENERGY POLICIES IN DEVELOPING COUNTRIES

PROSPECTS AND GENERAL DISCUSSION

PREFACE

L'un des problèmes les plus angoissants auxquels l'humanité doive faire face avant la fin de ce siècle est le problème de l'énergie. Nous savons tous que notre civilisation est née et s'est développée sur la base d'une énergie épuisable. Tous les efforts doivent être faits actuellement pour trouver non seulement des méthodes plus efficaces et plus économiques d'utilisation de nouvelles sources énergétiques, mais aussi les moyens d'utiliser des sources énergétiques renouvelables.

Il ne faut pas oublier que si la source principale d'énergie pour notre planète est le soleil, nous sommes encore loin de pouvoir l'utiliser comme nous le désirons.

Sa Sainteté Jean Paul II, en s'adressant aux participants de la Semaine d'Etude sur l'Humanité et l'Energie, a bien défini les points les plus importants du problème. Celui-ci ne se limite pas à des questions d'ordre scientifique et même économique, mais il dépasse ces domaines et, de plus, est rendu plus complexe par des erreurs qui trouvent leur origine dans le contexte culturel de chaque pays.

La Semaine d'Etude, dont les travaux sont publiés dans ce volume, a essayé d'aborder la question de façon globale. Toutefois, malgré les efforts très considérables des participants, malgré l'extension de leurs connaissances, malgré le désir de trouver la formule — peut-être magique — qui pourrait résoudre le binôme humanité-énergie, le problème n'a pu être complètement résolu, car, dans une partie de ce domaine — je dirais même dans la plus grande partie de ce domaine — non seulement il nous manque des connaissances scientifiques indispensables, mais les données d'ordre économique et sociologique dont nous disposons varient de telle façon qu'une prévision précise est impossible.

Je pense néanmoins que la Semaine d'Etude, dont l'organisation avait été confiée à l'Académicien Pontifical Prof. Blanc-Lapierre, a été couronnée de succès, grâce à la liberté d'expression qui caractérise les travaux de l'Académie Pontificale des Sciences et aussi au choix très représentatif des participants et au désir de tous les présents de contribuer d'une façon positive à la compréhension et à la solution de ce problème. Le présent ouvrage est donc sans aucun doute une contribution importante et il pourra servir de base à de nouvelles discussions pour l'étude des différents projets. Ce n'est pas ma tâche de souligner les données principales qui ressortent des conclusions, mais je crois qu'elles sont substantiellement correctes et qu'il sera indispensable d'en tenir compte pour faire progresser la solution d'un problème qui préoccupe le monde industrialisé et les pays en voie de développement.

Je désire remercier pour son constant dévouement et pour le travail compliqué que représente l'organisation d'une Semaine d'Etude, l'Académicien Pontifical Prof. Blanc-Lapierre, qui, aidé par le Prof. Jean Bussac, a, pendant toute une année et avec un zèle extrême, mis toute son intelligence au service de cette entreprise. Certes, sa position éminente dans le monde scientifique et technologique l'a aidé, mais j'ai admiré, au cours de ces mois où il a travaillé au succès de sa mission, le dévouement et l'intérêt constants qui lui ont permis de mener de façon brillante sa tâche à bonne fin. Les pages de cet ouvrage en sont témoin.

Je désire en outre exprimer ma sincère appréciation au Révérend Père Enrico di Rovasenda, Directeur de la Chancellerie de l'Académie, et à Madame Michelle Porcelli-Studer, Secrétaire de la Chancellerie, ainsi qu'à Monsieur Silvio Devoto pour l'impeccable organisation de la réunion et pour leur zèle infatigable et leur précieuse assistance lors de son déroulement.

Enfin, mes remerciements vont également à Madame Gilda Massa pour son aide dans la transcription des discussions et la révision finale des Actes.

CARLOS CHAGAS
Président de l'Académie Pontificale des Sciences

FOREWORD

One of the most distressing problems which humanity must face before the end of this century is the energy problem. As we all know, our civilization is based on expendable energy. Every effort must now be made to find not only more effective, more economical methods to use new sources of energy, but also how to use renewable sources in a way that is effective and economic as well.

We must bear in mind that the principal source of energy on our planet is furnished by the sun and that we are still far from being able to use it as we would like.

His Holiness Pope John Paul II, addressing the members of the Study Week on Humanity and Energy, very clearly pointed out the most important aspects of the problem. This is not limited to questions of a scientific or economic order; it goes beyond these limits and is complicated by the errors arising from the very context of the culture of each country.

The Study Week, whose proceedings are published in this volume, attempted to approach the problem holistically. Evidently, despite the considerable efforts of the participants, the extent of their knowledge and experience, and their desire to find the perhaps magic formula which could solve the binomial mankind-energy, the problem has not been completely solved. This is because in one part of this field — I would even say in its major part — we still lack not only the indispensable scientific knowledge but also the information of a sociological and economic order, which varies so greatly that it makes precise forecasting impossible.

Nevertheless, I believe that the Study Week, which was organized by the Pontifical Academician Professor Blanc-Lapierre, was a great success, thanks to the freedom of expression which characterizes the work of the Pontifical Academy of Science, to the very representative choice of the participants, and to the desire of all those present to make a positive contribution to the understanding and the solution of this problem. The *book which we here present is undoubtedly a contribution to this important question and can serve as a basis for further discussions in the study of the different projects. It is not my intention here to emphasize the important data contained in the conclusions reached, but I believe that they are substantially correct and indispensable to progress regarding this problem which preoccupies both the industrialized world and the developing countries.*

I wish to thank the Pontifical Academician Prof. Blanc-Lapierre — assisted by Prof. Jean Bussac — for his constant dedication and for the very difficult work of organizing a Study Week. For a whole year, with great zeal he has placed all his intelligence at the service of this undertaking. Surely, Prof. Blanc-Lapierre's preeminence in the scientific and technological world has helped him, but what I have especially admired during these months in which he has worked for the success of his mission is the constant devotion and interest which have permitted him to accomplish his task brilliantly. The pages of this text bear witness to this.

Furthermore I wish to express my deepest appreciation to Rev. Father Enrico di Rovasenda, Director of the Chancellery of the Academy and to Mrs. Michelle Porcelli-Studer, Secretary of the Chancellery, as well as to Mr. Silvio Devoto for the flawless organisation of the meeting and their constant zeal and help during its development.

Finally I also want to thank Mrs. Gilda Massa for her help in preparing the transcriptions of the discussions and the final revision of the proceedings.

CARLOS CHAGAS

President of the Pontifical Academy of Sciences

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AUDIENCE DU SAINT-PERE

Le 14 novembre 1980 à midi Sa Sainteté le Pape Jean-Paul II accorda dans le Palais Apostolique une Audience particulière aux Participants à la Semaine d'Etude et à leurs familles. Le Groupe était guidé par le Président de l'Académie Pontificale des Sciences, Son Excellence le Prof. Carlos Chagas et le Directeur de la Chancellerie, le Rév. Père Enrico di Rovasenda.

Le Président s'adressa au Souverain Pontife en ces termes:

Très Saint-Père,

Permettez-moi, Sainteté, de Vous remercier au nom de l'Académie Pontificale des Sciences et de tous les scientifiques qui participent à la Casina Pie IV à la Semaine d'Etude sur le thème « Humanité et Energie », d'avoir bien voulu nous recevoir en audience.

Le sujet est très vaste et de nombreuses réunions ont déjà été tenues et auront lieu encore, étant donné l'énorme importance que revêt l'énergie dans notre société. Je crois que notre Colloque a été très fructueux et ses comptes-rendus auront certainement une très grande répercussion dans le monde entier. Une réunion, ayant un nombre restreint de participants, qui peuvent exprimer leur opinion en toute liberté, sans aucune contrainte, peut apporter de nouvelles idées et orientations que les grandes Conférences internationales, gouvernementales, submergées par des intérêts politiques de chaque gouvernement, ne peuvent pas offrir. En outre, les aspects scientifiques, techniques et économiques ont été intimement liés durant nos séances aux questions du service à rendre à l'homme et à notre société. Ces aspects, moins apparents dans certains documents de travail, ont été particulièrement soulignés au moment des nombreux débats qui ont suivi leur présentation. D'autre part, comme dans tant d'autres problèmes mondiaux, une entente internationale est plus que nécessaire.

Les études sur l'énergie qui, jusqu'à une quinzaine d'années se tournaient surtout vers les problèmes des pays industrialisés, se dirigent à présent également vers les pays en voie de développement. Elles ont eu une place importante dans nos travaux. Je signale surtout que le développement énergétique des pays en voie de développement est sans doute un des facteurs les plus significatifs pour la paix du monde. J'aimerais souligner enfin l'effort de compréhension et de collaboration qui doit être fait par tous les pays pour qu'une politique de collaboration et de coopération soit mise en route.

Sainteté, il me serait impossible de Vous présenter toutes nos conclusions au moment où notre attention se tourne vers Votre personnalité et que nous attendons les paroles d'orientation que Vous allez prononcer. Je désire seulement Vous dire à titre personnel que d'une façon générale on peut affirmer qu'en répondant aux besoins sociaux, économiques et nationaux, toutes les formes d'énergie sont, et ont toujours été, complémentaires.

Afin que notre civilisation puisse faire face aux défis de la minute qui vient, le charbon et l'énergie nucléaire, ainsi que le gaz naturel, avant le troisième millénaire, doivent suppléer ou remplacer le pétrole, dont l'avenir comme matière première pour la pétrochimie ne doit pas être oublié.

D'autre part, il est nécessaire que des efforts considérables soient faits par les gouvernements et la communauté scientifique internationale pour renforcer la recherche et le développement des sources renouvelables. L'acquis obtenu par l'utilisation de l'énergie solaire dans certains pays, malgré les difficultés économiques qui se présentent et la participation réduite qu'il apporte à la macroéconomie des pays en cause, justifie cette assertion.

Je pense enfin que des mesures doivent être adoptées pour assurer la santé et prévenir les désastres de n'importe quelle source d'énergie.

En vous remerciant au nom de tous de Votre bonté en nous recevant, je puis Vous assurer que tous les participants continueront leurs efforts pour que l'énergie soit accessible au monde entier.

Le Saint-Père daigna répondre par le Discours suivant:

Excellences, Mesdames, Messieurs,

Vous savez le prix que j'attache à la recherche des membres de notre Académie Pontificale des Sciences. C'est vous dire ma joie de vous rencontrer ici, avant que ne s'achèvent vos travaux qui honorent le Saint-Siège, pour vous exprimer moi-même mon estime et mes encouragements.

La semaine d'étude qui vous a réunis traite d'une des questions les plus graves que l'humanité doive affronter aujourd'hui. Et précisément votre analyse des données scientifiques sur l'énergie est orientée vers le souci du sort de l'humanité: « Energie et humanité ». Je vous félicite, moi qui, à la tribune de l'UNESCO, le 2 juin dernier, ai insisté sur la nécessité d'éviter que le progrès de la connaissance scientifique désintéressée ignore les responsabilités des consciences (nn. 20-22).

Permettez-moi maintenant d'évoquer devant vous, d'une façon très simple et dépouillée de technicité, ces données qui vous sont évidemment très familières; je le fais seulement dans le but de vous manifester mon intérêt pour vos échanges et de partager avec vous quelques préoccupations d'ordre éthique.

Au cours de son histoire, l'homme a développé les formes d'énergie dont il avait besoin, passant de la découverte du feu à des formes d'énergie toujours plus riches, en arrivant enfin à l'énergie nucléaire, bouleversante à tant de points de vue. En même temps, le progrès de l'industrialisation a donné lieu, surtout ces derniers temps, à une consommation chaque jour croissante si bien que certaines ressources naturelles sont en voie d'épuisement. Notre civilisation, — avant tout ses scientifiques et ses techniciens —, doit chercher des mé-

thodes nouvelles pour utiliser les sources d'énergie que la Providence divine a mises à la disposition des hommes. Il est nécessaire en outre que les gouvernements eux-mêmes mènent une politique énergétique unifiée, de telle sorte que l'énergie produite dans une région puisse être utilisée dans d'autres régions.

Il semble bien que le soleil, première source d'énergie et la plus riche pour notre planète, devrait être étudié plus attentivement par les chercheurs; il doit devenir une de leurs principales préoccupations. S'il est vrai que l'utilisation directe de l'énergie solaire est encore lointaine, cette perspective ne doit pas atténuer les efforts des chercheurs ni l'appui des gouvernements. Au reste, des résultats ont déjà été obtenus et on en profite déjà en diverses parties du monde. En outre, d'autres formes d'énergie, telles que l'énergie éolienne, marine ou géothermique, ont déjà été utilisées, même si c'est de manière encore limitée, et en fonction des conditions géographiques.

J'ai appris que l'utilisation de la bio-masse a attiré votre attention et que vous vous êtes arrêtés sur la nécessité du développement des études concernant la photosynthèse.

Le bois prend place parmi les sources d'énergie les plus anciennes. Dans les pays en voie de développement, il restera sans doute pour longtemps la principale source d'énergie. Mais il est nécessaire que l'usage de cette forme d'énergie traditionnelle et importante ne donne pas lieu à des déboisements et à des destructions de forêts qui créent de graves déséquilibres écologiques. Il faudrait donc prévoir un reboisement actif, à mener à bien par les botanistes, les écologistes, les pédologues, et sa réalisation devrait être l'objet de soins attentifs de la part des planificateurs et des hommes politiques.

En ce qui concerne d'autres formes d'énergie, telles que chutes d'eau, charbon, pétrole et énergie nucléaire, leur choix se fonde évidemment sur des facteurs divers dépendant des ressources naturelles et humaines, de la croissance démographique, des modes de développement, de l'économie. Je suis sûr que vous aurez pris en considération dans vos discussions les règles qui s'imposent pour éliminer les périls qui mena-

cent, de près ou de loin, ceux qui sont exposés à subir les dommages éventuels provenant de l'utilisation de certaines sources d'énergie, et aussi pour promouvoir toujours la sauvegarde écologique, la protection de la faune et de la flore, pour éviter la destruction des beautés naturelles qui remplissent le coeur d'admiration et de poésie.

J'ai pu constater par moi-même les dommages causés à la beauté de la nature par des implantations industrielles qui auraient pu être placées ailleurs ou conçues autrement. J'ai connu surtout par expérience personnelle les souffrances des mineurs de charbon, dont les poumons sont imprégnés de la poussière qui empoisonne les galeries des mines. Je veux espérer que sont d'ores et déjà adoptés, au nom des droits de l'homme et pour l'amélioration de la qualité de la vie, des méthodes nouvelles et efficaces pour l'utilisation des sources conventionnelles d'énergie, et qu'il n'y aura plus ainsi à voir mettre en péril, outre le milieu naturel, les travailleurs et les populations.

Il convient de réfléchir enfin sur les périls d'ordre économique et moral qui sont dus à ce qu'on appelle la civilisation de consommation actuelle, et à ses structures. Comme je l'ai écrit dans mon encyclique Redemptor Hominis: « *On connait bien le cadre de la civilisation de consommation qui consiste dans un certain excès des biens nécessaires à l'homme, à des sociétés entières, — et il s'agit ici des sociétés riches et très développées —, tandis que les autres sociétés, au moins de larges couches de celles-ci, souffrent de la faim et que beaucoup de personnes meurent chaque jour d'inanition et de dénutrition...* ».

L'ampleur du phénomène met en cause les structures et les mécanismes financiers, monétaires, productifs et commerciaux qui, appuyés sur des pressions politiques diverses, régissent l'économie mondiale: ils s'avèrent incapables de résorber les injustices héritées du passé et de faire face aux défis urgents et aux exigences éthiques du présent. Tout en soumettant l'homme aux tensions qu'il crée lui-même, tout en dilapidant à un rythme accéléré les ressources matérielles et énergétiques, tout en compromettant l'environnement géophysique, ces structures font s'étendre sans cesse les zones *de misère et avec elles la détresse, la frustration et l'amertume » (n. 16).*

Les frustrations auxquelles est sujet l'homme d'aujourd'hui à cause de la consommation excessive d'une part et de la crise énergétique de l'autre, peuvent être résolues seulement si on reconnaît que l'énergie, quelle qu'en soit la forme ou l'origine, doit coopérer au bien de l'homme. L'énergie et les problèmes qu'elle pose ne doivent pas servir les intérêts égoïstes de groupes particuliers, qui cherchent à augmenter leur sphère d'influence économique et politique; à plus forte raison, ils ne doivent pas diviser les peuples, mettre des nations en état de dépendance par rapport à d'autres, augmenter les risques de guerre ou d'hécatombe nucléaire.

L'énergie est un bien universel que la divine Providence a mise au service de l'homme, de tous les hommes, quelle que soit la partie du monde à laquelle ils appartiennent, et il nous faut penser aussi aux hommes de demain, car le Créateur a confié la terre et la multiplication de ses habitants à la responsabilité de l'homme.

J'estime qu'on peut considérer comme un devoir de justice et de charité l'effort résolu et persévérant accompli pour ménager les sources d'energie et respecter la nature, non seulement pour que l'ensemble de l'humanité d'aujourd'hui puisse en profiter, mais aussi les générations à venir. Nous sommes solidaires des générations à venir. Et j'espère que les chrétiens, mus de façon particulière par la reconnaissance envers Dieu, par la conviction du sens de la vie et du monde, par l'espérance et par une charité sans limite, seront les premiers à apprécier ce devoir et à en tirer les conséquences.

Je vous remercie, Mesdames et Messieurs, d'avoir répondu aussi nombreux, étant donné votre haute compétence, à l'appel que vous avait adressé l'Académie Pontificale des Sciences, et je forme les voeux les meilleurs pour que vos travaux servent au bien de toute l'humanité. Je prie Dieu de vous assister dans cette noble tâche, au moment où je pars en Allemagne commémorer Saint Albert le Grand, dont l'oeuvre scientifique fut considérable pour son temps, à côté de sa réflexion philosophique et théologique. Je prie également le Seigneur de bénir vos personnes et vos familles.

Translation of the speech to the Holy Father by the President of the Academy:

Most Holy Father,

Permit me, Holy Father, to thank you in the name of the Pontifical Academy of Sciences and of all the scientists taking part in the Study Week on « Humanity and Energy » at the Casina Pio IV, for granting this audience.

This subject is vast indeed, and many meetings have already been held and will still be held because of the great importance of energy in our society. I believe that our meeting has been very fruitful and its reports will certainly have great repercussion throughout the world. A meeting composed of a limited number of participants, who have complete freedom to express their ideas without any restraint whatsoever, can contribute new ideas and orientations which large governmental conferences, subject to the political interests of each government, cannot. Moreover, the scientific, technical and economic aspects have been very closely related during our meetings to the question of the service to be rendered to man and to society. These aspects, though less apparent in certain working documents, have been particularly emphasized during the numerous discussions which followed the presentations. Here, as in so many other world problems, international agreement is more than necessary.

The studies on energy which until some fifteen years ago were concerned mostly with the industrialized countries, are now giving attention also to the developing countries. These have had an important place in our discussions. I wish to mention especially that energy development in the developing countries is undoubtedly one of the most significant factors for world peace.

Finally I should like to stress the effort at understanding and collaboration which must be made by all countries in order that a policy of cooperation and collaboration may be established.

Holy Father, it would be impossible to give you all the details of our conclusions at this moment when all our attention is turned toward your holy person and when we are awaiting your words of guidance.

I want only to tell you in person that we can say in general that in satisfying social, economic and national needs all forms of energy are and have always been complementary.

In order that our civilisation can meet the challenges of the immediate future, coal and nuclear energy, as well as natural gas must supplement or replace petroleum before we enter the third millenium, but the future of petroleum as raw material for petrochemistry must not be overlooked.

On the other hand, considerable effort must be made by governments and the international scientific community to encourage research and development of renewable sources. The progress made in the use of solar energy in certain countries, despite economic difficulties and the reduced participation which it brings to the macroeconomy of the countries concerned, justifies this position.

Finally, I believe that measures must be taken to protect health and anticipate and prevent disasters caused by all sources of energy.

Thanking you in the name of all for your kindness in receiving us, I can assure you that all the participants will continue their efforts to make energy accessible to the whole world.

The Holy Father answered with the following Discourse:

Your Excellencies, Ladies and Gentlemen,

You know the value I attach to the research work of members of our Pontifical Academy of Sciences. This tells you how happy I am to meet you here, before the end of your work which honours tbe Holy See, to express to you myself my esteem and encouragement.

The Study Week which has brought you together deals with one of the most serious questions that humanity must cope with today. And precisely your analysis of the scientific data on energy is geared to concern with tbe fate of mankind: « Energy and Humanity ». I congratulate you, I who, at the tribune of UNESCO, last June 2, stressed the necessity of preventing the progress of disinterested scientific knowledge from ignoring the responsibilities of consciences (nos. 20-22).

Allow me now to recall before you, in a very simple way, free of technicalities, these data which are, of course, very familiar to you; I do so only for the purpose of manifesting to you my interest in your discussions and of sharing some ethical concerns with you.

In the course of his history, man has developed the forms of energy that he needed, passing from the discovery of fire to ever richer forms of energy, and arriving finally at nuclear energy, which is disquieting from so many points of view. At the same time, the progress of industrialization has given rise, especially in recent times, to ever increasing consumption, to such an extent that some natural resources are becoming exhausted. Our civilization — above all its scientists and technicians — must look for new methods in order to use the sources of energy that Divine Providence has put at the disposal of man. It is necessary, furthermore, that governments themselves should pursue a unified energy policy, so that the energy produced in one region can be used in other regions.

It certainly seems that the sun, the first source of energy and the richest one for our planet, should be studied more attentively by researchers; it must become one of their main concerns. While it is true that direct use of solar energy is still far away, this prospect must not reduce the efforts of researchers or the support of governments. Moreover, results have already been achieved and are being used to advantage in different parts of the world. Furthermore, other forms of energy, such as wind, marine or geothermal energy, have already been used, even if to a limited extent as yet, and depending on geographical conditions.

I have learned that use of biomass has drawn your attention and that you have dwelt on the necessity of developing studies concerning photosynthesis.

Wood takes its place among the oldest sources of energy. In the developing countries, it will undoubtedly remain for a long time the main source of energy. But it is necessary that use of this traditional and important form of energy should not give rise to deforestation and destruction of forests, which creates serious ecological imbalances. It would be necessary, therefore, to plan active reforestation, to be carried out by botanists, ecologists and pedologists, and its implementation should be the object of attentive care on the part of planners and politicians.

As regards other forms of energy, such as waterfalls, coal, oil and nuclear energy, their choice is based, of course, on various factors depending on natural and human resources, population growth, ways of development, and the economy. I am sure that you will have considered in your discussions the rules that are necessary to eliminate the dangers that threaten, from far and near, those who are exposed to possible harm due to the use of certain sources of energy, and also always to promote ecological safeguards, the protection of fauna and flora, to avoid the destruction of natural beauties which fill the heart with admiration and poetry.

I myself have seen the harm done to the beauty of nature by industrial installations which could have been placed elsewhere or planned differently. Above all, I have had personal experience of the sufferings of coal miners, whose lungs are impregnated with the dust that poisons the mine tunnels. I hope and trust that, in the name of human rights and for the improvement of the quality of life, new and effective measures have already been adopted for the utilization of conventional sources of energy, and that in this way we will no longer have to see jeopardized not only the natural environment, but also workers and populations.

Finally it is opportune to reflect on the economic and moral dangers due to what is called the consumer civilization of today, and its structures. As I wrote in my encyclical *Redemptor Hominis*: "Everyone is familiar with the picture of the consumer civilization, which consists in a certain surplus of goods necessary for man and for entire societies — and we are dealing precisely with the rich highly developed societies — while the remaining societies, at least broad sectors of them, are suffering from hunger, with many people dying each day of starvation and malnutrition...".

So widespread is the phenomenon that it brings into question the financial, monetary, production and commercial mechanisms that, resting on various political pressure, support the world economy. These are proving incapable either of remedying the unjust social situations inherited from the past, or of dealing with the urgent challenges and ethical demands of the present. By submitting man to tensions created by himself, squandering at an accelerated pace material and energy resources, and compromising the geophysical environment, these structures unceasingly make the areas of misery spread, accompanied by anguish, frustration and bitterness" (n. 16).

The frustrations to which man is subject today due to excessive consumption on the one hand and the energy crisis on the other, can be solved only if it is recognized that energy, whatever its form or origin, must contribute to the good of man. Energy and the problems that it raises must not serve the selfish interests of particular groups, which are trying to increase their sphere of economic and political influence, far less divide peoples, make some nations dependent on others, and increase the risks of war or of a nuclear holocaust.

Energy is a universal good that Divine Providence has put in the service of man, of all men, to whatever part of the world they may belong, and we must think also of the men of the future, for the Creator entrusted the earth and the multiplication of its inhabitants to man's responsibility.

I think it can be considered a duty of justice and charity to make a resolute and persevering effort to husband energy resources and respect nature, so that not only humanity as a whole today may benefit, but also the generations to come. We are bound in solidarity to the generations to come. And I hope that Christians, moved particularly by gratitude to God, by the conviction that life and the world have a meaning, by unlimited hope and charity, will be the first to appreciate this duty and draw the necessary conclusions.

I thank you, Ladies and Gentlemen, for having responded in sucb large numbers to the appeal that the Pontifical Academy of Sciences had made to you in view of your high competence, and I express my best wishes that your work may serve the good of the whole of humanity. I pray to God to assist you in this noble task, at the moment when I am setting out for Germany to commemorate St. Albert the Great, whose scientific work was considerable for his time, as well as his philosophical and theological reflection. I also pray to the Lord to bless you personally, and your families.

TRAVAUX SCIENTIFIQUES
ET
DISCUSSIONS

INTRODUCTION

A. BLANC-LAPIERRE

At the opening of our Study Week on "Mankind and Energy" Needs - Resources - Hopes, I would like to underline very briefly what should, it seems to me, be the general orientation of our work.

I think the first questions that come to mind are the following: *Why such a Study Week?* There have already been a rather large number of meetings concerning energy over recent months. *And what specific characteristics does the Study Week assume, given that it is taking place here, at the Vatican?*

It is quite obvious that energy plays a very important role — not an exclusive but a very important one, surely — for the life of mankind, for its material life, and also, through the latter, for its social, intellectual, cultural, and spiritual life. All these dimensions of human existence are intimately interrelated, as His Holiness John Paul II said in his speech at UNESCO, last June 2: they condition each other "like a vast system of communicating vessels". It is thus completely natural that such a subject directly concern the Churches and, specifically, the Catholic Church, and that this subject be reflected upon here. Moreover, I think this kind of reflexion is entirely fulfilled by the "Study Week" format, which, for six days, brings together a small number of recognized experts who among themselves cover a very broad geographical and conceptual spectrum and who have come here to present and discuss their points of view on a capital issue in a spirit of synthesis and broadmindedness.

It is self-evident that energy problems are tightly linked to those concerning raw materials and their processing, food production, land use, and so on, and, of course, man's labor, an essential factor for all progress. We cannot ignore these interrelationships, but we shall have to find a middle path between an impossible and unrealistic over-concentration on the energy aspect alone and an overblown globalization which would restrict us to generalities and obvious statements. It is for this reason that our program includes both parts that will gather and discuss the significant data concerning different major energy sources, and others more directly oriented towards synthesizing the technical, socio-economic, cultural aspects, . . .

The slowdown in world growth linked to oil-price rises and to the fall in oil-production concerns the whole of humanity; *it is especially serious for the developing countries not producing oil.* For the world this is one of the foremost problems; if not resolved, it could become a source of serious conflicts. World stability is deeply conditioned by this question. Obviously, this stability is not uniquely the function of energy questions, but these are an important factor, and this must be taken into account in our work here.

Clearly, the following question is at the core of our reflection: *how to combine opportunities afforded by diverse energy sources, both those presently available for use and those potentially available, and sources resulting from energy savings (decreasing waste or improving energy use by applying technical progress to production processes), not only better to face the present crisis but even to find ways to permit mankind to develop harmoniously, that is, to be more just, more fraternal, happier.*

I do not want to get ahead of our discussions. I would simply like to make some rather obvious observations:

a) The first applies to the nuanced attitude that to me appears necessary if one wishes to define or, more modestly, to outline *the conditions of the happiness and well-being of mankind.* Let us cut down the problem to a large degree by contenting ourselves with talking about the world's "economic health". I am not an economist, but I doubt that Gross National Product (on the national level) or its equivalent on the world level, which certainly constitutes an important criterion, is exhaustive, i.e. that it captures alone the essence of reality. Does it encompass, for example, everything touching on jobs, unemployment, re-assigning of wealth between major objectives and major activities, which influences its distribution among collectivities and individuals?

b) The second remark pertains to the following fact: the problem is indisputably a *world* problem, but the system studied on the world scale is subject to *multiple local, national, and regional constraints*:

— energy resources are unevenly and diversely distributed across the planet; this leads different countries to adopt largely varying solutions, in particular to conserve a minimum of independence the desire for which goes beyond the issue of prices;

— the conditions of energy use vary greatly depending on whether one is considering industrialized countries, geographic areas whose economic take-off, even if significant, still remains rather weak, or the poorest regions;

— finally, political factors, conditioning trade and transfer activities, obviously play a large role.

All this means that global solutions, seemingly reasonable at the level of international accounts, may in fact not be so, since in many regions they may correspond to local conditions that are absolutely untenable or totally unrealistic.

c) The third and last remark relates to the time factor. The time-scale relevant to energy problems may be measured in terms of decades. This is true for the production side. It is also true, except in times of profound crisis, for the way in which energy is used, which is closely linked to way of life and type of existence. Furthermore, concerning energy, we are confronted much more with transient phenomena, rather than really long-term ones, bearing on one or more decades and whose social and geopolitical aspects are capital. Lastly, whereas it is essential to contribute as rapidly as possible to today's problems, we must not lose sight of the fact that it is humanity's fate in the year 2000 or 2030 that concerns us. In the meantime, humanity itself will have evolved in a way that is very predictable along several of its parameters, for example along those related to demography, but in a much more random fashion in matters of politics or changes of individual and group behavior, in short, in changes in ways of thinking. In the final analysis, time is a scarce commodity that we have to manage carefully. There is no chance whatsoever that in twenty years — or more or less — we will be able to avoid the consequences of what we will have done in the domain of energy . . . or what we will not have done. Thus the urgent necessity to choose. And yet parameters unknown to us now will gradually appear as time goes by. This, I think, is an incentive to action, vigorous, certainly, but not excluding a degree of flexibility and diversification, action whose results will have to be examined constantly by testing them against the facts.

* * *

What are our objectives during this week?

First of all, an examination and evaluation of mankind's present situation with respect to energy problems. In particular, a look as dispassionate and objective as possible at the present state of techniques respectively applicable to the exploitation of diverse energy sources, at their potentials, their costs, risks, impact on the environment and living conditions, a look at the time necessary to put them into use or to increase their use substantially, and, lasty, at their foreseeable evolution.

In response to these evaluations, our activities should converge toward a *synthesis of what one might call "Solutions for the Future" and the highlighting of several coherent scenarios or models for the middle term with longer-term projections.* It is clear that different models will be obtained depending on the positions adopted on the ways of life preferred for mankind, on the weight given to aid to developing countries, and on the relations one accepts as existing between development of living standards and the quantitative growth of energy consumption. I shall make an effort to summarize the activities of the Study Week and to draw "conclusions" from them, or, better yet, to describe the tendencies — even in the diversity they may exhibit — in the morning of Saturday, November 15, soon enough so that this summary and these "conclusions" may themselves be discussed and all reservations and disagreements made explicit. I believe this is essential for objectivity and clarity. Likewise, it seems to me that our activities could lead to the need to promote research on points that appear to us to be very important and presently underanalyzed. Such points surely exist, and I think that, if this happens, we will have rendered a real service.

* * *

As you know, the texts of the papers and the contents of the discussions will be published. Beyond the audience reached through this dissemination, it is obvious that they will be carefully analyzed by the Holy See, which gives our work a very special importance.

* * *

I must mention two modifications to the programme. As a consequence of recent difficulties, Mr. RODRIGUEZ ELIZARRARAS, Secrétaire

Exécutif de l'Organisation Latino Américaine d'Energie (OLADE), and Pr. H.K. SCHNEIDER cannot attend. Their papers will be delivered by Dr. GABRIEL SANCHEZ and Dr. Dieter SCHMITT respectively.

* * *

Last of all, I would like to join Professor Carlos CHAGAS in thanking Father Enrico DI ROVASENDA, Director of the Chancellery of the Academy, and Mrs. Michelle PORCELLI STUDER, Secretary of the Chancellery, for their contribution to the organization of this week.

Professor J. BUSSAC and Doctor A. APARO, kindly accepted the task of rapporteurs for our activities. I wish to thank both them and our colleagues Umberto COLOMBO and Jean TEILLAC who made this collaboration possible. I am also grateful for her help to Mrs. GRANDE of the Comitato Nazionale per l'Energia Nucleare.

OVERVIEW AND CURRENT STATUS

Chaired by Professor C. Chagas

ENERGY AND SOCIETY
EVOLUTION AND CURRENT PROBLEMS

JEAN COUTURE (*)

I. General history

1. *Role of energy in human evolution*

a. *Introduction*

If the use of fire and domestication of animals are considered to be sources of energy, it can be said that the evolution of Man has, from his farthest origins, largely depended on the sources of energy which appropriate technology has enabled him to master.

This relationship has been particularly pronounced in recent history, dramatically highlighted during the "oil era" which can be said to coincide with the third quarter of this century.

After World War II, the major industrial countries were able to rebuild and later develop their economies without any problem of energy supplies, thanks to oil, abundantly supplied by a small number of countries mainly in the Middle East.

But over the last few years, events in this part of the world, coupled with the subsequent reverberations on the energy markets, cast doubt on the proper course of the curve — quasi-representative up till that period — which traced world crude oil production as a function of time.

(*) Much of the information used in this paper was collected and organized by Mme Francine Breniere, Director of the French Energy Institute Documentation Center. Some also came from the Atomic Energy Commission, with the kind help of M. Jean Teillac, High Commissioner (cf. bibliography).

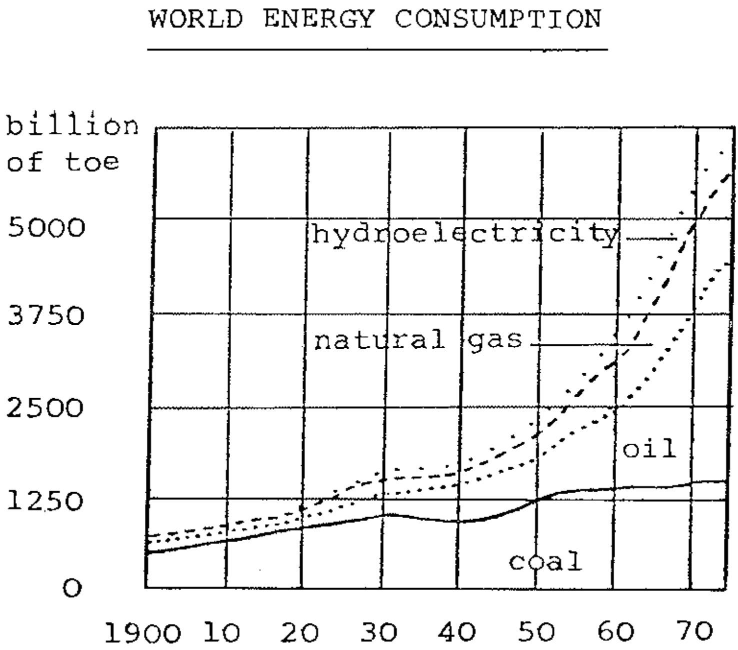

Fig. 1. Annual production and consumption (Oil equivalent in MT).

At first, some people thought that this was due to a mere accident of circumstance and claimed that the enormous price increase would be sufficient to stimulate supply; the market mechanism would therefore be the therapy. But even if this line of argument is not fundamentally wrong, it is now upheld by fewer and fewer people. The volumes concerned and response times are such that every single Government judged it necessary to intervene in some way, with varying degrees of vigour and success (pure liberalist thinkers do not hesitate to question the efficiency of the measures taken — sometimes rightly so). There is, however, no doubt that all the nations in the world are today up against a very different situation from that known, or tacitly admitted, until now. Our aim in this week of study is therefore to consider this situation, its recent and already significant evolution and possible future developments.

The present talk is intended to be an introduction to the work we will be doing and is basically retrospective. However, as part of our mission, we will be considering the problematics of such future developments on a world-wide scale. The most important points to which we hope to find some answers will therefore be raised in the conclusion.

b. *Chronology of socio-energetic events*

The attached synoptic table does not pretend to be complete and accurate: it is only designed to bring out some important dates in the joint evolution of energy techniques and human society from their farthest known origins. Without going into detail, we believe that it calls for two different remarks on the quantity and time scales. Firstly, a rough estimate of the energy consumed by the different societies from primitive man to "technological man" is given with a factor of approximately 100 between the two extremes. Roughly speaking this breaks down into two multiplications of 10, the first spanning the many thousands of years between primitive man and the "advanced agriculturists" and the second, the last two hundred years in which agricultural society has given way, in the West at least, to the industrial civilisation which we know today.

As far as the time scale is concerned, the acceleration of technico-socio-economic change is obvious: the initial time, hundreds of thousands of years, required for each stage of development, is reduced to a mere thousand then to a century and finally to a decade. One may ask if this is not, to some extent, an optical illusion and if we are not underestimating the extraordinary breakthroughs made by the discovery of iron metallurgy and crop cultivation: a closer look may well reveal these events to have had more impact than the development of private automobiles over the last fifty years in countreis which already had railways.

There has, however, been an undeniable acceleration, largely due to a combination of three factors: all knowledge is cumulated including both information and conceptual tools, mathematics, physics, etc. which improves research output; the growing number of researchers is due to the increase in population and proportion of intellectuals; results obtained are almost instantly communicated world-wide. This remark seems to be justified when one tries to probe into the future. As opposed to what is happening for certain natural resources which, we now realize, are running out, human resources have every chance of continuing to grow — at least for a few decades.

A few years ago, a politician remarked that if we totalled the number of sciencists produced since the beginning of mankind, 90% of them would probably be alive today. This may not be valid a century hence, but the percentage would very likely remain extremely high. It would therefore be very shortsighted to underestimate the scientific, and therefore technical and economic, possibilities which the future holds for our

DATES	TYPE OF ENERGY		USE OF ENERGY		PLACE
	THERMAL	MECHANICAL	THERMAL	MECHANICAL	
-3 000 000		Muscular (man)		gathering, hunting, fishing	EAST AFRICA
-600 000	Fire (natural) (plant wood) artificial lighting				Aix en Provence (France) then HUNGARY CHINA
from -9 000 to -2 500		Muscular (animal) sheep oxen ass horse	Lead-copper metallurgy Pottery	agriculture human and then animal energy dams potter's wheel	IRAK. CYPRUS JARMO MIDDLE EAST ..... FAR EAST GREECE-INDIA
from -2 500 to -1 760		breeding	bronze Iron	weaving loom	MIDDLE EAST CHINA
from -1 700 to - 400		horse camel	glass bronze iron	Irrigation 2-ox yoke coins culture	GREECE MIDDLE EAST SCANDINAVIA CHINA EUROPE
from - 400 to - 300			iron	hoisting engine mechanization: screw pulley, oil crusher, engines of war, saddle and bridle	EGYPT GREECE CENTRAL ASIA
-38 -20		Hydraulic energy water mills	Blown glass	Hydraulic Persian wheel	CABIRE DANS LE PONT ROME ANATOLIA
from 85 to 500	Gunpowder (thermal type)		Burnt bricks	Fireworks Horse harnessing SARBEGAL mill Work with camels	CHINA - PROVENCE ARABIA MAYA
from 500 to 1 350		Wind power	Refractory clay furnace Artificial blowing	Windmill Nailed horseshoe Sailing ship with mast	IRAN PLATEAU ZELECHOVICE (BOHEMIA) WEST AND BIZANTIUM OSBERG NORWAY

DATES	FORME D'ENERGIE		UTILISATION DE L'ENERGIE		LIEU
	THERMIQUE	MECANIQUE	THERMIQUE	MECANIQUE	
de : 600 à : 1 350		Energie éolienne		Moulin à vent	PLATEAU IRANIEN
			Four argile réfractaire soufflage artificiel		ZELECHOVICE (BOHEME)
				Fer à clous (chevaux)	OCCIDENT ET BIZANCE
				Navire à mât et à voile	OSBERG NORVEGE
en : 850		Poudre à canon (utilisation mécanique)		Artillerie	EUROPE
			Production de sel (chaudière)		SALIN TARRAGONE
				Moulins à vent	
				Collier d'épaule (cheval)	EUROPE (OCCIDENTALE)
				Roue élévatoire	TOLEDE
				Moulins à marée	
en 1 180				Moulins à vent	NORMANDIE
			Distillation du grain		CHINE
				Brouette	EUROPE
				Soufflets hydrauliques en sidérurgie à chaude fourneaux	
			Bronze		PEROU
de : 1 550 à : 1 750	Charbon				GRANDE- BRETAGNE
				Machine à combustion interne de Huyghens	PAYS BAS
				Machine à vapeur de (denis Papin Savery)	FRANCE GRANDE BRETAGNE
			Exploitation bassin houiller d'Anzin		FRANCE
1 750			Fonte au Coke Acier au Creuset		SHEFFIELD

in 850		Gunpowder (mechanical use)		Artillery	EUROPE
			Salt production (Boiler)		SALINE
				Windmills Horse collar	TARRAGONA (WESTERN) EUROPE
				Elevating wheel	TOLEDO
in 1 180				Tidal mills Windmills	NORMANDY
			Grain distillation		
				Wheelbarrow	CHINA EUROPE
				Hydraulic bellows in iron & steel works with blast furnace	
			Bronze		PERU
from 1 550 to 1 750	Coal				GREAT-BRITA
				Huyghens internal combustion engine	NETHERLANDS
				Steam engine (Denis Papin Savery)	FRANCE GREAT-BRITAIN
			Anzin basin coalworks		FRANCE
			Coke iron Le Creuset steel		SHEFFIELD
1 750					
from 1 769	Start of conversion of thermal energy into mechanical energy		WATT's steam engine		GREAT-BRITAIN
from 1 792 to 1 802	Gas lighting		Soho gas factory in :		MURDOCH (GREAT-BRITAIN
from 1 800	Start of electricity		Column battery Aluminium electrolysis		DAVY (GREAT-BRIT
1 827			Fourneyron hydraulic turbine at:		PONT S/L'OGNON
1 828			Faraday's electric engine		GREAT-BRITAIN
from 1 859	Oil		Oil wells		TITUSVILLE (U.S.A.)
1 860			Lenoir's gas engine Otto & Beau de Rochas' 4-cylinder engine		FRANCE & W. GERMANY
1 884			First Gaulard electric power station in:		BELLEGARDE (FRANCE)
-			Charles Parson's steam turbine		
from 1 893 to 1 897			R. Diesel's diesel engine		W. GERMANY
1 906			H. Holzwarth's gas turbine		

1 937	Natural methane		
1 942	Nuclear energy	Fermi reactor	U.S.A.
1 955 1 956	Solar energy	Odeillo solar furnace Nuclear power station at : (electricity production)	FRANCE MARCOULE (FRANCE)
1 966 1 975	Tidal energy	Tidal power plant - Rance Phenix breeder reactor plant at Themis solar energy plant	MARCOULE U.S.A. & FRANCE

children. And this considerably alleviates any anxiety we may have concerning the fate of future generations: they will undoubtedly be better prepared than we are.

c. *Energy and domestic product*

One can also consider the relation between energy and society by comparing average per capita energy consumption in different countries, at a given time, with their per capita gross domestic product (GDP).

Although a little out of place in this historical chapter, Figure 2 is nevertheless worth considering. Each point represents the log-log coordinates for a country in 1976. One must not, of course, overestimate the accuracy of such a graph: apart from real statistical uncertainty, the quantitative definitions include a fairly high arbitrary constant when comparing different types of energy and also attempting to measure levels of technological development in different countries, using a single unit such as the U.S. dollar.

There is a very definite correlation (0.93) between the two magnitudes even though, naturally, not a real relation. The line of averages of the scatter of points shows a coefficient nearing 1.3. It should be remembered that this relates to a scatter for a given year (1976) and that one should not therefore deduce that the same coefficient would measure the average value, over a given period and for a given country, of the relation between variations in energy consumption and G.D.P. In fact deviations of 2 are very common. This is, for example, the case for Great Britain and Sweden which have roughly the same per capita energy consumption rate, whereas Sweden's per capita GDP is double that of Britain's. There may also be a systematic error due to the fact that "non-commercial" forms of energy, such as collected kindling wood and all

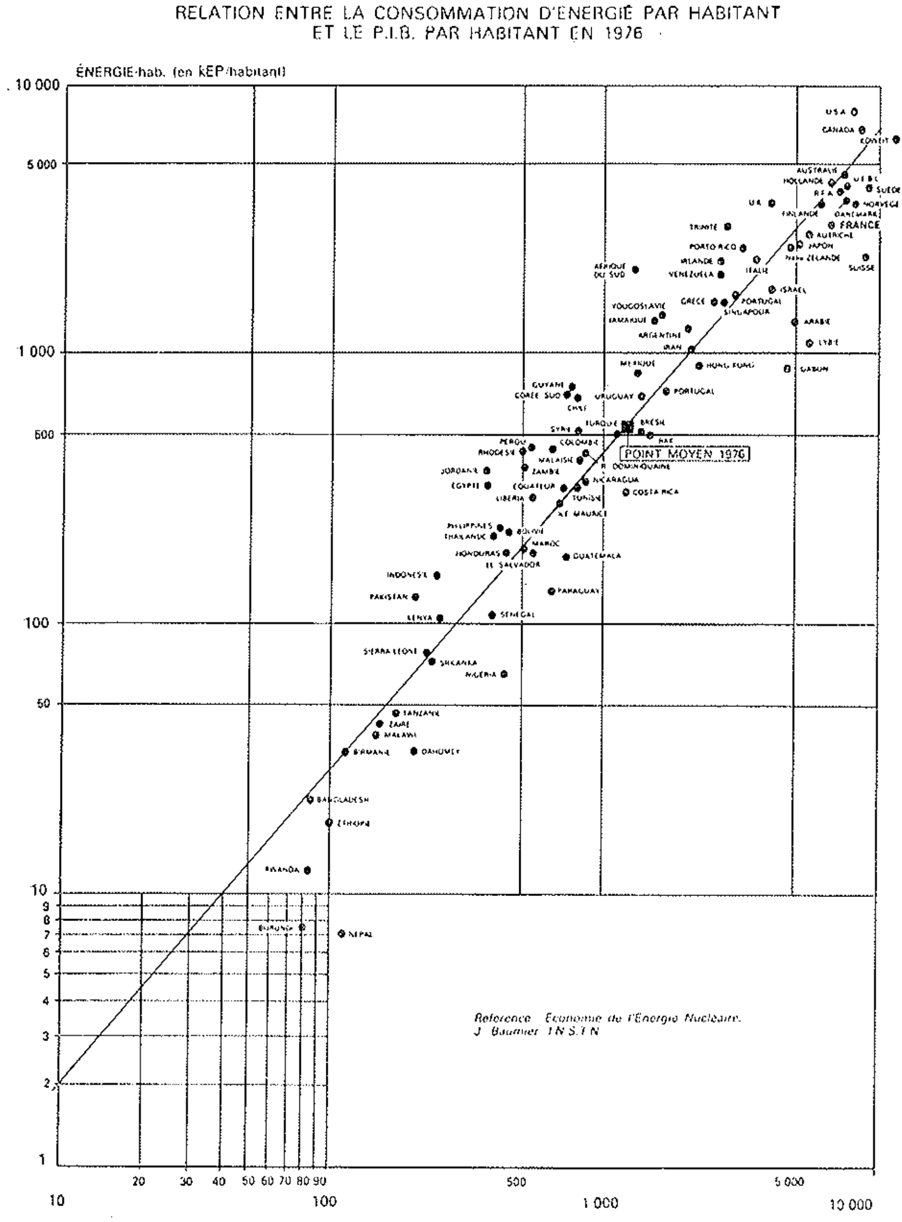
RELATION ENTRE LA CONSOMMATION D'ENERGIE PAR HABITANT
ET LE P.I.B. PAR HABITANT EN 1976
ÉNERGIE-hab. (en kEP/habitant)
10 000
5 000
1 000
500
100
50
10
1
10
100
1 000
10 000
USA
CANADA
KOWEIT
FRANCE
POINT MOYEN 1976
Reference Economie de l'Energie Nucléaire.
J. Baumier I.N.S.T.N.

FIG. 2

kinds of waste, etc., are not sufficiently considered. If this is true, the points representing the most impoverished countries should be shifted upwards, thus decreasing the coefficient of regression. It will, however, be noticed that the anticipated (or at least hoped for) improvement in living standards may tend to do away with these resources of energy assets. If the "distance-to-go" is to be measured, it is therefore better not to take such factors into consideration.

The 1.3 coefficient also calls for another comment: one might think, a priori, that it would be lower considering the fact that output more often than not improves with technological development — at least a factor-of-10 saving is made for a given effect between primitive machines and those around the asymptote. The inverse is also true, namely that social developments have, particularly in the recent past, introduced obvious waste such as insufficient thermal insulation in "modern" buildings or the ill-considered development of "greedy" private automobiles especially in America. One can therefore presume that the second factor takes precedence over the first, making a favorable evolution hopeful. Thus, if the trajectory for the less wealthy countries is in future drawn on the same graph, one can reasonably expect a much slower escalation than that bringing them to the current positions of the wealthy countries.

2. *The oil era. The oil crisis*

a. *The "grande illusion"*

It is sometimes said that the real energy explosion just after World War II was unprecedented in human history. This is not entirely true: one must not forget that during the 18th and 19th centuries, coal arrived just in time to take over from wood, thereby allowing a high energy-consuming society to develop.

It is, however, true that the industrial countries developed much faster from about 1950 to 1975 than at any time during a previous technological revolution. Oil and gas meant that world energy consumption, mostly concentrated in the developed countries, tripled, whereas coal declined considerably in America and Europe, even if it was on the increase globally. It was clear that such evolution could not go on indefinitely. And, the initial success of nuclear energy was greeted with great enthusiasm, ironically enough to us now. But the inevitable limit of hydrocarbon energy growth was never really taken into account, neither in industrial behaviour, which is easily understandable, nor in the policies adopted by countries whether individually or jointly.

The recent development of different countries can be compared on a log-log graph similar to that mentioned above, tracing a vector representing the evolution of a given country between two given dates. The slope of the vector shows the elasticity between the per capita energy consumption and GNP differentials. The vector measures the importance of this evolution. This thus provides a fairly vivid picture of the policies adopted, or rather of their effects, without having to go into too much detail.

Figure 3 illustrates this: it shows the transformation which took place between 1955 and 1972 (years selected purely for statistical convenience) for a certain number of countries. The shortest vectors concern countries where the evolution was not as favorable as elsewhere, either because the "take off" was difficult (India) or because already high GDPs did not improve very much (U.K. and to a lesser extent, the U.S.A.). Brazil, the U.S.S.R., France and West Germany made good progress, with an average slope. Japan beat the record for getting rich and Italy that of energy waste.

b. *The penitence*

Available statistics stop at 1976 and we have therefore had to limit our studies to this period to show the effects of new oil and energy data in the same way.

Figure 4 gives the vectors linking the points representing 1973 and 1976, traced as in the previous example. Any interpretations should be treated even more cautiously since the period is much shorter.

Without dwelling on the GDP/cap. decrease for certain countries (U.K., Zaïre), the striking fact is that the U.S.S.R. continues its trajectory quite happily while Japan and the U.S.A. show that they can react quickly by considerably cutting unit consumption. Sweden remains steady, while increasing its GDP/cap, France does a little better with good growth and slightly reduced consumption; both U.K. vectors are negative . . .

To conclude, and without forgetting the uncertainty of the data, the comparison of the movements recorded for different countries during the two periods concerned provides a fairly good indication of both their "heavy trends" and their vulnerability to external events. These evolutions should be carefully followed. But it does seem that the adjustment

DEVELOPMENT OF PER CAP. ENERGY CONSUMPTION
COMPARED WITH PER CAP. GDP : 1955-1972

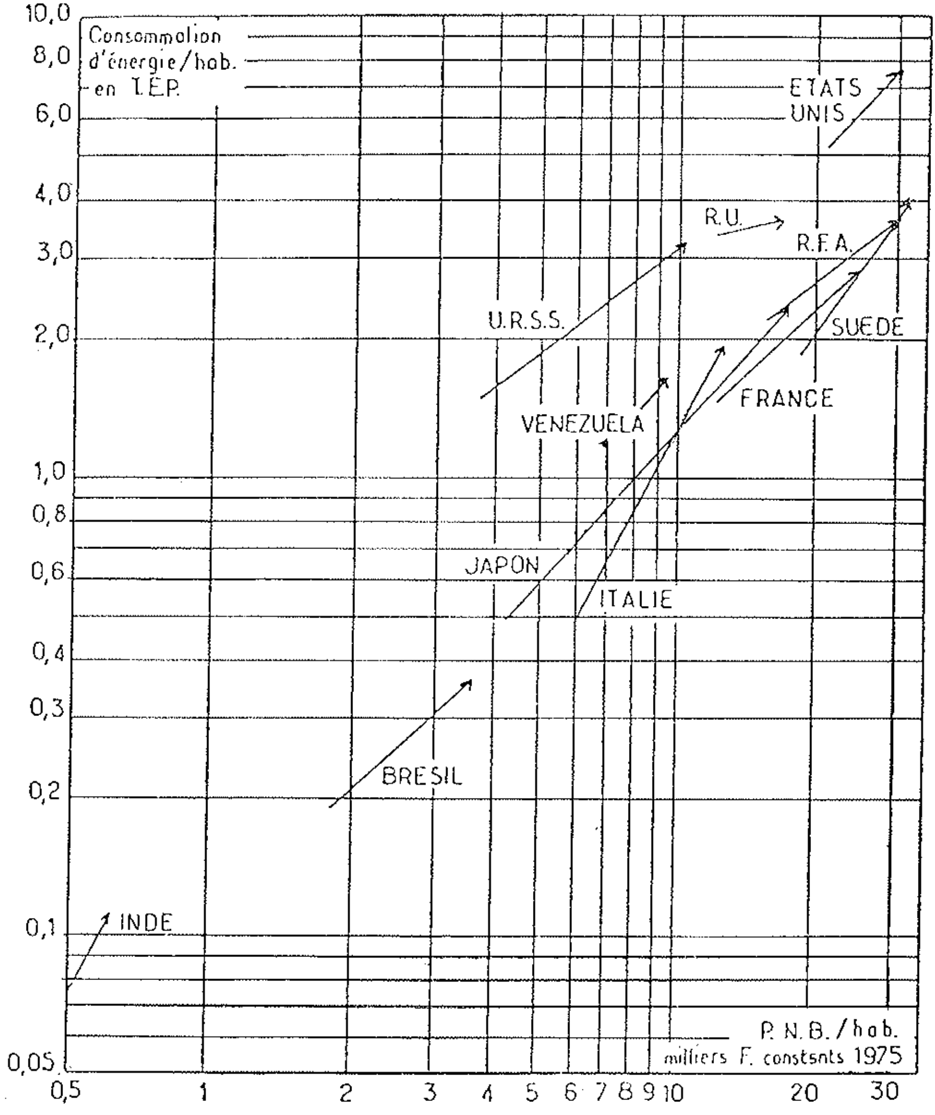

FIG. 3

DEVELOPMENT OF PER CAP. ENERGY CONSUMPTION
COMPARED WITH PER CAP. GDP : 1973-1976

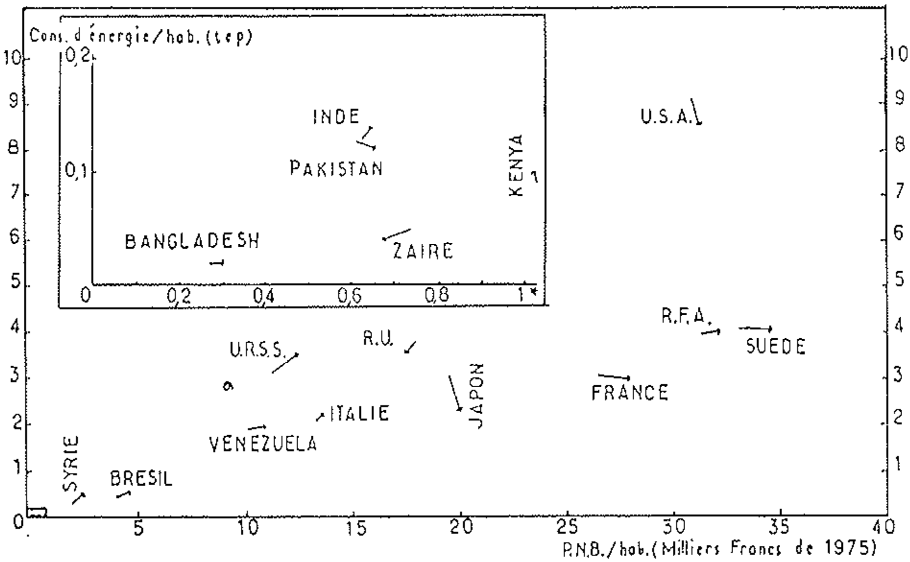

FIG. 4

required is being made or planned in countries with market economies. With higher response times, those countries with planned economies should follow the same path. The moderate optimism shown by these indications is confirmed by the fact that they take into account all energy consumption but do not show up the stabilizing effects of replacements which have been carried out, favourizing safer resources.

II. WORLD ENERGY PROBLEMATICS

1. *Current imbalance*

The "oil crises" of 1973-1974 and 1979-1980 have had at least two basic consequenes for the world economic situation. The first basically concerns the relations between oil and gas importing and exporting countries. The second has to do with the ternary balance between these two groups and the Third World.

a. *Relations between exporters and importers*

The current situation is very simply characterized by the fact that since 1973, Western industrialized countries have realized that supplies of oil and gas from OPEC are no longer guaranteed. Any break of more than a few weeks or months at most would most definitely disrupt the entire industrial production, and consequently the life, of these countries.

This serious dependance of the whole western world on OPEC decisions is therefore obviously one of the basic factors in world strategy. Without going as far as a total embargo, the exporting countries could progressively cut down on exports and thereby "finely tune" Western economic activity.

At the same time, prices continue to increase whatever the market situation: the considerable price increases before and after the OPEC meetings in Caracas in December 1979 and Algiers in June 1980 were decided while there were enormous stocks.

b. *The Third World and financial recycling*

The Third World countries, almost all of whom have chronic trade deficits, were obviously hardest hit by oil price increases.

At the same time, the accumulation of surplus oil-revenue in a certain number of oil exporting countries, gave rise to unprecedented problems for interuational financing mechanisms. The situation did, however, improve from 1974 to 1979 and has only worsened again since the Iranian crisis and the ensuing series of price increases.

Two things must be considered in regard to the Third World:

— Firstly, it is clear that liquid fuel has considerable possibilities for countries with underdeveloped and disorganized economies which have no alternative energy sources, since it is easy to transport, distribute and use.

— Secondly, the question which must be asked is how economies of this type should develop in order to improve conditions for the populations concerned. It is a great temptation to follow the example of Western countries and it is extremely doubtful if this is a good model. Advisors from Western countries who warn Third World leaders of this, will naturally, receive bitter criticism and will therefore have to be particularly careful in this respect.

As concerns the flow of capital, OPEC surpluses for 1980 are forecast as around 125 billion dollars, representing a 55 billion dollar deficit for the industrialized countries and 70 billion for the underdeveloped, non-exporting countries. This is obviously quite out with the latters' financial resources and will therefore considerably reduce their economic growth rate, perhaps rendering it strongly negative, if the other two groups of countries do not give more financial aid.

In many cases, their foreign debt is very high and they will only be able to arrive at a more or less acceptable position if they can increase their foreign exchange earnings. And moreover, OPEC must be able to find other outlets for their surplus apart from gold or purchases of movable or immovable assets in the West. To be more precise, the required, efficient mechanisms must be introduced so that such surplus investments are redeployed with respect to the importing countries' deficit, whether they are industrialized or not.

In this extremely difficult triangle, this redeployment of industrial structures in the Western countries so often referred to, must not only consider energy problems, by reducing unit consumption or increasing other resources than those from OPEC. Room must also be made for products from the Third World so that these countries can develop employment and economic activity.

2. *Geopolitical uncertainty*

What has been said up to now, does of course require a high level of international cooperation and can hardly take place without a reduction in tension mainly due to events in the Middle East.

Obviously, it would take more than one week of studies to analyze the problems of the West. But it is absolutely impossible to ignore this aspect during our discussions. The interplay of the major powers: the U.S.A., U.R.S.S. and China; the influence of the other industrialized countries (Europe and Japan) and developing countries particularly in South America; the political situations in the Third World are all subjects for hypotheses and it is all too easy to include a simple verbal precaution, as economic studies often do, such as: "excluding any worsening of the situation due to international conflicts". The question which may arise is how this problem will be dealt with during our study week. One way taking this into account to a certain extent, would be to consider different scenarios as did the authors of the VIIIth Plan in France: pink, black, grey depending on whether international factors were basically forecast as favorable, bad or middling. Another possibility, which we prefer, would be to adopt a middle-of-the-road perspective, i.e. continuing tension for many years with limited periods of crisis, and from there, examine the consequences of serious supply shortages.

It would be interesting as well as difficult to study the measures which might lessen the probability of such events, and, if they happened, limit their consequences.

III. Questions for the study week

We hope that you will forgive us for having perhaps in the previous pages transgressed the "ne ultra crepidam, sutor!" by suggesting some orientations whereas our role was only to summarize the current situation together with the problems to which solutions will have to be found. The aim of this last section is to set out these problems, which can be done in many ways: we hope that the following outline, which although not the best, will nevertheless be useful in organizing our discussions.

Is the oil era really over, as so many say? The truth is that consumption can only progress and the forecasts for the end of the century are that all crude oil demands will be considerably higher than current consumption. The oil producing countries, however, seem intent upon limiting production. Even if considerable efforts are made into researching new resources, there is a high risk of a stagnation or moderate reduction in world crude oil production during the next decade.

The following questions must therefore be asked:

1. Is this dual evolution of supply and demand probable for the next ten years despite the current oil glut?

What idea can one form of these evolutions for the last decade of the century?

2. What possibilities are there of bridging the possible gap between potential demand and supply of liquid fuel by non-classical or synthetic oil?

When the question of natural gas is raised, great similarities with oil appear particularly as regards production and areas of consumption but there are also considerable differences due above all to transport.

Firstly, the permanent link between the producer and the user which is obvious in the case of gas pipe lines is just as strong if methane tankers are used. Secondly, transport costs are both very much higher and increase much faster as a function of distance than for oil. Moreover, estimated gas reserves are about the same as the oil reserves. Since annual consumption is about half, long-term quantity perspectives are relatively favorable. Finally, low or medium heating value synthetic gas is fairly easy to obtain from coal or other fuel. It is more difficult, but nevertheless possible, to obtain substitute methane gas. One can therefore ask:

3. What contribution could natural gas make to future energy supplies?

4. What will be the role of poor or rich synthetic gases?

The estimated demands mentioned above are to a large extent the result of implicit or explicit extrapolations of past trends. If liquid or gaseous fuels for the developments envisaged are not available, other solutions will have to be found.

5. How far can solid fuel replace the forecast consumption of liquid and gaseous fuels?

6. Depending on their price, what could be the contribution of the other sources of energy:

— renewable energies: different forms of solar energy, geothermal and tidal energy?;

— nuclear energy?

7. How do the capital expenditures required for developing these different resources compare?

Obviously this question involves the complete energy chain from ore extraction through processing and transport to user investment and plant for industries supplying equipment.

8. How can resources be suitably allocated internationally according to the facility with which the different energies can be distributed, the density of use and the state of technico-industrial development in the different areas?

The financial imbalance mentioned in II-1-b above and any fears one might have concerning hydrocarbon supplies could be reduced at the same time if supplementary resources were worked in Third World countries which are at present deprived of them. The most desirable of these resources is oil, but gas, coal, etc. would also be welcomed. Great priority must therefore be given to research and possibly to the development of these resources.

This brings us to the following questions:

9. What encouragement could be given to such enterprises? What guarantees could be offered against all types of risk, especially political ones? Could an international organizaiton be set up for this purpose?

Such matters cannot of course be discussed without considering the aspects relating to the environment. We believe, however, that a distinction must be made between the local aspects (e.g. "esthetic pollution" due to constructions) and broader factors (e.g. heating of riverwaters or a marine area) and also very general problems (such as the risk of secular climatic change due to CO_2 build-up in the outer atmosphere).

The first two categories of factors should be incorporated in the replies to the various questions above.

But it seems better to keep the next two apart:

10. Do the risks of serious and irreversible deterioration to the entire Earth which originate from human activity mainly concern pacific energy?

How can they be controlled?

Finally, reactions from public opinion, influenced by different pressure groups, are more often than not determined without rational criteria and tend to set orientations without an objective balance having been established between the different options possible.

Experience has shown how hard it is to inform the man in the street who changes practically overnight from almost total (*) indifference to passionate indignation. Hence the two questions below which are as difficult as they are important.

11. Can support be given, on a world scale and in each country, to setting up eminently respectable organizations responsible for informing the public as to the advantages and benefits, drawbacks and real costs of a wide range of possible options, including those entailing stagnation or regression of available energy?

(*) Apart from periods when their attention is drawn by specific events, approximately 4% of the French population watches televized scientific programs, dealing with nuclear energy.

12. How can one get out of the alternative in which many countries are becoming trapped:

— either force the State's decision on the people without any real possibility of appeal;

— or leave all opponents, whether sincere or not, the freedom to endlessly delay the work which is to be for the good of all concerned.

There is no doubt that here we are dealing with a subject which goes beyond that of energy: it is a matter which touches at the very structures of our society. That is no doubt another good reason why it should not be ignored.

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DISCUSSION

Starr

Two comments. The first one was about figure 2 which can be made more significant:

a) by correcting for market value of local currencies

b) by including biomass fuels in energy consumption of under developed countries.

The scatter of the points will be reduced. The second one is about the oil economy: Oil is valuable because of its high energy density. It is difficult to find a substitute for transportation use. However, there are some technical possibilities:

1. Direct use of powdered coal.
2. Coal conversion to liquid fuels.
3. Electrification of public transport and of automobiles.
4. Information and communication systems which can reduce the transportation needs.

Colombo

Just one short comment on the alleged "energy prodigality" of Italy resulting from fig. 3. The fact is that Italy, being at the center of the Mediterranean Sea, and in a stage of rapid economic development after World War 2, chose to base its industrialization process on energy intensive sectors, such as petroleum refinery, petrochemicals and other basic transformation industries.

Then, it is not by chance that Italy has had this performance, which may appear "bad" if looked at from an energy-conscentious point of view.

It will take, however, a great effort of structural transformation of the country's economy if the goal of a less energy intensive economic growth has to be achieved. This transformation will involve a substantial change in the mix of products and processes used in industry. It will take some decades, during which the country's economy will be rather vulnerable.

TEILLAC

Je voudrais faire un commentaire sur l'importance du facteur temps dans la recherche et la mise en place de solutions aux problèmes énergétiques. Dans le passé, les mutations énergétiques ont porté sur des intervalles de temps beaucoup plus longs que de nos jours: l'utilisation du charbon s'est développée au cours du 18ème et du 19ème siècles, celle du pétrole à la fin du 19ème. Aujourd'hui, les mutations industrielles et la mise en exploitation d'importantes sources d'énergie ne prennent plus qu'une ou quelques décennies. L'urgence des solutions à apporter aux problèmes énergétiques découle de cet ordre de grandeur et je crois qu'il est très important d'avoir clairement à l'esprit cette échelle de temps dans les discussions que nous allons avoir. Il serait dangereux de ne penser qu'au long terme et de ne pas prendre rapidement les solutions indispensables pour couvrir nos besoins jusqu'à la fin du siècle.

LEPRINCE-RINGUET

On se représente souvent, en Europe occidentale, les Etats-Unis comme un pays où le gaspillage est institutionnalisé. Chaque jeune américain a appris qu'il fallait gaspiller: « l'American way of life » pousse à changer de voiture chaque année, de chemise chaque jour, à éclairer au maximum, afin de faire tourner les industries du métal, les blanchisseries, les industries électriques... En fait, les USA absorbent une grande partie du pétrole mondial. Peut-on « psychologiquement » obtenir du citoyen américain qu'il change complètement cette mentalité et devienne « économe », contrairement à toutes ses habitudes?

C'est une question que je pose à nos amis des USA.

STARR

I answer to Pr. Leprince-Ringuet.

1. In the United States, traditional use of energy was based on its low cost. The efficient economic use of time, and equipment, placed energy economy on a low priority.

2. The present high cost of energy is altering this situation. For example, automatic transmission on automobiles and large engines are becoming obsolete, and industry is now recovering waste heat.

WILSON

In fact, the second oil crisis has produced great changes. Over the next ten years the ratio of energy growth to GNP growth would be, in the US, about 0.5; it is to note that in the previous 20 years, before 76, this figure was about 1.0.

Now, very much of this is the result of legislation. But it is also due to the response of the market to the price increase.

BLANC LAPIERRE

I want to ask two questions:

1. How to realize an appropriate distribution of the energy between the different countries taking particularly in account the needs of the developing countries.

2. How to reduce the sensibility of economic systems with regard to discontinuities in the energy production and in energy prices? Probably, the diversification of the several sources of supply and the most important utilization of local resources are elements of equilibrium.

ANGELINI

Je suis tout à fait convaincu que la première source « virtuelle » d'énergie à exploiter réside dans les économies d'énergie et les mesures de conservation des sources non renouvelables d'énergie. Permettez-moi de rappeler ce que j'ai eu l'occasion de souligner au cours de la session plénière de la Conférence Mondiale de l'Energie (Detroit - 1974) sur la possibilité d'utiliser les grandes ressources en énergie hydraulique qui existent dans certains pays en développement. Il s'agit d'une capacité de production globale de l'ordre de 5.000 milliards de Kwh par an. Lors de la session plénière de la « World Energy Conference » de Munich (Septembre 1950) et en d'autres occasions, on est revenu sur les problèmes posés par l'utilisation de ce considérable potentiel d'énergie et on a analysé la possibilité de concentrer la fabrication des « energy intensive products » dans les régions du monde encore riches en ressources hydroélectriques, inexploitées à ce jour, par suite de leur distance des centres de consommation.

SALVETTI

I find the proposal of Mr. Angelini a very interesting one. But we have to observe that large energy resources (in particular hydro-power) exist today in countries characterized by a certain political instability. I want to recall, in this context, the proposal presented a few years ago by Zaire to build a large international uranium enrichment plant using the cheap electrical power of the Congo River: for the above mentioned reasons, the proposal had no follow-up.

COUTURE

I want to reply to the different comments made on my paper:

1. I agree with Dr. C. Starr's remarks on the diagram relating energy consumption to GNP for different countries and I thank him for mentioning the factor "value of money" for internal use and for international exchanges.

Also, he very rightly pointed out in answering to Prof. Leprince-Ringuet, that you must not call "waste" an optimal use of energy when its price was very low.

2. Prof. Colombo's remarks on Italy's evolution are, in fact in the same line of thought and it was, I agree, not unwise for Italy to be a center for oil industry.

3. Prof. Teillac rightly insisted on the "time factor" and I am in complete agreement with what he said.

FOSSIL FUELS AND PROSPECTS

Chaired by Professeur C.L. Wilson

INTRODUCTION

CARROLL WILSON

Fossil fuel in the form of coal constituted an essential foundation on which the Industrial Revolution was built. In the late 18th century renewable fuel in the form of wood was being rapidly depleted and was wholly insufficient as fuel for iron, steel, railways, steamships, and factories. Coal was used directly or converted to coke which resembled charcoal for iron and steel production. Coal mining grew rapidly as did sea-borne coal trade.

Then in 1860 commercial oil production from wells began. Quickly an industry was built to find, produce, transport, refine and distribute oil products. Being easier to produce and transport and more versatile in its uses especially to meet the rapidly growing demand for motor fuels, oil use grew rapidly, especially from 1950 to 1975. Moreover, the absolute scale of total energy use grew to an enormous scale from 40 mbd in 1950 to 115 mbd by 1975. By 1978 half the world's commercial energy was supplied by oil (63 mbd), 26% by coal (33 mbdoe), 17% by gas (21 mbdoe), 5% by hydro (6 mbdoe), and 2.4% by nuclear (3 mbdoe).

Thus with fossil fuels — oil, coal and gas — supplying 93% of the world's energy it is fitting that we examine at the outset of our week of studies the prospects for future availability of oil, gas and coal.

One of my friends in the oil industry remarked recently that if oil and gas had never been discovered and developed we would not have an energy crisis today. We would have learned to use coal for our many needs and would have developed other energy systems much more vigorously. But oil and gas were developed and now supply 2/3 of the world's energy. Therefore we turn our attention first to global prospects for these two vital fuels.

THE FUTURE OF CONVENTIONAL OIL IN THE WORLD ENERGY OUTLOOK: THE CASE OF DEVELOPING COUNTRIES

P. DESPRAIRIES
Chairman of the Board of Administration of the Institut Français du Pétrole

Oil will continue to be indispensable for the world economy to keep on functioning until the end of the century. There is great danger that it may not be available in sufficient amounts and at prices which do not hinder growth. If supplies should be interrupted or greatly decreased, the resulting upheavals could even be at the origin of armed conflicts.

As has been requested of all speakers, the present talk will begin by a general overview of the world energy problem before taking up the specific case of oil.

We will speak only of so-called conventional oil during the next 20 years. The adjective "conventional" simply means that it is the oil we use every day, produced at moderate cost by means of processes in current usage, by drilling wells onshore or offshore when the water depth is no greater than 300 meters.

This afternoon Dr. Schneider will tell us about other oil, unconventional, which is much more abundant but considerably more expensive and more difficult to produce, as well as natural gas.

Part 1

WHAT IS THE WORLD ENERGY CRISIS ALL ABOUT?

Essentially, a slowing down of the growth rate of the economy, in particular as the result of the available energy production, and a reconversion of the world oil economy toward other more abundant energy sources on land, and with lower prices. Since the World War, the economy of the earth has undergone exaggeratedly fast growth, which oil alone has been able to nourish, thanks to the exploitation of the enormous fields in the Middle East. The excessive growth rate of the years 1955 to 1970 could not be maintained, and it was broken off in 1973. We are in the process of the following developments: (a) returning to a slower rate of economic growth, (b) consuming less energy for the same growth, and (c) consuming less oil and more coal and nuclear electricity while waiting for the renewable energy sources of the 21st century.

This transformation will take from 10 to 20 years and will be accompanied by high prices and shortages which will depend in seriousness on two factors: (a) the world economic growth rate which will entail energy consumption and (b) the rate of investments that will have to be undertaken to reduce the demand for energy and to increase the supply. If sufficient amounts are invested early enough to make rational use of energy and to produce and use coal and nuclear electricity, we should once again find the abundance of supplies and stabilized prices between 1990 and 2000.

This return to abundance should be accompanied by the doubling of the energy market which today is a single one and is dominated by oil and its high prices. This situation will last as long as a latent shortage exists. After 1990, except if we assume that the world's economy will collapse into a sort of chaos or will be broken up and scattered in a hundred pieces hiding behind their own protectionist measures, we must assume that the excessive prices for energy will incite a great many entrepreneurs throughout the world to produce energy in the form of oil, natural gas, coal or nuclear electricity. We can thus assume that a certain abundance will return and that prices will become stabilized after having contributed, by their excess, to slowing down world growth.

Oil, whose production capacity appears limited and seems to have practically reached its ceiling, will probably be reserved for noble uses such as transportation, petrochemicals and the essential needs of the developing countries not having any industrial infrastructure. On the primary-energy market, its share will probably be reduced from 45 to 30 percent. Its selling price will probably be stabilized at a maximum of between one and a half and two times its present price, i.e. the price of synthetic fuel produced from coal, or between \$ 45 and \$ 60 (1980 dollars) per barrel. It is not excluded, although less probable, that it will return to a level similar to the present price (1).

The price of natural gas will tend to approach the price of oil. Its outlet will tend to become limited to household or specialized uses as a result of this.

Coal and nuclear electricity will become the basis for the energy supply with more than half of the market (they now represent less than 30 percent). Prices of nuclear electricity will be the ones that will be approved or set by the different countries depending on the cost prices. Coal prices will be established on the basis of cost prices as well, under the effect of international competition. It is supposed that they will be approximately half the price of oil, i.e. between \$ 50 and \$ 20 per BOE (2). However the penetration of coal and nuclear electricity will be slow. It requires large-scale and costly transformations of transportation facilities and equipment to use it (coal furnaces for electric power plants or industries, construction of industrial furnaces and equipment operating with electricity, insulation of houses, etc.). Coal is currently being slowed down by the outlets, the clientele, and not the supply. In the United States there is a production capacity of 100 Mt of unused coal per year which does not find any taker despite a price which is approximately one quarter of oil in energy equivalent.

Between now and this hoped-for return to abundance, a passage via a period of shortage appears inevitable if growth is to remain relatively high, and this is so because of the insufficiency of equipped and available production capacities. Some 100 surveys undertaken since 1974 by international teams of geologists, economists and industrialists all reach the same conclusions. If world economic growth were to be appreciably higher than 3 to 3.5 percent (3 percent in the industrialized countries and 5 percent in the developing countries for example), the insufficiency of energy supplies risks being a factor slowing down growth. This growth was slightly less than 5 percent in the world between 1960 and 1976, including 6.4 percent in the Third World and 4.6 percent in the industrialized countries. Calculations leading to this alarming conclusion assume that an appreciable effort has already been

(1) The price in October 1980 is \$ 30 to \$ 35 per barrel. There is an average of 7.3 barrels in one metric ton of oil. The cost per barrel of oil is an average of \$ 4 or \$ 5. This varies between \$ 1 (Middle East) and \$ 10 to \$ 15 (North Sea and difficult conditions).

(2) BOE = barrel oil equivalent.

made for energy conservation, with a world elasticity coefficient ([3]) of 0.85 to 0.9, and the good start-up of production of coal, nuclear electricity, gas and oil outside of OPEC. It is known that OPEC wants to reduce its production. The danger of an energy shortage appears great if OPEC should decide to stabilize its production at a level appreciably below 25 million bbl/day (1,250 million tons/year), whereas economic growth would be between 3 and 4 percent. The tendency of OPEC is currently to maintain production between 25 and 30 million bbl/day. Therefore to prevent the slowing down of growth, energy-conservation efforts would have to be increased (for example, reducing the energy elasticity in the GDP from 0.9 to 0.7 or even 0.6, which might be possible at the price of high investments), and to increase the production of non-petroleum energy (coal, nuclear) and that of oil from outside OPEC. These figures and this reasoning assume that the planned-economy countries are self sufficient or exporters of energy and, naturally, that no political or military crisis will occur in the Middle East.

Unfortunately, to replace oil for which the resources are leveling off, savings in consumption and new energy production are possible only if high investments are made and with a lead time of six to ten years, whether with regard to a nuclear power plant, a coal mine or a new oil or gas field. These lead times are incompressible in open border economies working in a climate of competition. They could be reduced on the assumption that an economic mobilization were brought about so that cost prices were no longer taken into consideration.

The OPEC countries are currently in a favorable position and the consuming countries in a situation of dependency, and the latter situation will last as long as the necessary investments are slow in being decided upon.

The next ten years will thus see a strong tendency for oil prices to rise, along with those of natural gas which is an immediate substitute for oil without any costly modification of the equipment using it.

The price of coal may also increase in the years to come if the demand is high (for example, if a great many thermal power plants decide to convert from fuel oil to coal) and if new coal mines are not opened quickly.

The price rises of the major energy sources thus risk being great

([3]) Ratio of growth of energy consumption to growth of GNP.

between now and 1990, the average lead time for responding to energy investments, unless the world economic growth should be reduced, for example, to about one to two percent, slowing down the demand and the price rises. The energy economy is international — very few countries are autarkic — and its prices are the prices of the international market. Electricity is the only one that escapes from this rule because it is difficult to transport over long distances and its prices are controlled by the governments.

The energy scenarios for the future that can be imagined to reflect the path to follow are three in number:

(a) A dark scenario which involves the cutting off for six months to one year of one third or half the oil supplies from the Gulf, i.e. the reduction of world oil exports by one quarter or one third. This is the true crisis situation. The state of political and military instability in the Gulf makes it a real and serious danger. The Iraqi-Iranian war is an illustration of this. However, it is impossible to evaluate the danger. Its occurrence automatically leads to measures of a political order, including rationing, and in some dramatic hypotheses leading to the threat of armed interventions (deliberate stifling of the purchasing countries who declare they are ready to pay very dearly for oil and to accept a plan, for example to reduce their purchases). The dark scenario is beyond any planning possibilities.

(b) A rosy scenario assumes the conclusion of an agreement between producing and consuming countries, calling for scheduled price rises and production levels, which would enable both sides to make investments in production and use between now and 1990 to 2000. This solution is the reasonable one, but there is little chance of reaching such an agreement without going via a moment of truth involving one or several more or less serious economic crises that will show each of the groups of countries the limits to what it can obtain from the other and the need to negotiate.

(c) A gray scenario assumes that such a moment of truth occurs and that it is accompanied by discontinuous and excessive price rises that will lead both sides to take the problem as seriously as it deserves, i.e. to invest and to negotiate. Energy prices would become stabilized as a result of this dual effort, probably some time between 1987 and 1990, let us say "around 1990".

Therefore, in the next 20 years energy will be a threat to world economy in two ways. The first danger is of an economic nature because it is a sharp price rise. This is certain and relatively measurable. The second danger is political because it is a reduction of a large portion of the world oil supplies. Its chances of occurring and consequences are not measurable, but this danger is just as real as the first one. Both of them must be taken into consideration for determining the insurance premium that must be paid in the form of investment and collective discipline.

The main effort to be undertaken in the next 20 years has to do with fossil and fissile energies. If renewable energy sources are demanding intensive technological efforts beginning now, this is to prepare the replacement in the next century of the stock of fossil fuels we are now living on. However, these new energy sources will not be able to give us anything meaningful to solve the crisis of the next 20 years. No matter what financial and technological efforts we devote to them, they cannot provide us with much more than five percent of the resources required for economic growth.

Part 2

Conventional Oil between 1980 and 2000: How to Widen the Bottleneck?

Between now and the year 2000, oil will remain at the heart of our problems. We cannot do without it. It now represents 45 percent of our world resources, and it will still account for 40 percent in 1990. It is only in 2000 that its share could drop to around 30 percent. Indeed, the demand has a great many reasons for remaining high and for causing tension with regard to prices:

— non-petroleum energy sources will not be available before 6 to 10 years;

— investment costs in equipment for producing non-petroleum energy, with the exception of coal, are much higher than those of oil;

— the economic take-off of the developing countries, which are the greatest demanders of additional energy between now and 2000, will mainly be based on oil because of the lack of electricity and gas networks;

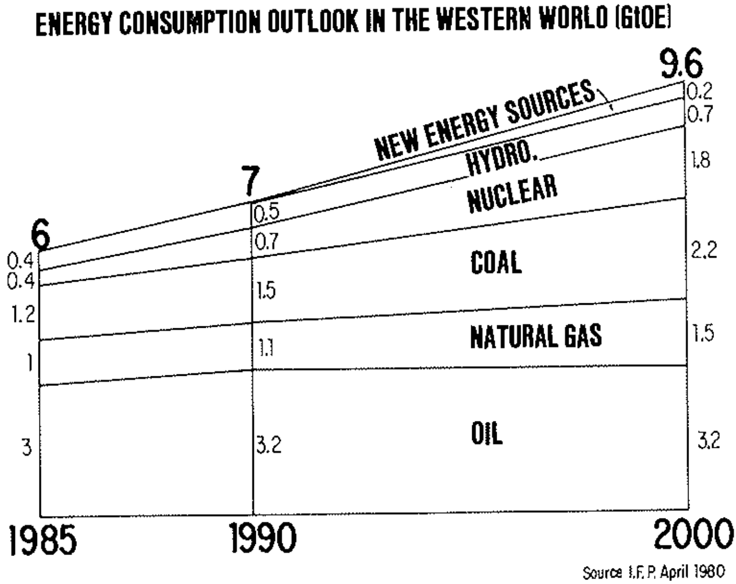


FIG. 1

— reconversion to non-petroleum energies, with the exception of natural gas, requires a long and costly adaptation of existing equipment;

— oil is the only shock-absorber energy which possesses large amounts of reserves that are more or less instantaneously available in case of fluctuations in growth, i.e. 400 to 500 million tons per year at present, without raising problems of employment.

What must be done to obtain a better balance between supply and demand of oil and to prevent a shortage? How can we reduce the demand and increase production?

Let us begin by trying to analyze the general situation in both the industrialized and developing countries. Then let us review the remedies which may be applied to improve this situation.

1. Analysis of the Situation

1.1 *General Description*

In an attempt to illustrate the oil crisis by a familiar picture, we could say that, as opposed to what is sometimes thought, it is not a

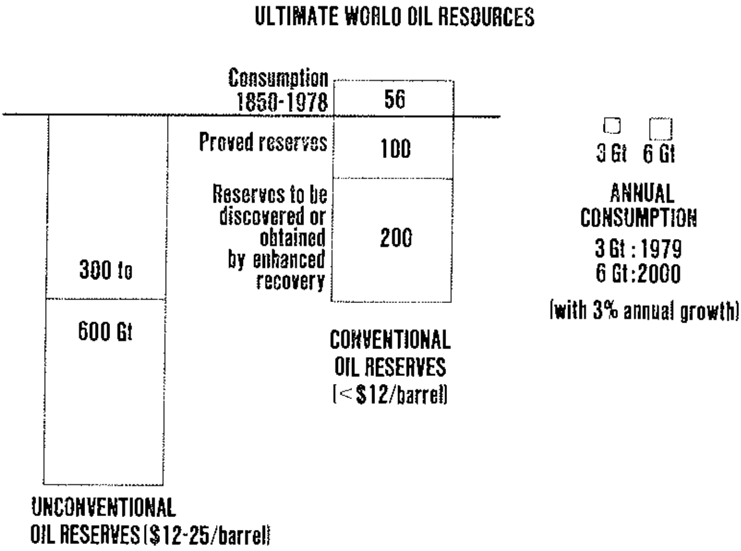

ULTIMATE WORLD OIL RESOURCES
Consumption 1850-1978
56
Proved reserves
100
Reserves to be discovered or obtained by enhanced recovery
200
300 to
600 Gt
CONVENTIONAL OIL RESERVES (<$12/barrel)
UNCONVENTIONAL OIL RESERVES ($12-25/barrel)
3 Gt
6 Gt
ANNUAL CONSUMPTION
3 Gt : 1979
6 Gt : 2000
(with 3% annual growth)

Fig. 2

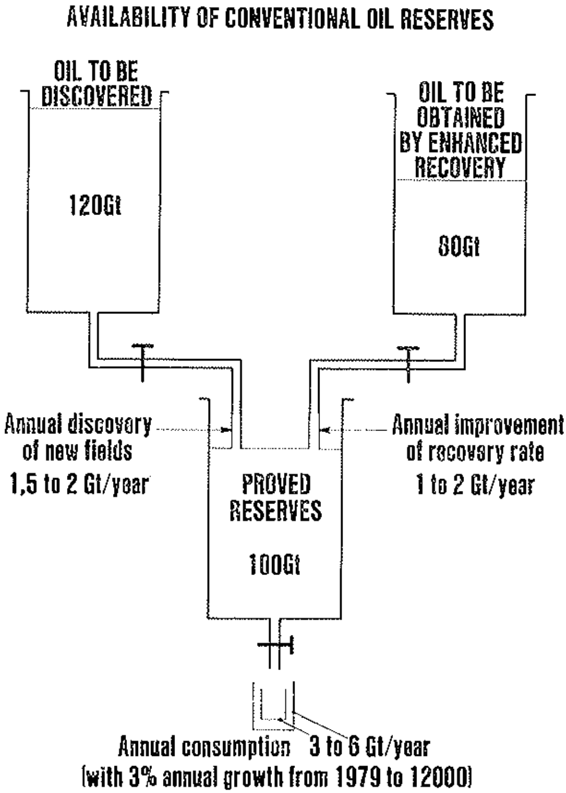

AVAILABILITY OF CONVENTIONAL OIL RESERVES
OIL TO BE DISCOVERED
120Gt
OIL TO BE OBTAINED BY ENHANCED RECOVERY
80Gt
Annual discovery of new fields
1,5 to 2 Gt/year
Annual improvement of recovery rate
1 to 2 Gt/year
PROVED RESERVES
100Gt
Annual consumption 3 to 6 Gt/year
(with 3% annual growth from 1979 to 12000)

Fig. 3

problem of the tank but one of the faucet. The physical resources remaining to be recovered from the earth's crust are enormous and have bardly been exploited. Five sixths of the initial fossil amount of conventional oil remains to be produced, i.e. approximately 300 billion tons out of 350. This is enough for another 100 years at the present rate of consumption, including the socialist countries. The difficulty comes from the fact that, for economic and political reasons, the annual world production capacity today of slightly more than 3 Gt/year (3.2. Gt in 1980) is in great danger of being a lasting and definitive ceiling, whereas since 1950 the production capacity has been doubling every 10 years.

This blocking of production capacities has economic and political causes.

1.1.1 The decrease in the amount of oil discovered each year since 1965 does not allow much bope for any increase in production capacities very much higher than one percent per year (4) unless discoveries

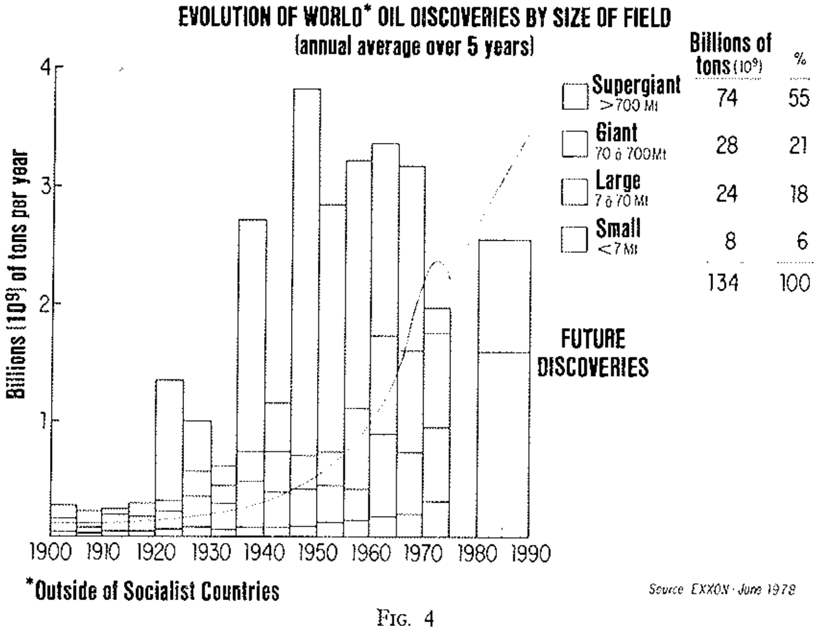


FIG. 4

(4) See the paper by F. PARRA, *World Producing Capacity of Hydrocarbons,* presented

are made, although this is now not considered as very probable, of a series of exceptionally large fields comparable to the ones found in the Middle East between 1945 and 1960. It is not impossible that Mexico may end up by being a very large petroleum province. Its scale is currently only one seventh or one sixth of the Middle East. Despite extensive prospection efforts, our second harvest of oil is in tbe form of fields that are smaller and more difficult than the ones found before 1970. Exploration and production costs are appreciably higher, and ten reservoirs must be found where a single one sufficed 20 years ago. For ten years now we have been consuming twice as much oil as we have been finding. Therefore, it has become difficult to increase annual production without decreasing the level of proven reserves, a "buffer tank" of some 90 billion tons available by just turning the faucet which supplies the world economy with its daily oil.

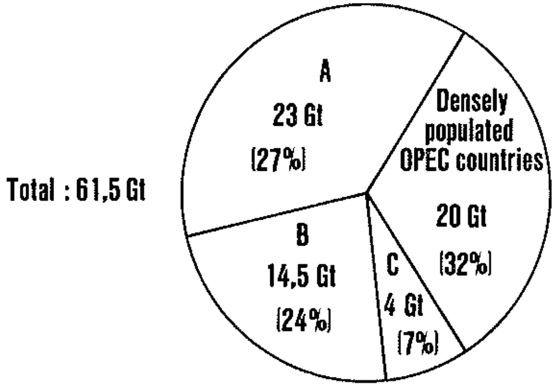
1.1.2 Political reasons exist in addition to economic reasons for reducing production.

1.1.2.1 The Islamic revolution in Iran in January 1979 demonstrated that Islamic opinion wanted neither oil production at too fast a pace nor headlong industrialization. "We want to produce our oil over 70 to 100 years and not over 30 or 40 years as is now the case". The goal sought after is to adjust production rates for longer and more realistic industrialization lead times, to prevent social and religious uprooting and to husband a unique fossil capital that is accruing in value each year, whereas inflation is whittling away the value of the currencies used for payment. The temptation to reduce production to the level of expenditure capacities might be particularly strong among the densely-populated large-producer countries in the Arab peninsula (770 Mt produced in 1979, more than half of OPEC production) and Libya (100 Mt/year).

The share of production which merely creates financial surpluses that cannot be spent quickly must be considered as "undesirable" production. The present and foreseeable financial excesses (G $ 50 to 100 per year) must make 200 to 400 Mt/year be considered as such, i.e. 15 to 30 percent of the current production of OPEC. These countries are

at the 10th World Petroleum Congress (Bucharest, September 1979), analyzing world discoveries and exploration effort between 1966 and 1978.

PROVED OIL RESERVES OF OPEC COUNTRIES (on 1/1/79)



Densely populated countries : Nigeria, Venezuela, Algeria, Iran, Iraq, Indonesia.
Sparsely populated countries : A. Saudi Arabia
B. United Arab Emirates, Kuwait, Qatar.
C. Libya, Gabon, Ecuador.

FIG. 5

feeling, or risk feeling, considerable encouragement to accompany any reduction in the world demand by a decrease in durable and, if possible, definitive production to prevent prices from decreasing. Saudi Arabia is in a decisive and delicate position. It supplies one third of the output of OPEC and takes in one half of its financial surpluses. Its desire to prevent disorder in the Western countries leads it, along with the United Arab Emirates, to be resigned to the existence of financial surpluses. Since December 1979, OPEC production has followed the decrease in world demand and has dropped 10 percent (150 Mt/year), including only 40 percent (60 Mt/year) as the result of Iran.

1.1.2.2 The objective sought after by the OPEC countries is not to strangle the West but to obtain the best possible price for an irreplaceable resource which is the only way to finance their development. The picture we should have of the producing countries is distorted by the one we have of the Arab peninsula. The very great majority of the countries making up OPEC are poor and densely populated. Despite their oil production which is sold at actual prices that have sextupled since 1972, their annual per-capita income is less than

$ 1000 in 1980 dollars, i.e. approximately one tenth of the income in industrialized countries. Furthermore, oil accounts for 90 to 95 percent of their GNP. OPEC can thus legitimately consider that it represents the developing countries. It wants to negotiate its "oil capital" against "development, industrial and agricultural capital", i.e. investment, technology and access to markets in the industrialized countries. These latter countries, which are in the throes of underemployment, will not be any part of such a negotiation unless they are forced to be so. The OPEC countries, on their side, will not hesitate to do this as long as they are not sure of having achieved the best prices for their oil. How can they be sure of this as long as the customer countries can pay the prices demanded without having their growth slow down? The OPEC countries point out that one percent of the growth of the industrialized countries represents ten times more income per inhabitant than one percent in their own countries.

The goals of OPEC were set forth in a document completed in February 1980 by a long-term strategy committee chaired by the Minister for Petroleum of Saudi Arabia, Sheik Zaki Yamani. After having been discussed on a high level during the summer, the document was scheduled to be submitted for approval by the OPEC heads of state meeting in Baghdad in early November. However the present military events have caused a delay in this meeting. The document proposes in particular: (a) a quarterly indexing formula for the floor price of oil based on the rate of world inflation and the growth rate of the industrialized countries, with the effective price being set above that if market conditions so allow; (b) the principle of an orderly reduction in production in case of a surplus; (c) the transformation of the Special Development Fund for Third World Countries into an OPEC development agency endowed with an initial capital of $ 20 billion. Its assets would serve to partially compensate for oil price rises in the developing countries and to help them produce oil and energy in their own territories. The industrialized countries would be associated in the financing of this Fund. The suggested shares appear to be two thirds for the industrialized countries and one third for OPEC. (d) the statement of demands that might serve as a basis for a dialogue with the industrialized countries includes the following: (1) a guarantee of financial investment by the OPEC countries against monetary erosion, (2) greater participation by the OPEC countries in the management of IMF and IBRD, (3) an increase in aid by industrialized countries to developing countries, (4) the development of petrochemical industries in the OPEC countries and access for their output to markets in the industrialized countries, (5) participation by the industrialized countries in oil exploration in the OPEC countries, (6) the providing of technology and research-and-development to these countries, (7) the installation in OPEC countries of basic processing industries using natural gas, and (8) better integration of OPEC businesses in the economy of the industrialized countries.

Agreement was not reached on all the proposals in Vienna on 17 September 1980 before the conflict broke out between Iraq and Iran, and so concerted action on an OPEC strategy is delayed for an indefinite length of time. Iran, Libya and Algeria continued to call for more severe conditions for the industrialized countries. The leading points of diversion continued to have to do with the nature of the Aid Organization for the Development of the Third World (bank, increase in present OPEC funds, creation of a fund associating OPEC and tbe industrialized countries); the formula of more or less closely indexing the prices of crude oil (to inflation in the industrialized countries or to the higher inflation in the OPEC countries); the initial price should be what was indexed, i.e. $ 30 or $ 32 or even $ 40, if not $ 45 per barrel? The only point of agreement appeared to be the refusal for an OECD/OPEC dialogue on oil that would be separate from a general discussion encompassing all North/South economic problems.

* * *

The demand for oil is tending to increase, while the supply is tending to level off or diminish. Insufficient amounts of oil available on the market could result in new price rises and, in the years to come, could cause purchasing competition among the industrialized and developing countries. The proposals by the OPEC Long-Term Strategy Committee consider that this situation is favorable to the organization.

1.2 *Dependence of Industrialized Countries*

With rare exceptions, the industrialized countries will apparently remain importers of oil for a long time. The United States imports 40 percent of its consumption, Japan 97 percent, and Western Europe 85 percent. There is no longer any serious hope of making large-scale discoveries in any of these three groups of countries. Despite greatly increased prospection efforts in the United States (16 percent more wells will be drilled in 1980 than in 1979, practically equaling the record set in 1956), the production by this country is predicted to decrease during the decade and, at best, to remain stabilized at its present level in 1990. At around that time, production from the North Sea should have begun its decline, and neither in the remainder of Europe nor in Japan are any plans being made to increase production in any other than a marginal way.

The oil dependence of the industrialized countries thus appears durable, and it is by reducing energy consumption as a whole and by conversion to energy sources other than oil that they can hope to improve their position. These efforts will be based on large-scale investments which appear feasible on account of the standard of living but which will weigh heavily on the income of their inbabitants.

It is not so much the importance of imported oil in their BNPs — approximately 4 to 5 percent (1 to 1.5 percent before 1973) — which makes this dependence such a serious constraint, but rather the unpredictability and abruptness of the rises which set off effects in cascade in the fragile mechanisms making up modern economies and go way beyond their slight theoretical and arithmetic impact. The imbalance in foreign trade — in which oil accounts for 15 to 25 percent of the imports — together with inflation and monetary erosion are causing governments to take steps to cool off the economy, going beyond any direct impact. Energy is at the heart of all economies moreover, and the abrupt rise in prices has psychological effects going beyond any mechanical effects. On the other hand, planned rises could be absorbed without any harmful effects.

1.3 *The Dependence of Developing Countries Is Much More Preoccupying*

The burden of oil imports in their balance of payments is a very heavy one. The growth of their needs promises to be fast, particularly in the field of oil, and this will be a fundamental aspect of their economies for a long time to come. There are interesting possibilities of making oil discoveries which are not being taken advantage of in these countries.

1.3.1 When imports are reduced to what is indispensahle, oil takes the place of essential consumer and capital goods. It makes up a high or very high portion, in some countries as much as 50 or 60 percent of the imports, or even 70 percent (India, Brazil). This imbalance leads the developing countries which can do so to sharply increase their exports (India, Korea), thus increasing competition on the world market and contributing to aggravate export and employment problems in the industrialized countries. Each country tends to transfer its trade deficit to other countries to pay for its vital imports.

The growth of the developing countries, which are moving on from the agricultural stage to the beginnings of industry, requires much more energy than that of the industrialized countries for the same GNP growth rate. The elasticity coefficient of energy in the GNP, which in our countries is 0.8 to 0.9, in the developing countries amounts to 1.2 or 1.3 percent additional energy consumption for one percent growth.

A series of recent surveys has revealed the increasing share of the developing countries in the world demand for energy. Messrs. Giraud and Ferrari, in a paper presented in September 1977 at the Institut d'Etudes Politiques in Paris, showed that between 1975 and 2000 their consumption would quintuple and go from 0.6 to 3 billion tOE per year and from 14 to 32 percent of the world demand. Four fifths of this increase would be brought about by countries undergoing economic takeoff, while the consumption of the poorest countries would remain very small.

1.3.2 A highly interesting survey described by Romain Frisch at the World Energy Conference in Munich in September 1980 ("Horizons énergétiques du Tiers Monde 2000-2020; une approche régionale des consommations et des approvisionnements") confirms these trends. The Third World will account for 35 percent of world energy consumption in the year 2000, and the countries already caught up by the pace of growth, in particular those in Latin America, will undergo exceptionally high increases in consumption. In the year 2000 the developing countries should have a commercial energy consumption of 4.4 GtOE, which is almost equal to that of the industrialized countries in 1976 (5 GtOE). Between 1976 and 2000, the developing countries should thus account for 40 to 45 percent of the increase in world energy needs as compared with only 28 percent of this growth between 1960 and 1976. "The Third World countries will thus progressively take over from the industrialized countries in making up the world demand for energy", writes Mr. Frisch. The population growth is such, however, that energy consumption per inhabitant in the Third World must remain on a modest level, with 0.9 tOE per year per inhabitant in the year 2000 (compared with 0.4 in 1976), i.e. one fifth of the present consumption per inhabitant of the industrialized countries.

* * *

1.3.3 Of course, there is no certainty that the economic growth of the developing countries will follow the rate which is reasonable, a priori, given by Mr. Frisch. Considerable investments would be required, and they would have to be made quickly and would entail great changes in customs for the inhabitants of the Third World in the year 2000 to have a standard of living equal to approximately one half (1 tOE) of that of Spain in 1980 (2.5 tOE) and two thirds of this level in 2020 (1.5 tOE).

However, the trend is clear, and oil will continue to play a predominant and irreplaceable role in the growth of energy consumption in the Third World for many years to come. For the developing countries, oil is the energy of everyday living and for the beginning of economic growth. It is absolutely essential for lighting, heating, farming, essential transportation and the first industrial installations. The population of such countries is generally scattered, there is an absence of industrial infrastructure, the technological level is not very high, no networks exist for distributing gas and electricity, coal is not abundant and nuclear electricity is a thing of the future. For this reason, oil plays a much more important part in the low level of energy consumption in such countries than it does in the industrialized countries. Contrary to what might be thought, oil is thus much more the basic energy source for poor countries than for rich countries.

The delay in the appearance of energy sources to replace oil will thus begin by penalizing the countries in the Third World. Michel Pecqueur, the General Director of the French Atomic Energy Commission, speaking in Munich in September about the canceling of 48 nuclear projects between 1977 and 1980, which will be compensated for by just 38 new projects, said, "All these canceled megawatts are the oil that will be lacking for the developing countries".

OIL IN THE ENERGY CONSUMPTION
OF THE DEVELOPING COUNTRIES (1976)

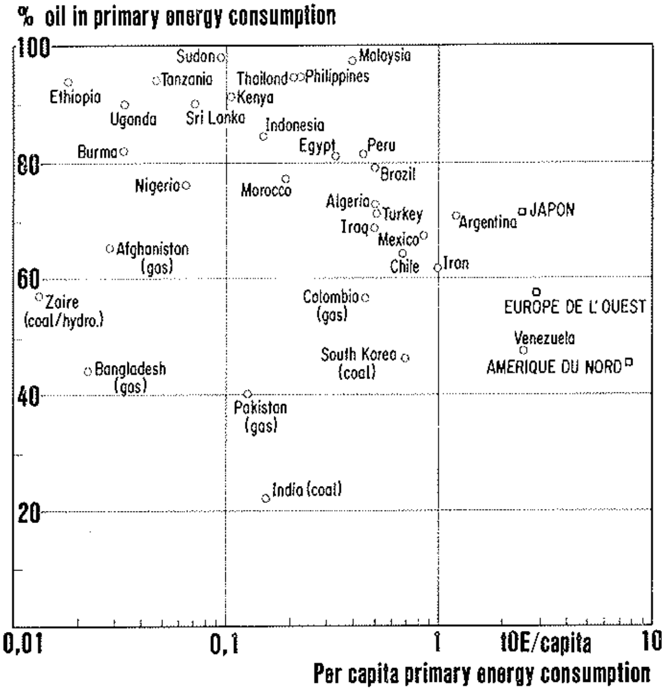


Fig. 6

Therefore, Mr. Frisch's survey rightly foresees high rates of oil consumption in the Third World in the year 2000. Excluding China which is considered to be self-sufficient and which uses exceptionally high amounts and proportions of coal, the survey foresees that between 1976 and 2000 the oil consumption of the Third World should quadruple, going from 350 to 1.370 million tons. Whereas the share of oil in the energy consumption of the industrialized countries will drop from 46 percent to approximately 30 percent between now and the end of the century, it should remain at about 53 percent in the Third World (compared with 59 percent at present).

The share of the Third World countries in world oil consumption, which is now approximately 12 percent, would thus rise to 43 percent of world production if the level of this production were assumed to be equal to the present level of 3.2 Gt. The needs of the OECD countries

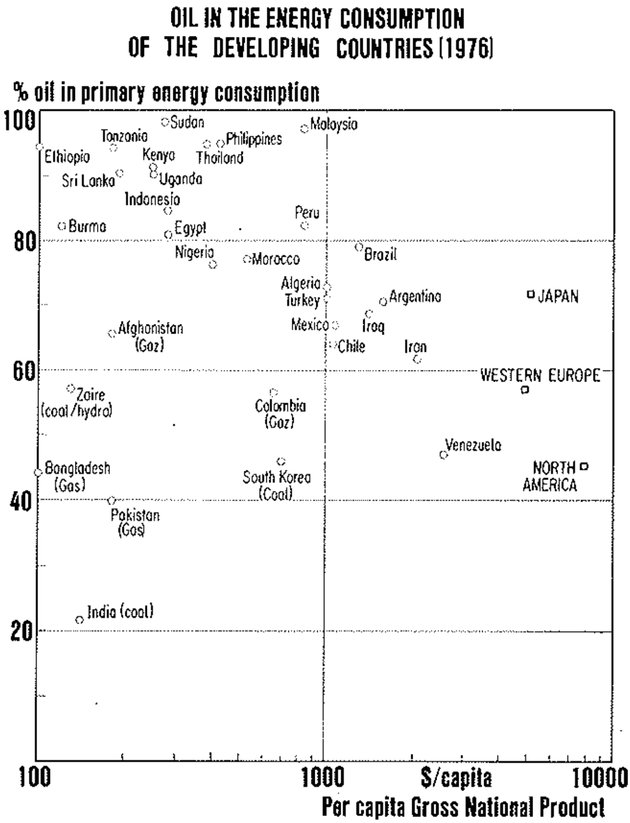


FIG. 7

and the planned-economy countries, according to present forecasts, would then amount to a total of approximately 3 billion tons. However, only 1.8 billion tons would be available to them once the developing countries had been supplied. It can thus be seen that a serious rivalry is in the offing with regard to oil resources if world economic growth and especially that of both groups of countries continues at the rate now being forecast.

The OPEC countries are aware of this. Different studies and declarations in recent months as well as the report by the Long-Term Strategy Committee point out that OPEC oil must be earmarked in priority to fulfilling the needs of the developing countries after the energy consumption of the producing countries themselves has been covered. Yet this consumption by the producing countries is now 175 million tons oil equivalent per year, including 100 million tOE/year of petroleum products, and it should increase to 310 MtOE in 1990 and probably 600 MtOE in 2000. Nonetheless there is hope that a large share of these needs will be covered by natural gas.

1.3.4 At the same time, the developing countries, which have large potential reserves of oil and gas, do not have the capital required for prospection, and exploration efforts by oil companies are unfortunately concentrated on the subsoil of the industrialized countries.

1.3.4.1 A poll of the Delphi type carried out in 1976-77 by the Institut Français du Pétrole for the World Energy Conference, and with opinions from 29 of the most qualified world oil experts (government services, oil companies, geological consultants), showed that, outside of the socialist countries, 125 billion tons remained to be discovered in the world. An approximation of the results of the poll showed that about 55 percent of the amount in question (70 Gt) will probably be found in the OPEC countries, 20 percent (25 Gt) in the industrialized

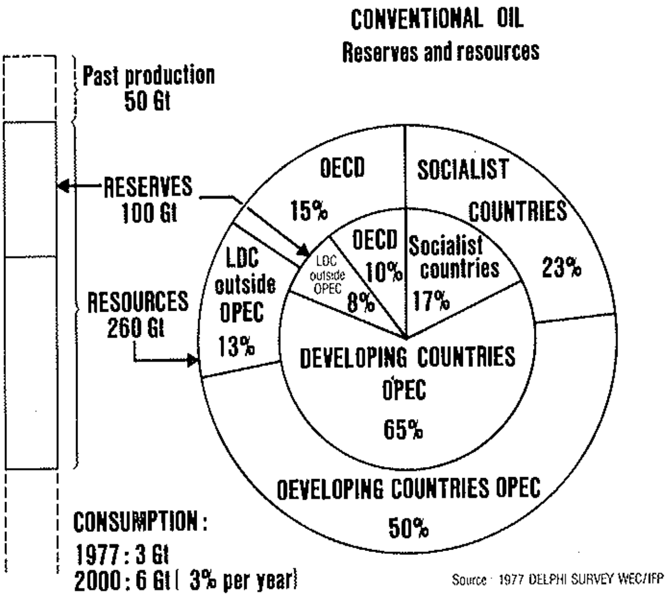


FIG. 8

countries, and 25 percent (30 Gt) in the developing countries that are not members of OPEC (5). Some of them, such as Mexico, are already large producers and do not want any assistance from foreign investments. There is still a large number of Third-World countries that have interesting discovery potential in South America, Africa and the Far East but that are not the scene of systematic prospection that would apparently be justified by such expectations.

A series of surveys made by the World Bank between 1975 and 1978, and republished in a recent report by this organization ("A Program to Accelerate Petroleum Production in the Developing Countries", January 1979), points out that the drilling of wildcat wells in 1975 and 1976 in the non-oil-producing developing countries represented only five percent of the world total. This report, which was compiled before the latest price increases, states that out of 38 countries which might be the scene of oil prospection only 8 have been satisfactorily explored, and 30 others are excellent candidates for prospection, includ-

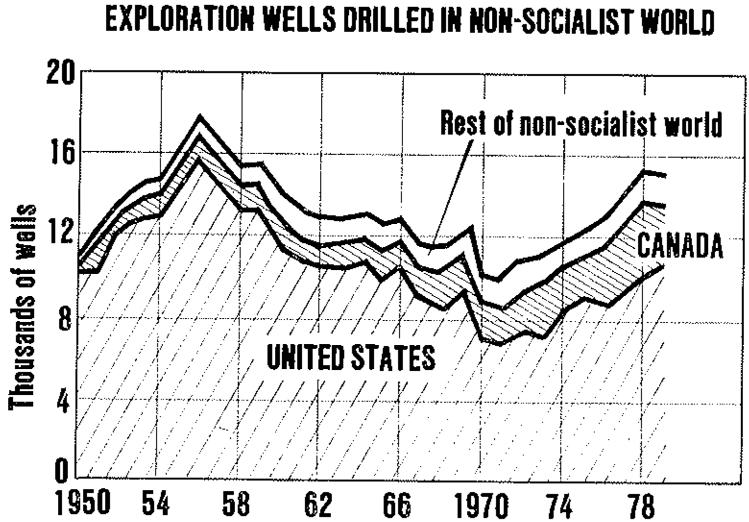
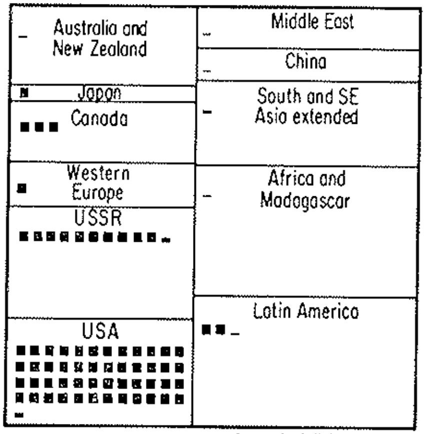


Fig. 9

(5) An older survey made in 1975 by the World Bank gave figures that were not so high but were still quite large, with 12 Gt of ultimate recoverable oil reserves in 84 developing countries not belonging to OPEC.

WELLS DRILLED IN RELATION TO PROSPECTIVE AREAS AROUND THE WORLD



Source: Dr. B.F. Grossling-1976

Comments:

- Black squares represent cumulative exploratory and development drilling to end 1975
- A full square represents 50,000 wells
- Rectangles for country or area represent area of petroleum prospects to scale
- Both onshore and offshore prospects are included to a water depth of 200m

Fig. 10

OIL DISCOVERIES (United States)
Barrels discovered per foot drilled (1930-2000)

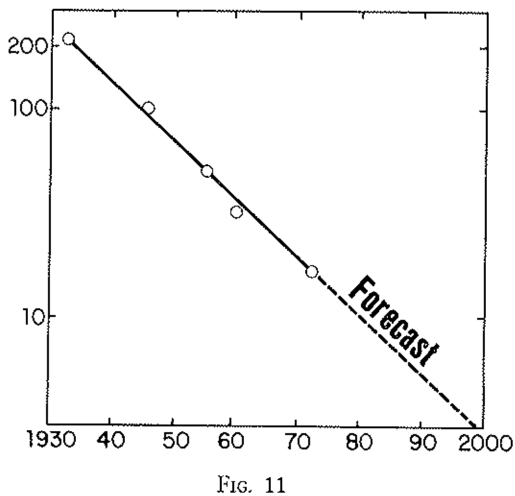


Fig. 11

ing 16 having high or very high potential. Among the countries in which such exploration could be carried out, there are large or relatively large consumer countries such as Argentina, Colombia, India, Pakistan, Peru, the Philippines, Turkey and Vietnam.

Other surveys have emphasized the unequal distribution of world prospection efforts. With regard to exploration expenditures outside of socialist countries, 70 percent are now being made in the OECD countries (including 50 percent in the United States alone). North America by itself is receiving 85 percent of the exploration drilling, and the developing countries are receiving less than 10 percent. Among the developing countries, the non-oil-producing countries are particularly neglected. Those already producing oil, in particular in Latin America, are in a relatively favorable position.

The results of these prospection efforts confirm their unequal distribution. The amounts of oil discovered in the United States between 1950 and 1978 decreased from 150 to 12 barrels of oil per foot drilled [6], whereas, as shown by the now classical study by Mr. Grossling for the U.S. Geological Survey, each foot of exploration drilling in recent years discovered 150 to 200 barrels in Latin America and 800 to 1.000 barrels in Africa.

1.3.4.2 The reasons for this unequal distribution of prospection investments are well known:

a) The low returns which are generally proposed for capital invested in developing countries, i.e. 20 to 80 cents per barrel produced on an average, whereas the return is $ 3 to 4 in the United States and Europe. The producing countries would doubtless accept a higher rate of return if an appreciable portion of these returns could be contractually reinvested at home. This distribution should be the subject of discussions and agreement. There is a wide basis for a consensus. Countries such as Argentina, Brazil, Pakistan and Turkey have found formulas enabling exploration investments to be attracted.

b) After the nationalization at the beginning of the 1970s, the fear of companies that a unilateral change will be made in the contract once a discovery has been made.

c) The desire of a certain number of OPEC countries, already

(6) *PIW*, 18 February 1980, page 2.

suffering from financial excesses, not to increase proven reserves available for production (the case of countries in the Arab peninsula).

d) The desire of a great many producing countries to use their financial resources coming from oil for their own economic development rather than for prospecting for oil which they will not consume.

All in all, a great many countries are not yet ready, often for quite legitimate reasons, to pay the price that would convince oil investors to run the risk of prospecting operations concerning their subsoil.

* * *

2. What Can Be Done?

The negotiation of an overall agreement between oil producing and consuming countries with regard to prices, amounts and development is the true solution to the problem that the world economy is facing with regard to what will take over from oil. However, it is difficult to hope that a dialogue will be begun as long as the stakes involved are a product so ardently sought after and whose availability and price remain so uncertain. First of all, world energy supplies must be made more reliable, the world oil market must be better balanced, and prices must be more or less stabilized for two or three years. To begin this process, there must be a reduction in world demand and an increase in world supplies of oil.

2.1 *Rebalancing the World Oil Market*

This effort will require behavioral changes, investments and pragmatic arrangements. To differing degrees, these three lines of action are already being pursued in a more or less confusing and hesitant way.

2.1.1 *What Can the Industrialized Countries Do?*

2.1.1.1 First of all, they can reduce their own demand for energy by investing to change their consuming equipment while reducing their consumption to achieve the same results. At the same time, the public can be encouraged to pursue a systematic behavior for energy conservation. This is a long and expensive task.

In some cases, existing equipment can be improved (e.g. by insulating homes that have already been built, by modifying a furnace or boiler, by insulating heating circuits, by replacing heat exchangers, etc.). Such a transformation is more costly per tOE saved than procuring new equipment that is basically designed to consume less energy. A great deal of energy conservation will thus come progressively as equipment is renewed in buildings, homes, industries, administrations and businesses. This will take 10 to 15 years or more to replace or revamp plants, homes and offices.

2.1.1.2 At the same time, the industrialized countries will have to make more investments in non-petroleum energy sources (coal, nuclear electricity) and in more efficient equipment for using them.

2.1.1.3 They can be more active in training manpower and in transferring their know-how so as to enable the developing countries to increase their own oil production. However, it must not be supposed that this training can be achieved in less than two to three decades.

2.1.1.4 The industrialized countries must maintain an attitude of understanding and openness with regard to the producing countries so as to prevent any open conflict and to advance real cooperation whenever it is to the advantage of both sides.

The aim of the energy policy of the OECD countries is to promote ventures of this type. It must be admitted, however, that since 1974 these policies have mainly remained verbal. The decrease in consumption in the industrialized countries has been the consequence more of price rises than deliberate effort. The attempt to establish a North/South dialogue in Paris in 1975-1977 was a failure. It probably had the defect of being premature.

2.1.1.5 At the same time, the industrialized countries can make collective contributions, in association with the OPEC countries, to energy production in the developing countries. This idea was put forth by the French Minister for Energy, Mr. Giraud, at the OPEC seminar in October 1979. A 50/50 OPEC/OECD fund would lend one billion dollars per year for the development of energy resources in the poorest countries. The SEV countries could join in financing this fund. It has been calculated that such a venture would mobilize four times more money for prospection. The countries benefiting from loans would participate in the management of the fund, and the World Bank would be the agent in charge of the execution of the projects. The low-interest loans would be repayable only in the case of discovery.

2.1.2 *What the OPEC Countries Can Do*

2.1.2.1 The OPEC countries, on their side, can concentrate on planning production to meet the needs of the market so as to limit any jumps or drops in supplies. This is the line that they have followed to date, except for the embargo in 1973-1974 caused by the bardening of the Israelo-Arab conflict. Production reductions (150 Mt/year between January 1979 and July 1980, of which 60 Mt can be attributed to the unintentional halt of Iranian production) were mainly limited to keeping pace with the drop in the demand.

2.1.2.2 The OPEC countries can also compensate for the rises caused by the oil-importing developing countries. They have undertaken this in several ways since 1974. Compensation generally occurs in the form of reimbursable loans. As the point of departure, the OPEC countries consider that the oil is sold at its true price and that this price must be the same for all customers. They have refused various proposals, in particular ones by Lybia and Iraq, that would tend to establish a dual price by maintaining a lower price for the poorest countries. They want to prevent any reselling and profit taking on the market. They also point out that the loans they grant represent a net deduction of approximately two to five percent of their GNP, which is much higher than that resulting from aid provided by the industrialized countries to the developing countries (0.3 to 0.5 percent). This taking of positions and these affirmations can hardly be contested, but the aid generously granted by OPEC and distributed by the Special Fund created in 1976 (increased to $ 4 billion available in 1980), even when added to the aid from other Special Funds (Kuwait, Abu Dhabi, etc.), represents only a portion of the surcharge imposed on the purchasing countries (7). If the debt is not canceled some day, it will merely be added onto a debt that is already very high, and which the rises in 1973-1974 have helped to increase, with respect to both the oil selling countries and the industria-

(7) Some documents add up the loans from the Special Fund and those from the Funds of the member countries (Saudi Arabia, Kuwait, Iraq, Abu Dhabi) and indicate a total of $ 42 billion loaned between 1973 and 1976, i.e. $ 10 billion per year, more than half of which is loaned under very favorable conditions. Other documents indicate an aid of $ 16 billion, i.e. $ 4 billion per year. In both cases it is difficult to determine whether the countries have made credits available to the Fund, whether loans have been granted to purchasing countries, or whether sums have actually been paid.

lized countries which sell their capital goods (the debt of the Third World was $ 366 billion at the end of 1979 compared with $ 119 billion in 1973). The Long-Term Strategy Committee has the project, put forward by Venezuela and Algeria, to transform the Special Fund into an Agency by endowing it with a capital of $ 20 billion. The proposal of the Committee is apparently to cover price rises to the amount of $ 3 billion per year and $ 2 per barrel imported by the developing countries. The principle is similar to the one for the Joint Fund created by Mexico and Venezuela in July 1980, guaranteeing the countries in Central America and the Caribbean that they would receive loans covering 30 percent of the price of oil for five years with an interest of four percent or for 20 years with an interest of two percent if the money is used for development projects. The agreement covers 8 million tons per year. These initiatives are generous for countries whose income is approximately $ 1.000 per inhabitant and for which oil is the only resource, but the principle involved effectively appears to be that of a partial compensation for the rises. Whatever the case may have been in the past, the problem of the price for the oil imports of the Third-World countries is raised for the future if the producing countries want to maintain links of solidarity with the purchasing countries in the Third World, as they apparently are very eager to do.

2.1.2.3 The OPEC countries could doubtless invest in the developing countries to help them produce their energy, and for this they could use some of their available assets which are now invested in the American or European markets. These annual surpluses of some $ 50 to 100 billion — this is the figure forecast for the next four or five years — would be highly useful if invested this way, although this would be more risky.

The idea mentioned above of cooperation among OPEC, industrialized countries and international institutions to develop the energy resources of the Third World, as proposed by the OPEC Long-Term Strategy Committee, deserves to be examined with interest. A multilateral fund could be created that would apparently be independent of the OPEC Special Fund. This point has not been decided upon. The OECD countries would participate by contributing to cover the price rise of their exports to the developing countries and by providing their technical experience. The report also mentions the World Bank, the United Nations and the socialist countries among eventual sources of credit.

This proposal by OPEC experts stems directly from an Iraqi proposal in the spring of 1980 for a Fund associating OPEC and the developed countries. It is encouraging to note that it is not very far away from the French proposal made in October 1979.

2.1.2.4 The non-oil-producing developing countries, if they want to look for oil in their subsoil, as well as the producing countries whether or not they belong to OPEC but desirous of such exploration (this is often the case of densely populated countries which need to finance their development), will probably have to change their attitude with regard to investors. The financial and commercial conditions that are proposed must be such that they do not force the eventual explorer to prefer zones where conditions are much more favorable, even if there is less chance of discoveries being made. For example, it is better for a country to give one dollar per barrel in case of success so that the country in turn can earn $ 20 or 25 than not to have any exploration of the subsoil. Mutually acceptable formulas have been found in different countries in the last two or three years, particularly in South America, and exploration has resumed there (Argentina, Brazil, Pakistan, Turkey).

2.1.3 *International Organizations*

The World Bank has the very great merit of being the first to initiate loans to facilitate the energy equipment of developing countries, first in the form of hydroelectric dams and coal mines, then beginning in July 1977 for the development of oil fields, and finally for oil exploration beginning in January 1979. This excellent initiative has led to encouraging results. In the spring of 1980, nine loan projects were being discussed for prospection (Madagascar, Somalia, Tanzania, the Ivory Coast, Morocco, Argentina, Bolivia, Honduras and Benin). Kenya, Ghana, Liberia, Turkey and both Yemens were added to the list during the summer ([8]).

The presence of the World Bank as a lender for prospection along with private oil investors must necessarily reassure these latter without arousing the susceptibility of the host country. Unfortunately, even

([8]) In all, loans by the World Bank and IDA in the exploration and production sector more than tripled between 1979 and 1980, going from $ 112 to 385 million (including $ 256 million loaned by the Bank and $ 128 million by IDA). There appears to have been a real take-off in 1980.

though it has opened up considerable credits (G$1/year for exploration), the World Bank comes on as a banker and not an investor who is risking his capital. It proposes loans that are repayable in any case (failure or success) accompanied by relatively mild repayment conditions, but at a relatively high interest rate (10 percent), and the low percentage of success of wildcat drilling often makes borrowers hesitant.

At the summit meeting in Venice in June 1980, the heads of state of the leading industrial countries recommended "a major international effort to help the developing countries to increase energy production", and noted that this preoccupation was progressing in the oil exporting countries. The heads of state asked the World Bank "to examine how to improve and increase its energy loan programs, in particular by creating new subsidiaries and new lending facilities". In agreement with this recommendation, the Board of Administration of the World Bank and the International Monetary Fund proposed the creation of a subsidiary of the World Bank for the purpose of financing the valorization of the energy resources of the Third World. Its initial capital would have been set at $ 5 or $ 7 billion, a figure which appears to be on a scale in keeping with the scope of the problem. The OPEC countries would be invited to participate in the capital of this subsidiary.

Likewise, in a study prepared in July 1980 (Energy in the Developing Countries), the World Bank forecast a 50 percent increase in the oil consumption of the Third World between now and 1990, and it proposed the doubling of the loan program now in progress for all energy projects, which would be increased from $ 13 to 25 billion. These loans would serve to finance $ 92 billion worth of projects. With regard to oil alone, the loans would be increased from $ 4 to 8 million (including one quarter for prospection). They would be used to finance an oil project amounting to $ 24 billion, which is double the project currently supported by the World Bank.

2.2 Towards a Negotiation?

The convergence of the initiatives and proposals coming from OPEC, the World Bank and the heads of the industrialized countries for the development of the oil and gas resources of the Third World is undeniably an encouraging sign. It has become possible if not probable that, in the coming years, the development of energy sources and especially oil in the Third World may start up vigorously. Is this convergence a premonitory sign of a thaw in the North/South relations? Any hope seems premature.

At the beginning of 1981, in principle, global negotiations are scheduled to begin at the United Nations in an attempt to define a new world economic order, including the problem of energy. The OPEC countries, in Vienna in September, declared themselves to be favorable to this type of negotiation. It is still difficult now to be very optimistic on its chances of success. The first meetings and discussions revealed more divergencies than points of agreement, despite a conciliatory initiative by the EEC. Will this UNO session be anything other than a new public demonstration of bidding higher and higher? Would not the effective method be to reach exemplary partial or regional agreements, on the style of the Lomé agreements, or even less ambitious bilateral or trilateral agreements which might then snowball? We must await the beginning of the future session to decide on this.

No matter what the procedure may be to get negotiations under way, two parties must he on hand to engage in negotiating together. It is far from obvious at present that the producing countries and the industrialized countries want this. Are the former ready to agree to a programmed rise in oil prices to reach \$ 45 or 60 (in 1980 dollars) between now and the year 2000? And are the latter ready to agree to open their markets to products from the young OPEC industries?

The report by the OPEC Long-Term Strategy Committee, in its incomplete form, puts forward some interesting ideas. It must be considered as preparing the way for unanimity by the producing countries more than as a possible basis for negotiations with the industrialized countries. A floor price, for example, cannot be a negotiating goal for the purchasing countries.

Neither one nor the other appears very conscious that their economic growths are linked together if borders remain open, which is in their mutual interest. Can it be seriously considered that the industrialized countries could undergo a crisis or an economic growth reduced to one or two percent, while the Third World countries would see their GNP increase by five or six percent per year? Up to now, growth in the Third World has never been any higher than 40 to 50 percent of growth in the industrialized countries.

If the two groups of countries should insist on denying their interdependence, there is good reason to fear that more or less gray scenarios would come to pass, with the outcome for all countries in the world being the cruel ordeal of an economic crisis whose seriousness might eventually equal the one which occurred in 1929.

It is difficult for OPEC/OECD or North/South discussions to be carried on with mutual determination to achieve an outcome as long as the oil market, the key to the world energy problem, continues to be so unbalanced and its prices so uncertain. A sharp drop in world demand which would be the result of a decrease in economic growth, the active development of replacement energy sources or of both these causes currently appear to be the necessary path toward negotiations. The war between Iraq and Iran is paralyzing, for an uncertain length of time, the development of a longterm strategy by OPEC. It risks creating difficulties of supply and price rises comparable to the ones in 1973 and 1979. If these difficulties, which are unfortunately probable, should open the eyes of the industrialized countries and make them decide to undertake the difficult energy-reconversion effort required for rebalancing the oil market, some far-off but serious hope might possibly be found in the midst of the anxieties of the present moment.

THE WORLD-WIDE PROSPECTS OF NON-CONVENTIONAL OIL AND NATURAL GAS

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1. Premises and the Questions to be Answered

The results of projections carried out by various institutions or groups show unanimously that the global need for energy will increase strongly in absolute terms until the turn of the century and beyond regardless of the decreasing specific need for energy per unit of world social product. The demand increase may figure 50% of the present level in case of a harmonious development of the international division of labour and the national economies. Larger disturbances will reduce the need, but only in the case of warlike and similar world-wide complications will the demand cease to increase or even decline in the next decades.

The message therefore reads: To keep a lack of energy from hampering world-wide production of goods, the supply of primary energy must be expanded on a global scale.

This is in the interest of all countries and groups of countries, it is simply vital for developing countries, since an expansion of their energy supply is a prerequisite for their favourable economic development. It is mainly the task of the developed industrial nations to create the conditions for an increased supply of energy. They possess the technical know-how and the capital. The low absorbers among the OPEC-countries should also make a higher contribution to the provision of capital.

1.1. Recent critical investigations of the future world-wide exploitation of conventional oil (WAES, IEA, industry) agree in the conclusion, that world oil production will not be able to keep pace with rising global needs for energy and that a new swing supplier is necessary to supply the additional demand and to substitute for oil. Considering the known uncertainties regarding the future supply strategy of OPEC, it is more realistic to assume that world oil production will not increase anymore (viz WOCOL).

Departing from this cautious hypothesis, the percentage of oil in world energy supply will decline from a present 47% to less than one third until the year 2000. Thus oil will remain the most important source of energy. Its main suppliers, the OPEC, will in this period continue to determine — or at least take a decisive influence on — the level of world energy prices.

It is a realistic assumption, that the real (i.e. adjusted for inflation) price of crude oil will in the long run and in general trend rise in line with the real rate of interest, which would be tantamount to another doubling until the year 2000. Natural gas producers will most probably try to follow the same trend but even if they suceed in the near future, an assumption that to me seems to be very doubtful, they will have to realize that in the long run prices for natural gas and crude oil not necessarily will develop in parallel; most probably they will not. The reason is the fundamental difference in markets to be supplied by an increasingly lighter end of the oil barrel and natural gas.

1.2. Hence, the question this paper is faced with is the following: Which role can be played by non-conventional oil and natural gas in satisfying rising world energy needs under these conditions?

The heading: non-conventional oil and (natural) gas summarizes a broad variety of energy resources. They differ by physical state (from gaseous to different kinds of liquids), stage of technical development, regional distribution, market penetration, economics, market conditions, ecological impacts of production, transport and usage etc. The differences are so large, that it is almost impossible to discuss them together.

But there is one remarkable exception: The resource base for all these different kinds of energy is so large, that it multiply exceeds the amount of ultimate recoverable convention oil.

Table 1 summarizes the result of the 11th World Energy Conference's Survey of Energy Resources:

As can be seen the resource base of natural gas and non conventional oil (and gas) considerably extends the availability of conventional oil. It would allow for sustaining the supply of an even increasing demand far beyond the time when conventional oil is going to he exhausted or will

TABLE 1 — *Reserves and resources of fossil kinds of energy.*

— 10^9 toe -	Proved recoverable reserves	Est. Additional recoverable resources	Total
Conventional oil	89	212	301
Natural gas liquids	7	12	19
Natural gas	64	167	230
Non-conventional oil from tar sands heavy oil deposits and oil shale	86	369	455
Coal (as resource base for coal liquefaction)	447	6772	7220

be restrained by conservation policies of oil producing countries, i.e. far into the next century.

Decisive factors for the velocity of mobilisation of that potential however are the technical means and their improvement to produce, transport, treat and use these resources, the prevailing economic, social and ecological restraints and the attitudes of potential producers towards capital investment into these resources or towards exports.

2. Resource base and methods of production

2.1. *Natural Gas and Gas from Coal*

2.1.1. The world proved recoverable reserves of conventional natural gas are at present calculated at 74.000 Billions m^3 (70×10^{12} m^3) (See: WEC, 1980, Survey of Energy Resources). The additional recoverable natural gas resources are estimated nearly three times as much as the proved reserves (192×10^{12} m^3). Natural gas is, though reserves and resources are smaller in absolute terms than those of conventional oil, less scarce than conventional oil owing to a substantially lower level of consumption and exploitation. With a production of about 1700×10^9 m^3 1978 the ratio of proved gas reserves to production is more than 43/1, against a comparable figure of less than 30/1 for conventional oil (an average figure that does not show the huge regional differences in advantage of the Middle East). This ratio for the total recoverable gas resources figure out to 156 and 100 for conventional oil.

The reserve position of the big gas consuming countries is better than in the case of oil. Nevertheless it has to be stated that here too the OECD countries are in a rather bad position (1) and again the OPEC countries are in a comparably good position. Possessing a reserve situation that is good to very good and a comparatively small production they are technically able to make a considerable increase in production capacity in the short to middle term to supply an increasing gas consumption of the world either in traditional gas consuming countries with small or diminishing resource bases, especially the Western European countries and Japan, or new to be developed gas grids in other countries. But production profile, export policy and prices are highly uncertain.

Great uncertainty characterizes the future additional supply of the USSR e.g. to Western Europe. At the moment a new deal is going into its final stage between a consortium of Western European companies and this country to nearly double the share of Russian gas export to Western Europe. Nevertheless it's almost impossible to estimate how much gas from this country will be available for the world market. Among other factors the main reason is that energy exports are determined by political considerations.

On the other hand the knowledge about the total resource base in the case of natural gas is comparably low as steadily finds (e.g. in oil production areas) show. The today energy price level allows for enhanced recovery methods and drilling into up till now less favorable or costly regions or structures. Especially the recent development in the USA as the result of a deregulation is impressive.

2.1.2. The potential of non-conventional natural gas is even larger. This is defined as that kind of natural gas which cannot be explored and produced with current methods.

The resources of methane from coal beds and the resources of gas

(1) OECD share of gas consumption: 60%
share of gas reserves: 16%

from shales alone, are each estimated at an order of magnitude which corresponds to the reserves of conventional natural gas. The largest resource of non-conventional gas is geopressured gas in the earth's crust. However, the technical, economic and environmental problems of mobilisation of these resources are yet unsolved.

At least for less developed countries great importance as a resource could accrue to the bioconversion from biomass, although only on a local or at most regional level.

2.1.3. The resource base for the production of gas from coal is the most abundant of all fossil fuels. According to the WEC 1980 coal has a share of 64% of all proved recoverable reserves, and of 90% of the estimated additional resources. There is a wide range of different gases, which are or will he supplied as principal or by-products. Correspondingly, there are various technical methods of production. Current efforts for new and further developed techniques are focused on the production of synthesis gas and substitute natural gas from coal or lignite.

The procedure for the production of synthesis gas is regarded as the most advanced, in West Germany e.g. the most advanced process, developed and currently tested is based on lignite. Synthesis gas allows for the production of products as follows.

— Synthesis gas as feedstock for the chemical industry, as fuel for heating purposes in industrial boilers, or as basis for the production of methanol or synthetic gasoline;

— reduction gas for metallurgical purposes;

— hydrogene as chemical feedstock and for the hydrogenation of coal;

— low BTU-gas for electricity generation.

In the long run, the production of substitute natural gas (SNG) that may be freely intermingled and augment the available supplies of natural gas will be of special interest.

These procedures are under development. Also, the possibility of using nuclear heat is being analysed, as this could save up to 40% of the coal or allow for a correspondingly higher production of SNG. For substitute natural gas the threshold of economic operation has not yet been reached even if the cheapest coal is used, in the case of synthesis gas for instance on the basis of lignite the break even point is at least not far away.

2.2. *Non-conventional Oil I (Oil shale, Tar sands and Heavy Oil)*

2.2.1. Compared to the knowledge available on conventional deposits, the state of knowledge on the configuration and composition of deposits of oil shales and bituminous sands is relatively small. For this reason it is impossible to formulate clearly divided definitions in the same way as has been made for the classical deposits. Non-conventional oil could be defined as that kind of oil or similar material, the prospection and/or production of which is not possible with current methods of oil exploitation. This includes:

— enhanced recovery, that is increased production from the remaining residual oil after conventional exploitation;

— oil in deep water and arctic zones;

— oil shales;

— tar sands and heavy oils;

— synthetic fuels produced from coal or from biomass.

This paper deals only with oil shales, tar sands, heavy oils (bituminous sands) and synthetic fuels from coal. It is assumed, that the enhanced recovery and oil in deep water and arctic zones will also be discussed in the paper on conventional oil. The technical and economic prospects of the exploitation of this rather inaccessible oil and of the increase in the rate of recovery in the forseeable future will probably be larger than those of the other forms of non-conventional oil, which can be expected to obtain great importance by the year 2000 and especially afterwards.

2.2.2. Natural Deposits.

a) Oil Shale.

The term "oil shale" (a clayor marlstone) encompasses such shale deposits that possess a high concentration of organic materials (kerogenes) which can be converted to oil and gas by a heating process.

The term "bituminous sands" encompasses such deposits of sand and sandstone that contain a high concentration of bituminous hydrocarbons, from which oil can be recovered by a heating or other extraction process. Deposits of "heavy oils" and "bitumens" of higher density and viscosity that are not economically recoverable by conventional methods due to insufficient natural reservoir energy are also included. The calorific value of oil shale is determined by its content of organic substance and it varies considerably.

The resource base of oil shale as well as tar sands and heavy oil is tremendous. As can be seen from table 1, the proved reserves of both categories are app. 86×10^9 t, i.e. as large as the proved recoverable reserves of oil from conventional deposits. The estimated additional resources are even larger (and perhaps these figures have to be considered as conservative). Other estimates about total proved and recoverable reserves and additional resources of oil shales and bituminous sands are much higher.

	Oil shale	Bituminous sands
WEC 1980	333×10^9 t	116×10^9 t
BGR [2]	490×10^9 t	338×10^9 t
Desprairies	400×10^9 t	300×10^9 t

In this connection it should be taken into account that up till now relatively few incentives existed to find and develop these resources. On the other side we have to realize the large differences between (and within) deposits of different kinds of energy resources. Although the quantity of oil in place of certain non-conventional oil deposits is very large, the recovery potential is very often limited because of recovery technology, fragmentation of reservoirs, reservoirs quality etc. Estimates range from as low as 3% up to 10% of the oil in place being recoverable. For instance it makes no sense at all to take into consideration those (tremendous) deposits which are so poor that the energy input to extract the oil is higher than energy output or if costs exceed even strongly increasing oil prices. Nevertheless, we can expect that with additional efforts new deposits will be investigated and with increasing prices (and/or technical development) resources will be transferred to reserves and submarginal deposits to recoverable resources.

As table 2 shows the bulk of the known deposits of non-conventional oil is to be recovered in the Western Hemisphere, a lot in non OPEC-Countries.

Compared to conventional oil deposits, one of the most obvious differences in the composition of oil from oil shales (and bituminous sands)

(2) German basic research Institute on geophysics.

TABLE 2 — *The availability of oil from oil shales and bituminous sands: Results of the inquiry* SURVEY *1980 (**); Figures in* 10^9 *t of recoverable oil.*

	proved recov. reserves 1-1-1979	additional resources 1-1-1979	production 1978	proved recov. reserves 1-1-1979	additional resources 1-1-1979	production 1978
Canada				19300	16300	4
U.S.A.	28000	236000		1		
Australia		490				
New Zealand	1					
Thailand	2015					
USSR	6820	49180	37			
Argentina	(*)					
Brazil	84		(*)			
Venezuela				20000	50000	
Zaire	(*)					
Jordan	800	7000		700	10000	
Morocco	7400					
Federal Republic of Germany	250			50		
Austria			(*)			
Sweden	880					
Spain	12					
	46262	292670	37	40051	76300	4

(*) Figures under 1 Mt.
(**) *Turkey* quotes 202 Mt recoverable reserves and 5196 Mt additional resources of Bitumen and Asphalt. In 1978 the production was 485,000 t.
Venezuela quotes an additional 2000 Mt of proved recoverable reserves and 3000 Mt additional resources of Asphalt.
Source: WEC 1980.

is the considerably less favourable relationship of hydrogen to carbon, and also the high proportion of other elements present. Relatively high proportions of asphalts and a high content of sulfur, nitrogen, oxygen and heavy metals make it necessary to use special treatment processes during conversion to marketable products, the most important being the addition of hydrogen and the careful adjustment of suitable reaction conditions (pressure, temperature, catalysts etc.).

The extraction of oil shale has so far been taking place in surface-mines and in underground mining with above ground processing. Methods of in-situ processing are being worked on.

The deposits of oil shale are — more distinctly than those of conventional oil — typically of an extremely different quality with the oil poor deposits predominating. It seems doubtful, whether an oil content under say 40 l/t can be counted as a non-conventional oil resource at all. In any case it is not conceivable, whether a utilization of this potential resource will be possible even with advanced in-situ processing methods. With presently available techniques the energy input is approximately as high as the energy output, currently even higher.

Even the oil-rich shale deposits are not all to be judged as technically and economically exploitable, as their exploitation is subject to partly inconvenient geological and technical constraints (thickness of the seam, depth, accessibility).

Nevertheless, the knowledge of the deposits of oil shale is still incomplete. The economic interest in a prospection of these resources was extremely small in times of low oil prices. Consequently, information on reserves and resources of oil shale and the regional distribution of the deposits is incomplete and uncertain.

b) Tar Sands and Heavy Oil.

The deposits of tar sands and heavy oil are similar to those of conventional oil in as much as the oil in liquid form has moved upwards from the sediment rocks to layers near surface. The main differences to crude conventional oil are their low viscosity and lower content of hydrogen. The extraction takes place in surface mining through drilling with injection of steam or partial in-situ burning.

Tar sands and heavy oils are abundantly found, too, in natural deposits which are located in various countries, but also here, knowledge of the existing resource is still insufficient, the largest known deposits are found in Canada (Atabasca and Cold lake), Venezuela (Orinoco) and Jordan.

Other authors (3) give information about large deposits, too, in the USSR, Madagascar, U.S.A. and Trinidad.

With the open cast technology presently available, only up to 10% of these in-situ resources are recoverable. Only a large advance in technology, which would make underground exploitation possible, could raise the proportion of recoverable oil up to above 50%.

For heavy oils, the inventory is even more incomplete than that of tar sands. Only through the strong economic interest in the exploration of this resource and in the development of methods of exploitation which has been created by rapidly increasing oil prices, will a furthering of our present state of knowledge be accomplished.

2.3. *Non-conventional Oil II (Liquids from Coal)*

Coal is, as shown, the most abundant of primary energy. It also has a wide geographical distribution and the conditions for a rapid expansion of coal production seem to be universally advantageous (see the WOCOL-study and C. Wilson's paper). One of the crucial conditions for an expansion of coal use is the development of technologies to convert coal into products, that can be easily marketed with an existing infrastructure and that fulfill the requirements of comfortable environmentally safe use.

For the production of liquids from coal there are basically three methods of processing available which have been developed in the first quarter of this century:

— the process of Bergius and Pier (coal-hydrogenation);
— the Pott-Broche-process (coal-extraction);
— the Fischer-Tropsch-process (synthesis).

The process of coal hydrogenation yields different output shares of hydro carbon gases, gasoline and medium and heavy oils, depending on the nature of further processing. Main objective is to get gasoline. Extraction yields a product which contains little sulphur and which can be used like heavy oil for combustion under boilers. The gasoline synthesis is based on a completely different technical principle. First it produces "synthetical gas" which can be further processed under pressure and

(3) C.W. Bowman and M.A. Carrigy, see World Energy Resources 1985-2020, WEC 1978, S. 71.

together with catalysts to light as well as heavy hydrocarbons, fuel and basic materials for the chemical industry.

The procedure of coal hydrogenation has found the widest application on the basis of bituminous coal and lignite during the second world war in Germany, which was also the period when Fischer-Tropsch installations were taken into operation on a large scale. The total capacity 1944 reached about 4 Mio t/y. After the war, the gasoline synthesis was further developed in South Africa (Sasol) where one plant is producing oil, gasoline and chemical products from app. 4 Mio t/y of coal. Sasol II, just ready, produces 2 Mio t of gasoline, Sasol III is planned to go in operation 1982. In other countries, there have been no large scale technical developments in the field of coal liquefaction until quite recently. Since the first large jump in oil prices in 1973 basic methods are being improved and new ones (Mobil Oil - process e.g.) explored in various industrial nations.

Meanwhile it seems nearly impossible for an outsider to give an overview of the different processes, their characteristics, stage of development, output or costs. It's only in the FRG that more than 10 gasification procedures have asked for subsidies within the "coal liquefaction and coal gasification program", announced by Chancellor Schmidt early this year ([4]). Similar activities have been started in other countries especially in the U.S.A. Part of the projects are organized under the heading of international cooperation, as the construction of the big coal liquefaction plant (SRC II) in West Virginia.

All these efforts follow one objective: To develop processes that will economically produce coal gases or liquids under ecological sufficient conditions.

All data about the economics of the processes now to be developed are necessarily preliminary. There remain large uncertainties till the pilot plants have been operating under "normal" industrial conditions. But the present results, more, the broad industrial engagement justify some optimism.

Table 3 contains preliminary cost data for new installations presently expected with different coal cost assumptions. All estimates are subject to considerable uncertainties as long as no large plants with extensive industrial experience have been in operation.

Three products being produced: The solvent refined coal according

([4]) Another couple of companies developing liquefaction technologies will follow next year.

to the SRC II-procedure, a fuel of a medium to heavy constitution, with the lowest degree of hydrogenation; Syncrude, which lends itself to the use as an input-product for refineries is characterised by a significantly higher degree of hydrogenation; finally, gasoline with the highest degree of hydrogenation.

Cost of Liquids from Coal - $/t product output - (1979 US-$)

	SRC			Syncrude			Gasoline by hydrogenation		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Coal	33	107	165	53	172	265	60	195	300
Capital	81	81	81	18	18	18	227	227	227
Operating & maintenance	11	19	11	16	16	16	23	23	23
./. Revenues from by-products	26	26	26	4	4	4	2	2	2
Total cost	99	173	231	183	202	295	308	443	548

Source: SCHILLING, WIEGAND, STROBEL: Wirtschaftliche Perspektiven der Steinkohleverflüssigung in der Bundesrepublik Deutschland, ZfE 4/1979 with different coal price assumption.

(1) Based on 20 $/tce coal price assumption.
(2) Cost of imported coal cif ARA (65 $/t).
(3) Cost of German coal (100 $/t) (SCHILLING *et al.*: 174 DM/t = 97 $/t).

It can be seen, that the cost of production increases rapidly with a rising level of hydrogenation and that the costs of coal as well as the costs of capital are of great importance. On the other hand, the earnings from the produced liquids will also rise along with the degree of hydrogenation, which may even overcompensate the increase in cost.

The application of the Fischer-Tropsch-synthesis opens a wide range of possibilities regarding the planning of the product output. Whereas e.g. Sasol I produces mainly diesel oil, Sasol II is supposed to yield primarily gasoline. Tbe specific capital expenses and tbe costs of coal are much higher for the Fischer-Tropsch-synthesis than for coal hydrogenation. An economic superiority of the Fischer-Tropsch-synthesis can only arise if the cost of coal is very low and if the earnings from by-products are high. At least in the case of Gasoline production the European situation in regard to the supply of coal and the prices of coal (including the price of imported coal) seems to be in favour of coal hydrogenation judged from an economic and present view point as it is shown in the following table. Coal liquefaction on the basis of indigenous coal in Europe is far from competitive. The average earnings from "coal gasoline" in the FRG will actually range between 550 and 670 $/t as compared to actual gasoline prices (from crude oil) ex refinery of 340 $/t.

Comparison of Costs to produce Gasoline from Coal - $/t Gasoline (1979 US-$)

	Gasoline produced by					
	Hydrogenation			Fischer-Tropsch-Synthesis		
	(1)	(2)	(3)	(1)	(2)	(3)
Coal	60	195	300	92	299	460
Capital cost	227	227	227	267	267	267
Operating & maintenance	23	23	23	46	46	46
./. Revenues from by-product	2	2	2	106	106	106
Total cost	308	443	548	299	506	667
1 US-$ = 1,80 DM						

Source: SCHILLING, WIEGAND, STROBEL: Wirtschaftliche Perspektiven der Steinkohleverflüssigung in der Bundesrepublik Deutschland, ZfE 4/1979 with own assumption on coal prices.

(1) Based on 20 $/tce coal price assumption.

(2) Based on imported coal cif ARA 65 $/t.

(3) Based on German coal (100 $/t) (SCHILLING *et al.*: 174 DM/t = 97 $/t).

An interesting refinement of the procedure for the production of synthetic gasoline is that of Mobil Oil actually demonstrated with public support by New Zealand. Presumably, this procedure will also be of interest primarily to countries witb low coal prices and less so for the industrial countries in Europe.

3. Prospects of Natural Gas and Non-conventional Oil

3.1. *General Remarks*

The determinants of the development of the various sources of energy, which are ascribed to the terms natural gas, non-conventional gas and non-conventional oil are very different. Most of these factors are highly uncertain.

Uncertainties accrue from:

— market conditions: Natural gas and non-conventional gas are only partial substitutes, whereas non-conventional oil — at least with the proper refining — represents a complete substitute for conventional oil. Therefore, the market conditions are essentially different;

— reserve situation: Differences lie in the reserve situation and the geographical distribution of the reserves. The largest reserves of natural gas in relation to indigenous consumption are located in the eastern hemisphere and in the OPEC-countries, whereas the largest reserves of non-conventional oil are found in OECD and to some extent also in developing countries which are otherwise not abundantly endowed with energy resources.

— state of technology: The state of technology in resources exploitation shows wide variations and its development has not yet been terminated for the various sources of energy. The volume of extractive reserves of conventional natural gas may even be increased substantially through the application of non-conventional methods. An advanced standard of technology has been achieved in the procedures for the production of synthetical gas from coal, while some of the procedures for the exploitation of non-conventional natural gas are far from preliminary viability. Similarly, the techniques of non-conventional oil exploitation have reached different stages of development. Oil from shale has been produced for decades, oil from tar sand is produced in Canada since 1968, liquids from coal in South Africa since the early 50's, but advanced technologies will not be available before the 90's. Problems arise especially from environmental considerations.

— costs: The estimations of the costs are all the same uncertain. From today's point of view only few of the various sources of non-conventional oil have approached or reached the level of profitability.

There exist cost figures for

— oil from oil sands	(25 - 28 $/b)
— oil from shale	(25 - 35 $/b)
— oil from liquefaction	(25 - 45 $/b)

which would allow for commercial production under present economic conditions of at least limited amounts.

But all these figures are highly influenced by resource costs and inflation and need regularly updating from time to time. The cost figures for shale and coal liquefaction are only favorable estimates from proponents who use to make the best of their own technical approaches. They all have to be proved by reality.

The rate of development of natural gas and especially of non-conventional gas and non-conventional oil will be determined also by the developments in the field of conventional oil. Should it be possible to increase the reserves of conventional oil by unexpectedly large advances in the exploration and development of fields or by improved techniques of recovery within the next years, this could cause a considerable delay particularly in the exploration of non-conventional oil. The incentives to explore non-conventional oil could also be lessened substantially by a decline in the demand for oil persisting for several years, which could result from a world-wide recession or from an intensified conversion of heavy fractions to middle and light distillates.

On the other hand, a set-back in the development of alternative sources of energy as especially in nuclear energy may lead to a strong acceleration in the development of the sources of energy discussed here.

Last not least it has to be kept in mind that natural gas and non-conventional oil will have to be developed in competition with a multitude of alternatives to conventional oil. The spectrum of these, to some extent partial and to some extent complete substitutes, includes the combustion of solid fuels (coal and others) and the use of nuclear energy for heat production and the generation of electricity, the gasification of coal and various forms of renewable energy, as well as the more efficient use of energy, like district heating from combined electricity and steam production, heat pumps, better isolation etc. Therefore an isolated evaluation of the future contribution of natural gas and non-conventional oil would be misleading.

All these factors cannot be predicted exactly. Therefore, an evaluation of the future development of natural gas, non-conventional gas and non-conventional oil is subject to considerable uncertainties.

It would be extremely optimistic to assume, that natural or synthetic gases, and non-conventional oil in any case will be developed quickly enough as to be able to supply an increasing demand and in the same moment substitute for decreasing oil supplies. This would rather under-estimate the fundamental differences between these resources and conventional oil and the huge problems still to be solved.

On the other side it would by far be too pessimistic only to point to the technical, economical and political difficulties that arise from an expanded use of these resources. It is true, the mobilization of the hydrocarbons of non-conventional oil deposits and the treatment of the raw material to marketable products, the gasification and liquefaction create still manifold technical, economical and ecological problems and the recent behaviour of main gas exporting countries raises the question how much gas at all will be produced and marketed under what kind of conditions on a worldwide scale. But the technological development and the broad worldwide engagement of industry, supported by far reaching measures from governments, the energy price level meanwhile reached and expected to increase, support some optimism.

3.2. *Natural Gas and Non-conventional Gas.*

The conditions for a further expansion of worldwide natural gas supply are favourable but not fully clarified.

The resources are found and proved, the techniques to produce, transport and use this energy source with high consumer preferences and favorable ecological characteristics are available, national grids in consuming countries can easily and with low investment be expanded.

On the demand side, a persistent increase in demand by residential and commercial consumers as well as by the industry and for non-energetic uses has to be expected under the condition of competitive natural gas prices. Economic policy will also encourage, or at least it will not aim at discouraging the substitution of fuel oil for heating purposes. Nevertheless it is improbable, that the increase in demand as universally observed in the last two decades will persist up to the year 2000. With declining indigenous production of natural gas in the traditional consumer regions it is necessary not only to meet the additional needs of these regions but also the requirements due to reduced production with natural gas from very distant regions. Opposite to oil, these international gas flows have a significant cost disadvantage concerning transportation, which will affect the prices and thereby constrain the volume of realized total demand.

Still much more important are the disadvantages that natural gas faces with respect to the low load factor of major consumers (with main impacts on the costs of the capital intensive gas supply system) and the smaller benefits that belong to the fact that oil products increasingly will be sold on premium markets and gas remaining on the heating markets.

On the supply side, the economic chances for a mobilisation of the (conventional) natural gas reserves have been improved considerably as a result of the huge jump in prices for crude oil which has already taken place as well as of the expectations of further increases of the oil price. A larger proportion of the natural gas which has so far been flared at the production sites and which in 1978 amounted to app. 15% of the world gas production sold on the markets, will in future be provided for use. Also natural gas from distant and smaller deposits will be explored and made available for future economic use. The techniques for long distance transportation over land and over sea have been improved and the efficiency and flexibility of the transport system will be increased through further investments.

The decisive question with respect to the share of gas supply of world-wide PER however is, if the producing countries will price their gas at competitive conditions and produce the amounts required by the markets. The actual efforts to fix the gas price to the price for crude oil totally neglect the increasingly different conditions that face these kinds of energy. Such a policy is counter productive and must reduce the possibilities to penetrate. If these intentions are successful, this will curtail the development of demand. The sale of natural gas would concentrate on premium uses, a wider substitution of oil would not be possible.

Taking into account the recent development it is uncertain whether the investors on the supply and demand sides will show the willingness to carry out the large projects needed for the expansion of the international trade with gas on a sufficiently large scale and in time which are necessary because the geographical distribution and availability will increasingly diverge. These are primarily investments in the LNG-business. LNG presently accounts for only 22% of the international gas business, which roughly figures 170 Bill. m^3. It is estimated, that international trade with natural gas will double until 1990 with the proportion of LNG rising to 40% (Brecht, WEC 1980). Estimates for the 1990s and up to the 2000 are similar. An expansion of LNG trade of 100 Bill. m^3 within the next ten years, would call for investments at an order of magnitude of

50 Bill. $ (at present prices). It is important to note, that each LNG-chain requires capital expenses of a couple of Billion $ which can only be provided by the partners if contracts exist, that secure a fair price and a fair risk-sharing as well as security for every group of investors. So far, this condition is not generally fulfilled.

In the field of non-conventional gas, the production of synthetical gas will presumably be the first to be developed on a large scale, yielding the various products listed above, and thereby indirectly or directly making a contribution towards easing the oil market.

SNG will probably not begin to supplement the supply of conventional natural gas until the 1990s. It could, after 2000, slowly be developed towards a back-stop-technology for natural gas and thereby taking strong influence on the formation of prices in the gas market.

Concerning the other forms of non-conventional gas it is not possible to make predictions on the expected rate of exploration. It remains to be seen how successful the planned mobilisation of the potential of these resources in the USA turns out to be.

The projection of the 10th world oil congress, according to which the world demand for natural gas will rise to 1800 Bill. m^3 in the year 2000 (as opposed to 1400 Bill. m^3 today) and the supply will be large enough to satisfy demand is to be judged as rather conservative. On the other hand, the estimation of the 14th world gas conference in Toronto, whereafter an increase to 4000 Bill. m^3/year can be expected up to the year 2000, seems to be overoptimistic. According to the WEC potential production could increase to 3600 Bill. m^3 (1979: 1500 Bill. m^3) but fall back to 3100 Bill. m^3 in the year 2020. The estimates of the further development of natural gas demand recently published by the WEC and some international oil companies lie within this range. But only production according to the upper level would allow natural gas to sustain its actual market share. After 2000 natural gas will increasingly be supplemented by non-conventional gas.

3.3. *Non-conventional Oil.*

The short and medium term conditions for the development of non-conventional oil seem to be less favorable though main efforts to develop this resource base have been started around the world. As it was pointed out, it is not the resource base that limits a quick development, but the technical, economical and ecological restraints.

The published cost data would allow commercial production. But they are only valid for the best deposits or sites, or are only the result of favorable assumptions in calculations for plants still to be built, often still to be developed. All the processes to produce oil from non-conventional oil are highly capital intensive. (The most recent plant in Canada planned to go in operation 1986 with a production of 8 Mtoe/y will require 7 Billion $). Thus, these processes are heavily influenced by inflation. Advanced techniques to be used have still to be developed, part of them will not be available before the 90's. Last not least all these processes create beavy impacts on natural and social environment.

All these problems have to be solved. Witb the results gained up till now it can be expected that it will be possible to find solutions, but time is necessary. And this might be the reason why univocally only a slow development is expected. Most experts estimate the oil production from non-conventional oil to the year 2000 to increase to not more than 200 Mtoe (one company to 400 Mtoe) (from today some 10 Mtoe!), most of it and at first from tar sands in Canada, then heavy oil in Venezuela, followed by shale oil in USA and coal liquefaction. This seems to be a rather small fraction of global demand, but it is nevertheless remarkable at least to the countries engaged in this production.

The magnitude of the problems that arise only from such a moderate development may become clear if we take into account that a 200 Mtoe non-conventional oil production (from tar sands) in the year 2000 (only 1-2% of world PER) would require (in addition to the 2 large seale plants still in operation) another 50 plants with an investment of at least 250 Billions $ (in 1985 $), that is three times as much as conventional oil in the North Sea.

As these installments require a large number of qualified workers and engineers, countries like Canada cannot afford more than two projects in one decade. It should he noted, that the processes we are concerned with have high manpower requirements and hence, an extensive infrastructure for the accommodation and provision of the personnel needs to be erected. Concerning the deposits of heavy oil in Orinoco in Venezuela the point is that an adequate technique for their mobilisation still has to be developed.

Oil shale poses even larger problems of technical, ecological and economic nature than does tar sand. For the production of shale oil a mass of water three times the quantity of the shale rock is needed, which is not available for a large scale production in the main regions (Green river in the USA). Besides, with current methods of grinding the shale, a mass of scrap is produced which exceeds the oil shale extracted by 30%. Depositing this residue is a problem yet unsolved. It is mainly the result of various ecological problems of the production and processing of oil shale that the expansion of shale oil production will presumably show only slow progress. Only by developing the in-situ procedures of shale oil production it will be possible to reduce the ecological burden to a tolerable level and thereby to create the condition for a rapid and powerful expansion of this form of non-conventional oil production, especially in that country, which by far offers the best conditions for it due to its tremendous resources as well as the availability of capital and technical know-how, the USA. On the other side it should be emphasized that rising oil prices will increase, too, the profitability of investments into these resources.

The superiority of conventional oil opposite to coal hydrogenation, which is still existing today, will be diminished stepwise, too, if the price of crude oil should in future keep on rising more quickly than tbe price of coal. At present, however, a prediction of how this difference in prices will develop is not possible because the various determinants of these markets cannot be forecasted, as they depend, among others, upon future economic policy and future entrepreneurial decisions. The course of events for example in the field of nuclear energy will have a significant influence on the development of the prices for steam coal. Provided that the expansion of nuclear energy will also in future be strongly restricted, the price of steam coal will show larger worldwide increases as in the case of a rapid expansion of nuclear power plants. This would in turn reduce the profitability of coal hydrogenation as compared to that of conventional oil or different procedures for the production of non-conventional oil.

It is expected that non-conventional oil after the year 2000 will become more and more important and should produce in the year 2020 520-1000 Mtoe, i.e. about 1/3 of all oil to be consumed at that time. But at utmost even at that time natural gas supply will exceed that of non-conventional oil by at least 100%.

4. Conclusion

So natural gas and non-conventional oil will contribute to the supply of worldwide demand to a remarkable degree, the supply from these resources after the year 2000 exceeding the share of oil. The adjusting process of industry to the changed conditions on the world energy market which has already begun could be increased by political efforts. Again we face the problem of exhausting time. In any case it is necessary that the development of techniques to use the huge potential takes off now because of lead times that very often are longer than a decade. The second crucial condition for the development of natural gas and non-conventional oil is confidence. Companies as well as consumers must be allowed to calculate on the basis of stable economic and political conditions. Above all it seems to be necessary to reduce the risks that not only belong to the long time capital is engaged. It might be necessary to search for public support to develop technologies that will enable us to use the available resources and to limit further price increases for oil to the production costs of these resources. We would appreciate if this study week could give some signals in this direction.

THE ROLE OF COAL IN THE FUTURE

CARROLL L. WILSON

INTRODUCTION

My focus is on the next twenty years.

Twenty years is only a moment in the life of that great and most enduring of all human institutions — the Roman Catholic Church. Twenty years is one percent of the lifetime of the Church in whose seat we meet this week. For two thousand years leadership from here has provided spiritual nourishment for a substantial fraction of all mankind.

Amidst ever changing circumstances over the centuries leaders of the Church have had to understand and interpret the material world and the implications of changing circumstances. And so it is fitting and timely that we meet here this week to pool our experience and wisdom on the subject of Mankind and Energy: Needs - Resources - Hopes.

What is expected to be different about the next twenty years from the decades which lie behind us in this or earlier centuries? I see three ways in which the next 2-3 decades will be different from those in the past:

Firstly, global limits to growth will press heavily upon humanity — the finite and shrinking carrying capacity of the planet will be over-stressed for food, land, water, materials and energy;

Secondly, the very inequitable distribution of resources among the world's people will exacerbate the plight of the poor in the absence of massive resource transfers from the rich for which there are no apparent indications yet;

Thirdly, the era of petroleum which now furnishes half the world's energy has passed its peak so the world must manage a difficult and urgent transition to other forms of energy in order to meet needs for economic growth in the future.

Nearby at the venerable Academy Lincei there was born on the banks of the Tiber in 1966 a unique institution called the Club of Rome. Its creator and inspiring leader, Aurelio Peccei, saw before others the World Problematique forming ahead and joined with him from many countries others who shared his concern for the future. In March of 1972 an analysis of the probable future collision of exponentially growing population, resource needs and pollution was published in the small book, *Limits to Growth.* A dynamic model of the global system showed a stark picture of expansion and collapse. The book was quickly translated into more than twenty languages and set record sales throughout the world.

Much that has been learned since then has confirmed the general direction of the findings in *Limits to Growth.* Especially in the developing countries the shrinkage of arable land, water and firewood for fuel in the face of expanding populations makes it most unlikely that declines in per capita availability of food, fuel and services can be avoided.

My paper is focussed on the role of coal in the future energy system. Its message of cautious optimism is directed principally toward the industrialized countries of East and West including the Peoples Republic of China and India which now use three fourths of the world's energy and are likely to be using nearly as large a fraction at the end of the century.

The Role of Coal in the Future

By the year 2000 world coal trade should increase five fold and account for a third or more of the fuel moving in world trade. By early in the next century it should resume its former position as the principal fuel in world trade. This projection is based on a conclusion of the World Coal Study that coal use should grow 3 fold and steam coal trade should grow 10-15 fold by the year 2000.

The World Coal Study was organized two years ago to learn whether coal could replace oil in meeting increased energy needs for future economic growth and to determine what it would take to bring about such a transition.

First, I want to explain why I invited people from the 16 countries shown in Figure 1. Altogether they use 75% of the world's energy, produce and use 60% of the world's coal and include 60% of the world's people.

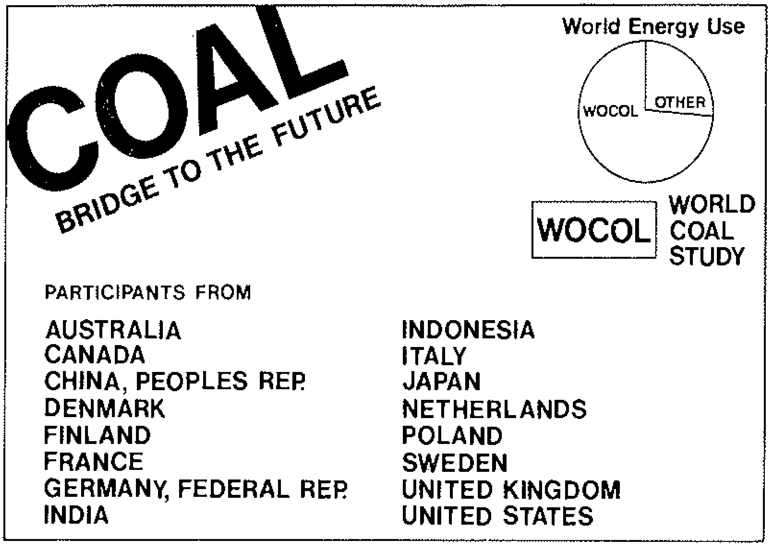

FIG. 1

Twelve countries are members of the OECD and account for 90% of the GNP and energy use in the OECD. OECD are the industrialized nations of North America, Western Europe, Japan and Australia which use 80% of the world's energy outside centrally planned economies and use 85% of world oil imports.

Participants were from public and private sectors and served as individuals at their own expense. Funding for the M.I.T. project came from private foundations, the U.S. Department of Energy, and some companies.

In 1974 the conclusion of the Workshop on Alternative Energy Strategies (WAES), a three year study by 75 people from 15 countries on Global Energy Prospects to the Year 2000, was that world oil production would level off — perhaps as early as 1983 if OPEC producers carried out their announced intention to restrict oil production to 33 million barrels a day. In 1977 the WAES estimate was considered pessimistic — in fact it proved to be optimistic. We said then, "The task for the world will be to manage a transition from dependence on oil to greater reliance on other fossil fuels, nuclear energy and, later to renewable systems".

The conclusions of the World Coal Study (WOCOL) are found in the report *COAL - Bridge to the Future* (Cambridge, MA: Ballinger Publishing Co., 1980 - Harper & Row International).

Here are the principal findings and assumptions which shaped those conclusions.

1. *Oil Imports* (Figure 2)

Available oil for OECD countries will decline even if OPEC continues to produce 30 mbd for the next 20 years — because of greater OPEC use, a likely change of the USSR from exporter to possible importer, and greater use by developing countries. Oil from non-OPEC sources will be insufficient to change this outlook.

Figure 2 shows a projection of estimated oil available to importers. It increased from 8 million barrels a day (mbd) in 1960 to 26 mbd in 1973 when it stopped increasing. We project a decline to 22 mbd by year 2000. It is not unlikely that the decline will be greater. In that case the demand for coal will also be greater.

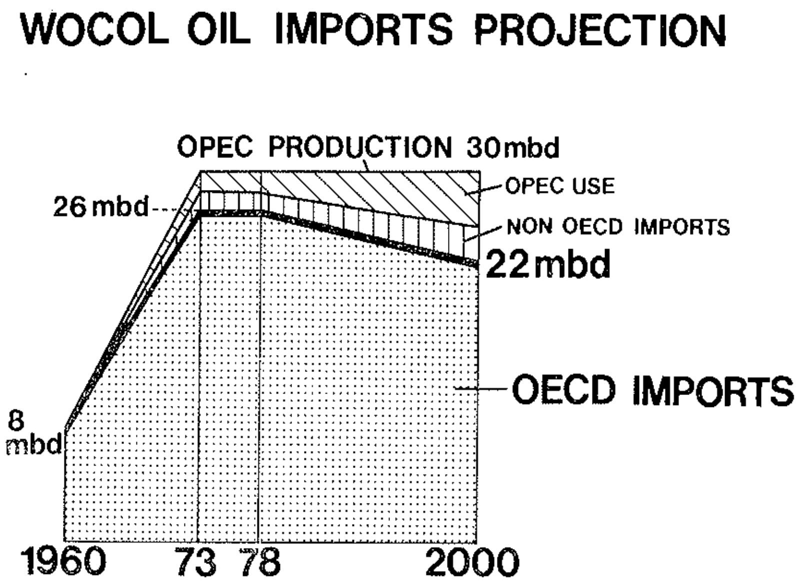

FIG. 2

2. *Effects of Oil Price Increases on Coal's Competitiveness* (Figure 3)

The doubling of oil prices during the past two years to $ 35/barrel has dramatically widened the gap between oil and coal prices so that coal prices are now 1/3 to 1/5 the price of oil on a heat equivalent basis.

This allows coal to be mined, moved and used in ways that conform to high standards of health, safety and environmental protection and still leave coal a "bargain fuel".

Figure 3 shows the significance of recent OPEC price increases on the economics of coal. The bar at the right shows oil prices at different dates since 1973. Since January 1979 the price of oil has jumped from $ 13 to about $ 35/barrel or the heat equivalent of coal at $ 165/ton. This rise in oil price has profoundly affected the economics of coal. The bar at the left is the cost for imported coal in Japan — $ 45/ton. The next bar shows the costs of meeting Japanese environmental standards — $ 35/ton. Added together coal costs $ 17/barrel oil equivalent or half the cost of oil today.

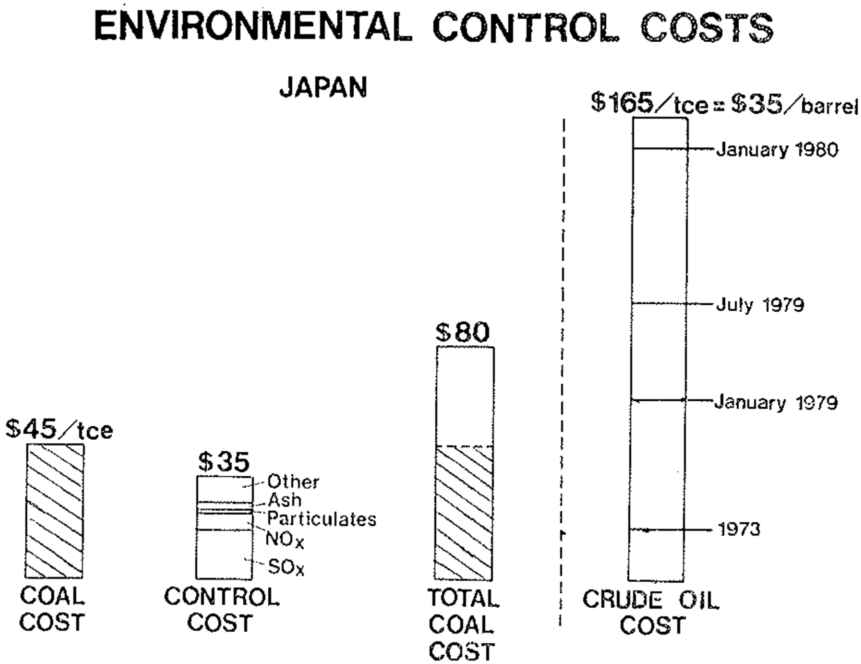

FIG. 3

The Japanese example is shown because Japan has the most stringent environmental standards in the world.

3. *Required Coal Expansion* (Figure 4)

Coal which already supplies 25% of the world's energy can supply the added energy needed to support world economic growth over the next 20 years if coal use doubles by 1990 and triples by 2000.

This would mean an average 5% annual growth which is achievable if decisions are made soon. This rate of expansion has been exceeded in the U.S. over the past two years, as U.S. production increased to a record level of 770 million short tons in 1979.

For the OECD countries in Figure 4 on the left is shown the 1960-77 period when oil use and imports rose dramatically and the use of coal stood still. If coal is to meet a large part of the increased energy needs in the next 20 years — as we believe it can — its use must double by 1990 when it would equal oil imports and triple by 2000 when it would exceed oil use.

The units are at the side of the chart — millions of barrels of oil per day — mbd — on the left and millions of tons of coal equivalent

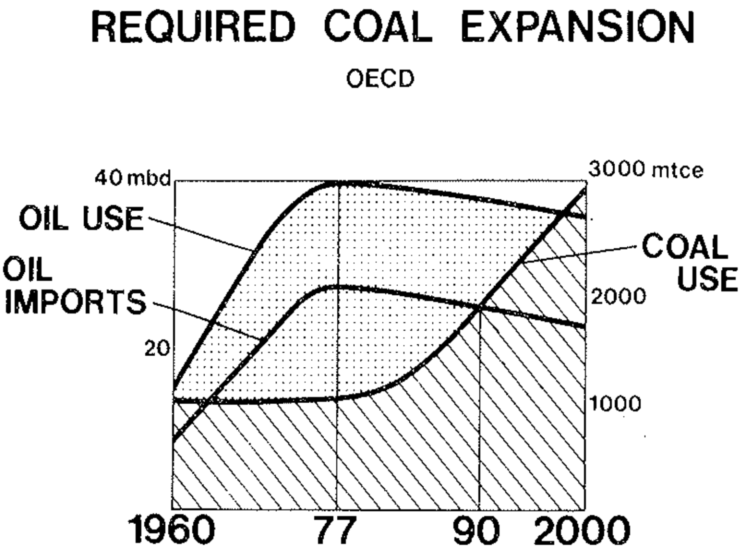

FIG. 4

per year — mtce — on the right. In the summary of this paper there is a page explaining the units used.

4. *Conservation* (Figure 5)

Next to coal, conservation through more efficient use of energy can be the largest contributor to meeting future energy needs. By year 2000 it can supply the equivalent of 2.5 billion tons of coal or 33 million barrels per day of oil equivalent.

Figure 5 shows the growth of various energy sources including conservation through better efficiency. At the left — during the period 1960-77 energy use and GNP grew at the same rate — 4.2% per year. From 1977 to 2000 WOCOL teams, on whose data these projections are based, estimate that a 3% GNP growth rate can be sustained by a 1.8% energy growth rate — a ratio of 0.6 instead of the 1960-77 ratio of 1.0.

Such conservation would supply the equivalent of 2500 million tons of coal. Next below in Figure 5 is coal use tripling to 2800 mtce. Next below is nuclear, hydro and solar supplying 1300 mtce. Gas increases to 1300 mtce.

The band at the bottom is for oil which declines from 3000 to 2700

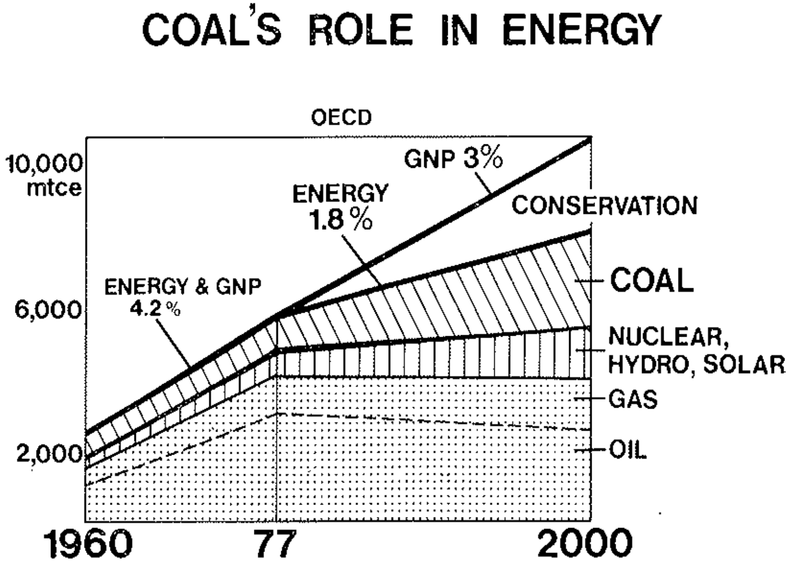

FIG. 5

million tons of coal equivalent. If the projected gains in energy efficiency are not achieved GNP growth would have to be reduced or coal use would have to increase.

5. *Coal's Share of Future Energy Increase* (Figure 6)

Coal can provide 2/3 of the added energy needed for the world's economic growth over the next 20 years. Coal would thus replace oil which supplied 2/3 of the added energy used during the past 20 years.

Figure 6 indicates that coal must supply 67% of future energy increase if nuclear grows 4 fold to 400 GWe and meets 20% of the needed increase. If nuclear capacity expands more rapidly — 6 fold — it could supply 32% leaving 55% to be supplied by coal.

Figure 6 also shows projections of the shares for gas, hydro and solar over the next 20 years. Oil can provide less than nothing — in fact 10% less, which must be made up by other fuels. Natural gas can provide 10%, hydro and solar 13%.

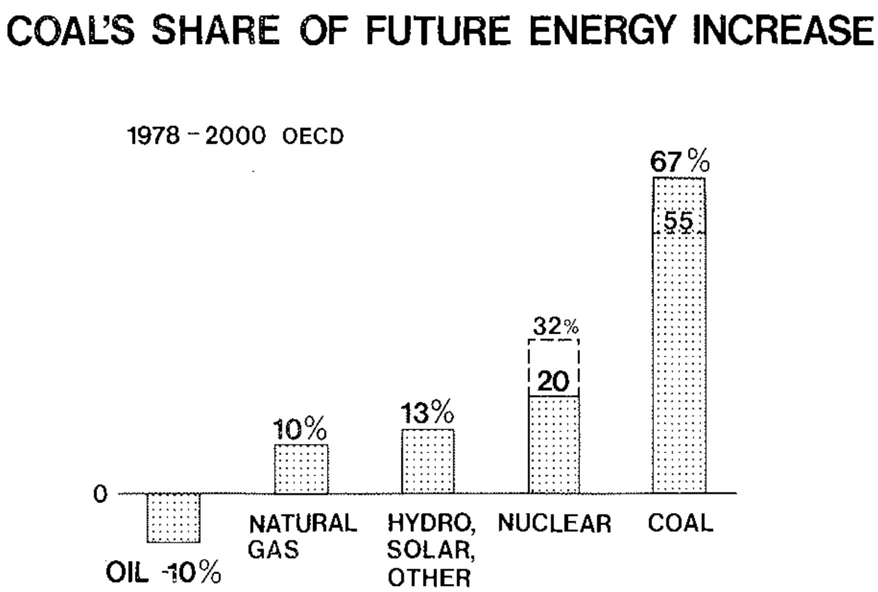

Fig. 6

6. *World Coal Trade* (Figure 7)

World steam coal trade would need to grow 10-15 times so that countries without sufficient domestic supplies could import coal to meet their needs for increased energy to support economic growth.

Total coal trade including metallurgical coal would grow 4-5 fold to 1,000 million tons a year. To carry, 1,000 million tons of coal over long trade routes would require a thousand ships of 100,000 DWT costing $ 40 million each. Most of these ships are expected to be coal-fired.

Figure 7 shows a projection of coal trade. The big increase is in steam coal from 50 million tons to 600-700 million tons a year.

7. *Exporter Potentials* (Figures 8 and 9)

If such world coal import needs are to be met, the United States must increase coal exports 4 to 8 fold over the next 20 years from 60 million tons in 1979 to 200-400 million tons by year 2000. Australia, Canada and South Africa must expand coal exports 4-5 fold.

Figures 8 and 9 show exporter potentials to meet an import demand of 800-1000 million tons.

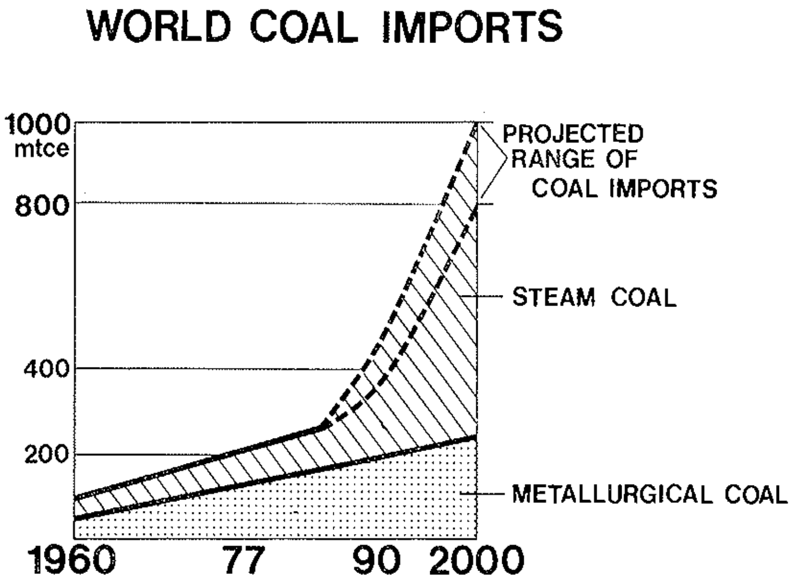

FIG. 7

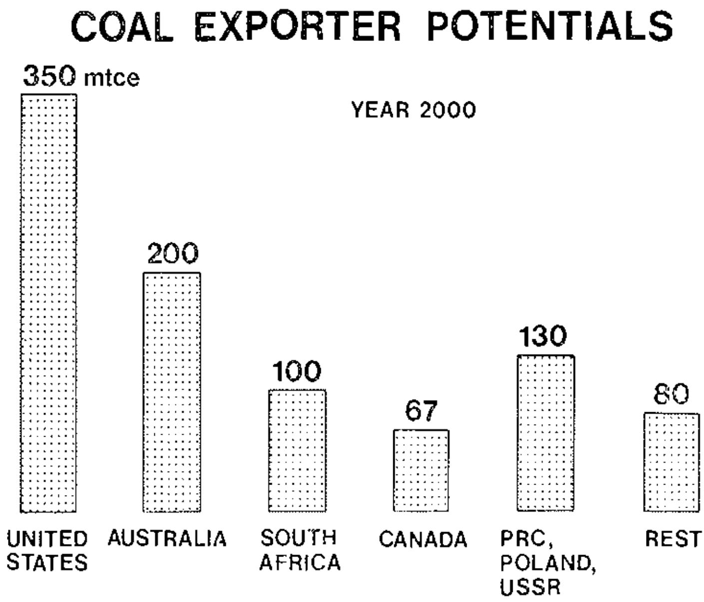
COAL EXPORTER POTENTIALS
350 mtce
YEAR 2000
200
100
67
130
80
UNITED STATES
AUSTRALIA
SOUTH AFRICA
CANADA
PRC, POLAND, USSR
REST

FIG. 8

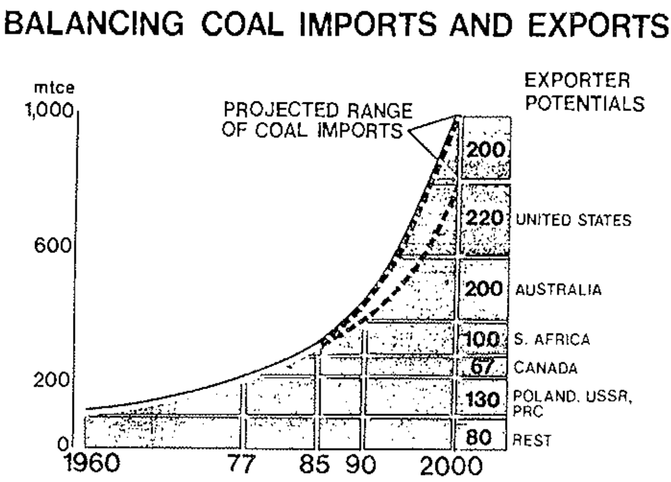
BALANCING COAL IMPORTS AND EXPORTS
mtce
1,000
600
200
0
PROJECTED RANGE OF COAL IMPORTS
EXPORTER POTENTIALS
200
220
UNITED STATES
200
AUSTRALIA
100
S. AFRICA
67
CANADA
130
POLAND, USSR, PRC
80
REST
1960
77
85
90
2000

FIG. 9

Only Australia and the U.S. are expected to be able to export more than 100 million tons by year 2000 and only the U.S. more than 200 million tons a year. As shown in Figure 8 the U.S. would become the "swing supplier" in a situation where coal import demands exceeded 800 mtce.

U.S. exports of 350 million tons in 2000 would represent about 15-20% of domestic coal use which is expected to grow to nearly 2 billion tons by year 2000.

8. *Reserves*

Economically recoverable coal reserves are very large — many times those of oil and gas — and capable of meeting increasing demands well into the future. Tripled world coal use by 2000 would use up about 15% of the economically recoverable reserves which are steadily increasing.

9. *Coal Prices*

Coal prices over the long run are likely to be related to costs. The present differential of 3-5 fold between coal and oil prices is likely to continue and may increase.

10. *Environment*

Environmental questions, including acid rain and CO_2, were considered thoroughly including measures that would have to be taken within each WOCOL country to comply with present and anticipated environmental regulations.

Conclusions on Environment are that:

— The technology exists by which exacting standards of environmental protection can be met, and much work is being done to improve such technology and to lower its costs.

— Coal can be mined, moved and used at most locations in ways that meet high standards of environmental protection, health and safety at costs that still leave coal very competitive with oil.

— Present knowledge of possible effects of carbon dioxide on climate does not justify delaying expansion of coal use.

11. *Technology*

The technology for mining, moving and using coal is well established and steadily improving. WOCOL projections are based on the use of existing technology with the improvements expected in the years ahead.

12. *Cost*

The final conclusion is that the capital needed in OECD countries would be one trillion dollars ($ 1,000 billion) — in today's dollars — to triple coal production and use and to expand coal trade. This is well within the capacity of the world's capital markets if early decisions are taken. Such investments are economically viable today. A comparable investment would be needed in the rest of the world.

These estimates of the order of magnitude of the capital investments needed to achieve the level of coal expansion projected lead to the following conclusions:

a) Three quarters of the total capital investment would he for the user facilities — principally electric power plants. Lead times for planning and building such facilities are generally longer than for any other part of the coal supply chain (mines, railways, ports, ships). Electric power plant investments will be large, whether coal or another fuel is used, if growing electricity demand is to be met.

b) Of the projected coal use in the OECD, about 70 percent would be for domestic consumption in the country where the coal is mined. The remainder — about 30 percent — is projected to enter world trade, with the largest investments to be made by producer-exporters. The investment needed for ships in $ 40-50 billion and is well within the capacity of the world's shipyards. A relatively smaller amount is needed for ports and internal transportation in importing countries.

c) The total investment over the period to the year 2000 is about $ 1,000 billion ($ 1978 U.S.) for WOCOL countries in the OECD whose aggregate gross capital formation for the period is estimated to be about $ 38,000 billion. There are wide differences among countries, but spread out over the period of two decades, the amount of capital needed lies well within the potential combined capacity of international and domestic capital markets.

d) The large investments for mines and transport will not be made unless users — principally electric utilities and industrial organizations — make early decisions to build coal-using facilities and accompany such decisions by long term arrangements to secure their coal supplies. Such decisions will be necessary to ensure the financing of coal supply chains — mines, railways, ports and ships.

13. *The Need for Action Now*

The central conclusions of the report is that coal can do all this if — and there is a big if — if the need and opportunity are seen quickly and if major decisions by users and suppliers are made soon. It will take 5-10 years to get such a large coal expansion into high gear. The lead times are long and all the links of the chains between mines and users must be in place.

Coal Use in Developing Countries

Deposits of coal have been found in 50 developing countries. Coal is produced in 30 such countries although most of the production is in 5 countries. In other developing countries coal is not used at all. Significant expansion of coal production in developing countries is not likely because of many institutional, human resource and financial obstacles. The World Bank has recently completed a study of coal in developing countries and reached such conclusions [1].

The conspicuous exception is the Peoples Republic of China where coal supplies nearly all of the primary energy. Coal is found and mined in many parts of the country. It is distributed to villages and communes where users can press it into briquettes for household uses. It is the fuel for transportation and industry. Firewood for cooking fuel disappeared in China long ago and was replaced by coal and in some regions is now supplemented by methane from biogas digesters. Oil is likely to be reserved for motor transport and agriculture.

Imported coal can in the future be substituted for oil in modern sectors in many developing countries, e.g. electric power and cement which in many cases are located on or near seacoasts. At present there are few

(1) Coal Development Potential and Prospects in the Developing Countries - World Bank - October 1979.

if any coal-receiving ports. Such ports are comparatively inexpensive to build and should be built soon. The savings through use of coal in place of oil are very large because of a three-fold or greater differential in price between oil and coal — a differential which we in WOCOL expect to continue and perhaps to become larger in the future. It is also the view of the World Bank and the International Energy Agency that the price gap between coal and oil is likely to widen over the long term due to the widespread nature and abundance of reserves, lack of ownership concentration and relatively few institutional constraints in the large producing and exporting countries.

An example will illustrate the gap between oil and coal prices. A new 200 MW(e) electric power plant will cost about $ 500/Kw if oil-fired and $ 700/Kw if coal-fired with extensive environmental controls (precipitators, scrubbers, etc.). Thus the capital cost for oil is $ 100 million and $ 140 million for coal. In most places coal can be delivered to ports for $ 50/T. The 200 MW plant will use 400,000 tons of coal/year for a total annual fuel cost of $ 20 million. Oil at $ 32/barrel or $ 150/ton coal equivalent will cost three times as much or $ 60 million per year or a difference of $ 40 million/year in fuel costs. Capital charges and operating costs will be somewhat higher for the coal-fired plant but the net savings will be a large part of the $ 40 million difference in fuel cost. A coal receiving port will be needed. It will cost about $ 15/ton of annual throughput or $ 6 million for a capacity to handle 400,000 T/year. Such an investment is a small fraction of the annual savings on fuel by using coal instead of oil.

A developing country building such a port would wish to include additional capacity to allow substitution of coal for oil in the cement industry where the capital cost to convert from oil to coal can usually be recovered in two years or less. In other industry the oil/coal price differential is leading to coal substitution for oil in many industrial uses all over the world. Thus the equipment and technology which the developing countries will need will become available on an increasing scale from many sources.

What about fuel for cooking for the large fraction of the people in rural areas far away from the modern sectors or the seacoast? Fuel is indispensable for cooking. Growing scarcity of firewood or dung confronts growing populations with an impossible problem unless coal (imported or indigenous) can be distributed to villages at prices users can afford or unless biogas digesters to produce methane can be built and operated as the Chinese have done. The technology of biogas digesters is not simple and successful operation requires careful control and maintenance. The fertilizer residue is of course a very valuable byproduct.

Perbaps tbe most acute problem affecting the welfare — indeed the survival of hundreds of millions — of people in developing countries is a supply of fuel for cooking as traditional sources disappear. Coal is the only low-cost readily useable fuel which can meet this need during the coming decades. It cannot be used without transportation and distribution systems which do not now exist. Nor do such systems appear in the plans of developing countries or in the plans of bilateral and multilateral aid agencies. This seminar could render a useful service by calling attention to this problem and the need for early action to solve it.

The peril of dependence on a daily flow of 20 million barrels of oil out of the Persian Gulf is clear. That peril can be reduced by choosing coal as the bridge to the future. Unless coal provides that bridge, the future is bleak. How to make that choice is explained in the WOCOL report and in detail for each country in a second volume, *FUTURE COAL PROSPECTS: Country and Regional Prospects*, Ballinger/Harper & Row, June 1980. That volume also includes estimates for all regions of the world outside the WOCOL countries.

DISCUSSION

PUPPI

I have two questions, the first for Mr. Desprairies, the second for Prof. Wilson:

1. Can you comment on the situation for production and reserves in socialist countries?

2. As a result of the work of analysis of energy problems in the world by many authoritative bodies, what is the inventory of the steps already taken?

DESPRAIRIES

A propos de l'URSS: il est probable que la production de l'URSS cessera d'augmenter dans les prochaines années. Les quantités exportables seront réservées par priorité aux pays d'Europe de l'Est et les exportations vers les pays d'Europe de l'Ouest diminueront. Néanmoins les sovietiques ont encore de grandes réserves mobilisables de pétrole et s'ils deviennent importateurs entre 1985 et 1990, ce ne devrait être que pour des quantités limitées.

En ce qui concerne la Chine, les prévisions de production (100 MT en 1980) qui allaient jusqu'à 400 MT par an en 2000 ont été sérieusement réduites en 1980 par le gouvernement chinois. D'autre part, les besoins intérieurs chinois sont très grands, et actuellement on imagine qu'entre 1990 et 2000, la Chine ne sera que très faiblement exportatrice de pétrole — si elle exporte.

WILSON

Answering to Prof. Puppi, I can say the following: The WAES Study defined problems and needs; the WOCOL Study identified more specific steps to get from here to there.

SCHMITT

I think studies work much more indirectly than directly. In the case of the Federal Republic of Germany, it was possible for us as consultants to the government to include the main findings of the studies in which we participated in basic investigations and projections prepared for the up-dating of the German Energy Programs. With respect to special and specific measures, I can report for my country on some very important efforts made to stimulate the use of the coal option:

— after 20 years of contingents on the coal market, the German government has recently passed a law according to which the coal market will now be opened, step by step;

— the German government has just announced a very broad and ambitious program for the development of coal gasification and liquefaction processes. Under the heading of this program, at the present time, about 20 different processes have been investigated in order to enable the government to choose those most advantageous for further development, maybe with public support. The first big commitment (about $ 1,6 billion) in this connection is a joint venture in coal liquefaction (SRCII) together with the USA;

— a remarkable shift of our R & D program, going from nuclear to coal and renewable energies.

Van Overstraeten

My question to Mr. Desprairies relates to the replacement of oil:

a) in industrialized countries it takes 10 years to build a nuclear power plant, or to develop a technology in order to make non-conventional oil competitive. It will not take more than 10 years to make photovoltaic conversion competitive with conventional plants for residential applications. Why not consider alternative energy sources more seriously? The opportunities look as bright as those of some conventional sources.

b) in developing countries, photovoltaic conversion requires no grid and no transport. Transport, required for oil and coal, is often a problem in developing countries. Photovoltaic conversion will soon be competitive with Diesel generators for pumping water (irrigation and drinking water) and for the electrification of villages. Why is it not included in your tables for the year 2000?

Desprairies

L'électricité des piles photovoltaïques sera sans doute un appoint important pour le prochain siècle, non pour les 20 ans qui viennent. Les quantités d'électricité photovoltaïque qu'on peut produire pendant les 20 prochaines années sont très faibles. Les coûts d'investissement sont très élevés ce qui est un grand obstacle pour les pays en développement. On mentionne souvent la nécessité de diviser par 100 — et non par 10 — les coûts de production, pour que les piles photovoltaïques soient compétitives. D'ici 2000, les piles photovoltaïques me semblent relever du domaine de la Recherche et Développement, pas de l'application industrielle, sauf dans un très petit nombre d'applications ponctuelles (consommations isolées).

Van Overstraeten

Photovoltaic electricity is more complementary than competitive with nuclear or with other conventional sources. At the present time, it is less than 10 times too expensive. I am rather sure that in 10 years, this gap will be closed.

Starr

I wish to make a few remarks to Prof. Wilson:

1. Externalities of coal use may determine how much it shares with nuclear power: social, political, economic considerations as well as national security.

2. Coal can be used for small plants, while nuclear power can only be economical for large plants.

3. Economic growth will determine the expansion rate of power production in the world, and energy costs will be a factor but not a limit on such growth.

Wilson

The question is how much nuclear, how much coal in industrialized countries? It isn't supply, it isn't technology, but a social, political decision in each country which will determine the quantity. During our study, this is what we were trying to illustrate: the interchangeability between nuclear and coal.

On the matter of ports, the major point I would like to make is the following: let us take for example a new 100 MW power station in a developing country. Such a station would use about 200 000 tons of coal a year. At a coal price of $ 50/ton this leads to $ 10 M a year which is about half or one third of the oil equivalent for the same power. But say I don't have a port. How much is it going to cost? For 200 000 tons/year, if the port costs $ 15/ton, that's $ 3 million, so the port will be paid within a year of operation of the plant.

PASZTOR

I, too, have some questions to ask Prof. Wilson. You mentioned that there would he no coal cartel, like the present oil cartel. Why not? It would certainly make sense for the USA and Australia to get together and form a cartel.

You mentioned also in your talk the environmental cost of hurning coal. The mining and transportation however has a lot of impacts as well. Don't you think that such imports will produce much more public opposition, similar to the opposition against nuclear power in many Western countries?

WILSON

About the coal cartel: Out of the three-fold increase in coal use, about 70% will be used within the country in which it is mined, only 30% will go into the world trade. Therefore there is a strong factor to bind the prices to the local cost.

The principal exporters are USA, Canada, Australia, South Africa, Poland, PRC (China). Why wouldn't there be a coal cartel, an OCEC? Our conclusion was that this would be unlikely because the US would be the largest coal producer and exporter, there are very large and widespread coal mines in operation (coal was mined in something like 30 states) and also in the United States the "anti-trust laws" are very severe indeed on any conspiracy in trade restraint and any agreement on markets and prices.

COUTURE

Prof. Wilson: a ratio of 2 to 3 between oil/coal prices in the international markets seems difficult to be considered as stable in the long term.

You assume that international prices of coal will reflect costs, which is not the case for oil. You don't need a cartel to have prices higher than cost: a restriction in production may be decided by Governments or taxes may be demanded by the people living in the mining districts: They may say: "the differences in cost belong to us!".

In short, it is probable that the supposed gap between cost and potential price (equal to oil or close to it) will be filled by some mechanism.

Wilson

Mr. Couture: if production is restricted, then prices can go anywhere, they can go up to the oil equivalent level. I think that, at least on the assumption that production is not restricted, new producers will enter the market when it becomes very profitable for those already in it. In other words, the market will work. The reserves are very large in relation to the output, many countries have reserves that are economical at slightly higher prices, so our conclusion was that there are enough producers and enough reserves to obtain adjusted prices.

Parikh

I would like to congratulate Prof. Wilson for paying attention to the problems of developing countries and their requirements for cooking about which I shall also elaborate during my talk.

However, the use of coal for domestic purposes is difficult in the developing countries for the following reasons:

1. It is difficult to use hard coal, which is meant for burning at high temperatures, for cooking which requires low temperature heat. Coal brickets or soft coke can be used but their uses are restricted around the coal-mine areas. In the case of India, the coal mines are centralized in one part of the country and only two mines are producing coal from which soft-coke can be made.

2. Extensive distribution systems for coal would be required, if it were to be used for domestic purposes. In the developing countries, where even distribution of basic needs such as medicines, soaps, paper for education etc. is inadequate, it is difficult to imagine a distribution system to handle this task.

3. One must remember that coal is also a non-renewable resource and, if it is imported, large amounts of foreign exchange are involved.

Thus, it would be more reasonable to promote charcoal production from firewood which should be grown in each village. Thus, one can eliminate all the difficulties mentioned above and provide energy for basic human needs from locally grown renewable energy resource for which no foreign exchange is required.

It was shown by Mr. Desprairies that 32% of production of the OPEC countries comes from populated countries. These countries have high population growth rates. Thus, by 2000, they may not be able to export oil any longer. Is this fact considered in the global oil export figures?

Secondly, Mexico — which is outside OPEC — has also high population and population growth rate. What is the export potential considering Mexico's own demand?

The next question is to Dr. Schmitt about non-conventional oil: which percentage does this type of oil represent and which kind of refinery do you use?

DESPRAIRIES

Mme Parikh: Oui, dans les calculs de l'offre et de la demande mondiale qui sont faits pour l'année 2000, on tient compte du fait que les pays peuplés de l'OPEC (Vénézuéla, Indonésie, Algérie, Nigéria) seront de moins en moins exportateurs du fait de l'augmentation de leur consommation intérieure.

SCHMITT

1. Before we go into ambitious programs for the liquefying of coal or the use of shale oil or heavy oils, we will find huge advantages to convert much more crude oil into light products. The processes are available, the costs are dependent on the kind of process, product, size of the plant, site etc... The higher the share of light products, the more expensive is the process. A rough figure, at least for the Federal Republic of Germany, says that a difference between prices of light and heavy product of about 150 $/t is enough to make intensified conversion.

2. An additional remark about coal prices: we believe that one of the crucial points is the cost and availability of nuclear energy. In my opinion it would be a dangerous illusion to believe that coal and nuclear are alternatives. Giving up the nuclear option means a high probability of losing the coal option too.

TABOR

Whilst a coal cartel (like OPEC) may not develop, it is my view that market forces will not permit — indefinitely — a large difference between the cost of coal (per unit of energy) and the cost of crude oil: it is extremely rare, in a free market world, to find two products that perform the same function, that differ in price by more than, say, 15%. I endorse the view of Dr. Couture.

WILSON

If there is a free competitive market, we think the market forces will work because the reserves are very large in relation to demand. So, in the long run, coal prices would tend to be related to cost. But this is a major issue.

COLOMBO

We have heard three most interesting papers which I should like to comment on.

First of all, the problem is not one of physical scarcity. There are abundant resources of fossil fuels, and we may hope that they will last several centuries, until "definitive" sources become available on a large scale. But there may be short and medium term problems (which Mr. Desprairies called "problèmes de robinet"):

About oil: It seems to me that, even if we adhere to the position of those who believe that total world resources are at least 300 billion tons, we should recognize that these resources will be both high in cost (coming from continental shelves, arctic or other remote areas...) and politically unsecure. It is therefore appropriate that on Wednesday afternoon our discussion will focus on the most important topic of "political implications of the energy problems".

About gas: This is a big incognito. Some authors believe that the resources of gas are extremely high. Dr. C. Marchetti of IIASA, for example, working on the basis of the Fischer and Pry Substitution model, has advanced the hypothesis that gas, rather than coal or nuclear, will be the next dominant source to substitute oil. Here again, even if one agrees on this view-point, consideration of price and national security for energy supply play a determinant role.

About coal: I too wish to congratulate Caroll Wilson for his brilliant and highly inspired work. I should however express my basic agreement with Jean Couture on the reasons behind producers' cartels, which could bring about higher international prices of coal. In my mind, we may get into problem areas at least on two subjects:

1. How free will coal export in the future be? Some countries might indeed decide that coal is a strategic resource and thereby limit its export.

The ultimate price of coal could well, in my opinion, be slightly lower — for the same energy — than the corresponding price of oil. The optimum time to take this position is not now, but rather when consumer countries have invested in huge infrastructures for import and utilization of coal.

2. Environmental and health problems might not be as simple and clear-cut as some believe. The CO_2 problem, in particular, could prove to be a severe one, ten or twenty years from now.

If I have made these comments, this is because I believe we should not repeat the mistake of the past of putting all our eggs in one basket. We need, I believe, coal, gas, more oil, nuclear and other alternative sources in a strategy of pluralism, calling on a variety of sources and technologies. And we should, indeed, pay particular attention to the problems of the less developed countries, to which fortunately our symposium will devote one session.

DESPRAIRIES

I'm going to answer some of Prof. Colombo's questions:

1. Yes, the cost of oil production will increase but should be kept within a limit of $ 10/20 a barrel, which is under the present price of $ 30/32.

2. The areas of production should not be insecure: enhanced recovery oil would come to a large extent from industrialized countries, new oil from polar zones and deep seas.

3. We do not believe, at the French Petroleum Institute, in either the mineral origin of hydrocarbons or in the possibilities of huge gas deposits at great depth.

4. Yes, I think that the price of gas will be increasing at about the same price as oil — for the final user — because it is the only energy which can replace oil in existing installations without asking for significant investment in the users' equipments.

WILSON

I agree with all that Prof. Colombo has said. Diversification of sources and risks is a basic principle which all buyers and users should follow. I recognize that the future of coal prices is a very important question which, probably, has to be analyzed more deeply than it was possible for us to do in the WOCOL study.

SCHMITT

I have some questions to ask Prof. Colombo and Mr. Desprairies: We see at least some possibility of a decoupling of gas prices from crude oil prices even if exporters try at the present time to bind them. The reasons are:

1. Gas shows with respect to transportation from distant areas of production to those of consumption noteworthy disadvantages.

2. Gas distribution leads to much higher costs than that of oil products because of the extremely low load factor in main consuming sectors like households and business.

3. Gas will forthcomingly be marketed on the heating market; oil will be converted more and more to a light product and sold on premium markets; the heating market shows the lowest degree of consumer preferences and the still highest degree of competition: nuclear, coal and last but not least more efficient use of energy. Thus if we succeed in using nuclear at least to a limited degree, there exist good opportunities of seeing gas prices increase in the future less than those for crude oil.

SANCHEZ-SIERRA

I have two comments: First, economic growth rates and energy growth rates go hand in hand. But the situation is very different for developing countries than for industrialized countries, which have already a high level of living. Energy growth rates for industrialized countries are based on economic considerations. Higher growth rates are needed for the developing countries if we want to develop them.

Secondly, I wish to point out that, in the oil market, the "Seven Sisters" were a cartel much before OPEC. And now they are going to control the coal market as well. We are not going to have a countries cartel, but a multinational companies cartel.

WILSON

Just a comment: It does not necessarily change perspectives, but as long as the Seven Sisters controlled oil prices, that is until 1973, they were in the neighbourhood of 1 to 2 dollars a barrel, whereas when the control of oil prices passed to the producing countries, the prices moved up to now $ 35 a barrel.

Chagas

Can you comment on the problem of coal mine accidents? Do you have statistical data on health improvement with the new methods of health protection for coal miners?

Starr

If you want a sure mining plant, your cost will be about 15% higher. But the real problem is gas and how you can allow the consequences of coal dust on miners. Deep coal mining is risky. Strip mining is, from that point of view, much less dangerous.

Couture

The risks in the deep mining industry certainly are important and some of them are in connection with "methane", which can lead to big explosions and, in very rare circumstances provoke accidents where many victims are involved.

But the biggest risk is the fall of blocks; it is mostly individual accidents which occur in that way, but, statistically, it is the major cause of fatal casualties.

A medium figure is about one fatal casualty for two million tons produced in deep mining (all causes taken into account).

Teillac

Nous avons assisté dans les dernières années à une augmentation considérable du prix de l'énergie. De nombreuses études ont été faites. Mais a-t-on pris dans les différents pays, développés et en voie de développement, toutes les décisions qui s'imposent (recherches, extractions, équipements divers) pour développer la production de pétrole et de charbon de manière à faire face aux problèmes énergétiques et à la menace qu'ils suscitent? Les vingt prochaines années seront cruciales.

Desprairies

For oil, my answer is yes, we are doing the maximum to expand oil exploration and production throughout the world, in market economy countries and in socialist countries too. We are trying to improve seismic techniques to see the configuration of geological layers; to improve drilling techniques on shore and off shore, in deep seas and polar zones and we are devoting much money to this. All the figures I showed on reserves are in recoverable reserves, which are supposed to be improved from now 30% of oil in place to 40% in 2000 and around 50% in the next century. The expenditure devoted to oil exploration has increased to a large extent since the 1973 oil crisis.

WILSON

There is a great contrast in the knowledge and the state of technology of oil compared to coal. Coal has been neglected for many years. Transport of coal has not changed for 50 years! There is no pipe for coal. Chemistry of coal is not well understood. On the coal mining side, a lot has already been done, but very little on the rest of the coal chain.

TEILLAC

Prof. Wilson, pensez-vous dans ces conditions que le programme indiqué dans le rapport WOCOL est réalisable?

WILSON

I think so, the projections I showed to-day are largely based on existing technology and the extension could be done.

MANAGEMENT AND BASIC RESOURCES

CONTENT OF ENERGY

Chaired by Professor A. Blanc-Lapierre

BASIC RESOURCE CONTENT OF ENERGY

L. PARIS
Manager of the Research and Development Department of ENEL
(Italian Electricity Board)

1. Introduction

The events in the last decade, referred to as "environment and energy crises", produced several changes in engineering thinking habits.

One of the most evident aspects of these changes is the lack of confidence in economic optimization as a basic decision tool, capable of ensuring the best management of resources. An attempt was made at finding a replacement of this decision tool in the large, universal, macroeconomic models. But, because of their complexity, they risk to remain centralized tools in the hand of a cultural elite and they cannot be conveniently used by most technologists, engineers and researchers for checking the solutions under study.

Today, therefore, in the energy debate, a given way of producing or consuming energy is referred to as "appropriate from the energy viewpoint" or "appropriate from the environmental viewpoint", overlooking whether such a way of producing or consuming energy is "appropriate" in economic terms.

This is misleading, makes choices highly debatable and generates difficulties to understand the mutual positions; moreover, it determines a cleavage between innovative thinking and reality, since our system rewards only economic choices.

2. The generalized economic optimization

To revalue economic optimization as a decision tool, consideration should be given to the fact that any product and service supplied to man consumes or utilizes other products or services, but, at the beginning of the chain, there are always the basic resources, which can he classified in three main categories:

Labor: that is time of human activity devoted to the production of goods or services;

Raw materials: understood as non-renewable substances residing in the earth crust in the state in which they occur in nature;

Land and environment: understood as space destined for human activities and for the forms of life that man wants to promote and conserve.

As it is possible to secure the same product or service by using different combinations of these resources and since they are available in limited amounts, it is absolutely necessary to choose the approach which minimizes their use on the whole.

To get a minimum overall use of so different quantities, it is necessary to measure them with the same unit; this unit has been money for centuries and the minimum operation is called economic optimization.

The universal value of this logic tool is unquestionable. On the other hand, it is obvious that longterm choices made exclusively in current economic terms may involve big strategic errors. Indeed, the current prices of some basic resources (such as land or energy resources) may be inadequate for their actual value and not take into account their progressive exhaustion.

While it is absolutely undesirable to neglect the economic optimization criteria, the value of money, in economic evaluations, should be given a more general meaning, which does not necessarily correspond to the current price of resources, but which conventionally accounts for the indirect consequences of their consumption.

This paper is aimed at considering the criteria to assess the basic resource content of goods and services referring, in particular, to the service of electric energy supply.

This method, indeed, can provide a substantial contribution to the energy sector, where the most conventional criteria of choice are being questioned.

For example, energy conservation is often called "a must"; but which basic resources are going to be conserved? Raw materials, environment, or labor? And what consumption of these resources does the energy conservation effort require?

3. The approximated analysis of the basic resource content

To apply this method of generalized economic optimization, however, it is necessary to know the basic resource content of the product or service being considered in physical terms; this is not the case in a market-oriented economic optimization, where this content is already incorporated in the cost of a product or of a service.

The problem of assessing the basic resource content of goods or services is time-consuming, but the result is so exciting and speculative that we are not the only ones who coped with it [1]. It is worth mentioning the study called WELMM, started by IIASA (which was made fully known in 1979) [2, 3].

The specialists of WELMM (Water, Energy, Land, Material, Manpower) conducted an analysis of human activities focused on quantities only, neglecting costs, and they set up a data base which is regarded as a pre-condition for any development and application.

Our work was centered around a simplified and rough analysis of the basic resource content of goods or services with the aim of checking the effectiveness of such approach in solving the problem of energy choices.

Our approximation in reconstructing the chain of goods and services consisted in measuring the quantities in terms of money at the current costs and prices; with this criterion it is sufficient to know the breakdown of the expenses of the companies producing goods or services into labor, energy, materials and capital.

Fig. 1 shows the analysis made to reconstruct the basic resource content of an electric transmission line; this is a product which appears in the chain of goods and services for the production and distribution of electricity, which is the topic of our presentation.

The analysis begins with the breakdown of the line cost into some fundamental items which occur in different and specified industrial areas.

Each cost item is in turn apportioned among semifinished materials, labor, energy consumption of different types and capital costs; the latter costs measure the resources indirectly consumed in the construction of the plants required for producing the product or service. The cost of semifinished products, which in turn occurs in different and well-defined industrial areas, is broken down with the same criteria into cost of raw materials, labor and energy consumption, and into capital costs.

As a result, a series of costs for labor, energy, raw materials and capital costs are obtained. The capital costs, that is the indirect utilizations

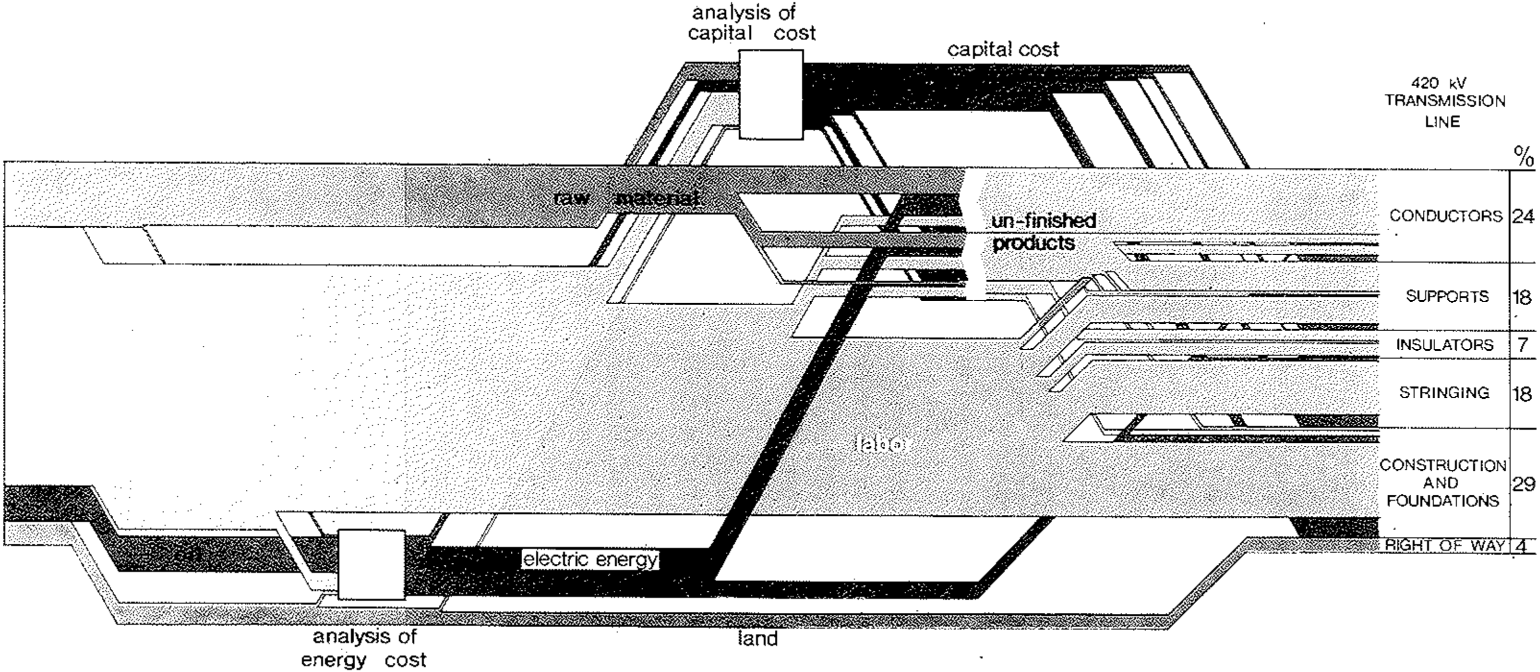

FIG. 1. Analysis of basic resources content of an high voltage transmission line.

of resources, are then broken down by analyzing the cost items of the plants to which they refer. This analysis, which is not indicated in the figure for the sake of simplicity, was conducted following the same approach as the one shown for the whole line.

Now, the energy consumption has to be analyzed (shown in the figure as electric energy and fuel) and this is the analysis which will be illustrated as the primary goal of this work. It is indicated very briefly in the figure, evidencing the raw material oil with respect to other raw materials.

The fact that the analysis of the overhead line, of which the analysis of energy consumption is part, is in turn part of the analysis of energy consumption should not raise perplexities: in a process of successive approximations, convergence is rapidly attained.

The complexity of the analysis is only apparent: each ring of the chain is represented by a percent apportionment of company expenses among items which can he easily singled out in industrial accountings.

This diagram also exhibits the costs deriving from the land used both by the same overhead line (right-of-way expenses) and by the industries contributing to produce raw materials. As a matter of fact, these costs poorly reflect the actual land and environment utilization, since the impact on the quality of the environment is not quantified today in any way. This aspect will be specifically dealt with later on.

4. Critical comments on the method and corrective actions

The approximated method just described has some critical points.

First of all, the market prices and taxes and especially those of some raw materials are extremely variable over time and from one place to the other. As it is difficult to find cost analyses conducted at the same time and at the same place, the constance of the unit of measurement of the quantities is lost. This is an intrinsic defect of the method which can be eliminated only with corrective actions taking into account the trend of the market prices of raw materials. But these actions are very laborious and can be applied only to the items which have a prevalent influence on the result.

Additionally, there are some specific aspects to which it is worth giving consideration: the measure of the resources indirectly used in the processes through capital costs and the evaluation of the land and environment resources engaged.

4.1. *The measure of the resources used indirectly*

In any process, to create a product or a service, resources are indirectly used, since the process involves facilities whose construction requires a consumption of resources.

Economic assessments take into account this indirect consumption through the so-called capital costs, which consist of depreciation charges and interest rates.

Moreover, these should necessarily be accounted for in an approach which considers quantities only. It is understandable that the resources consumed in the construction of the plant and which cannot be recovered at the end of its life should he charged to the products or services produced by the plant during its life: this, in financial terms, corresponds to the *depreciation charge.*

It is less evident, but equally necessary, to consider that a lockup of resources, even without consumption, represents a cost for the community involved and should therefore be penalized. In this case, we should assume that the lockup of resources for one year is equivalent to the consumption of a share of these resources: this, financially, corresponds to the application of an *interest rate on capital.* However it could be discussed about the application of this penalization and whether this must be applied only to labor or even to raw materials or to land and environment; in principle, for instance, it should not be applied to raw materials, because there is no different cost for the community in conserving this type of resources on site or in another place after extraction, or even incorporated in a product.

4.2. *The measure of the land and environmental resources*

As previously pointed out the analysis of market costs enables us to assess, in terms of outlay, the direct utilization of land but not the nuisance to the sorrounding environment and therefore the reduced useability of the land not directly engaged and which, generally speaking does not give rise to any outlay.

Any process of choice, which resorts to remuneration of the basic resources utilized, is to assess these effects in quantitative terms and express them in economic terms. This is what will be done in the following analyses.

First, it is necessary to express any type of environmental alteration in quantitative terms, then to assess, even if conventionally, the reduction in value of the land deriving from these alterations. Both problems are particularly difficult; as already pointed out, only for a total land occupation can a useful market evaluation be made.

Table 1 displays the various nuisances to the environment caused by electric generation, transmission and distribution systems, as well as the degree of difficulty in both measuring and economically penalizing each nuisance.

TABLE 1 - *Measure and Penalization of Environmental Nuisance.*

NUISANCE	DIFFICULTY DEGREE	
	MEASURE	ECONOMIC PENALIZATION
SPACE OCCUPATION: AT GROUND	•	•
SPACE OCCUPATION: OVERHEAD	•	•
IMPACT ON LANDSCAPE	• • •	• •
FALLOUT OF HARMFUL EFFLUENTS	• •	• •
PHYSICAL AIR & WATER ALTERATIONS	• •	• • •
NOISES, RADIOINTERFERENCE, OTHERS	•	• •
GLOBAL ALTERATIONS	•	• • •

However, even when the choice of the environment penalization values is highly arbitrary, the penalization criterion is still valid; if the penalization value is conventionally established, choices can still be made, perhaps not the best but certainly consistent with one another, and over time, the penalization value may be adjusted to satisfactory levels.

It is always possible to assume the economic value of an environmental alteration as a parameter in a sensitivity analysis, so as to explore the consequences of its different evaluation in the policies to be pursued. In the analyses which will be dealt with, the following criteria were adopted to estimate the costs linked with the land and environment utilization.

Space occupatiön - Space occupation requirements are easily determined considering the land which, because of system operation or for safety reasons, cannot be utilized for other purposes. The space occupation cost can be easily determined from expenses for purchase of land and right-of-way acquisition.

Impact on landscape - This nuisance is at present considered as the most difficult to quantify; even if many proposals were put forward, most specialists seem to lack confidence in their effectiveness; they need, therefore, further discussion and improvements to be commonly accepted.

A measurement of such alteration which was adopted in the following analyses is hinged upon the geometric evaluation of the occupation of the visual field by the disturbing element, corrected with some coefficients taking into account the extraneousness of the element in the landscape and other psychological effects that can be evaluated through opinion surveys [4].

Then, the nuisance to the landscape was penalized according to criteria very arbitrary in absolute terms for the different components of the power system.

To give an idea of this first-hand assessment of the nuisance to the landscape, the cost of this disturbance, attributed to a thermal power plant proved to be about 5 times the purchase cost of land for its construction.

Polluting effluents - On the economic assessment of air pollution damage and control costs, there is already a number of comprehensive studies; among these mention should be made of the report by Waddel [5], expressing the conservative attitude of EPA, and of that by Justus [6], expressing the attitude of the utilities.

Both methods refer to the damage caused at national level by air pollutants, attributing a share of such damage to power plants and correlating it with the kWh produced.

The differences in the results obtained by the two specialists are significant and mainly concern the share of cost to be ascribed to power plants. Waddel, who relates this share solely to the tonnage of emissions, uses values much higher than those adopted by Justus, who takes into account many other factors, including height of the emissions, dispersive characteristics between source and damage site, toxicity of the pollutant and exposure time.

In our approach, in order to quantify the pollution due to each pollutant, a weighted average of its ground concentration was assumed as a basis for the assessment of the penalty factor, which is connected with the worth of different land categories. While it is feasible to assess the quantifiable elements of damages (as in the case of vegetation, materials and urban property), it is problematic to assess the damages to human health and to the cultural heritage, which have a highly intangible component and which can only be assessed in a conventional way.

In performing such evaluation, the criterion was that any conventional penalization to he assigned to pollution effects on the environment, and specifically on health and the cultural heritage, should he severe but consistent with the keeping of other peculiar activities, besides energy supply, of our standard of life, such as road transport and home heating. In our analyses, a highly conservative level of such costs was chosen. The resulting damage costs of global emissions due to fossil fuelfired power plants is of the same order of magnitude as EPA estimates which, as previously highlighted, are to be regarded as rather prudential.

Air and water alteration - As concerns environment alterations induced hy cooling systems, thermal power plants were supposed to be water-cooled, as it happens today for the near-totality of them in Italy; consequently, no alterations were supposed in the physical conditions of the atmosphere. Further, it was considered that, in water-cooled power plants, local effects of the water temperature alteration have dropped to such levels that they do not cause damages to the aquatic environment. On the other hand, the availahility of cooling waters highly restricts the possibilities of power plant siting; this implies the use of valuable land, like the banks of large rivers and sea-coasts, which are often densely populated or used as tourist resort areas and when these areas happen to be completely wild they are likely to be protected as natural wildlife sanctuary. In other words this entails the use of more and more valuable land, that is more expensive environmental resource, which was taken into account in our assessment. Additionally, while on the sea coasts the availability of cooling water is practically unlimited this does not occur on the rivers. Therefore, it was deemed right to quantify this type of resource in such a way as to make equivalent the cost of plant installation on the rivers near the load and the cost of plant installation on the sea, far from the load: this was achieved by adding to the river plant production cost the extra costs for energy transmission from the closest sea coast, as a compensation cost for engaging the cooling water resource.

Global alteration: the problem of CO_2 - As possible source of global alterations, at least CO_2 emissions should be considered since these appear as the most controversial topic in the debate about the global balance of our biosphere.

The consequences of an excessive CO_2 concentration in the atmosphere are questionable and questioned: anyway, a conventional penalization per ton of CO_2 released into the atmosphere might be a tool for rationally limiting such release.

In our first-approach analysis, however, CO_2 penalization was overlooked.

Other polluting effects - Other minor effects were considered in the analyses, such as oil spills in the environment, in particular in the sea, during extraction and transport.

Each time, different quantification criteria were hypothesized.

It is obvious that such an approach implies a change in criteria for designing plants from the viewpoint of environmental impact, whereas, with the current criterion, the most economic solution is sought, meeting the limits of impact on the environment which are imposed by the legislation or which, somehow, are considered as acceptable. When there are criteria for quantifying the environmental damage, the minimum cost solution, including the cost of the damage, will he sought. By way of exemplification, Fig. 2 describes the trend of the environmental cost assessment for sulphur oxide emissions.

The graph exhibits the cost of pollution control and the cost of environmental damage, as a function of ground concentration of pollutant; the total of the two costs with its minimum determines the most appropriate compromise between pollution control cost and environment deterioration. By comparing such value with the pollution levels considered as acceptable by present laws, it is possihle to check whether the choice of the environmental cost is to be considered conservative or inadequate.

If the cost (for kWh produced) which the community must bear for sulphur oxide pollution is supposed to be 5 times higher, then (fig. 2b) the optimum pollution levels decrease to lower values. This involves an

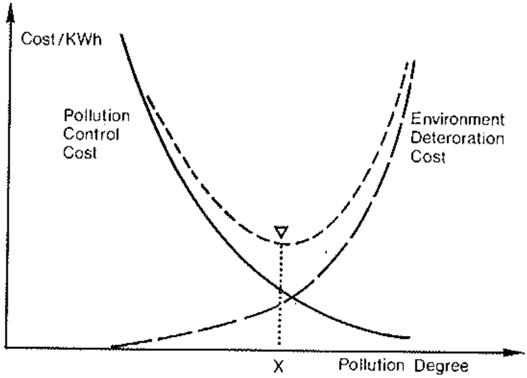

FIG. 2a

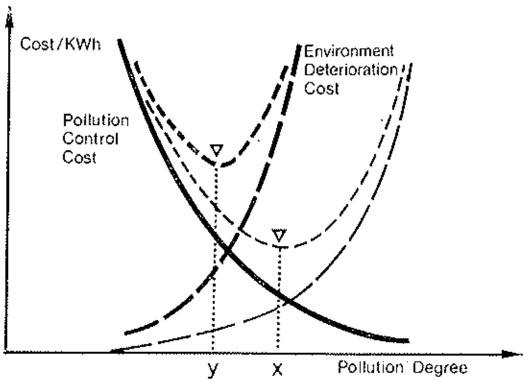

FIG. 2b

increase in environmental cost as well as more expensive control measures which would require more labor and raw materials.

5. THE BASIC RESOURCE CONTENT IN ELECTRICITY

The above method will be applied to assess the basic resource content in the service of electric energy supply.

To better evidence the qualitative meaning of the results, this report will present them in graphic, rather than numeric form.

In this study, the energy consumption in the different processes is supposed as covered using always oil as primary source; this is a simplificative assumption which, however, in a country like Italy, is very close to reality.

In the following analyses, the raw materials oil and coal are, in effect, indicated with the value they have on site before extraction, the other raw materials, for the sake of simplicity are considered at their value upon arrival at the factories which carry out their first processing; they thus contain also the labor, environment and raw materials necessary for extraction and transport.

5.1. *The electric power produced by fuel-oil-fired power plants*

Fig. 3 shows the entire process which originates from oil extraction, in terms of content of basic resources required for supplying to the user,

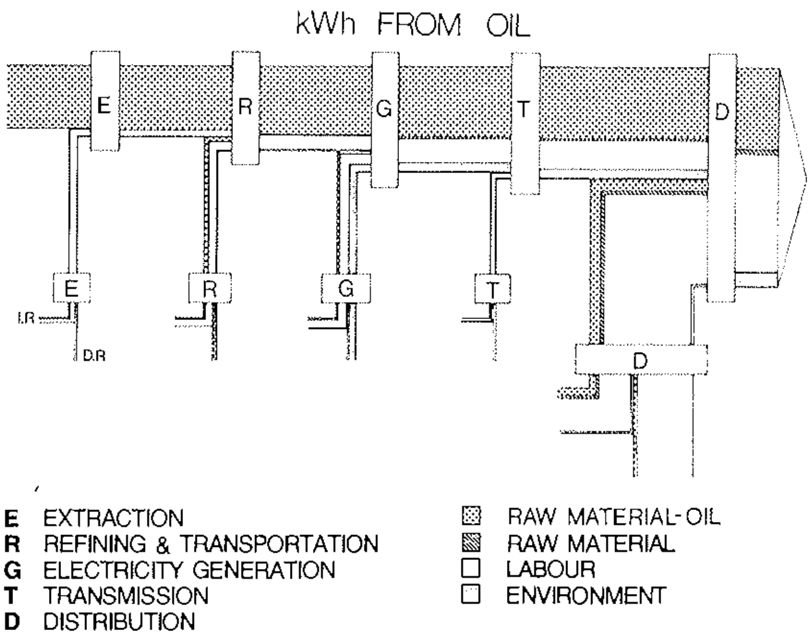

FIG. 3. Basic resources content of electricity produced from crude oil. At each stage, the left share is referred to indirect resources, while the right share is referred to direct resources.

at low voltage, a kWh produced by a conventional thermal power plant. In this figure, it is possible to observe the basic resource content in:

— crude oil on site
— crude oil
— fuel oil
— electric energy at the power plant
— electric energy supplied to large industrial consumers
— electric energy supplied to household users

These energy forms are obtained through the following processes:

— extraction
— refining and transport
— electricity generation
— electricity transmission
— electricity distribution

The basic resources are quoted on the basis of actual market costs, except for environment, whose costs are conventional.

Since, among raw materials, the "crude oil on site" is of special interest in our analysis, it was particularly emphasized.

To assign a value to the "crude oil on site", we deducted from the final crude oil market price, including royalties of the producing country and taxes of the importing country, the costs for extraction and transport to refinery, which were evidenced as consumption of labor, energetic and non-energetic raw materials.

Since the crude oil extracted has a market value related only to quality and not to difficulty and cost of extraction, with an assessment of this type the value of the energetic raw material is lower where the extracting costs are higher.

This produces some difficulties in the parametric analysis as a function of resource value; for this analysis, reference should necessarily be made to the value of the extracted resources but with a given origin.

Fig. 3 refers to an oil with a relatively high extraction cost (North Sea oil).

It is worth recalling that, as regards the environment, the direct occupation of space was considered at market value, while emissions into the atmosphere, heating of waters and impact on landscape were penalized with the conventional criteria mentioned in the paragraph 4.2. The impact on landscape is a decisive factor in power transmission and distribution.

In view of the above the following comments can be made:

— despite the fact that quantification of environmental costs is performed with quite severe criteria, the consumption of "land and environment" resources is limited at any level and it does not go as far as to call for alternative solutions, more drastically utilizing raw materials or labor to conserve environment.

This is strangely in contrast with the opposition of the public opinion which conditions the development of power plants and aggravates the energy crisis. This leads us to think that this opposition, which is not so strong against other more evident and irreversible land uses, is more linked with social relation problems than with actual land optimization ones;

— the labor resource content in the supply of power to the low-voltage user predominates over the energetic raw materials content, in spite of the present high cost of oil.

Obviously, the situation for electric power at generation level or large industrial consumer level, is quite different;

— at any rate, the energetic raw material content is already such as to suggest the research of alternative solutions using other energetic raw materials which are more available than crude oil, but which imply a higher use of other resources, namely labor for extraction, transport and conversion to electric energy, such as oil shale, coal or nuclear energy.

In the next paragraph, two of the most typical oppositions considered today will be analyzed: production of electric power from coal and from solar energy.

5.2. *Electric power from coal-fired plants*

The process relative to the service of supply of electric power from coal-fired plants, described in Fig. 4 in terms of resource consumption, is similar to that of the production of fuel-oil-fired plants.

Reference is here made to South African coal delivered in Italy to plants located near a harbour. After deducting the high costs of extraction

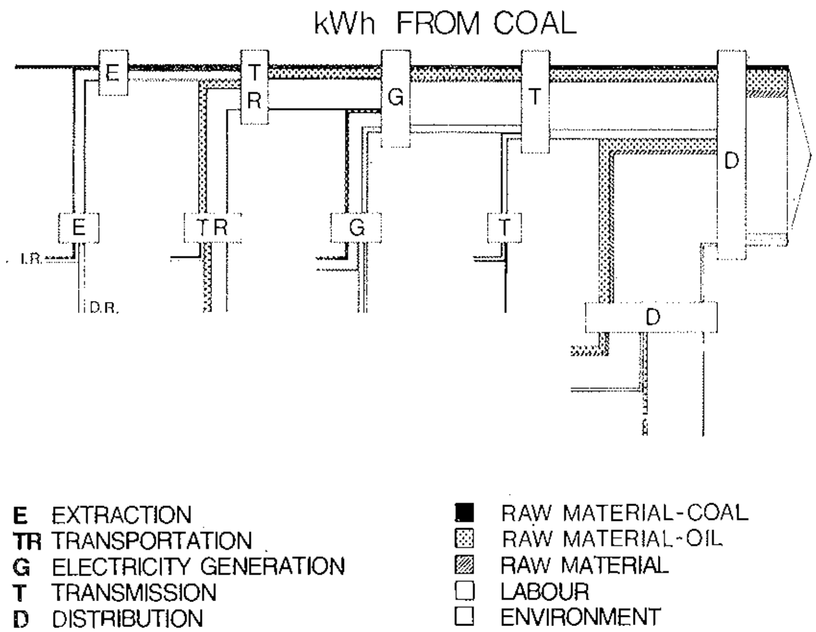

FIG. 4. Basic resources content of electricity produced from coal.

and transport, the value of the raw material coal (to be assessed on site before extraction) is very low; this corresponds to the very large availability of this energetic raw material.

It follows that the impact of the raw material oil consumed in the process is even higher than that of coal. It is necessary to underline that the production is supposed to be still set in an oil-based energy economy.

The value of the land and environment resources utilized is slightly lower than that in the previous case, since the low sulphur content of the coal considered largely offsets the costs (always conventional) deriving from particulate emissions.

The fundamental item of the resources consumed in this process, particularly at low-voltage level is labor; this is associated with a share of energetic and non energetic materials, which are normally associated with labor in any process. Energy conservation in this case means above all labor resource economy. Any energy economy obtained at costs higher than the cost of the energy saved would not have any meaning in this case, since it would entail a greater consumption of resources of the same type.

5.3. *The electric energy produced by photovoltaic solar power plants*

In this case, the process described in Fig. 5 is particularly simple; the stages of fuel supply, indeed, are completely missing. The stage of transmission is also missing. In effect, a relatively modest power plant size and a location near the loads were hypothesized. As a matter of fact, the total elimination of a transmission network could not be assumed in a climate like the Italian one, owing to the need of reserve in non-insolation periods. However, it was neglected, due to the moderate economic impact of this stage of the process.

The cost supposed for the solar power plant, in this case, is an extreme target; in other terms, this is the most optimistic cost projection made today [7, 8, 9].

This target implies that each of the several research programs under way for the different plant components reaches the minimum cost target and requires a mass production and an extremely high mechanization in the power plant construction. This is an extreme target, which in our opinion is not very likely to be reached, but it can be accepted as a challenge.

Today, costs are much higher, as shown by Fig. 6, which corresponds to a power plant cost which could be obtained at present with the best

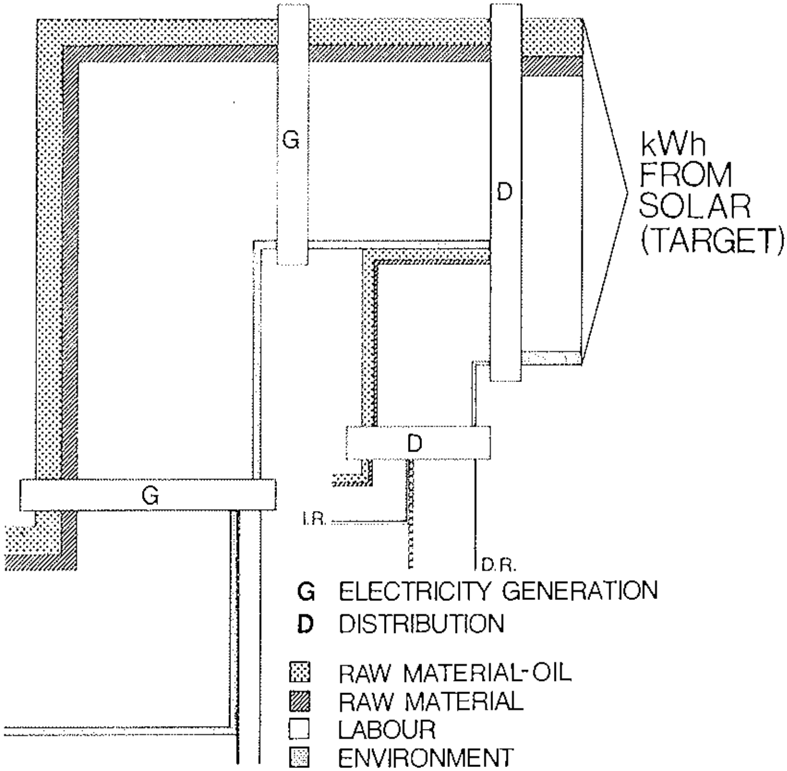

FIG. 5. Basic resources content of electricity produced from solar photovoltaic power plant. The values refer to a most optimistic target.

technological production processes and assuming a production already at an industrial stage.

Fig. 7 shows the breakdown of the kWh capital costs due to the solar power plant (indirect costs) among the fundamental cost items. Note that, in the target case, the share of the costs relative to the construction of power plants is relatively more important because the technological progress which can be achieved is lesser than the progress to be foreseen for cell production and module assembly. The environmental cost is represented in this case by the costs of land occupation only, in addition to the environmental costs linked with the construction of the plant components, and is totally independent of the impact on the landscape, which is difficult to assess, and of other possible climatic effects, which are still to be ap-

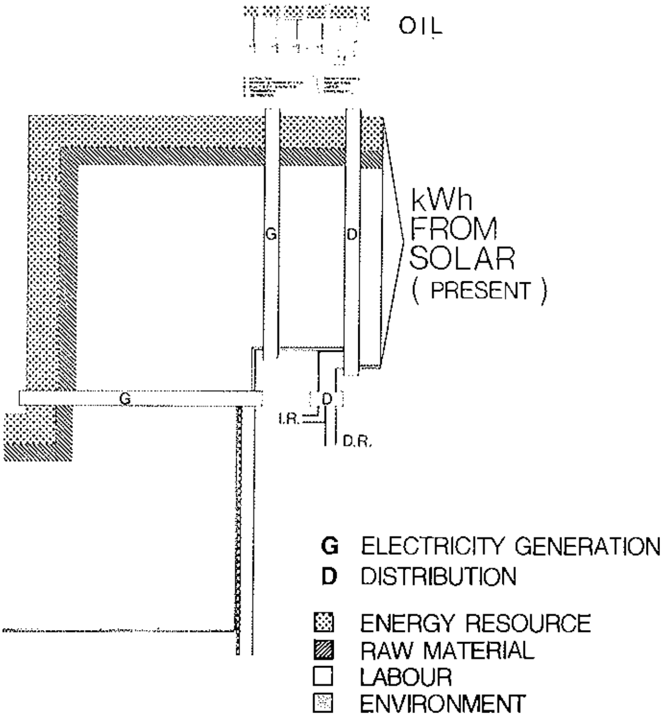

FIG. 6. Basic resources content of electricity produced from solar photovoltaic power plant. The values refer to the present best technological process and to a production at an industrial stage.

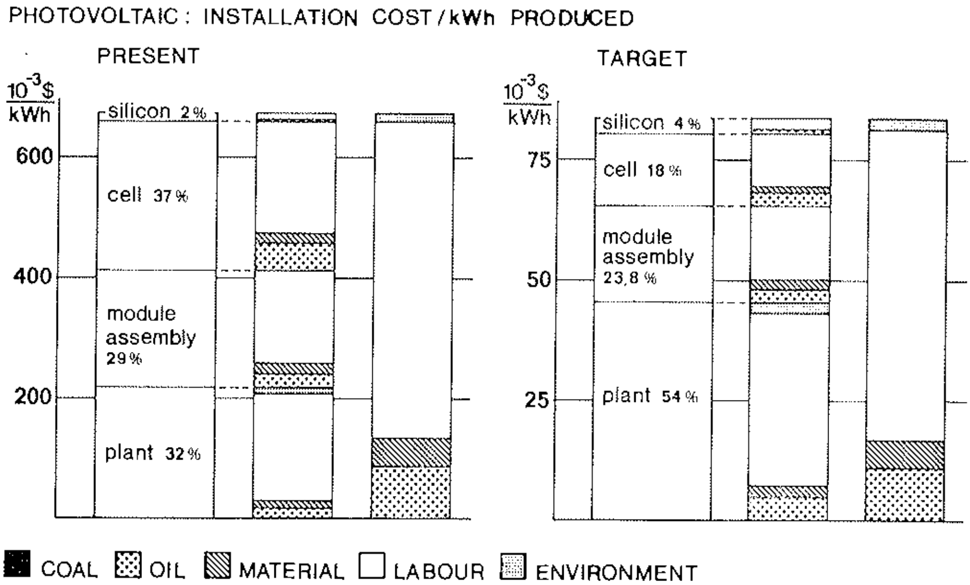

FIG. 7. Breakdown of the kWh capital costs due to present and target solar photovoltaic plant among the fundamental cost items.

preciated. The costs which can be attributed to the operation of the plant are hard to assess owing to lack of experience; also in this case, the assumptions made were particularly optimistic.

5.4. *Comparisons and comments*

Fig. 8 and 9 illustrate the results of the assessments of basic resources content of the kWh at generation level and at the low-voltage users level. It can be noted that:

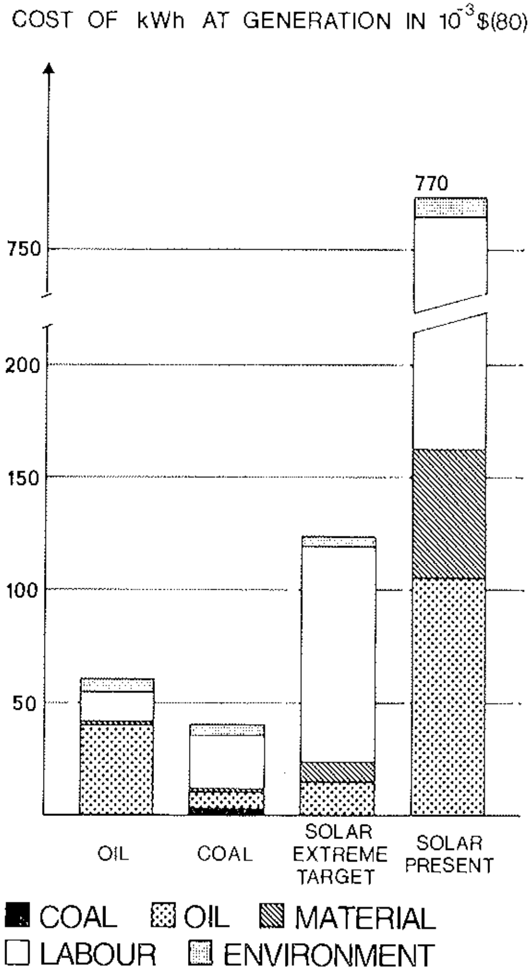

FIG. 8. Comparison of basic resource content of the kWh at generation level.

— the solar power plant, at the present state of the art, costs more, in terms of oil, than a fuel oil-fired plant; this is rather a curiosity, since nobody would ever build a solar plant at these costs or would build it only for experimental purposes;

— the solar power plant, even after reaching full development in the most optimistic assumption (target-case), would cost today, in terms of energetic raw materials, much less than an oil fired plant but more than a coal-fired plant; this would entail a higher requirement of labor and of non-energetic raw materials;

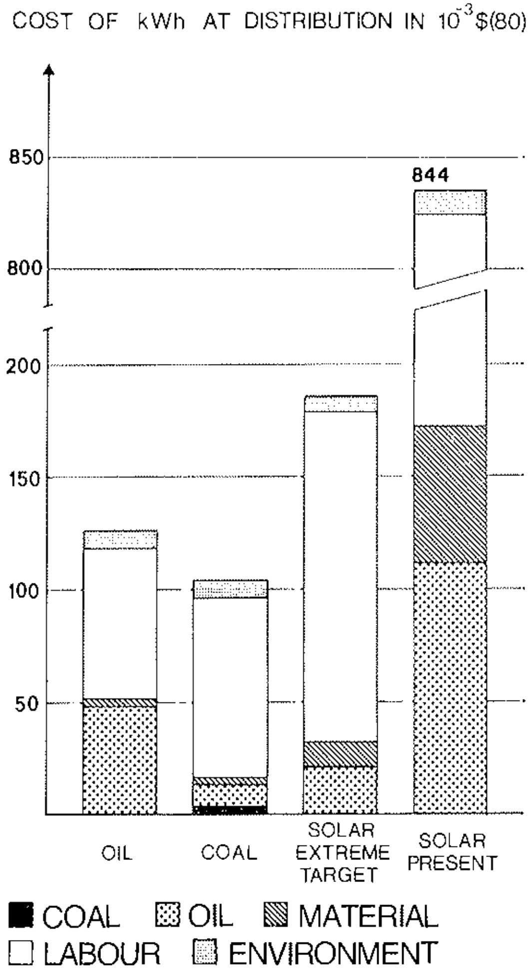

FIG. 9. Comparison of basic resource content of the kWh at distribution level.

— the land and environment utilization in the three cases is more or less comparable; the ecologic advantage of the solar plant, due to lack of emissions, is offset by the considerable land occupation which represents a form of total engagement of the environment.

It may be interesting to examine how competitivity comparisons would change if conventional costs higher than the market ones were supposed for energetic raw materials.

In order that the target-solar plant becomes competitive with the oil-fired plant, it would be necessary to assume a conventional value of oil at the origin approx. 3.5 times higher than today's market value (see fig. 10).

Starting from these conditions, in order to bring the coal-fired plant to the same level, we should assume a conventional value of coal on site over 40 times higher than today's market value (see fig. 11).

Both figures clearly set the solar plant outside the prospects of utilization for purposes of resource conservation. In particular, the assumption of a coal value over 40 times bigher than the present one is not justified, taking into account the large availability of this raw material.

The figures lead us to observe that, as the conventional prices for the energetic raw materials grow, solutions are sought, which increasingly require labor and other raw materials and it is increasingly laborious for mankind to secure its well being.

These considerations have only an indicative nature, because the variations considered for the costs of the basic resources are too high; under these conditions, all productive processes should be revised, so that the analyses made on resource content should be totally reconsidered.

A last consideration should be drawn with reference to the share of the final cost of the electric service ascribable to energetic raw materials; this cost consists of the cost of the energetic raw material consumed during the process and the capital cost of energetic raw material invested in power plants and other facilities involved in the energy chain; in particular, in the solar generation process, only such indirect costs are present.

From the standpoint of quantity rather than cost, it is necessary to reduce the capital costs, on the raw materials used, to depreciation alone (eliminating tbe costs deriving from interest on capital which represents, as we already stressed, the actual oil consumption to be attributed to the product.

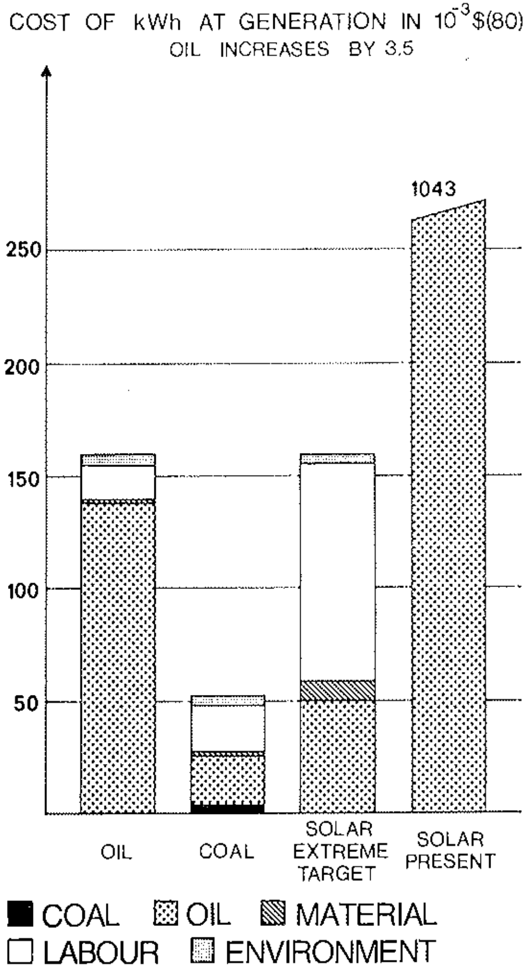

FIG. 10. Scenario with a conventional cost of oil increased by 3.5.

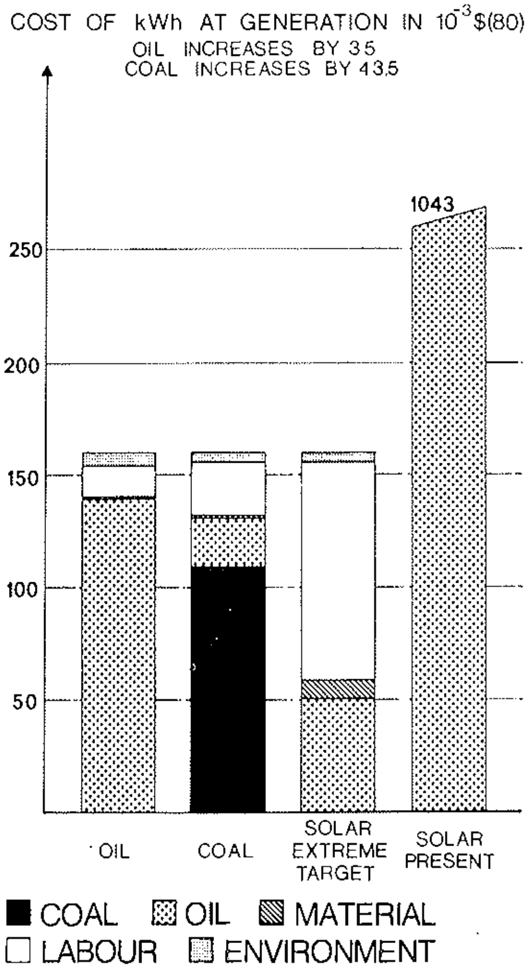

FIG. 11. Scenario of Fig. 10 with an additional conventional cost of coal increased by 43.5.

Figs. 11, 12 and 13 show the changes of Figs. 8, 9 and 10 according to this assumption.

Although, the share of oil in the solar electric energy becomes lower the distance of the solar power plant from competitivity remains significant.

6. Conclusions

The approach covered in this contribution is aimed at revaluing the economic analysis as a decision tool by replacing the market prices of goods and services with the conventional strategic prices of the basic resources utilized.

The fundamental advantage of the economic analysis is that it can be resorted to at any decision-making level, giving rise to a number of actions, all converging towards a common target; by supplementing the economic analysis with the tool of conventional strategic prices, this target should be the minimization of global resource utilization.

This contribution is not aimed at drawing conclusions but rather at providing elements to discuss the feasibility of such method of analysis.

First of all, it may be debatable whether the economic choices made on the basis of strategic conventional costs can lead to an actual optimization of the use of available resources to produce goods and services.

Then, it may be wondered whether this type of approach is feasible and effective at different decision levels.

Then, the discussion may be centered around the approximation which is required to assess the basic resource content of goods and services; it may be wondered whether an approach based on cost breakdown into different cost items can reach a sufficient approximation.

Finally, the discussion may concern the criteria for assessing the indirect resource utilizations (capital costs) and their actual significance in terms of resource minimization.

Acknowledgment

The Author wishes to express his appreciation to doctor Magagnoli of ENEL Electric Research Centre and doctor Longhetto of ENEL Thermo-Nuclear Research Centre, for their valuable contributions.

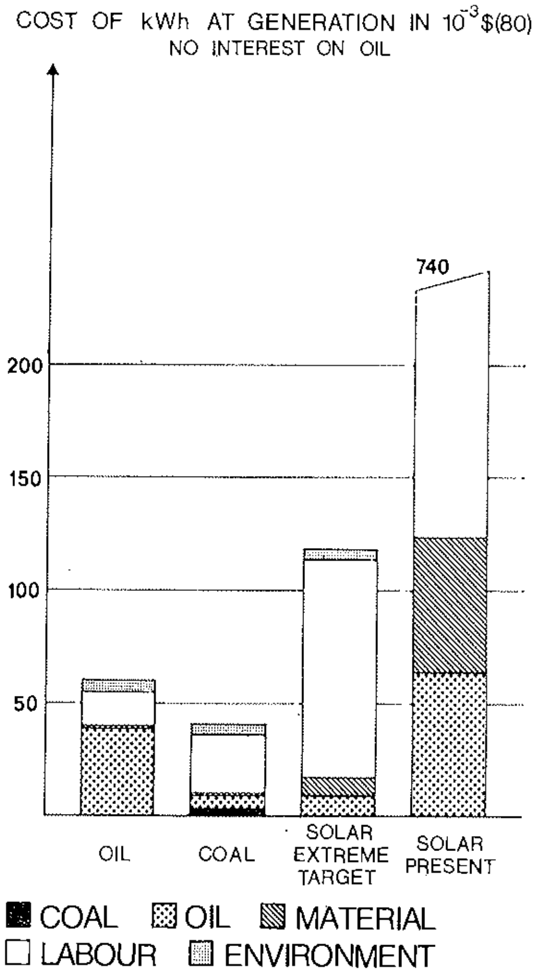

FIG. 12. Comparison of basic resource content when no interest rate is applied to the indirect use of oil.

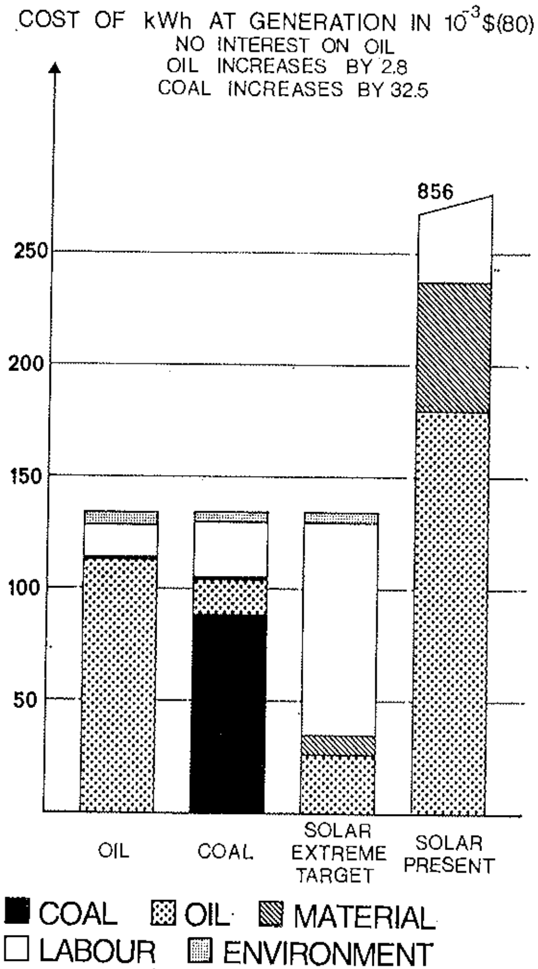

FIG. 13. Scenario of Fig. 12 with a conventional cost of oil increased by 2.8.

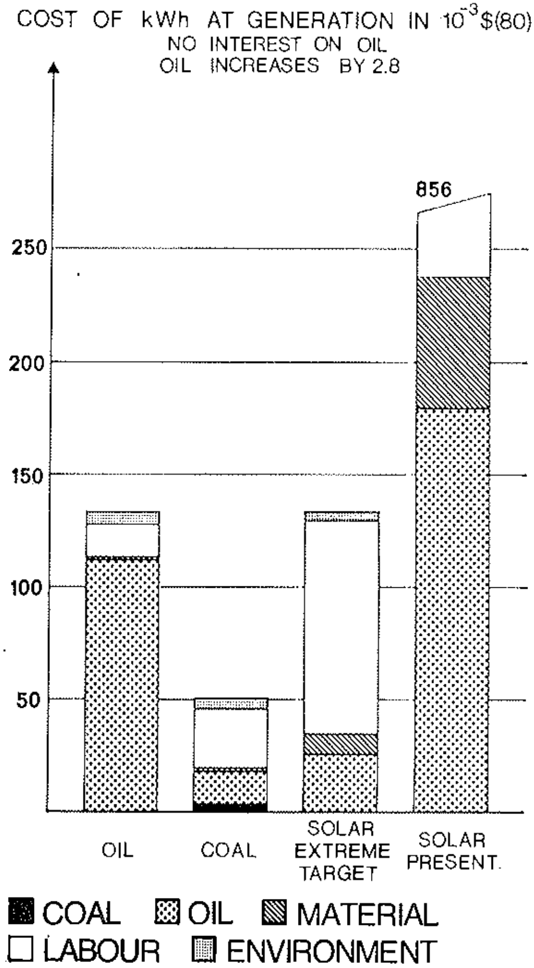

FIG. 14. Scenario of Fig. 13 with an additional conventional cost of coal increased by 32.5.

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DISCUSSION

SALVETTI

May I ask why you have not included nuclear energy in this comparison?

PARIS

Just because, being an exercise aimed at the assessment of a new method, we decided to take into account only some of the major energy chains.

As a matter of fact we did also some work on the energy chains to get electricity from hydroelectric and wind power plants, but we did not organize the data on time for today's presentation.

VAN OVERSTRAETEN

I would like to congratulate Prof. Paris for his interesting talk and I have to ask a question about the comparison between the different plants he considered. Considering the solar photovoltaic plant, did you consider it has been an independent plant? Or did you make your calculation based on the assumption that the photovoltaic panels can also be installed on the roof top of the houses as a residential application?

Did you use the distributed nature of solar energy or did you consider only a centralized plant? I think that it makes quite a big difference; I also think that, if you make a comparison, it is difficult for a solar plant to be competitive as an independent plant. I don't know how you took into account the problem of storage. Personally I do not see the future for solar energy, in the next twenty or thirty years, to be converted in independent power plants, but more as small residential plants which are connected to the grid and eventually have a very limited storage.

PARIS

The analysis refers to a centralized photovoltaic plant of about 10 MW connected to the electric network. But if you considered isolated installations you will get a much higher cost per kWh because of reserve facilities, control problems and, of course, storage.

Therefore I feel that my figures for electricity from solar energy are to be considered as a minimum cost. I agree with you that solar power installations in the houses may be less costly but only at condition that one can use marginal space and marginal work. That is to say "do it yourself". But, as soon as you require an organization and some special devices to install the panels, the cost of a small installation can be much higher than the specific cost of a centralized power plant. I want to recall that the target cost for solar plant requires a very high mechanization of plant installation, which is possible in a large power station but it is not possible in small plants.

PASZTOR

My question concerns the percentage of environmental cost comparing oil and coal; it seems from the oil figures that coal had a smaller environmental cost per kWh and that sounds strange. I don't know what the answer to that is.

PARIS

Yes, this is due mainly to the fact that we have considered a coal with less than one percent of sulphur like the one we use in Italy; in these conditions, the cost of the damage of the effluents is less, because, to the damage due to particles, we must add only the small cost to be attributed to the low sulphur oxide emission. Of course our coal plant is using control methods sufficiently sophisticated, and this is included in the cost of power station.

SCHMITT

I have three comments: first, we all know that it is not that are costs determinant in the market but prices. Therefore, I would say that it is a nice instrument you have developed but I wonder if we can get the right answer by using it. Second comment: I think that it is of high importance to take into account that the quality of resources is different; labour in one process is not the same as labour in other processes; land on one side is not the same as land on other sides; therefore I imagine that if you only compare quantities you come to the wrong results. Last comment: I think we have to include a fourth resource hase. And that is the human capability to combine resources; and I wonder how you can include this resource in your tool that you have just demonstrated.

PARIS

I am aware that my analysis is indeed an approximated one, and I agree that a major reason of this approximation is the difference of taking into account costs instead of prices. It follows that my approach cannot be used as the sole decision tool, but the type of information that is obtained may provide decision makers with additional knowledge of the basic resource aspects correlated to energy strategies.

For example, when we deal with energy conservation, which basic resources are going to be conserved? For instance, from the example I have shown it follows that electric energy at householder level consists mainly of basic resource labour: this fact has to be taken into account, because when you develop a way to save electric energy at this level, you cannot use too much labour in order to be consistent with your intended saving.

As for the different kinds of labour, environment and so on, my analysis can of course take into account that there are indeed several kinds of labour, exactly in the same way as I evidenced in my diagrams the energetic raw material among raw materials.

Since my approach translated all these different aspects into their costs (or prices), even the global indication has a meaning, even though it cannot be directly related to man-power requirements in hours.

STARR

First, let me start congratulating prof. Paris for a very important approach. As for the comments Doct. Schmitt makes, that market competition and market pricing is important, I say that, when you look at the long range national economies of major countries of the world, it is the use of raw materials, resources of labour and skills which determines the trajectory the country should follow, and so I think this is a very important contribution which does need amplification. I also think the recommendation of Doct. Schmitt of putting labour into different categories is a very important one. There is one detailed modelling approach which I would recommend prof. Paris look into, if he has not already done so: prof. George Danzig, the famous man who developed operational research technology, has, at Stanford Univ., something called the "Pilot Model" which includes all the basic resources used in the development of any kind of system and that model may be could help in the kind of work the prof. Paris has started. I would like to make one other comment on the environmental issues; the one thing which is left out of the environmental consideration is that the environmental impact is local, around the area of the plant, but the benefits of electricity or energy you use is distributed over a very big population. So there is a difference in a geographical sense and also in a time-scale as to who has the benefits and who has the penalty. And this means that one has to look some-what differently at how you evaluate environmental impact. For example in France EdF gives a special benefit to the people living around a nuclear plant because they suffer the risk of such plant but the benefits of having it goes to all the community.

I would also like to mention the comment by Prof. Overstraeten on the solar electric home use. Once you take solar electricity and do not give independent storage, that is if you tie it into the grid and then the grid becomes the storage facility, solar electricity, because of its intermittent nature, is just a fuel displacer; it displaces oil or coal when the solar installation is on; when the solar installation is not on, you still have to have the remaining plant. If you examine a very large community distributed over a big region so that the climate and weather conditions are averaged out, you find that if everybody built a roof top solar installation you might reduce the total capacity requirement of the grid by something like five percent or so. So that the savings that come from solar installation without storage is a very small element; you have to build most of your other power plants in order to use solar; it does save the fuel and that calculation is a very special one which was not included in the examples made by prof. Paris. So, if we want to examine the solar issue in its integrity, we have to go to a more complicated approach along the same line you have started.

TEILLAC

Just a small comment on what Dr. Starr said about the price of electricity in France around the nuclear power station. This low price around the power station is not to compensate the risk of living near the power station; it is to compensate the disturbance caused by the work during the installation of the nuclear power station; it is completely different, hecause we think in France there are no special risks living near a power station.

COUTURE

Dans la prise en compte des différents éléments (matières premières, travail, etc.), comment prend-on en compte la date à laquelle ces prestations sont fournies, comme on le fait habituellement dans le calcul économique?

PARIS

Dans l'évaluation économique globale de tout procédé, il faut retenir aussi les composants indirects, énergétiques ou non, qu'on a exploités avant d'arriver aux produits ou aux services procurés par le procédé lui-même.

Ces composants, tels que les matériaux et les sources énergétiques qui, après l'exploitation d'une usine, ne sont plus réutilisables, doivent être retenus dans l'évaluation du coût des biens produits: en termes financiers, on les appellerait charges de dévaluation.

Ces composants qu'on ne peut pas engager pendant la vie de l'usine sont, en tout cas, une charge capitale pour les pays, charge pour laquelle on doit retenir aussi un taux d'intérêt convenable.

Il y a beaucoup à discuter à ce sujet, mais, en principe, un métal a la même valeur, soit qu'on le garde dans le minerai, soit qu'on l'exploite dans un équipement quelconque; de la même façon, par la méthodologie indiquée, les atteintes à l'environnement constituent une charge à retenir dans l'évaluation, c'est-à-dire un composant du coût en capital.

CHAGAS

I think that, from the very interesting exposition of prof. Paris, I could take a cue to say that one of our preoccupations in developing countries is that energy considerations are often made on a gigantic base and, nevertheless, we have to consider the problem of commercial balance. Many times a smaller and even less efficient energy-producing establishment (which cannot be considered economical according to the classic theory of economy) can fe of great importance for a small country, because it can help to ease the commercial balance and it can have a social, distributive effect which cannot be achieved by gigantic power plants.

PARIS

A limit of my approach is that it considers the world as a whole and the economy of resources is made in an ideal world without any border. I have shown that the increase of the price of energetic raw materials (coal, oil) calls for the implementation of more labour intensive solutions; this apparently seems a positive aspect in those countries with huge available man-power, that is in the developing countries; but since the labour required to exploit new energy sources is a skilled and organized kind of labour, the availability of such huge mass of potential workmen cannot be used to this aim.

SANCHEZ-SIERRA

I like to ask prof. Paris if when he compared the environmental impact of coal plants with that of solar plants, he included the environmental impact of mining transportation.

PARIS

Yes, we included the environmental costs of both mining, (as use of land, land reclamation and medical care of miners) and transportation of coal (as dust and losses during railway transport, use of land for all facilities necessary to land and sea transport and loading/unloading operation) but always with the approximation limits I have underlined before.

PASZTOR

My question deals with the comments of Prof. Chagas and Doct. Schmitt. In the beginning of Prof. Paris' paper it is recalled that our system rewards only economic choices; now I appreciated your economical analysis, that is a very good tool and I think that we should go ahead with this kind of analysis, but we must remember that it is a very limited tool if it is not supplemented by the kind of analysis doct. Chagas was talking about. There are indeed other utilities: wich you have just mentioned, but there is also a social utility which cannot be measured in financial terms or energy terms or any other numerical terms and, in very many situations, those social utilities may be much more overriding than the economic utilities.

PARIS

I have explained that, in my approach, money is only a unit of measure which enables us to sum up different resources; therefore it is possible to express in such a unit any resource, even those considered as not marketable.

I do not believe that such an approach can be determinant in solving the political and social problems which trouble our societies, but I feel that it can help us in the process of decision making by allowing an optimal use of the several basic resources, which have to be measured through a common unit. In my effort I try to put into quantitative terms as many as possible factors; it is perhaps an utopic effort but I think we must try.

BLANC-LAPIERRE

Je suggère au Prof. Paris de tester sa méthode en l'appliquant aux problèmes de production d'énergie dans un pays de structure économique, industrielle, sociale... très différente de l'Italie. Le résultat de cette étude pourrait être instructif pour la méthode elle-même.

PRODUCTION, TRANSMISSION, STORAGE AND DISTRIBUTION OF ELECTRIC POWER AN INTEGRATED SYSTEM

ARNALDO M. ANGELINI

Introduction

Some remarks on electric energy production cycles

About a century ago, the fact that a single street was lighted by means of electric energy filled the headlines and drew a considerable crowd. Then, from a single street, public lighting spread rapidly to an entire neighbourhood and even more rapidly to an entire city. The ductility of this form of energy, evident since the beginning, increased the demand, above all for uses other than lighting, so that soon, after improving the possibilities of transmission, it was possible to meet the rapid increase of the demand, hy exploiting the water resources, starting from the more convenient. A slab, in a street of Rome indicates the very spot where, for the first time in the world, electric voltage was received from a small hydroelectric power plant at 30 kilometers' distance in the area surrounding Tivoli.

In just a few years, a great number of small electric utilities sprang up, though few supplied an entire town or covered a whole province.

However, in a few decades, the aim of offering the best and safest form of service at the lowest cost possible was achieved and to-day, for example, a single system composed of various partial systems or subsystems, all interconnected, covers practically the whole of Western Europe.

Now let us see how it is that electric energy, one of the most recent forms of energy employed by man, has had such a rapid and far-reaching evolution.

Generally speaking, energy can be employed in different forms whose utilization depends on the number and range of its applications.

Following is a summary of the particular features which are kept in mind when rating the various forms of energy:

— possibility of converting, through safe, reliable and economical processes, various forms of energy into the one in question and viceversa;

— continuity, safety and cost-effectiveness in adapting the production to the ever-changing trends of consumption; also, possibly, through the storage of energy between production and consumption phases;

— continuity, safety and cost-effectiveness in transmission of even large amounts of energy over long distances;

— capillarity of the distribution system.

Electric energy satisfies these requirements perfectly (excepting the very reduced possibilities of storage) and is thus one of the most flexible forms of energy from an industrial point of view.

A survey of the "production" process, i.e. the conversion of naturally occurring energy to electric energy, shows that due to the various kinds of sources and processes necessary for the industrial production of electric energy, a smooth functioning of this cycle depends on the solution of the problems which arise in the various phases of the conversion process.

Each phase has its own particular problems, some of which involve the primary energy sources, i.e.:

— availability and accessibility;

— extent of resources and their trend of development in time;

— processing and treatment prior to conversion into electric energy;

— ease of transport;

— environmental requirements;

— access to and interchangeability of the various sources.

Other problems related to conversion processes include:

— competitiveness, reliability and continuity of operation;

— the present state of technology and its future developments.

Other problems concern the possibility of primary energy storage in view of the production of electric energy.

Clearly, the problems in question cannot be dealt with solely from a technical point of view, for various, competitive, safety and environmental questions must be kept in mind for a satisfactory industrial application.

A short analysis and a synthesis of how the electric system is articulated

According to the modern system science and engineering each electric utility represents an « integrated system », subdivided in several subsystems belonging to a « hierarchical » framework which emphasizes the phenomena of interaction and interdependence that affect them. The element of such a system is the physical structure of the electric system, comprising all the facilities used in the production-distribution cycle, from the conversion of the energy contained in primary sources into electric energy to the transmission and distribution of such energy to users. The physical structure — "hardware" — of the system, however, would be of no use without the contribution of a series of conceptual structures — "software" — which enable the system to operate towards the achievement of the objectives set.

The physical structures include:

— plant, facilities, machinery, instrumentation.

The conceptual structures include:

— organization;

— information system;

— decision-making system;

— control system;

— technical, economic and marketing studies;

— research and so on.

Both the physical (hardware) and the conceptual (software) systems are subdivided into interdependent elements called subsystems. Subsystems can be classified according to a hierarchy established on the basis of their interdependence relations.

The structure of the electric system is based on the physical structure that carries out the energy production-distribution cycle.

The phases of this cycle are schematically represented in fig. 1. Figure 1 provides first the subdivision according to the primary sources used, which fall into four classes, and then according to the phases of the production-distribution cycle, i.e.:

— conversion into mechanical energy;

— conversion of mechanical energy into electric energy;

— transformation and transmission;

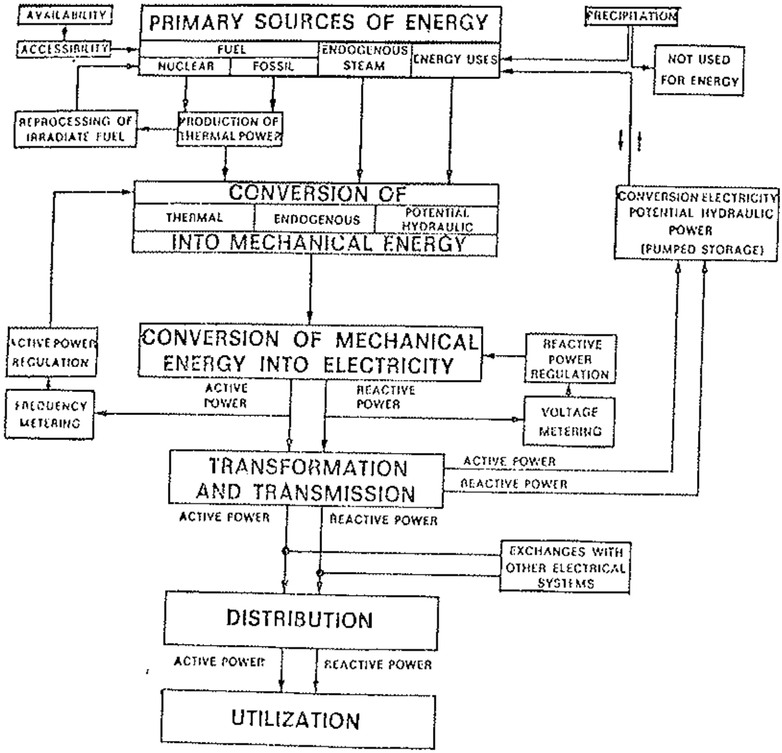

Fig. 1. Flow Diagram of the Power Generation and Distribution Cycle in an Electric System.

— distribution;
— utilization.

Figure 1 therefore only refers to the essential elements of the system as a whole, their functions and main interactions. On the other hand, Figure 2 gives a more detailed description of the system in view of its subdivision into principal sub-systems and their interconnections. This diagram shows that the sub-systems into which the system is divided concern:

— production;
— transmission and transformation;
— distribution.

The structure described for the energy system emphasizes the inter-

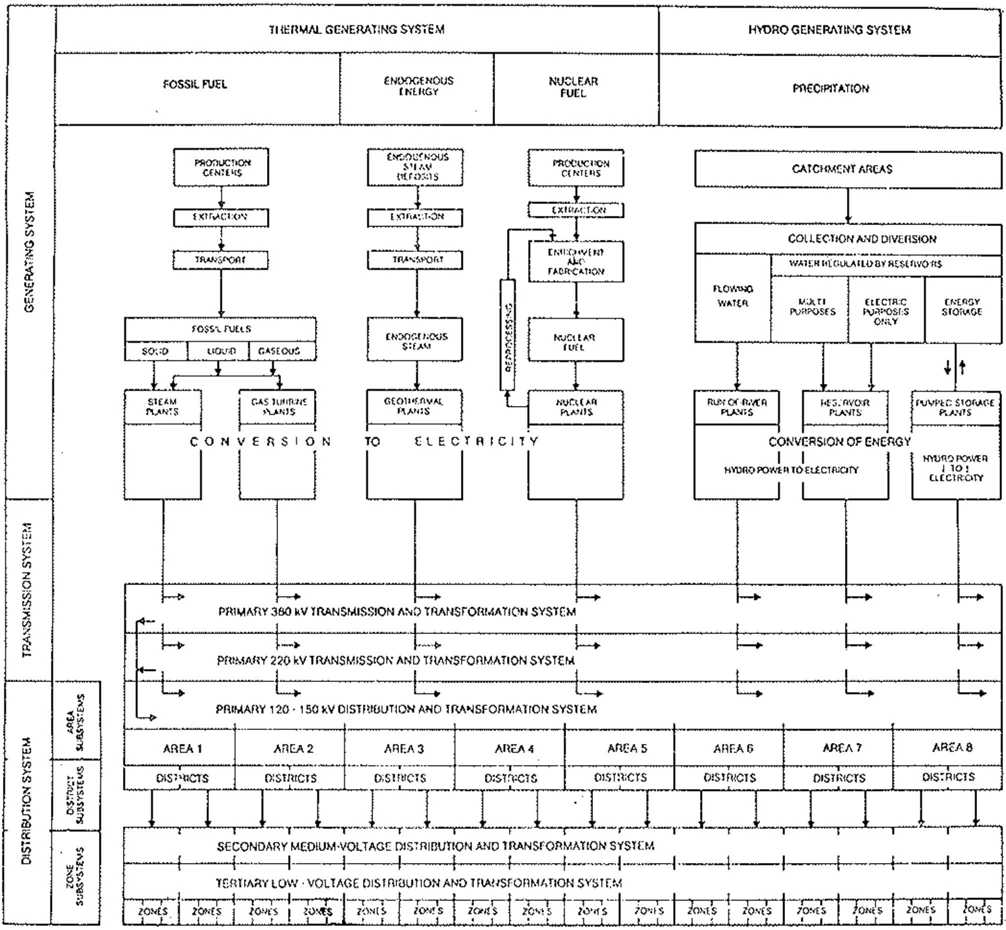

FIG. 2. Break-Down of the Electric System into Interlinked Subsystems.

connections between subsystems, which is characterized not only by input-output relations, but also by bonds that vary according to the nature of the elementary activities into which the system is subdivided.

Development of subsystems: structure and functions. Subsystem "generation"

Evolution of production technologies, increase of generators' unit sizes

The last twenty-five years witnessed a remarkable evolution of the relative incidence of the different primary sources available to cover electric energy requirements.

For instance, whereas in the past the hydroelectric supply was sufficient to cover all requirements in Italy, in more recent times traditional thermal production has become indispensable and nowadays nuclear energy is being developed. The evolution of the situation contributed to bring about a parallel evolution in the technological characteristics of the various conversion processes, also aimed at making plant and machinery more responsive to the changing needs of modern times.

In the hydroelectric field, for instance, the first plants exploited short stretches of rivers in correspondence of waterfalls or rapids. The extent of the works for water diversion and restitution was therefore very small; the capacity installed in the plants seldom exceeded that obtainable with the minimum flow rate of the river.

Later, growing requirements, the need for regulation and the evolution of machinery led to an increasingly intensive exploitation of waterways, the construction of reservoirs, enlargement of diversion and restitution works, and installation of greater and greater capacities. All this led to the integral and coordinated exploitation of whole catchment basins thus achieving the best possible conditions for a more thorough use of the available energy and for the creation of maximum regulation reserves.

It is interesting to note that countries like Italy, where the shares of thermal plants have remarkably increased in time, have been increasingly characterized by a tendency to enhance the operational flexibility and elasticity of hydroelectric plants and to entrust them with a growing number of tasks in the fields of regulation, integration and spinning reserve.

This evolution of hydroelectric systems was paralleled by an equally important evolution of machinery characteristics, dictated both by changing requirements and by technological progress. Improvements in turbine design and construction raised efficiency rates up to 90% and more, while the spreading tendency to reduce the number of plants in the same basin as well as the number of units installed in the same plant led to a considerable increase in unit rating. This allows the utilization of hydroelectric plants for peak production and capacity regulation-tasks for which they are particularly suited. Regarding pumped-storage plants, it is interesting to note the introduction of reversible pump-turbines with constantly higher unit ratings and efficiency.

Also traditional thermal plants have undergone substantial technical and economic advances in recent decades; this was mainly due to the development of metallurgy, of the design and construction techniques adopted for boilers and turbines, of water chemistry, controls and instrumentation, and combustion techniques.

These advances brought about an improvement in the efficiency and unit ratings of boilers and turbines, which in turn determined a substantial reduction of both installation and operation costs. The unit capacity of generators also recorded a particularly high increase: the maximum unit capacity of turbogenerators, which in 1946 was about 150 MW, now exceeds 600 and even 800 MW.

The strong increase of unit capacity beneficially affected specific installation costs, that underwent substantial reductions.

During recent years, remarkable progress was also achieved in the field of gas-turbines; these units, as is known, are characterized by good operational flexibility, higher specific consumption than traditional generators, use of valued fuels, relatively low capacity and low specific installation costs.

The progress recorded in this field gave rise to a wide diffusion of gas-turbine generators, especially in areas characterized by a limited number of sites suitable for pumped-storage plants for regulation, integration and reserve.

Regarding nuclear plants, the twenty-five years elapsed since the development of the first experimental prototypes have seen the deepening of the knowledge of the complex nuclear, thermal and hydraulic phenomena that are at the basis of the operation of reactors.

The impact of the progress made so far is clearly shown by the change that occurred in a period of only twenty years: from low-power experimental units, whose installation and production costs were often higher than those of traditional thermoelectric plants, to the modern nuclear plants characterized by units rated over 1,000 MW and by clearly lower kWh-production costs, with respect to those of fossil-fueled power stations.

Regarding the development of different types of reactors, the most important advances concern the development of techniques and trends that present a high potential for economic competitiveness with traditional sources and at the same time are geared to use the potential energy content of natural uranium.

The technological evolution that occurred in this field also concerns the recycling of plutonium in thermal reactors and in particular the development of fast breeder reactors. Together with "Electricité de France" and Rheinische-Westfälisches Elektrizitätswerk, ENEL is participating with its own people and means in the construction at Creys Malville (France), of a 1200-MW breeder reactor, cooled with sodium, representing the most advanced project in the world.

Priorities in the use of energy resources

During the last decade, and particularly in more recent years, energy problems have become outstandingly important as a result of the oil crisis and its consequences for the present and even more for the future situation: it is therefore imperative to tackle as systematically as possible the problem of selection and priorities regarding the primary energy sources used for the production of electricity. This is necessary since in the world energy balance, the production of electricity is now engaging 25-30% of primary resources in total and experts almost unanimously foresee that this figure will increase up to 50% before the end of this century.

The following remarks reflect the most widely accepted view of the situation as it emerged also at the recent International Meeting on alternative energy sources, organized by the Milan Fair.

The starting point for any discussion on energy is represented by an assessment of the requirements to be met in the short and in the medium term first, and then in the long term. Energy needs are mainly determined by the economic and social development of the country or the geopolitical area referred to, and secondly by related government programs. It is often an overlooked fact that all decisions in this fields are to be made by the public powers or, in other words, by the country's Governments.

It is this decision that determines the amount of energy required.

Another noteworthy factor concerns the general orientation about the sharing of national and imported supplies in the production of high energy-using products. Once again, the choice is up to the Government, and it certainly affects the assessment of energy requirements, at least before the decisions so far mentioned have been made.

The main issue involved in a systematic approach to production problems is the selection of the resources to be used and the setting of priorities for using them.

Everybody agrees in attributing the utmost importance to the resource represented by energy conservation measures, a resource that I have frequently defined as "virtual" because of its very nature. The scope of this report, however, does not cover a review of the action taken in order to obtain maximum savings in the use of energy in general and of electricity in particular, or the measures adopted to slow down the depletion of non-renewable sources.

The second priority is the use of all types of renewable energy sources available in the country or in the area examined.

Among these, attention is immediately drawn by water resources, in connection with the still possible exploitation of untapped waterfalls, whose potential in industrialized countries is unfortunately rather low. Another possibility is represented by the modernization of old hydroelectric plants (this type of work was and is being carried out on plants built over fifty years ago), as well as by the increasingly widespread adoption of pumping — which, incidentally, shows the strong similarities existing between Japan and Italy in this field. The final option is represented by the exploitation of tides, resorted to for the first time on a large scale in France, on the estuary of the river Rance.

Within the framework of renewable energy sources — even though with some reservations about its renewable character —, geothermal production is worth being carefully examined, in the light of the work carried out in Italy and abroad (particularly in the U.S. and in Japan) for its development; its contribution on a world scale, however, is still very modest — 8-9 billion kWh/year — and Italy's share is close to 30% of the total. Particular care is being devoted to exploration activities at great depth (an explorative excavation in Tuscany has reached a depth of 5,500 meters) and to the exploitation of low-enthalpy heat from thermal sources.

Interest is also being shown in solar energy, considering the advances recently made for a more efficient use of the thermodynamic value of the thermal energy obtained from solar radiation either used as such or for the production of electricity both through indirect conversion using concentrators, solar boilers and electric turbo-generators and through direct conversion using photovoltaic cells. It is worth noting in this connection that, together with Ansaldo and with EEC financial backing, ENEL has virtually finished work on a plant of this type at Adrano in Sicily. It has a peak capacity rating of 1 MW and an overall efficiency of 15%.

Special attention should be devoted to the problems of solar energy storage. The prospects of solar energy seem therefore to be extremely interesting, even though it should be remembered that its share before the year 2000 will be quite modest and mainly concern low-temperature room heating and hot water services.

Another form of energy of solar origin is represented by the wind, exploited through wind-driven generators; it is hoped that these devices will be further developed since they help produce energy from an unlimitedly renewable source. The largest wind-energy plant known in the world is the one that will come into operation in 1983 on the coast of Schleswig-Holstein in West Germany. It will have a total capacity of some 3 MW. The two-bladed rotor of its primary motor will have a diameter of about 100 meters. The share that wind will contribute to the total energy balance, however, is not expected to be higher than that supplied by solar energy.

The energy obtainable from sea waves — another form of indirect solar energy — belongs to the same category; it is being studied with particular interest by the coastal countries of the North Sea, since the potential of the Mediterranean countries in this connection is obviously very limited.

An interesting potential is also offered by the biologic processes triggered by solar radiations as well as by those related to biomass; their contribution to electricity production, however, will only be very limited.

It is believed by most experts that these options should be the object of intensive research in view of their perspectives in the medium and particularly in the long term. As occurs in other fields, the time-span of research activities is such that studying more immediate applications might prove fruitless unless ways to cover long-term energy requirements receive at least equal attention.

After getting as much energy as possible from renewable sources, the only thing to do is to resort to non-renewable energy; at this point, *a further fundamental decision is to be made between traditional fossil fuels and nuclear fuels.*

Before discussing this choice, it should be made clear that the share of savings and conservation measures as well as that of renewable sources is far from likely to meet global energy requirements for the future, even on relatively conservative growth assumptions.

It should be pointed out that the strictest measures adopted for the limitation of consumption affect, among fossil fuels, natural gas and oil in the first place. This is due to several reasons, as the progressive depletion of resources, the political implications and the ever more threatening consequences of energy dependence, which have already assumed extremely worrying connotations in Europe — and particularly in Italy —, Japan and, to a lesser but still significant extent, in other countries and geographical areas.

To cover residual energy requirements and keep oil consumption down, the alternative is between nuclear fuels and coal; existing coal reserves are expected to last one or two centuries.

In this case too, the choice is not up to energy producers but, in view of its strategical implications, it must affect and pertain to public powers.

The most widespread belief, applicable to most countries — Europe and Japan alike — is that the ideal solution to meet those requirements is represented by nuclear plants. In the future, breeder plants will be able to feed electricity production for centuries. Coal plants are the second-choice solution to be adopted until the nuclear solution will be allowed to develop at its natural pace, so far slowed down by persisting and unwarranted opposition.

As is known, there have been many warning signals of the distressing situation taking shape in the Western world as a result of the economy's persisting dependence on oil. The world has also been repeatedly reminded not to disregard the fact that replacing oil with another primary resource — and among these the most feasible is represented by nuclear energy — would mean contributing to dampen those tensions that have now become so serious as to involve even a risk of war.

More could be said concerning the costs so far borne and the enormously higher costs envisaged for the future, due to the delay imposed on plant implementation, i.e. what I once called the "creeping moratorium" which characterizes the construction of nuclear plants.

For the sake of brevity we will not go into other equally important problems that fall without the scope of this report, such as the social issues that go along with the technical and economic problems related to use of alternative energy sources.

The following section will deal with some specific remarks concerning the use of the main resources mentioned for the production of electricity.

Matching the Electricity Supply to the Varying Demand and the Role of Storage

In Italy as well as in other countries characterized by the use of different primary sources for the production of electric energy, a utility can resort to different plants to cope with the varying demand of users; the tasks assigned to each category of plants to cover the load are determined according to the technical and economic performance of each of them.

Figure 3 shows the ENEL load diagram for a working day.

As a rule, starting from the bottom of the load diagram, energy demand is met according to an order of precedence ranging from the type of energy with the lowest marginal cost to that with the highest marginal

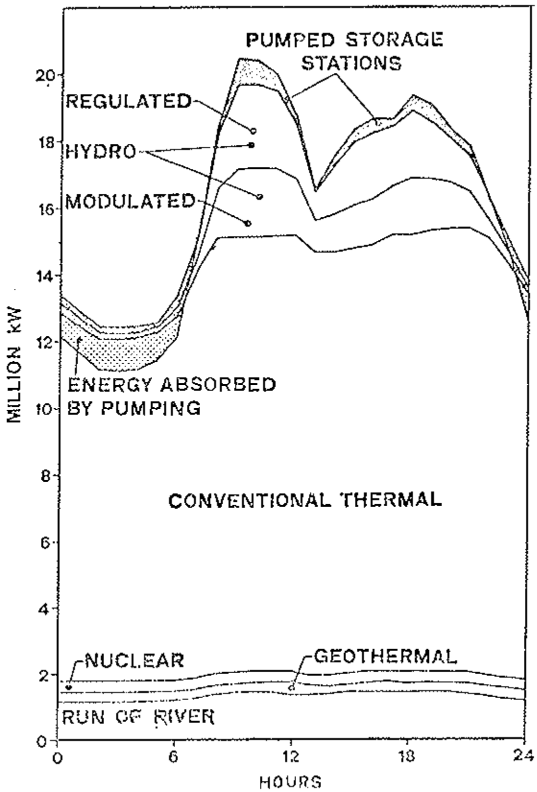

FIG. 3. ENEL Generation Curve on Febr. 18, 1976.

cost, with the exception of the energy produced by reservoir plants in general and by pumped storage plants in particular.

The different plants are used in the following order:

— run-of-river plants, whose energy marginal cost is practically nil;

— geothermal plants, whose marginal cost is very low, being determined only by the maintenance requirements of the borings used to extract steam from underground and by the need of new borings to replace those progressively clogged by sediments;

— nuclear plants (as is known, the marginal cost of nuclear plants is lower than that of fossil-fueled thermal plants);

— thermoelectric plants using lignite and domestic coal, whose low heating value requires use on the spot, in order to avoid high transportation charges;

— thermoelectric plants fed by domestic natural gas and imported coal and fuel oil.

Within the limits of available capacity and energy, the top of the diagram is covered by the production of reservoir and pumped storage plants.

This method generally ensures that the afore-mentioned requirements are met by adopting the best possible economic standards of electricity production.

In view of the importance of the subject being discussed, this brief description will be supplemented by some more detailed remarks, that have already been expressed on other occasions (1). The trend of electricity demand is characterized by substantial variations in the amount of power required during the day, the week, the season and the year. Elements illustrating this variability are shown in figure 4.

In order to constantly adjust the power generated to that required by users, the available power and the transmission capacity of lines must match the maximum demand values, augmented by a margin of safety needed to cope with possible malfunctioning of the generating and transmission systems.

This is obviously the basic condition to be met in order to perform the regulation of electric power; it is a complex task, characterized by

(1) Arnaldo M. Angelini, *Energy and planning*. Lincei Conference on "Science and planning". Rome, March 9-11, 1966.

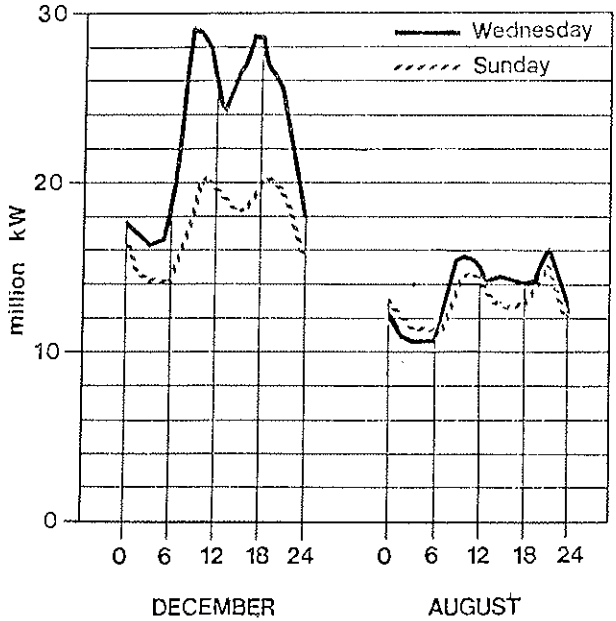

FIG. 4. Hourly Load Diagram in Italy on Typical Peak-load and Low-load Days, 1977.

extremely peculiar aspects, owing to the fact that electric energy as such cannot be stored, even for a very short time. Regulation affects the following systems:

a) the production system:

— through the compensation of differing trends in power requirements, achieved by means of the basic infrastructure of any electric system: the interconnection network;

— by means of hydroelectric production through reservoirs which allow the constant adjustment of supply to demand with an ample margin and without significant losses. The function of reservoirs is supplemented and enhanced by the transmission system, which extends their influence to very large areas;

— through pumped-storage plants, which are of special consequence because:

1) most versions are highly adaptable and can be employed for the regulation of the fastest variations in power requirements, for the

control of the network frequency and for the capacity reserve necessary in anomalous or emergency situations;

2) as they transfer energy from the low-load night hours to the daytime peaks, it becomes possible to employ the entire generating plant and thus level the diagrams in figure 3 and 4 compensating both the troughs and the peaks (a typical example of this levelling is illustrated in figure 3);

— through peak thermal power stations, mainly employing gas-turbine generators.

b) the distribution system:

— employing for each utility all the measures apt to limiting the power peaks by raising the "factor of non-simultaneity" of the drawing of the single utilizations;

— through the terminal storage of electric energy at the distribution-regulation centers or even at each utility.

Something ought to be said about the development of pumping as regards the spread of nuclear energy.

Storage by means of hydroelectric pumping is an important factor in the development of nuclear power plants. The economic and technical features of the latter recommend them for basic production i.e., a practically uninterrupted production. At present, however, nuclear power plants are being employed to the utmost of their technical limits. In future, the increasing utilization of nuclear energy in electric systems will extend the use of nuclear power plants, from basic production to supplying a part of the variable part of the load diagram. This will mean an availability of night-time and holiday nuclear capacity which, by means of pumping plants, will be transferred from the low load hours to the peak-load hours. Nuclear power plants will continue to develop and this necessarily implies a decrease in the functions of fossil-fueled plants envisaged for day-time use where storage is not practiced. This means a greater tapping of nuclear energy and a decrease in the consumption of fossil fuels.

Because of the wide range, capacity and high degree of interconnection of the electric systems, both the pumped-storage capacity and the marginal nuclear output can be pooled by various countries for maximum efficiency. European electric energy producers have long since set the example for international cooperation.

When possible and economically feasible, the development of pumping systems in a nuclear-based electric economy will on the one hand mean full utilization of nuclear power plants and, on the other, a decrease in their number, for pumping capacity will replace a nuclear capacity of almost equal size. From an economic point of view this would be a sure gain. From an investment point of view, with the financial requirements this entails, considerable savings could be obtained, if only we consider that given favorable orographic conditions, the investment in a pumped-storage plant can be even less than half of that needed for a nuclear plant of equal capacity.

An integrated system of pumped-storage plants and nuclear power plants is therefore an advantage from a technical, economic and financial point of view.

Over almost her entire territory Italy possesses an orographic situation that is particularly favourable for the development of these particular plants.

The first Italian pumped-storage plant was installed in 1912, the first generator with a unit rating of 50 MW in the late 40s, the first 1 million kW pumped-storage plant several years ago.

At present, the overall capacity of Italy's pumped-storage plants amounts to 3.5 million kW, with another 2.2 million kW under construction. Other plants for a total of 2.4 million kW will soon be under way as part of the ENEL operative program.

The other projects under way will enable Italy to reach a pumping capacity of almost 7,000 MW by the late '80s.

Pumped-storage plants will play an important role also in future. Most of this potential lies in the areas surrounding the Alps, which include parts of France, Switzerland, Austria and Yugoslavia, countries whose electric networks are closely connected with the Italian network on the one hand and with those of other European countries on the other. It is therefore possible for a great number of pumped-storage plants in Italy and neighbouring countries to be usefully employed in favour of a thorough-going regulation of the electric power of a great part of Europe. This will also mean a better functioning of a large complex of nuclear power plants located in various European countries.

These possibilities have also led to a renewed interest in the studies carried out several years ago to establish the Italian potential for the construction of competitive pumped-storage plants.

A systematic survey has been carried out to locate the most favorable sites for large-size pumped-storage plants, i.e. of the order of one million kW. A technical, and economic appreciation has also been made of these sites.

About fifty plants, with a unit rating of 500 to 1,000 MW, appeared to meet these requirements. About thirty of them are situated along the Alpine range.

Though storage in the productive phase has found an excellent solution in pumped-storage plants, storage is not such an easy matter in the distribution system. Terminal accumulation with cells is not yet economically feasible and research into the problems has started anew only recently.

A successful technical-economical development of electrochemical accumulators is of great importance, for it would mean having new, competitive, highly efficient and flexible systems:

— for storage and regulation in electric networks;

— as self-contained, permanent accumulators for the storage of highly variable sources, such as wind energy and solar energy, in remote areas (electrification of rural areas);

— as feeders for electric traction.

This final possibility would mean a new, vast market for electric power and consequently for nuclear fuels, a market which is at present restricted to liquid fuels derived from oil and, to a lesser extent, to gaseous fuels.

Influence on the environment due to the construction and operating of generating plants.

This survey cannot afford to ignore this problem but for lack of space we have to be rather brief. The problem of pollution is particularly relevant to fossil and nuclear fuel power plants.

Air pollution is caused by the discharge of gaseous combustion wastes (especially sulphur dioxide) through the stacks of conventional thermal power plants. In nuclear power plants, the fission of uranium takes place without direct contact with the exterior. However, the nuclear reactions produce radioactive substances, very small quantities of which are discharged into the environment.

Both types of power plants use large quantities of water to condense steam. The water used in this process is returned unaltered from a chemical and physical point of view, the only difference being an increase in temperature of about 8-10°C.

Coal-fed power plants present the problem of realising particulates to the atmosphere and creating large amounts of ash.

The influence of generating plants on the environment has been and still is a serious and, at times, instrumentalized problem.

The environmental constraints have become so tight in both the planning and operation of plants that in many countries, including Italy, it has slowed down their energy programs. The problem must be clearly examined in order to find the safest and most economical solutions.

Attention has been focused on water bodies because of their biological, hygienic and social relevance and because of their strong interactions with the generating plants. As regards the atmosphere, the main problems arise from the need to dissipate gaseous wastes as quickly as possible in order to avoid exceeding ground-level pollution limits. Here is an outline of the measures which are being taken to face these problems.

Intensive research is being carried out the world over to extend our knowledge of the environmental responses to pollutants. Data are being collected and attempts are being made to construct mathematical models of behavior of the environment so as to simulate situations for preventive measures.

The electric utilities are acting more cautiously and thoughtfully where the effect of their plants on the environment is concerned and are keeping the areas surrounding their plants strictly under control by means of increasingly intensive data collection networks.

The measures that are being taken to eliminate polluting agents include the following:

— the installation of closed-circuit cooling systems to lower the temperature of the water discharged into rivers;

— increased ascensional velocity of the flue gas to facilitate the dispersion of chemical compounds in the atmosphere, and the installation of high stacks;

— the adoption of suspended-matter dissipation devices for coal power plants;

— industrial recycling of ash for coal plants.

Nuclear power plant pollution calls for separate treatment.

Apart from the above-mentioned release of minimum quantities of radioactive elements, which only slightly increase natural radioactivity and water temperature, these plants are virtually non-polluting.

Serious pollution problems would arise only in case of leakage of radioactive material following a serious accident.

But nuclear technology has always met the required safety standards and has ensured that nuclear power stations have a high degree of compatibility with the environment. In no other technical sector however "advanced", has so much attention been paid to safety problems, from the early experimental stage, which was followed by pilot power plants, up to the large nuclear power generating plants that have been in operation on the grids in many countries for years. The result of all these efforts is that no accident of any significance, and even more important, such as to be a cause of concern for the future, has ever occurred.

The most significant evidence in this respect is provided by the outcome of the Harrisburg incident, the most serious nuclear accident of all times, and thus the most stringent test nuclear power stations have ever had to pass. The accident caused no fatalities, no injuries, no serious contamination.

Even the exposure of the power station personnel who received maximum exposure was well below the maximum dose allowed by international safety regulations.

Hydroelectric power plants, on the other hand, neither alter the temperature of the water, nor cause any discharge of waste.

Transmission sub-system

Evolution of electric power transmission in increasing quantities and over longer distances

The transmission of electric energy from production to consumption centers has reached a high degree of efficiency despite the fact the distance of transmission is often considerable. Technological progress has, in fact, made it possible not only to solve the problem of transmitting ever larger quantities of power by adopting increasingly higher voltages and limiting the number of lines thus restricting the occupation of the territory and interaction with the environment, but also to reduce the percentage power loss during transmission. The 10 kV used around 1890, thus rose to 50 kV at the turn of the century, 130 kV in the '20s and 220 kV around 1930. In Europe over the last twenty years, great impulse has been given to a new level of voltage, 400 kV, which represents today the supporting structure of the European interconnecting network. Some countries such as Canada, the United States and the Soviet Union are already using a voltage of 765 kV because of the great distances to be covered.

Particular attention is to be paid to the transmission of great quantities of power over long distances. It is technically and economically justified where large quantities of power, often derived from hydroelectric sources, are available at low costs in areas where their utilization is foreseen only in the distant future. The problem thus arises of transmitting this power to industrial centers that are often situated in far-off areas. On the other hand, the solution of these problems involves a meaningful contribution to the satisfaction of the needs arising out of the safeguarding of the environment and out of the energy crisis. In fact, as has already been stated, hydroelectric power is absolutely clean, i.e. non-polluting.

On the other hand, utilization of great quantities of hydroelectric power and the consequent transmission over long distances of large quantities of energy allows substantial quantities of oil to be saved, the shortage and price increase of which have caused the present energy crisis.

A typical example of the application of this concept is given by Sweden where large quantities of low-cost energy can be produced in the North while most of the country's industrial plants are situated in the South. This situation has motivated the Swedish interconnection which has used a voltage of 420 kV for the first time. Figure 5 shows the longitudinal structure of this interconnection system that is extended from the North to the South of the country, covering over 1000 km. This is not, however, a "meshed" type of network that entails problems of ensuring a continuity of supply, stability and voltage regulation.

Another good example is given by the Canadian interconnection, the first to be run at 765 kV, as is shown in Figure 6. Also in this case the distance to be covered is over 1000 km and the interconnection enables the industrial centers in the South East, and particularly in the areas around Quebec and Montreal, to utilize the hydroelectric resources of the Churchill, Manicouagan and Outardes rivers.

Projects envisaged in other countries are of even greater interest as they are often on a very large scale and allow for the utilization of considerable and remote hydroelectric resources. Suffice it to mention the Inga plant project which has a potential production capacity of over 100 billion kWh a year at low cost, to be mainly destined to the North Eastern and Southern parts of Africa over a distance ranging between

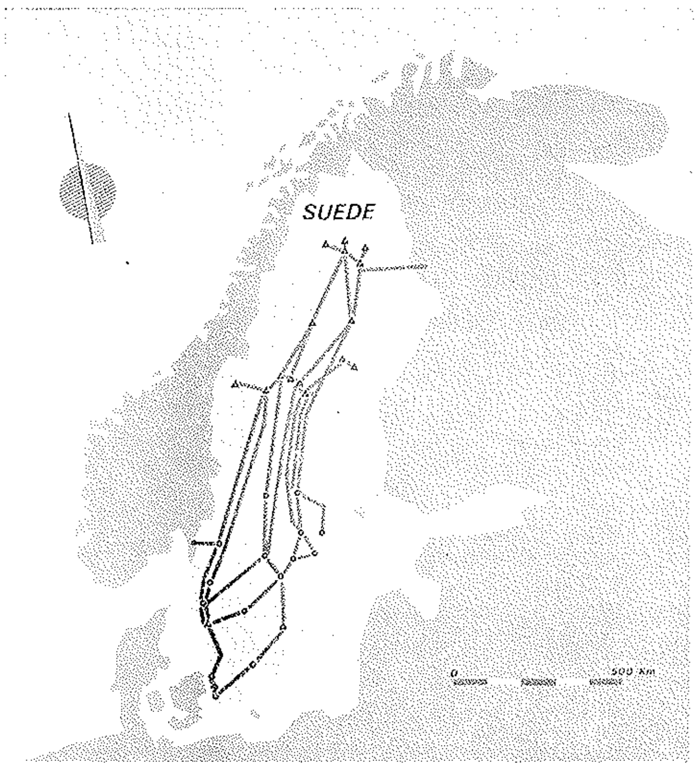

FIG. 5. Swedish 420-kV Transmission System.

1000 and 2000 km. Other possibilities of transmitting large quantities of energy over long distances are also foreseen in Asia and in many countries of South America.

Direct-current transmission

D.C. transmission current (Tab. 1) has so far been used for connections over long distances (over 600 km) by means of overhead lines and over relatively short distances (several tens of kilometers) by means of underground cables, especially used in overseas connections. The aim is to set up interconnections between non-synchronized networks and to transmit large quantities of electric power to remote areas.

The graph in Figure 7 shows the evolution of the applications of direct current transmission. It illustrates the considerable levels already

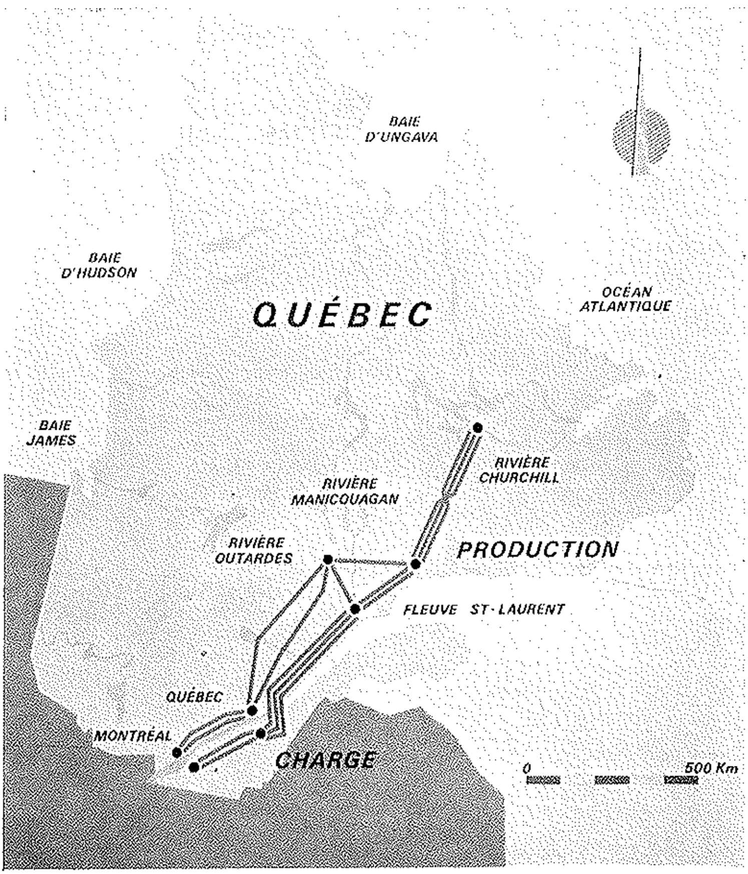

FIG. 6. 765-kV Transmission System in Quebec.

reached, which are, however, considerably lower than those attained by alternating-current transmission. The limits affecting this type of transmission are basically two:

— the difficulties encountered so far in setting up meshed transmission networks with terminal stations; in fact, at present, direct-current connections are almost exclusively used as links connecting two stations. In a certain sense, these connections are "rigid", that is to say they do not allow any adjustment of generation to load variations;

— fear of insufficient reliability, which is not comparable to that

TABLE 1 — *HVDC Systems in Service, under Construction or Active Consideration* (Situation as of January 1980).

HVDC System	Transmission Distance Km			Rated voltage kV × No. of circuits	Commissioning date
	Overhead line	Cable	Total		
a) Mercury - arc valve systems in operation					
Gotland - Swedish Mainland	0	96	96	150	1954/70
Cross Channel 1 (GB - F)	0	7+50+8	65	±100	1961
Volgograd - Donbass (SU)	470	0	470	±400	1962/65
Konti Skan (DK - S)	55+40	25+60	180	250	1965
Sakuma (J)	—	—	—	125×2	1965
New Zealand (NZ)	535+35	39	609	±250	1965
Sardinia - Italian Mainland	86+156+50	16+105	413	±200	1967
Vancouver Pole 1 (CDN)	total 41	total 33	74	+260	1968/69
Pacific Intertie (US)	1362	0	1362	±400	1970
Nelson River Bipole 1 (CDN)	890	0	890	±450	1973/77
Kingsnorth (GB)	0	59+23	82	±266	1974
b) Thyristor valve systems in operation					
Eel River (CDN)	—	—	—	80×2	1972
Skagerrak (DK - N)	85+28	127	240	±250	1976/77
David A. Hamil (US)	—	—	—	50	1977
Cabora Bassa - Apollo (MOC - ZA)	1414	0	1414	±533	1977/79
Vancouver Pole 2 (CDN)	total 41	total 33	74	−280	1977/79
Square Butte (US)	749	0	749	±250	1977
Shin - Shinano (J)	—	—	—	125×2	1977
Nelson River Bipole 2 (CDN)	930	0	930	±250	1978
CU (Underwood-Minneapolis, US)	710	0	710	±400	1979
c) Thyristor valve systems under construction or active consideration					
Hokkaido - Honshu (J)	27+97	44	168	125	1979
USSR - Finland	—	—	—	± 85×3	1981
Inga - Shaba (Zaire)	1700	0	1700	±500	1981
Acaray (PY - BR)	—	—	—	26	1981
Itaipu (BR)	783/806	0	783/806	±600×2	1983/85
Durnrohr (A)	—	—	—	—	1983
Ekibastuz - Centre (SU)	2400	0	2400	±750	1984
Cross Channel 2 (GB - F)	0	17+46+5	68	±270×2	1984
Nelson River Bipole 3 (CDN)	930	0	930	±500	1990

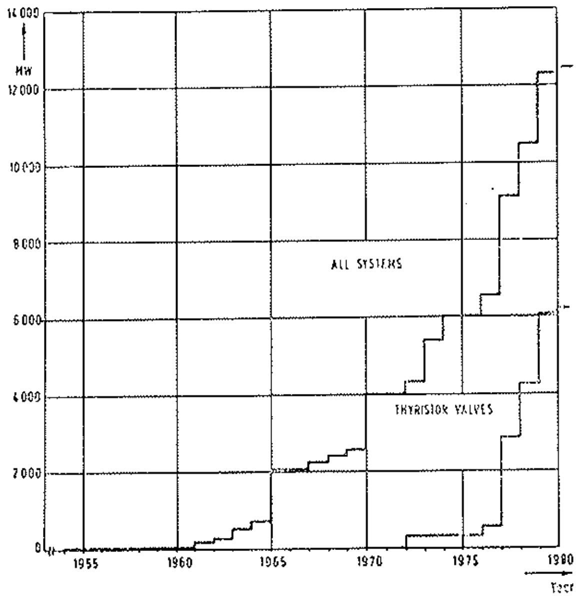

FIG. 7. Development of the Total Installed Capacity of HVDC Systems until 1980.

guaranteed by the corresponding system of alternate current owing to the complexity of the terminal conversion equipment and its control system.

If, as it appears likely, these problems find a satisfactory solution, an ever-widening field of application will open up to direct-current transmission.

An important contribution to reliability has been achieved by the use of semiconductors and conversion plants already equipped with solid-state converters, which are demonstrating satisfactory continuity of operation.

Evolution of transmission systems

The adjustment of the primary transmission system to the needs stemming from tbe increase of the levels of capacity and of the amount of electric energy to be transmitted from the generation to the distribution system is to be carried out in successive stages First, the number of lines are increased at the same level of voltage; then the existing system is overlapped by a network (to be made operative gradually) with a higher voltage and formed by lines with a capacity three to six times greater than in the preceding system.

It is worth while to mention the advantages obtained with the use of bundle conductors on transmission lines operating at 245 kV, 420 kV and higher voltages: they were initially two and subsequently three or even four per phase. It has proved possible in certain conditions to increase the characteristic power and consequently the transmission capacity by about 50% with a quadruple conductor instead of a simple conductor, at parity of cross section. At equal voltage, the corona effect and subsequent losses, as well as radio interferences and noise, are reduced.

In the European type networks, with the development of new voltage levels, the existing network loses its function of primary transmission to take on that of primary distribution which, in turn, is taken away from the lower voltage distribution network. As a system rarely contains more than four voltage levels, at every introduction of a new level there is normally a corresponding gradual suppression of another level alongside variations of the plants deemed necessary for their adjustment to a higher voltage or their occasional degradation to lower levels.

In view of this evolution the importance of choosing the values and determining the timing for the adoption of every new transmission voltage level becomes evident; the problem is complex inasmuch as it entails decisive action on the destination of lower level networks.

As is easily understandable, the development of a transmission network is closely interrelated with production trends, with particular reference to the siting of the power plants and the evolution of consumption over the territory supplied. This leads to a complex problem of planning the meeting of new needs to improve the quality of the service and to make investments and running costs as economical as possible.

The diagram in Figure 9 outlines this evolution and shows the increase of electric power sent out to the primary transmission system, the development of the corresponding network and the reduction of the average distance (mean power path) covered by electric power in a year ([2]).

Rational planning of the electric system and the reduction of the average distance exert a favorable effect not only on the economy of the

([2]) The average distance covered by electric power in an interconnected system is given by the sum having as numerator the sum of the product of the length of each line in the system by the relative amount of power transmitted and as denominator the total electric power transmitted by all the lines.

system but also, indirectly, on the safeguard of the environment, as it reduces the overall dimensions of the lines of the system.

All this justifies the experiments and studies carried out by all the European countries regarding the choice of voltages exceeding the current 420 kV value, in view of the power and energy variations predicted for the future.

Problems of transmission in relation to the environment

As we have already seen, the problems involved with planning the evolution of a transmission system are much more intricate today than in the past. In fact, other limiting factors are now added to the conventional economic imperatives; they are difficult to assess from an economic standpoint, and are related with the interference with the environment caused by overhead lines. These limitations are becoming ever more binding in densely populated countries.

In theory, any environmental problem stemming from overhead lines could be solved by replacing them with underground cables; however, the transmission costs would become exorbitant, that is to say, ten times greater than the previous costs and this would necessarily entail a global revision of the problems inherent in the transmission of energy in its various forms.

Power lines can interfere with the environment in various ways. Figure 8 shows the principal interferences created by a power line, in this case run at 420 kV, on the immediate surroundings, and more precisely:

1) the physical space taken up by the conductors;
2) corona-provoked radio-interferences and noise;
3) ground gradient.

These interferences with the environment generally involve those sections of territory subject to the right of way for overhead lines. In the more remote areas, the only interference that exists is represented by their clashing with the landscape, which today constitutes the major obstacle to the development of power lines.

The first condition to be met in order to reduce interference with the environment is to adjust the potential capacity of the line, connected at its own voltage, to the power to be transmitted, so as to incorporate the foreseeable developments over at least a decade.

As obvious as it might appear at first, this point has been discussed at length, as higher voltage lines apparently entail a more considerable deterioration of the environment. If, however, the greater interference is strictly correlated to the higher transmissible power higher voltage will undoubtedly prove to have great advantages.

Figure 9 clearly shows that: the transmittible power is represented by the cross-section of the solid around the line; the width of the base of this represents the right of way, the height is the power per unit width of the right of way itself. It thus becomes evident that the power transmissible per unit width of the right of way increases considerably with the voltage.

In addition to the measures aimed at limiting interference with the environment by reducing the number of lines, we must also give credit to the considerable efforts made to reduce interference with the environment due to the specific characteristics of every line.

Another solution to the problem of line interference with the environment is supplied by routing the lines through areas that are less sensitive to different types of disturbance. It is with this outlook that global methods of optimizing the routes were devised by starting from a map of the area to be crossed by the line; this map indicates the area's sensibility to the line disturbance. The degree of this "disturbance sensibility" is assessed on the basis of a detailed study of the territory that considers all the disturbance-derived effects.

It was found that environmental disturbance tends to diminish in relative terms with a voltage increase and that the cost ratio between an underground cable line and an overhead line increases quickly as the voltage increases. This means that the expenditure required to free 1 sq m of territory from the disturbance effect provoked by a power line, through its replacement with an underground cable line increases considerably at higher voltages.

Power lines are by far the best means of transmitting high voltage. In the GW range, the new technologies tend to curb the tendency of the ratio between cable line and power line costs to increase.

Within the framework of reduction of environmental disturbance, direct-current transmission might play a leading role: for equal amounts of power transmissible, the direct-current line is not only less expensive but it also takes up less space and causes less interference with the environment; furthermore, solutions envisaging direct-current underground cables are particularly interesting in the case of super-conductors. It is obvious, nonetheless, that in order to apply this system on a large scale

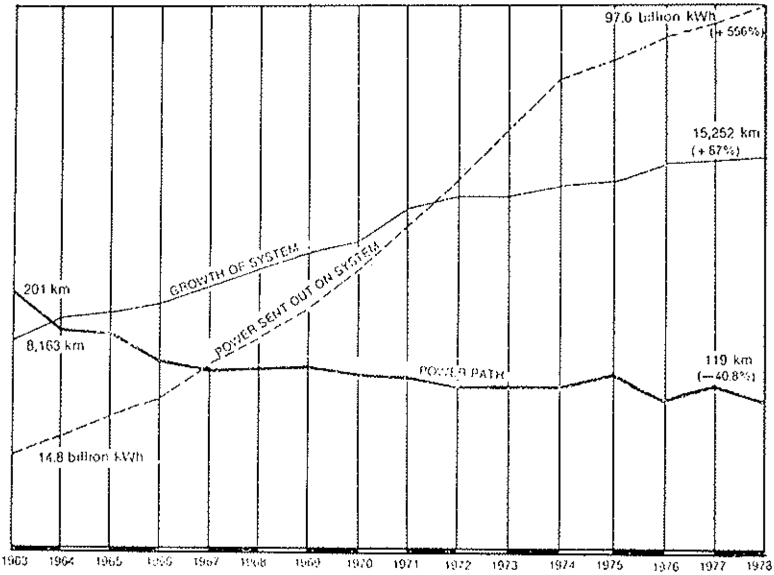

FIG. 8. Mean Power Path on Enel High-Voltage (220 and 380-kV) Transmission System.

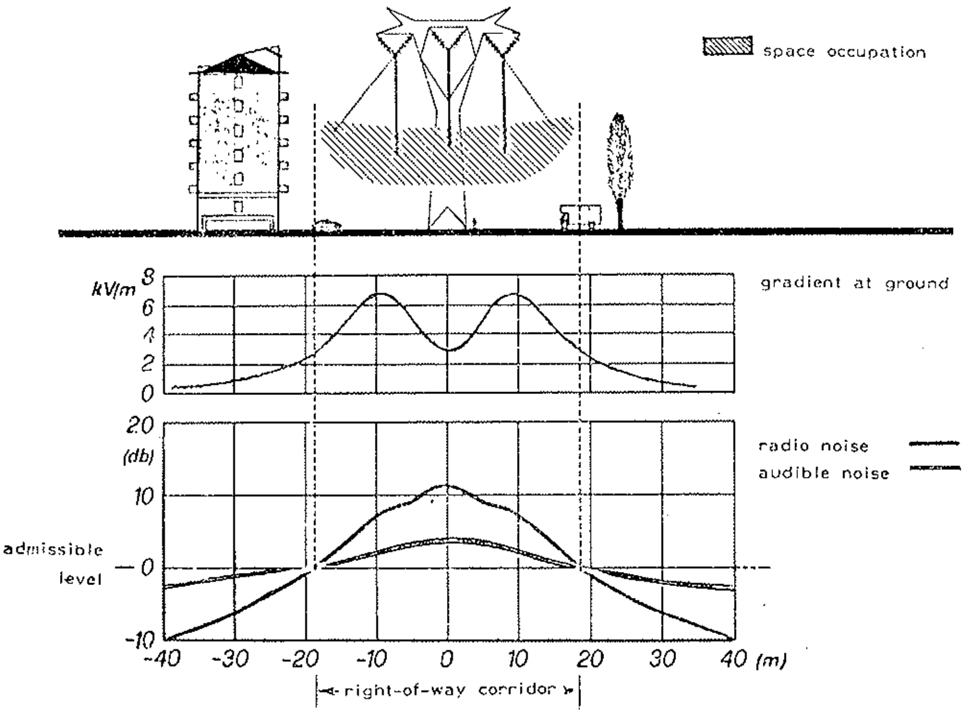

FIG. 9. Right-of-Way Corridor of an Overhead Line; Space Occupation; Profiles of Voltage Gradient at Ground, of Radio Interference and Audible Noise in the Neighbourhood of the Line.

the basic problems mentioned previously should be solved first. Unfortunately, the solution to these problems is still far away and will surely not be found before the beginning of the next century.

Future Prospects

Experience of the past and especially of the last 50 years, has shown that it is becoming increasingly difficult to make forecasts of the development of applied science and technology because, on the one hand, the pace of progress is accelerated and, on the other, the number of solutions suggested for each problem increases. This means that the choices made among all the possible solutions are characterized by a sense of uncertainty that grows in relation to the length of the period these forecasts are referred to. In relation to this, it would be very useful to study the trends of applied research for the development of new transmission systems.

First and foremost we should consider the development of direct-current transmission resulting from the progress in the application of static systems to convert alternate into direct current and vice-versa.

Forecasts on the development of electric power transmission by

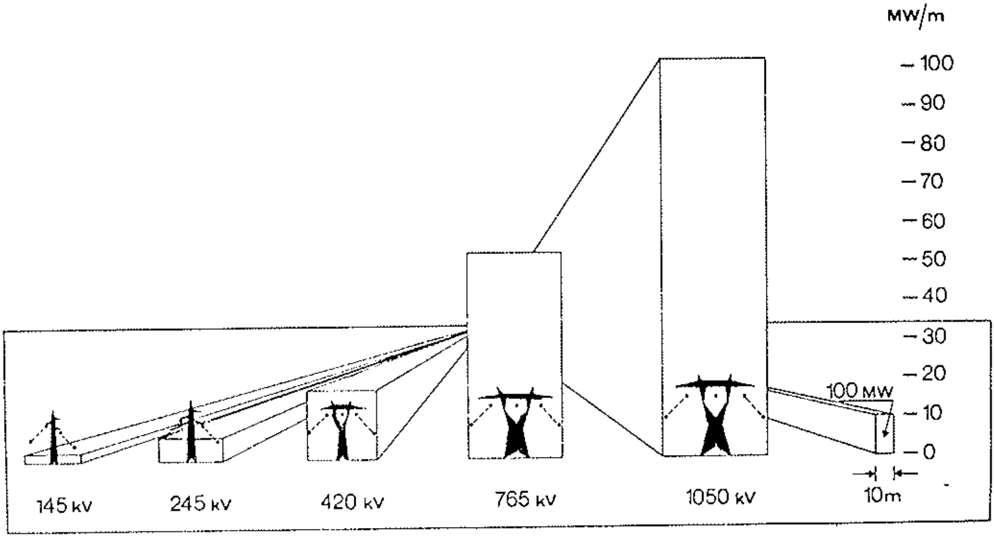

FIG. 10. Transmissible Power and Land Occupation of Transmission Lines.

means of super-conductors cables are by far more difficult to make. In this case, the objective aimed at is much more ambitious:

— very high transmission capacity equal to many thousands of MW per line;

— a much lower transmission voltage than the ones used in our high-voltage distribution networks (cables with a voltage of approximately 40-50 kV are envisaged for the transmission of 10 GW power);

— utilization of underground cable instead of overhead lines. With respect to the characteristics mentioned, the transmission costs by means of super-conductor cables could prove to be competitive with overhead-line electric power transmission. In the former case the losses would be negligible.

Lastly, super-conductor cables could represent the ideal solution of a problem that has attained considerable proportions and entails difficulties that will be particularly felt in the future: the "penetration" of transmission lines in the immense cities of the present and the "megalopolis" of the future. The prospects opened by this new system of transmission are important enough to fully justify similar efforts made by several countries.

Other prospects have been taken into consideration in the light of the progress recently achieved in the field of microwave generation with greater and greater power and their transmission by means of wave guides. These achievements, together with others concerning the conversion of growing quantities of direct current to alternating current at microwave frequencies and vice-versa, constitute the launching pad for the advanced research carried out in the field of wave guide power transmission.

Forecasts concerning the possibility of transmitting great quantities of power by means of laser beams are even more uncertain.

Transmission of other forms of energy

Electric power transmission is now in competition with the transport of primary and secondary sources of energy. For the time being, it is mainly a question of transport of energy sources such as coal, oil and natural gas. From the strictly technical and economic point of view, there is a certain amount of balance between the transport of these materials and electric power transmission which is still competitive on land but not across the sea (except for a few cases).

A substantial change in the above-mentioned balance could be brought about by research now being carried out on new "energy vectors" and hydrogen in particular, which in the future could represent a secondary energy capable of replacing most of the oil derivatives in the energy industry.

In this case, the issue of transport is strictly connected to that of production: in fact, high temperature nuclear reactors could be used for the production of hydrogen from water. The thermal process involved in hydrogen separation represents an interesting alternative to electrolysis inasmuch as it avoids the conversion of heat produced in the reactor into electric power, with a 30-40% yield and permits the use of the latter for electrolysis.

Furthermore, hydrogen transport offers several alternatives: transport by means of gas pipelines; transport in the liquid state by rail or by road in special containers or, finally, transport by a hydrogen-absorbing means.

Among the most promising solutions, mention should be made of the utilization of hydrogen (or natural or artificial methane) in fuel-cells. These electrochemical converters, once perfected, could prove to be of great use for the on-site production of electric power with considerable consequences for the role and utilization range of electric power transmission.

The control center as the essential structure for the integrated system of electric power production and transmission

Electric power production and transmission over a vast territory, and a whole nation in particular, represents a typical integrated system. In fact, the transmission system constitutes the essential infrastructure connecting the generation system to the utilization centers. The luck is particularly close both because electric power transmission is carried out without meaningful delays and because owing to its intrinsic characteristics, electric power cannot be stored for industrial uses in significant quantities. Furthermore, any local unbalance or perturbation spreads to and affects the entire system within a very short time and involves also very remote areas.

This brings us to the need to adopt modern systems to run the power plants, and to consider them both individually and as part of the whole, alongside the primary network. The principal components of these systems are the following:

— A highly reliable telecommunication network capable of ensuring continuous transmission, both to the peripheral control centers and to the center controlling the entire system, of all the data relating to the interconnection pattern and of all the fundamental measurements such as: active and reactive power supplied by the generators and traveling through the lines, voltage, currents, etc. At the same time, this network guarantees the remote control of the regulating devices of generators and substations allowing a constant power adjustment of the generators and network pattern to the varying conditions of operation in compliance with a previously set plan.

— A central computer, preferably interconnected with peripheral "satellites" which, on the basis of data relating to generating units and the lines constituting the network, determines in a continuous way, the generator contribution, the over-all pattern of the network and the load on its lines so as to obtain the maximum global operation economy within all the limitations related to:

1) reliability of the network, in normal and emergency conditions;

2) the need to minimize the effects of failures such as line interruptions, short circuits, etc.

3) the margins of safety to be respected with regard to the load on generators, lines, etc.

In highly automated control centers, the central computer and its satellites act directly, without manual intervention, on the generator regulators, on load tap-changer, as well as on the switch triggering devices, isolating switches, etc., so as to maintain the optimal operation conditions set by the computer program. This, in brief, is the function carried out by the control center that, thanks to recent technological progress achieved in data processing and transmission, today ensures a more efficient integration of electric power production and transmission at a national level.

For example, in Italy ENEL with its National Control Center, has succeeded in finding and making operational a system that is one of the most advanced in this field for dimensions and sophistication in planning. Once this system becomes fully operational it will allow the production-transmission network to be run not only with greater economy but also with higher safety coefficients.

The project for the Center was completed in 1976 and the start-up of the new system is scheduled for 1982.

Distribution subsystem

General characteristics and problems

Following the trend of energy flow from the source to the user, the subsequent phase of transmission is represented by the distribution subsystem.

This subsystem is characterized by a network which becomes proportionately denser as the voltage level decreases. It has the essential function of capillary energy delivery from the distribution centers to the single users. This function gives the distribution network a strictly territorial trait, closely linked to the users.

The principal problems with this subsystem are:

— territorial lay-out;

— technical-economic management of the subsystem on which the quality and continuity of the service (maintenance, spares, marketing) depend;

— relations with the consumers.

The distribution subsystem continuously evolves in conformity with the increase in the number of consumers, which means that its operation can not be considered separately from the structural characteristics of the consumer market.

It thus becomes essential to work out a plan on short, medium and long terms so as to give the distribution network the pattern capable of achieving the optimal economic goals set over a long period of time. Much has been done to solve this vast and intricate problem but there still is a lot to do. Generally speaking, these problems are somewhat similar to those of other public services (telephone, gas and drinking water): many of the basic elements useful in one of these sectors will also prove of great utility in the others.

The basic elements for the complex assessments of the future needs and territorial distribution required in planning for each area individually derive from the evaluation of the future population and the evolution of the standard of living. There should also be a parallel forecast for industrial users that consume large quantities of energy.

To these evaluations should be added forecasts of any changes in consumption due both to the technical evolution of the single consumption systems and to the economy-oriented choices that might entail industrial process variations. These evaluations should obviously be made according to a detailed plan so as to check them periodically in the light of more accurate and up-dated data.

The distribution system structure will evolve and take shape in harmony with the changes in power consumption trends.

As concerns the many aspects of management of the distribution systems, we will briefly say that the aim is to rationalize all the decision-making so as to increase the reliability of the system itself and improve the quality of the service. This aim should be pursued also with an effort to minimize operation costs.

What has been said so far throws light on the need for a continuous technological up-dating of the distribution system with a greater use of improved automation and remote-control teleoperation techniques. To this we may add the need to resort to more qualified personnel and to an organization more suitable to the changed and more pressing needs.

The relations with consumers constitute an essential point in the distribution objectives as they represent the real point of contact between the power utility and the public.

In these last few years, the customers of public utilities have thoroughly changed their behaviour by acquiring a greater awareness of their rights. On the other hand, in many countries the power utilities have invited consumers to implement energy-saving plans, thus causing them to participate more actively in the needs of the entire national energy system. This also explains the company's need to attentively follow the evolution of the consumers' needs.

Computer science in the distribution subsystem

The attainment of the aims mentioned above was rendered possible with the advent of automatic data processing. The success of this technology is also closely connected to the setting-up of information systems with distributed intelligence together with the development of techniques capable of facilitating man-machine communications. These aspects will open the way to the important development of electronic computers in the distribution subsystem.

As concerns planning, automatic data processing reveals all the meaningful data regarding the state of the distribution network with reference to the functioning components and to the quality of the service. This makes up the basis for calculations for network planning which are notoriously highly repetitive in order to achieve the optimal solution.

Present techniques allow planning of the whole distribution subsystem excluding the low-voltage levels whose evolution is always foreseen in global terms.

Automatic data processing is also applied in the management of technical activities. Thanks to the decentralization of means and calculation capacities, it is possible to know the availability of materials and means for maintenance (with great ease and where the materials are to be utilized) and to up-date the quantity of spares and optimize their management.

It is also worth while to note the great utility of mini-computers used in commercial offices in charge of customer relations. The aim of these computers is, for example, to facilitate contact with the public and improve the management efficiency. This is achieved through the high speed in data collection and up-dating. All this, besides improving the relations with the customers, contributes to a considerable diminution of operation costs and also supplies all pertinent information on each consumer.

Data processing is obviously widely applied in commercial invoicing.

Utilization of electric power

General considerations

There is no need to prove that electric power represents the most flexible form of industrially usable energy. It is enough to consider this flexibility from the viewpoint of:

— the variety of forms of energy from which it can be obtained by means of conversion processes that meet the need for safety, reliability and economy;

— the variety of forms of energy into which it can be converted at the above-listed conditions;

— the possibility of a continuous, safe and economical regulation of the output according to consumption needs;

— the possibility of transmitting the energy economically and with satisfactory continuity in industrially interesting quantities and over considerable distances with negligible losses;

— the possibility of "delivering" the energy in the requested form to a complex of consumers spread unevenly over a very extended territory by means of a diffused and "capillary" distribution network, safely and economically.

As has already been stated, the fact that electric power in its utilization phase is by far the "cleanest" among all the other available forms of energy is also of great relevance. In its utilization phase, electric power has no polluting factors.

Other relevant considerations can be added to the ones already stated: it suffices here to remember that for many applications of utmost importance, electric power is not even replaceable by other forms of energy; even if it could be, it would be difficult and expensive to replace it. This explains the great importance of problems concerning the utilization of electric power not only from a technical-economic standpoint, but also from the industrial and political planning point of view. This explains why, approximately 25-30% of the energy needs of industrialized countries are covered by electricity.

The main fields of utilization are briefly listed as follows:

Industry is the largest consumer of electric power at a rate of 50% of the total production. It is mainly used for motive power; then for use in the chemical sector, for heating and lighting. The highest rating consumers are the steel mills, metal processing plants and the chemical industry.

Electric power consumption in the transport sector amounts to about 3% of the total EEC power consumption and concerns city transport systems as well as railway electrification which has already undergone considerable and efficient development.

The urban electric transport systems throughout the EEC consume between 10 and 30% of the total amount of electric power utilized in this sector; their role is destined to be enhanced since they could give a positive contribution both to the problem of city traffic and, above all, to that of air pollution over the cities.

Heating and air-conditioning play an important role in North American countries although they are not so important in Europe. The success of these forms of utilization derives from the speed, ease and safety of use in addition to an improved standard of comfort. These applications are bound to increase in mixed heating systems (i.e. solar+electrical).

The last decades have seen a multiplication of the household uses of electric power which has led to an increase of power demand at a particularly fast rate. In fact, today, electric household appliances, television sets, recorders and, of course, lighting play a leading role in the home and give a considerable contribution to the quality of household life.

Public lighting is a particularly important item in the energy balance and any comment on its social importance is totally superfluous.

Further to the traditional applications mentioned above, we now have unfolding before us the possibility of witnessing the concrete success of electric motor-cars. These vehicles would prove to be advantageous from the standpoint of energy consumption as they could indirectly use any source of energy other than oil. Moreover this application would bring about a substantial improvement of the urban environment thanks to the absence of exhaust gases and to a drastic reduction of noise.

Electric power as an increasingly important means to save energy and primary resources

The recent evolution of the international energy market together with the increasing trend in consumption, which has been taking place throughout the world over many decades, has contributed to rendering the energy saving problem more important and note-worthy.

The tensions of the energy market, the geographical distribution of the deposits of liquid and gaseous hydrocarbons, for the most part concentrated in only a few countries, and the relatively negligible reserves of some primary sources raise serious concern for the future.

With respect to the various measures that can help keep the energy crisis at bay I would like to mention the potential role of the utilization of electric power. Electric power is a source of energy saving for many reasons:

— it can replace other forms of energy more efficiently: at present it is already utilized industrially also in the field of heat production; in the future the possible use of the electric heat-pump for home, commercial and industrial heating will produce considerable energy saving;

— it may help to save other forms of energy, for instance through the electric-powered information systems; it will suffice to think of the role that information has and may have in the rationalization of the distribution of goods avoiding useless transfers; the same may be said of more sophisticated telecommunication systems which can reduce the actual movement of people;

— it may integrate discontinuous energy sources thus allowing them to be used; the utilization of solar energy for heating can already count on electric integration, and research on the utilization of wind energy is being carried out in view of the connection with the electric network, both in order to exploit a very discontinuous intrinsically un-regulatable source and in order to utilize the network to stabilize the operation of electric equipment.

It is very difficult to outline a synthesis of the savings obtained in the recent past through the contribution of electric power. We deem it more useful to analyse all the possibilities of energy saving so as to allow an evaluation of saving in the light of the alternative offered by the use of electric power instead of other forms of energy. For an outline of this kind I refer the reader to my other work (3); here I only wish to point out that the savings, have been considerable and in the future these projects may become much more important.

Limiting our attention to the field of possible savings in the utilization of electric power, it must be said firstly that such savings should be considerable, even if electric power has had the benefit of receiving better attention than other energy sources. In fact, the interest in a more efficient utilization of electric power existed long before the energy crisis.

I would like to point out here that in the industrial field, leaving out some high-consumption productions (aluminum, magnesium, etc.), the low incidence of electric energy cost on the product cost, often leads to underrating the need to increase the level of rationalization and efficiency in its utilization.

Moreover, in the domestic and commercial fields, technical possibilities of energy saving exist in many utilizations: e.g. electric household appliances for energy consumption of which it is difficult to find a unified basis for comparison. After the oil crisis the "Istituto del marchio di qualità" (Brand quality Institute) set out to overcome this obstacle by means of informative labels indicating the standard power consumption of each appliance to prevent buyers and users from trying to economize on the purchase price of the appliances and end up paying a great deal more in terms of increased operating costs. This labelling has already been defined for water heaters and refrigerators. A similar proposal has recently been made also within the European Economic Community.

(3) A. M. ANGELINI, *Problems of Electric Power Generation. A System approach.* Accademia Nazionale dei Lincei, Rome 1978.

A considerable energy saving may also derive from the elimination of unnecessary consumption and waste. It is logical to think that a decrease in the waste and even more a better utilization of electric power in the household may be obtained by informing the users at grass roots level.

The limitation of consumption may be induced by efficient binding regulations, but measures of this kind must be preceded by wide ranging information aimed at giving assistance and technical advice to the users. In any case gearing prices to costs is essential in order to avoid, for instance, that certain rate levels may encourage a non-rational utilization of energy.

Power-saving provisions are all the more important in that the role of electric power is bound to have increasing importance in the future precisely in view of the exploitation of the nuclear energy source and of the hydroelectric resources still available.

In confirmation of this we can mention the forecast according to which in the year 2000, 40-50% of the primary sources will be converted into electric.

Conclusion

Electric power represents one of the most important factors in the economic and social development and has also played a fundamental role in the improvement of living conditions. In fact, with its innumerable applications, it not only constitutes an outstanding and greatly flexible means of alleviating man's physical toil but also the launching pad for innovations apt to support and help the human mind, which has led to the widening of our field of knowledge. The onset of automatic data processing, the outstanding development undergone by telecommunications, man's first steps on the Moon, the creation of the so-called "artificial intelligences", the conquests achieved in the past decades in every field of knowledge, have all been based on the essential contribution (often irreplaceable) of electric power.

All these innovations have allowed a greater spreading and widening of culture and lifted man to a new level of awareness that is no longer simply aimed at satisfying his own needs in the most convenient way possible but also at shaping them to suit the often contrasting requirements and complex balance of the environment in which he lives.

This work considers the totality of structures and organized activities apt to making electric power available to everyone as an integrated "system" in the sense of the term expressed in "System Science and Engineering".

As we have already seen, the electric power system can be fed by all industrially available sources of energy, convert them into electricity which is then transmitted to distribution centers and subsequently delivered to the consumers. This is not only a staple expressed in kWh but also and above all, a service represented by the power that the user can utilize freely according to his needs and following the changing trend of his requirements over a particular time-span: a day, a week, a season.

This characteristic of "free availability" for the user, together with the other above-mentioned characteristics and in particular the absence of polluting factors in the widest range fully explains the growing demand for it with respect to other secondary energy forms.

Acknowledgements

I wish to thank the Pontifical Academy of Science, its president and particularly Professor Blanc-Lapierre, for having invited me to discuss this interesting subject at this meeting.

DISCUSSION

Blanc-Lapierre

Le problème d'un système intégré, tel qu'il a été présenté, concerne un pays très développé. Que peut-on dire en ce qui concerne les pays en développement?

Angelini

A la question posée par le Prof. Blanc-Lapierre, je peux répondre que le « System Engeneering » s'applique tout naturellement aux systèmes électriques en cours de développement qui intéressent les pays auxquels il a fait référence. Sans entrer dans les détails, on peut dire que l'histoire du développement de l'industrie électrique dans les pays industrialisés constitue, en quelque sorte, un guide pour l'évolution de la même industrie dans le pays en développement. Il existe, cependant, des différences substantielles entre ces deux sortes de pays; elles sont fonction des différences dans la situation socio-économique de départ, dans les possibilités de développement de la consommation et, enfin, dans la disponibilité en matières premières et en sources d'énergie. A propos de ces dernières, je reviens sur le sujet que j'ai déjà eu l'occasion d'évoquer hier: la possibilité d'utiliser les abondantes ressources hydrauliques de certains pays pour alimenter la fabrication de produits coûteux en énergie. Il s'agit là d'un facteur capital pour le développement de l'industrie électrique et de l'industrie en général dans ces pays.

Blanc-Lapierre

Je pense que le Président Konan peut nous apporter le fruit de son expérience en Côte d'Ivoire et j'aimerais qu'à cette occasion il nous parle un peu de la coopération dans le domaine électrique à laquelle participe son pays avec de nombreux autres pays d'Afrique.

Konan

La question des ressources hydrauliques est importante pour les pays en développement. Il faut cependant noter que leur mise en valeur pose de sérieux problèmes, découlant essentiellement du manque de consommateurs importants et de la dispersion des populations. Il est parfois plus difficile de réaliser de petits projets adaptés à une telle situation que de construire, ailleurs, de grandes unités. C'est là un problème aigu dans les pays en développement.

Le Prof. Blanc-Lapierre m'a demandé de dire quelques mots sur l'Union des Pays Producteurs et Distributeurs d'Energie d'Afrique (U.P.D.E.A.). Cette Union a été créée en 1970, dans le but de contribuer au développement de l'énergie en Afrique. La complexité des problèmes rendait nécessaire la mise en commun des expériences acquises par ces divers pays sur le plan technique, en vue de la meilleure adaptation des moyens aux besoins.

L'U.P.D.E.A. a créé une Ecole d'Ingénieurs qui fonctionne depuis 1979. Elle est parrainée par l'Ecole Supérieure d'Electricité de Paris et par les Instituts Polytecbniques de Londres et de Lausanne. L'enseignement est dispensé en anglais et en français.

L'U.P.D.E.A. est apolitique. Ceci évite les problèmes qui se posent toujours lorsque cette précaution n'est pas prise.

Les pays membres de l'Union sont les suivants: Sénégal, Mali, Guinée, Libéria, Côte d'Ivoire, Togo, Niger, Communauté Electrique du Bénin, Haute-Volta, Cameroun, Gabon, Congo-Brazzaville, Ghana, Ile Maurice, Madagascar, Rwanda, Zaïre.

NUCLEAR ENERGY

Chaired by Professor J. TEILLAC

INTRODUCTION

JEAN TEILLAC

After yesterday's very interesting session on issues related to oil and coal, it seems natural to talk today about nuclear energy.

I would first like to recall two simple conclusions of yesterday's discussions which, although not new, are particularly important:

1) *The oil problem is basically one of limited production*

We cannot freely determine the level of oil production, which is and will remain limited.

The probability of major new oil fields being brought into production is low. In any case this would take more than 10 years from discovery of the oil.

This problem of limited petrol production is compounded by the need to make petrol more available to the developing nations and, as a consequence, some countries will be faced by a limitation or even a reduction in petrol availability.

2) *Coal exists in large quantities*

Development of the planet's abundant coal resources will require new infrastructures, but there are no technical obstacles.

The 1980s should therefore see a return to more intensive use of coal. However, the necessary investments will be high: I have seen the figure of 200 billion current dollars for the coming decade! A large part of this will have to be provided by the international banking community, as indicated by the World Bank in its publication: "Coal Development Potential and Prospects in the Developing Countries".

One of the obvious conclusions of all this is:

The need to start replacing oil as rapidly as possible with other energy producing processes and sources.

The replacement of oil is an immediate problem and should already have been started. If I understand correctly, this will take one or two decades, and the next 20 years will thus be a *period of transition.* During this period, we must make the appropriate investments and install the necessary equipment, and this will be possible only if we have recourse to *proven techniques.*

There can be no question of advancing at the rhythm of scientific research and progress for which feasibility is not yet demonstrated and industrial-scale development not assured. Solar energy, bio-energy, nuclear fusion power and so on need another 10 to 20 years of scientific R & D, then perhaps at least as long for industrial implementation.

All these alternative energy sources are needed for the future, and *they must be developed.* But, in the meantime, we must find the answer to limited oil production: economic growth cannot wait.

In this respect, recent technical progress has certainly made coal a good candidate for large-scale replacement of oil.

Is nuclear power also a good candidate?

Nuclear energy has special characteristics, some of the most obvious of which are:

— fissioning uranium releases much more energy than buring coal or oil;

— fission and resulting fission products also release radioactivity;

— nuclear fission has military as well as civilian uses.

Any discussion on nuclear energy must consider both the positive as well as the negative aspects concerning its use.

Today's presentations will include some technical data, to guide our discussion, but it is not intended to go deeply into technical aspects.

For my part, and to conclude, I would like to indicate some of the key questions which I feel should be addressed today:

1) Is production of energy from uranium now:
— technically mature?
— cost competitive?

2) Are world uranium resources sufficient for nuclear power plants to make a significant contribution to world energy production? If so, for how long and under what conditions?

3) Does developing nuclear power have detrimental consequences for mankind and the environment?

4) Does developing nuclear power in the world increase the risks of nuclear weapons proliferation?

5) In view of the answers to these questions, and the current energy context, should use of nuclear power be recommended, at least for some countries?

6) What types of need are best satisfied by nuclear power? Is it useful for developing nations? Are there serious problems in respect to technology transfer?

7) What should we think about opposition to nuclear power in certain sectors of the public and in some countries? Can the lack of a sufficiently broad public consensus hinder development of nuclear power?

8) Finally, are we doing all we should in these areas?

A PERSPECTIVE ON CURRENT REACTOR TECHNOLOGIES

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1. Nuclear Power Plants - Introduction

A conceptual way of viewing all nuclear reactor systems is to consider them essentially as electricity-producing black boxes. The basic input to such a device is an external stock of natural uranium. In a light water reactor, which will be the predominant nuclear plant on a world-wide scale until the end of this century, it is necessary to use slightly enriched uranium in order to maintain the fission chain reaction. The fraction of the fissile isotope of uranium — uranium-235 — must be quadrupled from 0.7% in natural uranium (the rest is the nonfissile or fertile isotope ^{238}U), to about 3%, in order to extract the required amount of energy over the residence time of the fuel in the reactor's core. The selective enrichment of the fissile isotope fraction is carried out in a uranium enrichment plant, which is the largest component of the nuclear fuel cycle as it exists today. A generic basic description of annual reactor operation is shown in Figure 1, based on a recent report [1].

The nuclear chain reaction results in three major products or outputs. About 75% of the initial fissile uranium-235 input is destroyed by the fission process, thus releasing large amounts of thermal energy, which is recovered in the turbine generators to produce electricity. The fissioned ^{235}U is split into two smaller nuclei (referred to as fission products) and between two and three additional neutrons, which are mostly used to perpetuate the chain reaction. The fission products, which are highly radioactive and decay eventually with a half life of about thirty years, are the major waste products of the reactor operation and need to be

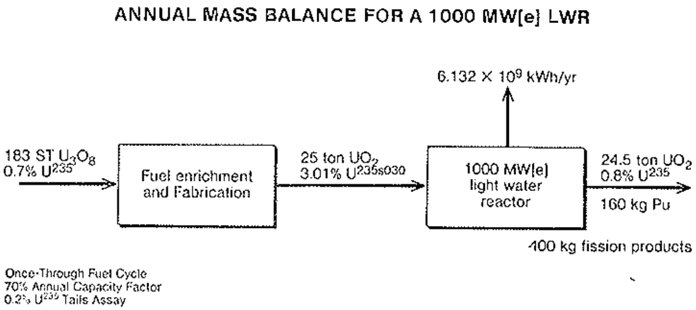


FIG. 1

disposed of. Nuclear physicists now specify that a highly radioactive substance that has decayed over approximately twenty half lives, [i.e., its activity has decreased to one-millionth (1/1,000,000) of its original value] has become relatively harmless and does not pose a greater danger to life than naturally occurring radioactive sources. In the case of the nuclear high level waste — the concentrated stream of fission products from the chain reaction — isolation from the biosphere for a period of 600-900 years is required in order to reduce the residual radioactivity to such levels. It is only when the fission products stream includes a small amount of long-lived radioactive heavy elements, due to incomplete separation, that the required waste storage periods are considerably increased.

The third major product of the nuclear chain reaction is the newly produced or "bred" fissile elements. Some of the neutrons emitted in the fission process are absorbed by the fertile fuel isotope and after a series of two radioactive decays produce new and relatively stable elements that can be utilized as nuclear fuel in other power plants. When the major fertile component of the fuel is the uranium isotope ^{238}U, the bred fissile element is plutonium. When fertile thorium atoms are employed as diluents in advanced fuel cycles, the bred fissile isotope is uranium-233.

In most of the reactors described here, a large fraction, about 50%, of the newly produced fissile isotopes are destroyed as they themselves are fissioned, and only the remaining fraction is discharged from the reactor at the end of its annual operating cycle.

A schematic of the fuel cycle is shown in Figure 2. The "front end" of the fuel cycle, from the mining of the uranium ore until insertion

ILLUSTRATIVE CLOSED FUEL CYCLE

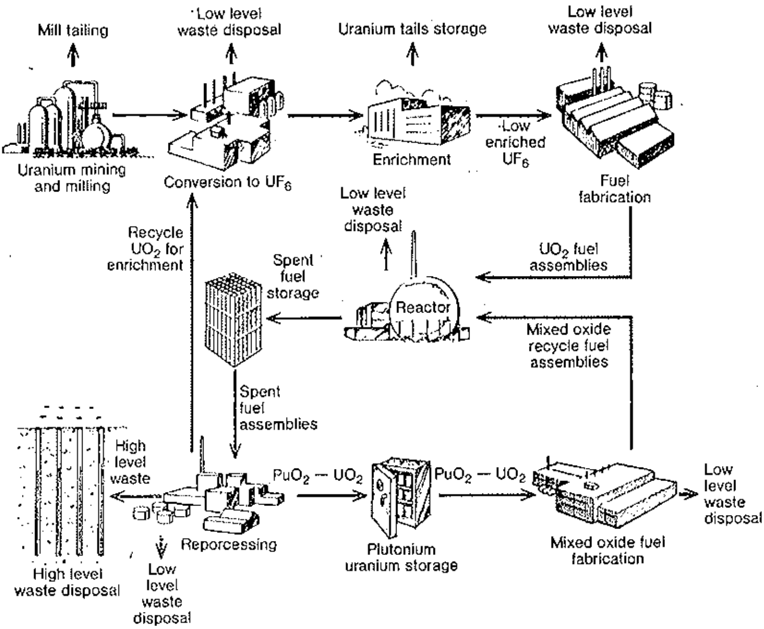


FIG. 2

into the reactor, includes three major components: uranium mining and milling, uranium enrichment, and fuel element fabrication.

The "back end" of the fuel cycle, includes all activities involving the discharged fuel elements. A current mode of operation is the open or throwaway fuel cycle. The discharged spent fuel is stored intact in properly cooled storage basins for a long time, and eventually sent to a permanent burial site. As the title implies, all the potentially useful components in the spent fuel, i.e., the remaining unfissioned uranium and the bred plutonium, are sent to the wast repository, together with the fission products. This scheme avoids the need for chemical separation.

On the other hand, such a cycle is extremely wasteful of fuel resources, which is particularly significant in this conservation-conscious period, and results in a large economic loss. It has been calculated that the value of the remaining uranium in spent U.S. fuel elements (disregarding the potentially greater value of the bred plutonium in breeder reactors) already amounts to about 1.5 billion, 1980 dollars [2].

The other generic kind of a fuel cycle involves a closed loop, where the spent fuel is chemically separated, the fission products are concentrated and sent to the waste disposal plant, and the useful uranium, or both the useful uranium and the bred plutonium, are recycled into the fuel fabrication plant at the front end of the reactor cycle, and are reconstituted as new fuel elements. Physics calculations according to [1] and [3] have indicated that uranium recycling would save 22% of the uranium required in the throwaway fuel cycle, and both uranium and plutonium recycling would save between 35% and 40% of the external annual fuel requirements of the once-through cycle. Savings of up to 25% of the uranium enrichment demand would occur in the case of complete recycling, thus reducing the size of the required fuel enrichment plant. Another potential use of the separated fissile material is to inventory a different kind of a nuclear plant — the breeder reactor — which is more efficiently operated on plutonium based, rather than uranium fields.

2. Classification of Reactors and Fuel Cycles

Several generic families of reactor technologies exist in the world today and can be classified according to the fuel, chain reaction moderator, and coolant utilized. Recent descriptions of the various reactor concepts can be found in [1], Volume 9 of [3] and [4]. The most widely commercialized concept is the light water reactor (LWR), which comes in two distinct subfamilies cooled with pressurized or boiling water. These reactor concepts, which evolved in the U.S. and later in the USSR, are based on the use of low-enriched uranium, 3% uranium-235, as basic fuel input, thus requiring fuel enrichment technology, and an ordinary, or light, water for maintaining the chain reaction and extracting heat from the reactor core. More than 80% of all operating nuclear plants today are based on this technology.

The second major family of commercial nuclear plants existing today are the gas-cooled reactors (GCRs), built mostly during the 1950s and 1960s in Britain and France. These reactors are based on natural or slightly enriched input uranium fuel; however, they use graphite as the moderating material in the reactor core, and extract the fission heat by helium or carbon dioxide gas flow through the reactor. This technology is now slowly heing phased out in favor of the LWR.

A modern offshoot of the older gas cooled reactors is the high temperature gas reactor (HTGR) which operates on medium (about 20%) or highly enriched uranium, is moderated by graphite and cooled by helium gas. Two relatively small demonstration plants now operate in the Federal Republic of Germany (FRG) and in the U.S. As its name implies, the HTGR operates at higher coolant temperatures than the other reactor families, and thus, could find useful applications as a source of high temperature heat for coal gasification, as proposed in the FRG, for steelmaking, as suggested in Japan, and for district heating as constructed in the USSR.

The third commercial reactor concept existing today is the Canadian Natural Uranium Deuterium Reactor (CANDU). This tecnology is currently based on the use of natural uranium. The fuel elements are held in pressure tubes in a calendria arrangement, instead of in a thick-walled pressure vessel, as in the LWR plants. The moderation of the chain reaction and heat extraction from the core are accomplished by heavy water (enriched in the deuterium isotope) instead of the natural (or light) water as in the LWR. As CANDU reactors are manufactured in smaller sizes than the LWRs — 500 to 750 MW (e) vs. 900 to 1300 MW (e) ranges as pressure tubes construction is simpler and less technically demanding than pressure vessel fabrication, and as heavy water production is relatively easier than uranium fuel enrichment, this technology is perceived as the likeliest route for independent nuclear power development by the newly developed and industrializing nations. Both India and Argentina are actively developing such reactors as the future mainstay of their nuclear power programs, and Pakistan, Brazil and Rumania are attempting to develop such capabilities.

Several other advanced converter reactor concepts (ACRs) have been proposed over the past 30 years but have not progressed beyond paper studies and small demonstration projects. These include the spectrum shift converter reactor (SSCR), the light water breeder reactor (LWBR), and the fast mixed spectrum reactor (FMSR).

Further on the reactor evolutionary chain stands the fast breeder reactor (FBR). A comprehensive discussion of this technology was recently published [5] and [6]. Unlike the converter reactor discussed above, the breeder produces annually slightly more bred fissile material than its cycle consumes to maintain the chain reaction. The term "fast" in the reactor's name applies to the energy of the fission neutrons. Whereas the moderator in the convertor reactor slows the neutron energies down to low or "thermal" values, the "fast" reactor core does not include any moderator material, and the chain reaction is maintained at high or "fast" neutron energies which are especially suitable for efficient fissioning of plutonium-based fuels. The fast breeder reactor is designed so that there is a net loos of fissile material in the reactor core. Unlike the converter reactors, the breeder's core, however, is surrounded by a "blanket" of fuel elements, in which additional fissile material is bred, due to interaction with the excess neutrons produced in the reactors' core. The design of the breeder reactor is optimized so that the net fissile production in the blanket slightly exceeds the net annual loss of fissile material in the core, thus providing a positive net production for the reactor plant. This material balance, based on data from [5] as optimized for different reactor sizes, is shown in Figure 3. The excess fissile production, discounting losses in the chemical separation process can be set aside annually, and over a period of 15-35 years may accumulate so that a new reactor plant can then be started. The time required for a breeder reactor to produce sufficient excess fuel to start up a new plant is referred to as the doubling time. It is usually required that the breeder's doubling time be similar to the electric demand annual growth rate, so that in the 21st century, when these reactors are utilized for bulk electricity generation, sufficient FBR capacity could be installed to meet the increasing demand. As an example, a relatively low electric demand growth rate of 2.5% per year would imply a breeder doubling time of

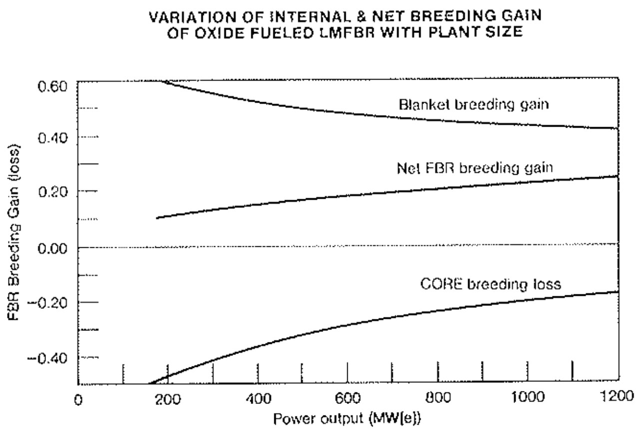


FIG. 3

28 years. This doubling time is well within the capabilities of the current breeder reactor technologies. The relationship between the required doubling time and net annual fissile production is shown in Figure 4, as computed from data [5].

The breeder reactors now developed are predominantly based on the plutonium-fueled and sodium-cooled liquid metal fast breeder (LMFBR) concept. Several medium-size 250-600 MW (e) demonstration plants operate today, and additional larger-size plants are proposed or are under construction. Recent surveys of FBR programs have appeared in [7-9]. Two other breeder concepts, the gas-cooled fast reactor (GCFR) and the molten salt breeder (MSBR), have not progressed beyond laboratory experiments. The main development trend of the industrial nations has been the reactor progression from the LWR to the FBR, while intermediate technologies, which have been considered as potential alternates, have not yet been commercialized, nor has their manufacturing infrastructure yet been established.

All the above-mentioned reactors can operate on tbe conventional uranium-plutonium fuel cycle or on the uranium-thorium-U-233 fuel cycle. Each of these fuels could be utilized in the open-ended or throwaway mode, or in the fuel recycle mode. The fissile enrichment of the fuel can be varied from natural (0.7% fissile), to low, medium, or high (above 20%) enrichments. This fissile content could be made

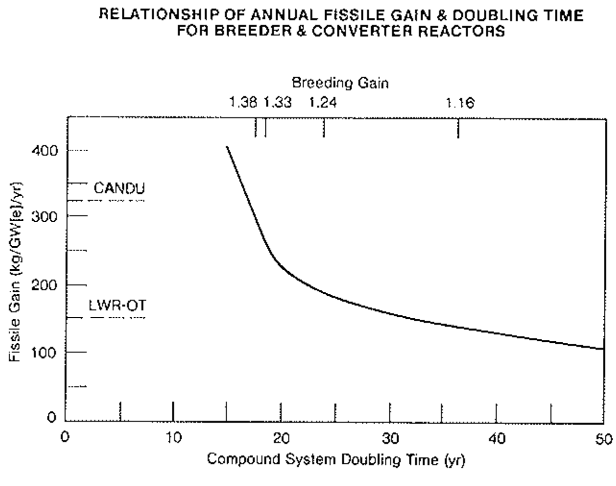


FIG. 4

up of the ^{235}U isotope only, or mixes of ^{235}U, ^{233}U and ^{238}U (which are referred to as denatured fuels), or mixes of fissile uranium and plutonium isotopes. Combining the number of reactor families with the number and mode of operation of the various fuel cycles, we obtain a large number of nuclear power plant variants, which describe an almost continuous spectrum of reactor performance characteristics. It is thus important to find ways of ranking this plethora of reactor concepts. The obvious way of comparing different energy technologies is to rank them by their electricity generation costs. This comparison is, however, difficult as many of these reactors have not been commercialized and only a few of the potential fuel cycles have been demonstrated. Thus, we will attempt to classify nuclear technologies by their physical performance characteristics, i.e., by the efficiency with which they utilize their external fuel supplies and breed new fuel to conserve the limited economic supply of natural uranium. In order to do this, we will define a basic physical measure of the conversion ratio, using our black-box view of the light water reactor.

3. Nuclear Fuel Utilization

The conversion ratio is the ratio of newly created fissile material (both internally "burned up" and discharged) to the annual consumption of input fuel required for reactor operation. A mass balance, normalized to an input of 100 kg/year of fissile materials, has been prepared for various 1000 MW (e) reactors operating at an annual average capacity factor of 70%, based on reference data [1], and is shown in Figure 5. This figure shows the input-output fissile balance from which the conversion ratio can be estimated. The PWR operated on the once-through cycle (OT) has consumed 75 kg of fissile ^{235}U (100 kg in and 25 kg out) and has discharged 21 kg of fissile Pu which represents about a half of the total production (42 kg). The conversion ratio would then be $42/75 = 0.55$. A nuclear reactor would be fuel self-sufficient if it discharges as much fissile fuel as it consumes. The fissile elements discharged are different from the fuel charge composition, and it is the function of the nuclear fuel cycle to separate the useful components and recycle them and to isolate and concentrate the waste for eventual disposal. The more fissile material is cycled back within the nuclear power complex, the lesser would be the requirement for an external fuel supply.

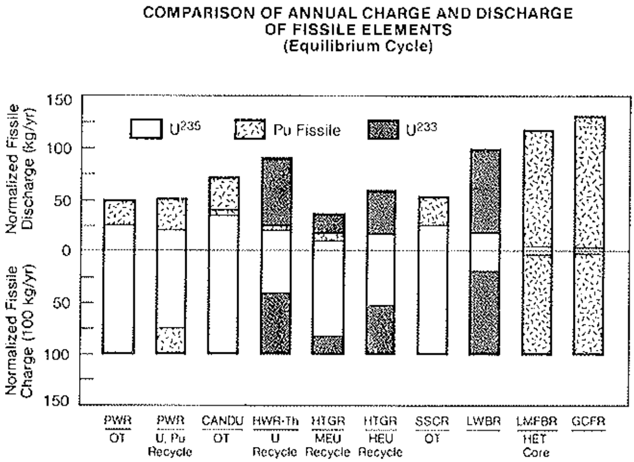


FIG. 5

As Figure 5 indicates, there exists a continuous progression in the amount of fissile discharge per unit charge as more advanced reactors than the light water reactor are considered, as recycle and advanced fueling schemes are employed, and as various kinds of breeder reactors are deployed. Advanced convertor reactors could achieve a conversion factor of 0.95, and breeder reactors would show a conversion factor of 1.0 and above. The conversion ratio in excess of 1.0 is referred to as the Breeding Gain.

Since the recycled fuel will be fissioned in the reactor a year or two after discharge, it is important to note the amounts of excess fissile material which accumulate — unused within the various fuel cycles. This comparison is shown in Figure 6 based on data from [1], where net annual charge and discharge figures are provided in real physical units. As seen in Figure 6, the reactors with the higher conversion ratio will require smaller net input of external fuel, and FBRS will become self-sufficient in their charged fuel supply. The once-through fuel cycles are the most inefficient in that they require larger amounts of net fissile fuel supply and they produce large amounts of fissile material, plutonium, which remains unutilized within the spent fuel. It is of interest to compare the net production of plutonium in the LWR and CANDU reactors and in the LMFBR. As seen in Figure 6, the CANDU reactor is the most prolific producer of excess plutonium, and the LMFBR would produce larger or smaller amounts of fissile Pu than the LWR, according to its design doubling time. LMFBRs with doubling times of more than

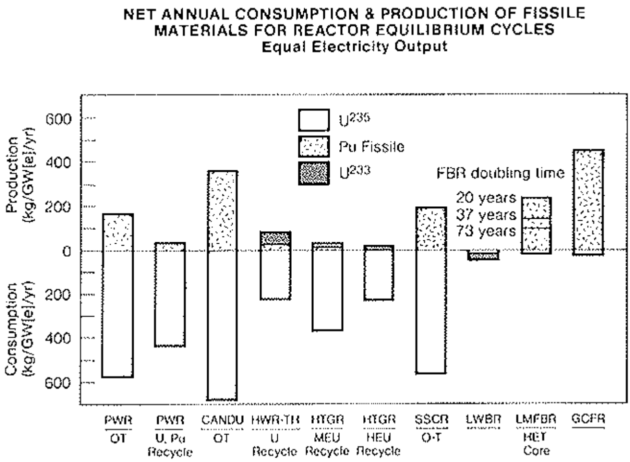


Fig. 6

20 years would produce smaller annual amounts of excess plutonium than a LWR.

Another fuel supply consideration which will affect national decisions on reactor construction strategies is the relation between the initial fissile investment in a new reactor vs. the annual fissile fuel makeup requirements, which were discussed before. If the initial fuel demand is large, it might be more difficult to start up a large number of reactors during periods of limited fissile fuel availability. The data in Figure 7 taken from [1], indicates that there exists an inverse trade-off between the annual requirements and the initial inventory which varies among the several reactor families discussed above. The once-through fuel cycles are the largest consumers of annual fuel make-up; however, the initial fissile requirements are moderate. The more advanced fuel cycles involving fuel recycle and thorium-based fuels save on annual fuel supply at the expense of larger initial fissile investment. This tradeoff is of importance to a growing power system and might affect nuclear growth strategies during the first half of the next century.

A summary of the progression of reactor characteristics from the current LWRs to the breeder reactors is shown in the table below and in Figure 8, based on data recently compiled by the United States Department of Energy [1]. As more efficient reactor systems having improved conversion ratios are installed, the plant capital costs are likely to increase; however, the fuel costs will decrease due to smaller depen-

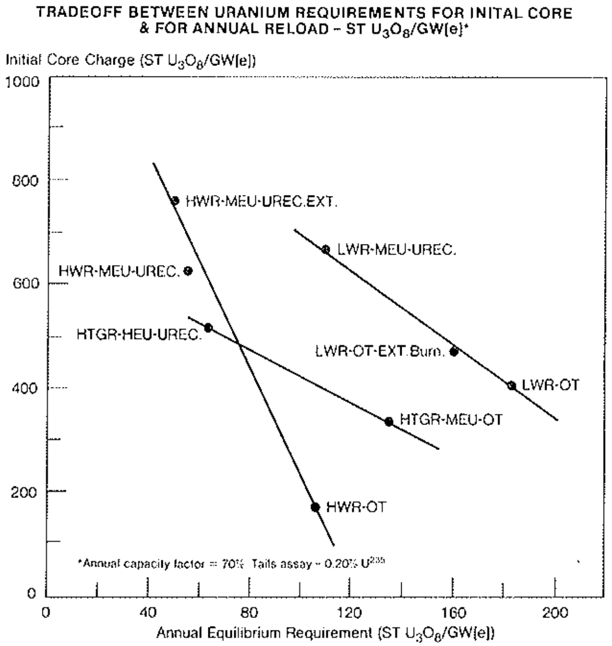

TRADEOFF BETWEEN URANIUM REQUIREMENTS FOR INITAL CORE
& FOR ANNUAL RELOAD – ST U_3O_8/GW(e)*
Initial Core Charge (ST U_3O_8/GW(e))
1000
800
600
400
200
0
HWR-MEU-UREC.EXT.
LWR-MEU-UREC.
HWR-MEU-UREC.
HTGR-HEU-UREC.
LWR-OT-EXT.Burn.
LWR-OT
HTGR-MEU-OT
HWR-OT
*Annual capacity factor = 70% Tails assay = 0.20% U^{235}
0
40
80
120
160
200
Annual Equilibrium Requirement (ST U_3O_8/GW(e))

FIG. 7

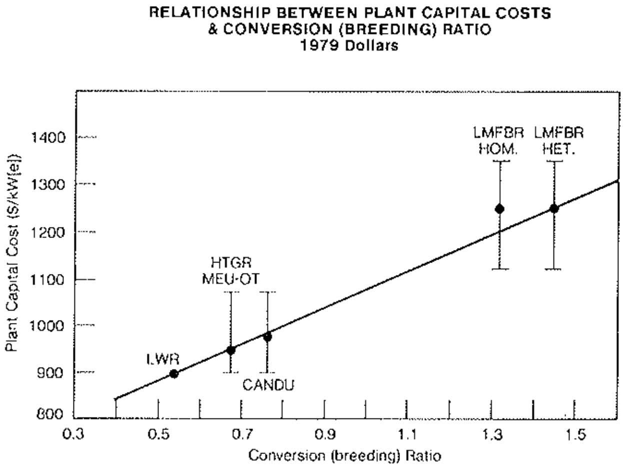

RELATIONSHIP BETWEEN PLANT CAPITAL COSTS
& CONVERSION (BREEDING) RATIO
1979 Dollars
Plant Capital Cost ($/kW(e))
1400
1300
1200
1100
1000
900
800
LMFBR HOM.
LMFBR HET.
HTGR MEU-OT
LWR
CANDU
0.3
0.5
0.7
0.9
1.1
1.3
1.5
Conversion (breeding) Ratio

FIG. 8

dency on external fuel supplies. With the rising costs of all energy fuels, including uranium, the more energy conserving systems will eventually become more economical, despite the large initial capital outlay. It is within this context that we foresee the role of the FBR.

Nuclear Reactor Characteristics

Reactor *	Relative Capital Costs	Relative Fuel Cycle Costs	Conversion Ratio	Uranium Utilization Percent of Uranium-235 Burned
LWR	1.00	1.0	0.55	0.5
CANDU-HTGR	1.25-1.50	0.8-0.6	0.65-0.75	0.9-1.3
ACR	1.10-1.75	0.9-0.6	0.75-0.95	1.3-5.0
FBR	1.25-1.75	0.7-0.5	1.15-1.35	50.0-60.0

* Meaning of reactor acronyms given in text.

4. The Role of the FBR

The fast breeder reactor represents the ultimate improvement in nuclear plant conversion ratio. The fact that a net positive breeding gain is achievable implies that the FBR could, once started, provide all its fuel requirements without recourse to an external source of fuel. Proper optimization of the reactor design would also ensure that a sufficient amount of excess fuel would annually be produced to start up another plant. It is this property of not only conserving its own fuel, but also providing for the eventual growth of additional generating capacity which sets the breeder aside from other essentially renewable power plant concepts. The basic fuel for the startup of an FBR is a sufficient stock of plutonium which has accumulated in fuel discharged from conventional light water reactors or from other operating breeders. A stock of natural or depleted uranium is also required as a blanket fuel material where ^{238}U atoms, mostly unutilized in the LWRs, can be converted to a useful supply of fresh plutonium. As the employed blanket material is the uranium "waste" from the LWR cycle, no fresh uranium supply is required, so long as the waste stream from the fuel enrichment plants can be utilized. The United States' fuel enrichment operations have accumulated over the last 35 years a stock of more than a quarter of a million tons of depleted uranium in which the average fissile U235 content has been reduced from 0.7% to 0.25%. It has been calculated that this depleted fuel source, if properly recycled in breeder reactors, could supply the U.S. total electricity requirements for several hundred years, after the year 2000, assuming sufficient FBR and capacity is installed [11]. This possibility of deriving a very large amount of electric power — an essentially renewable resource — from an unused fuel source is appealing from the resource conservation point of view.

A measure of the efficiency with which different reactors utilize the input uranium supply is the amount of kWh extracted per pound of uranium oxide consumed. This data is shown in Figure 9, computed from reference [1], for various reactors and fuel cycles. As seen in this figure (a logarithmic scale is employed), the fuel utilization efficiency of advanced reactors operated on advanced fuel cycles could, if commercialized, be about double that of the current light water reactor. The FBR and other breeder reactors could, however, provide 60 times as much energy as the LWR per unit of natural uranium consumed. Hence, the attractiveness of the breeder as an efficient uranium (and plutonium) burning technology.

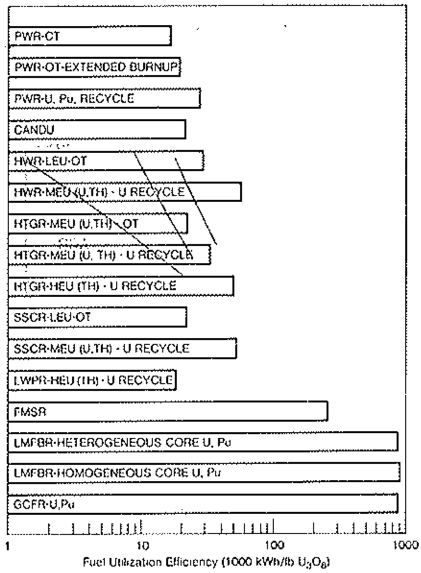


FIG. 9

This characteristic has two important implications related to total uranium supply and electricity generation costs.

The increasing demand for electricity in the next century will, to a large extent, have to be met by nuclear power plants. Dependence on the light water reactors only (operated on any of the fuel cycles discussed above) will eventually result in the consumption of all the currently known reserves and estimated additional uranium resources. Speculative estimates of additional large amounts of uranium resources have been made by many organizations; however, we must regard these estimates for what they really are, speculations and inferences, without direct evidence in the field. Even if a part of these speculative resources may eventually be converted into known reserves, this may be accomplished at prohibitively high cost and negative environmental impacts. Certainly from the point of prudent long-range planning, dependence on these resource estimates is dangerous. A discussion of this subject was recently provided [11].

The breeder reactor is the only nuclear technology which essentially decouples power generation from the limitations of uranium supply. This point is made in Figure 10, based on calculations [5]. Large-scale com-

WORLD CUMULATIVE URANIUM CONSUMPTION AS A FUNCTION OF TIME FOR VARIOUS DEPLOYMENT OPTIONS

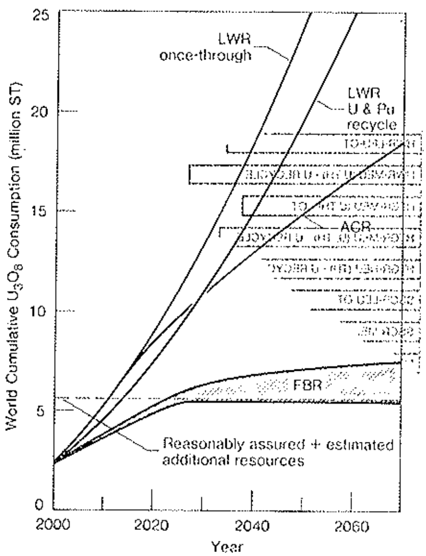


FIG. 10

mercialization of the FBR will allow long term growth of electric power capacity, as much as deemed socially desirable, unencumbered by the problems of resource availability and provision of enrichment services. Dependence on the FBR will require an internationally coordinated fuel cycle, capable of annually handling considerable quantities of fissile material. We should recall, however, that a 1000 MW (e) FBR requires 15 tons of plutonium-based fuel as an annual reload. A LWR will require 150 tons of uranium oxide per year and a coal-fired power plant will burn between 2 and 3 million tons of coal annually. Thus, the progression to a breeder reactor system dramatically reduces fuel transportation and handling requirements.

The FBR has an important role to play much before the last ton of uranium has been mined. By virtue of its independence of uranium supplies, the breeder will cap the price of economically recoverable nuclear fuel. A projection of electricity generation cost and the expected range of cost uncertainty for U.S. conditions is shown in Figure 11 based on [12].

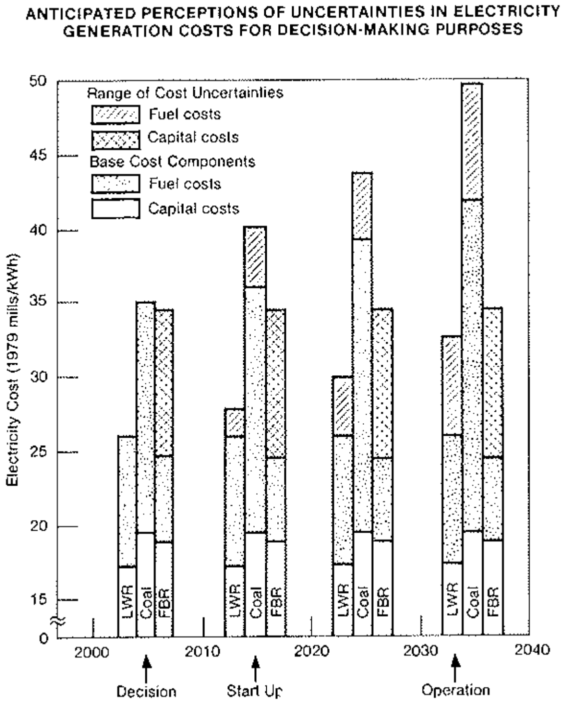


FIG. 11

A LWR and a coal-fired power plant face increasing fuel costs over the lifetime of the plant. Future uranium prices may remain unchanged in constant dollars, or following oil prices, uranium costs may double every 25 years. Coal prices are assumed to increase annually at a real rate of between 1.0% and 1.5%. The uncertainty in the evolution of fuel prices results in a large and continuously increasing spread of expected generation costs. The fast breeder reactor is mostly free of this kind of fuel cost increase. The uncertainty in FBR electricity costs has to do with the capital cost of the plant which is expected to be larger than the LWR or coal-fired plant initial capital investment. A capital cost increment range of 10% to 75% above the cost of an LWR is shown in Figure 11. Unlike the uncertainty associated with the LWR or the coal plant generation costs, the *range* of FBR electricity prices could potentially *decrease* in the future as standardized plant construction reaches a level of maturity. Capital cost uncertainty is technology controlled and more manageable and predictable than fuel supply and price estimation. The recent events in the Middle East really remind us of this basic observation. The possibility of long-range economic electric power supply is the motivation for the development of the FBR program, since the early days of its inception, more than 35 years ago.

5. Nuclear Waste Management Problems

The current controversy surrounding nuclear waste disposal is having a major impact over the fate of many nuclear reactor projects. Several European countries and states in the U.S. are attempting to link the future growth of nuclear power with the demonstration of safe radioactive waste disposal technology. The presumed unavailability of such methods is used as a weapon to stop nuclear electricity generation.

In this section, I'll discuss two issues: the hazards of nuclear fission wastes, put in perspective, and the available disposal technology.

In determining the public risk from nuclear wastes, we need to compare it to other and similar, naturally occurring or man-made risks, such as natural hackground radiation, and emissions from nuclear or from coal-fired power plants. A comparison of radiation hazards has been made in Sweden [13], where the ultimate dose to the Swedish population over a very long period, due to the existence of a high level nuclear waste repository, has been estimated. A comparative evaluation of the radiation risks is shown in Figure 12. As seen in this figure, the maximum dose

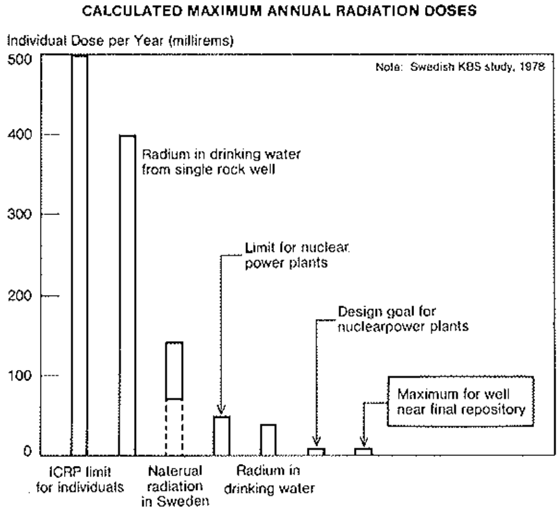


FIG. 12

to a nearby resident over a period of more than a million years is between one and two orders of magnitude lower than the natural background radiation. The expected exposure is a very small fraction of the radiation dose limit promulgated by the International Commission on Radiation Protection (ICRP).

The conclusion that a high level waste repository could be designed for safe operation with minimal likely exposure to the nearby population over very extended periods of time, measured on a geologic time scale, is not unique to the Swedish study. A summary of the results of seven different waste repository exposure studies is shown in Figure 13 based on data [14]. The best estimate of the likely population exposure from the waste disposal facility is 10,000 to 1,000,000 times lower than background radiation levels, as seen in this figure. The conservative or extreme radioactive exposure assumptions fall within the Swedish study results of 2-3 orders of magnitude below background radiation.

These estimates do not indicate the expected time evolution of the radioactive dose from the waste disposal site. The potential decomposition of the waste canister and the leakage rate of the high level waste within the biosphere are balanced by the radioactive decay of the fission products. A potential time path of radiation exposure was computed in the Swedish study referred to above and is shown in Figure 14 taken from [13]. The

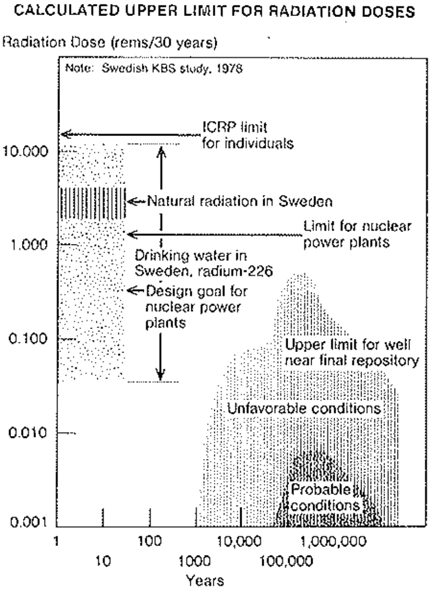


FIG. 13

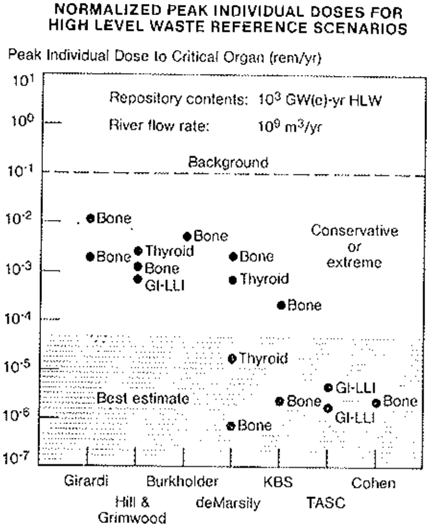


FIG. 14

dose rate from several natural radiation sources, and established limits are also shown. The results of this study indicate that under the probable conditions specified, the expected dose from the waste site is one order of magnitude lower than lowest exposure limits from nuclear power plants or from radioactivity in drinking water. Even under the worst conditions, the maximum exposure from the waste facility is below the design limit from nuclear plants and between one and two orders of magnitude below the ICRP limits.

The clear conclusion of the scientific and technical community, see for instance [15], is that it is possible to design a practical waste disposal system, which adequately protects public health and safety, using available technology. A number of barriers are available to provide the required isolation of the waste. These include the geologic medium in which the waste is emplaced, the solid waste form, i.e., the glass or ceramic matrix, the waste canister (or a set of canisters) and the overpack or buffer material between the canister and the geologic medium.

The French fuel cycle company COGEMA is now operating a plant at Marcoule which immobilizes high-level waste in a glass matrix. A similar, larger-sized plant will be constructed in the French fuel reprocessing center at Cape La Hague, west of Cherbourg. The pilot plant has operated routinely in a continuous mode, and the product solidified waste is now stored for further cooling before emplacement in a final repository. The glassy solidifying matrix used by the French is a borosilicate amorphous material with an extremely low leachability. This nonleachable characteristic adds another safety barrier. Many geologic strata would make acceptable repositories. The most commonly considered ones are in crystalline formations, such as granite or salt beds, although others may also be suitable. Each rock type has its advantages and disadvantages with respect to ultimate safety, but geographical location and political acceptability are perhaps as important in choosing a repository site. A summary on international waste management programs is given [16].

The ultimate guarantee of the safe disposal of nuclear wastes does not however rely on engineering. It is dependent on the basic physical and chemical laws of nature, in particular the natural sorbitive capability of the earth to immobilize toxic elements for long periods of time. The engineering solutions all aid nature by providing additional barriers to the migration of radionuclides; however, the basic reliance rests on nature itself. An example of the ability of the soil to absorb and immobilize nuclear fission wastes for hundreds of millions of years was discovered at the site of the natural reactor in OKLO, Gabon. The OKLO phenomenon was extensively reviewed [17-19]. The ore veins at the OKLO uranium mine are about 2 feet thick. Given the 3% concentration of U^{235} in uranium some 1700 million years ago and the availability of ground water in the open-pit mine, a naturally occurring and self-regulating nuclear chain reaction was maintained for hundreds of thousands of years until the fissile uranium concentration at the mine was depleted.

In all the millions of years since the natural reactors at OKLO burned out, none of the fission products generated or the plutonium produced have leaked away from the site of the chain reaction. Some of the fission products have migrated in the soil, but their migration distance is measured in feet and not in miles. All the important isotopes from the biological hazards point of view were immobilized. The plutonium isotopes which have since completely decayed have migrated only a short distance from the natural reactor, despite the continuous availability of ground water and rainfall.

The OKLO phenomenon is a demonstration of the earth's ability to immobilize and sequester radioactive wastes for geologic time periods. This is the ultimate protection from the hazards of nuclear waste products even after all the engineered barriers may have failed.

The technology to handle radioactive fission products exists today, as demonstrated in the French AVM process and other pilot plants around the world. Ongoing research activities may provide better encapsulation and disposal technology, and ultimately the risk to the public from fission wastes can be reduced to any arbitrarily small value desired. What is delaying demonstration of safe disposal techniques is the lack of consensus as to what risk is acceptable. This is essentially an institutional issue that requires resolution, not a technical one. If these political and institutional questions were resolved, a demonstration could proceed since the adequate technology exists.

6. Nuclear Proliferation Issues

A set of problems that is currently perceived as detrimental to the worldwide growth of nuclear power generation is the assumed linkage between civilian nuclear power, and nuclear weapons proliferation. Attention has recently focused on the chemical separation plant as the potential source of a clean stream of separated fissile material which could presumably be diverted for weapons production purposes. The perception of the weak link in the nuclear fuel cycle is, however, time and technology dependent.

6.1 *Time Dependent Proliferation Hazards*

The current hiatus in new reactor orders and the slow rate of commercialization of reprocessing and fuel recycling in the developed nuclear nations indicate that the supposedly imminent risk of the plutonium economy is not likely to materialize before the end of this century. This point was discussed in [3] Volume 5, and [20].

The substitution of the present once-through open-ended fuel cycle for the ultimate closed fuel recycle system, as currently advocated by the U.S., has resulted in the creation of two new weak links from the proliferation point of view. The most evident danger point is the spent fuel storage pools which will have to be installed in all nuclear power nations, not having access to reprocessing plants. It could be argued that spent fuel should be stored only in nuclear weapons states' pools; however, the record shows that the U.S., with the largest potential storage capacity, is not eager to accept foreign spent fuel for indefinite storage. Other nuclear power nations are even more lukewarm in accepting spent fuel for storage purposes only, and the opposition to Britain becoming "The Dustbin of Europe", as voiced several years ago during the THORP reprocessing plant hearing, is symptomatic of such attitudes. The only acceptable global open-fuel-cycle is the construction of a large number of storage pools in all nuclear power nations, and the establishment of IAEA safeguards over these pools. This solution, however, is likely, in time, to be as bad as the problem it was supposed to solve. With the decay of the short-lived fission products activity, as seen in Figure 15, the spent fuel elements may lose their self-protective radioactivity, especially when handled under water, and may become an easy target for fissile materials diversion. The spent-fuel storage pools may turn into a potential source of plutonium for the host nation or subnational groups, thus becoming, in effect, future "plutonium mines". This subject was discussed by W. Marshall [21].

Another major disadvantage of the spent-fuel storage concept is the temporary nature of the proposal. Ultimately the spent fuel will have to be disposed of, either by encapsulation and burial, or by reprocessing and recycling. Pool storage will just delay the development of the final disposal technology solution, and introduce another element of uncertainty into long-range national nuclear planning.

The other weak link in the once-through fuel cycle is technology driven: the evolution of relatively simple fuel enrichment processes, such as the gas centrifuge process. The high separation factor of each centrifuge machine, the low electric power requirements, and the availability of high quality centrifuges and components on the open markets, all enhance the potential for the misuse of this technology. Two potential fissile fuel production modes using centrifuges can be envisioned: one involved the construction of a clandestine dedicated military plant for the production of highly enriched uranium, as apparently is happening now in Pakistan. The other method involves clandestine recycling of slightly enriched uranium in an existing centrifuge plant, for further reenrichment, as seen in Figure 16, based on analysis [22]. The use of advanced thorium-based fuels in ACRs is also susceptible for misuse in clandestine centrifuge enrichment facilities. The denatured fuels can easily be reenriched to weapons quality uranium, using a small number of centrifuges, as seen in Figure 17, obtained from [22].

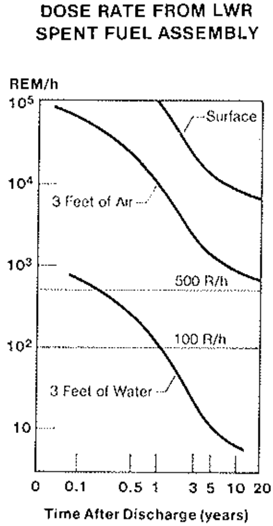


FIG. 15

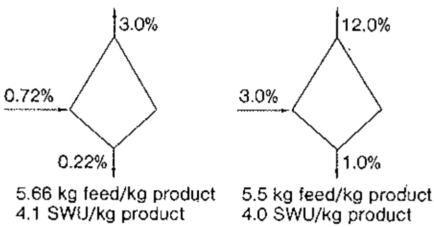
6.2 *Comparison of Open-Ended and Closed Fuel Cycles*

It thus seems that the throw away fuel cycle will in time create as many proliferation-related problems as it was supposed to solve. We have to reevaluate the weapons proliferation problems associated with fuel reprocessing, in order to compare them with the potential hazards of the

Most cascades capable of producing low enriched uranium are capable of producing higher enrichment by:

- Cascade modification
- Recycle

Exception: Processes with high uranium inventories



SWU: A measure of the amount of separation which is produced by a given separative element. Also, the number of separative elements to produce a given enrichment.

FIG. 16

FEED AND SEPARATIVE WORK REQUIREMENTS TO PRODUCE ONE NOMINAL CRITICAL MASS PER YEAR

20 kg U-235 @ 93% — 10 kg U-233 @ 93%

	Fissile Fraction		*Feed*		*Number of*
	Feed	*Waste*	*(kg U)*	*SWU*	*Centrifuges**
Natural Uranium	0.0072	0.0022	3720	4540	1135
LWR Fuel	0.03	0.01	920	1100	275
Denatured U-233 Fuel	0.085	0.03	160	200	18
Denatured U-233 Fuel	0.15	0.05	90	120	11
Denatured U-233 Fuel	0.20	0.07	70	90	8

* Centrifuge rated @ 4 SWU/yr for U-235/U-238
@ 11 SWU/yr for U-233/U-238
Centrifuge SWU output ~ $(\Delta M)^2$

FIG. 17

open fuel cycle discussed above. It is now recognized that all closed fuel cycles have equal proliferative characteristics. This is due to two factors: first, the total amounts of fissile fuel discharged per unit electricity generated are relatively similar, when both U^{233} and plutonium are considered. Second, the critical node is not so much the annual fissile discharge but the capacity of the associated reprocessing plant. From the point of view of diversion detection, the important factor is the size and the observable "signal" of the reprocessing plant. It is immaterial whether this plant is served by a LWR or by a CANDU reactor which produces almost twice the annual amount of plutonium. The critical flow is the amount of clean separated fissile output from the chemical separation plant.

One of the major conclusions of the recently concluded International Nuclear Fuel Cycle Evaluation (INFCE) study [3] is that the overall proliferation resistance of all fuel cycles, both open and closed, is relatively equal. The weak nodes are different as discussed above, and are likely to be accentuated at different time periods. The choice of an appropriate fuel cycle, as suggested in the INFCE study, should be based on other than nonproliferation grounds.

Many nations now have the technical knowledge to build and operate small facilities dedicated to producing weapons material. These are simpler, smaller, and much less expensive than commercial scale reprocessing plants. The threat of proliferation via this route should thus be regarded and addressed as a political and not a technological problem.

6.3 *The FBR/CIVEX Fuel Cycle*

The previous discussion on resource conservation and nuclear generation economics points toward the breeder as the most desirable reactor plant to commercialize. This requires recycling and chemical processing. Recent studies by EPRI scientists and their British collaborators [23], has identified an FBR fuel cycle which is highly diversion resistant, and should pose similar barriers to fissile fuel diversion as the current LWR once-through cycle. This FBR cycle has been named CIVEX, or Civilian Extraction to distinguish it from PUREX, the plutonium extraction process now employed mostly in the nuclear weapons programs.

The CIVEX fuel cycle is conceived so that at all points, the coextracted uranium-plutonium fuel mixture does not exceed the roughly 20% Pu necessary for fresh FBR fuel. The CIVEX fuel is only partially decontaminated from the radiation-emitting fission products and is therefore highly inaccessible. Such a separation plant is not only technically feasible, but can be designed to be economically acceptable. This means that the system should achieve the traditional technical targets set decades ago for economically optimal breeder cycles, namely, the ability to handle very high-power density, short-cooled discharged fuel, and to provide a rapid reprocessing into usable fuel elements, both criteria intended to reduce the external fuel inventory. If one combines this economic breeder objective with that of maintaining limited accessibility due to high radioactivity levels from the partially decontaminated fuel, this leads to coextraction and shielded fuel refabrication (rather than the use of hand-operated glove boxes) and probably coprecipitation of the fuel material. Neither step is now part of the Purex cycle system, which decontaminates both the uranium and the plutonium and provides pure streams of both. It is also planned that the CIVEX-type plant will meet other design conditions for safeguarding controls that would inherently increase its diversion resistance.

When all those features are incorporated into a working fuel cycle center we will have constructed a diversion resistant means of closing the fast reactor fuel cycle — with inherent hardening against the diversion of weapons materials, at least as good as that of the once-through LWR fuel program. Such technology could enhance the logical extension of the global nuclear power system into a LWR-FBR symbiotic operation mode, originally proposed more than 30 years ago.

6.4 *Internationally Closed Fuel Cycle Regime*

The CIVEX cycle for fast reactors, coupled with safeguards and political controls, would provide a highly diversion resistant worldwide nuclear power system. Such a scheme will be based on light water reactors producing the plutonium inventory to start the fast reactor systems, and will eventually result in the transition to principally a fast reactor system. The CIVEX plant would have as its input the stored spent fuel from light water reactors or the spent fuel from fast reactors, and its output would be radioactive refabricated fuel ready for insertion into fast reactors. International cooperation in managing and regulating fissile fuel flows will be based on a concept recently elaborated by our colleague Dr. Walter Marshall of Britain [24]. A schematic flow diagram of such arrangement is shown in Figure 18.

This concept is based on the premises that worldwide spread of spent fuel storage, as well as breeder reactors, is undesirable, and that the best way of destroying fissile plutonium is to burn it in a breeder reactor. The proposed international regime involves trading spent fuel from nonbreeder nations in exchange for fresch LWR, provided by FBR countries that can release their LWR stockpiles and produce the required electric power from

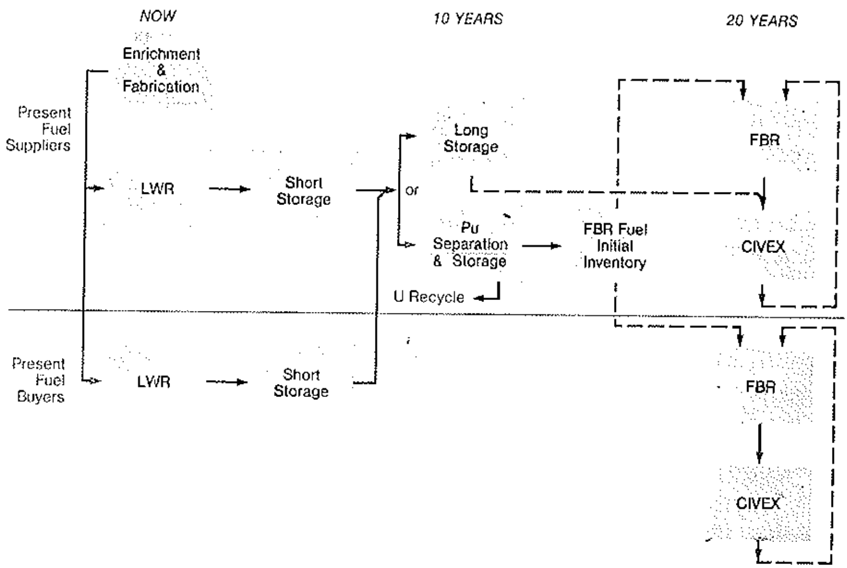


FIG. 18

FBR plants. An equitable trade of plutonium containing spent fuel for low-enriched fresh fuel may benefit both the breeder and the nonbreeder nations. The breeder nations which will reprocess the spent fuel will recover the plutonium required to start up their FBRs; the nonbreeder nations will get rid of their spent fuel, obtaining on a per-fissile unit an equal amount of fresh fuel. This concept may well represent a desirable situation during the early phases of the worldwide commercialization of the FBR. In time, with the international acceptance of the breeder technology, more countries may wish to obtain this reactor system and its associated fuel cycle, much as we see in the world today as regards the LWR. The long-term commercialization of the FBR and its fuel cycle on a worldwide basis may require a secure fuel cycle technology that can, in time, be transferred to developing nations with minimal proliferation hazards. Such technology is the CIVEX fuel cycle facility mentioned above.

The fissile fuel exchange arrangements proposed by Dr. Marshall, coupled with the FBR/CIVEX fuel cycle, will allow the gradual transition to FBR based electricity generation system. This system due to its efficient resource utilization could provide electric power supply essential indefinitely, in an environmentally and socially acceptable way.

7. *Summary*

In this paper we have described the current nuclear power technologies — the LWR and HWR, and discussed other reactor concepts proposed as more efficient or proliferation resistant follow-on to the current generation of converter reactors. The survey of reactor concepts and characteristics results in the evident conclusion that the preferable route to a renewable and economic nuclear electricity generation system is based on the transition from the LWR or the HWR to the FBR, made possible by the commercialization of an advanced FBR fuel cycle, such as the CIVEX concept. Implementation of the FBR/CIVEX scheme would allow the long term continuation of nuclear power generation.

Two publicly perceived problem areas may hinder the growth of nuclear power production — the issues of ultimate waste management and of nuclear weapons proliferation. We have tried to demonstrate that acceptable technologies for waste disposal now exist from the technical point of view. The demonstration of a waste disposal scheme is a matter of political will and not of technological capability. The tenuous link between civilian nuclear power production and weapons proliferation can be decoupled using advanced fuel cycle technology as proposed above together with appropriate political arrangements for safeguarding the civilian fuel cycle against misuse by insecure national regimes or subnational groups.

Eventually, a choice must be made between providing adequate power supply for the current and future generations, and living with the residual risk of nuclear weapons proliferation, which is essentially independent of the existence of nuclear power. Our society and civilization are based on the existence of an industrial base which provides for our economic well-being. Giving up a major energy option for the provision of an economic and renewable base load electricity supply, will erode the economic base of our society and may result in worldwide upheavals. To those of us with a lifetime professional background in opening the atomic age, its risks and uncertainties appear very manageable and to be a very small price to pay for its benefits.

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NUCLEAR ENERGY: RESOURCES AND OUTLOOK

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Introduction

There is no energy shortage today, nor will there be one in the future. In and of itself, solar radiation, both direct and indirect, provides this planet with over 10,000 times more energy than mankind currently consumes. Unfortunately, this gigantic, inexhaustible source is highly diffuse and difficult to recover. It is better suited to individual needs than to the requirements of industry which, on the contrary, demands heavy concentrations of energy. Until the time of the industrial revolution, man primarily exploited this energy source through photosynthesis which provided him with wood from the forests. Since then, however, he has turned to fuel extracted from the ground, including coal, oil and, most recently, uranium. These are the only forms now capable of providing the huge, concentrated amounts of power our industrial societies require.

The scale of energy needs has led to heavy use of these resources lying in the ground. In the next few decades access to these reserves and the means needed to extract sufficient quantities of them will pose crucial problems. There will be no physical shortage in either the near or medium term. However, the combination of anticipatory buying caused by a growing awareness of the limited nature of oil reserves which can be recovered at low cost and the political problems created by the concentration of these reserves in a small area of the world has sent prices skyrocketing and reduced output. This cutback is difficult to offset by a corresponding increase in output from other sources given the slow reaction time of the cumbersome energy industries.

A glimpse at the very long term is equally useful. Energy sources extracted from the ground are consumed with virtually no renewal during our time frame. We can legitimately ask ourselves whether or not several generations of mankind have the right to exhaust limited reserves and deprive future generations of these resources. On the other hand, conserving existing reserves for future generations without establishing some sort of timetable would mean not using them at all while keeping present generations from benefiting from these reserves. Hence, it is our duty to set out a rough time frame of conservation within which to work. A 50-year horizon is unquestionably a minimum. This is the time required by major industrial developments if not more. Consequently, extending our frame to 100 years can put things in even better perspective. Beyond the century mark, however, I feel the future is too heavily determined by the unpredictable discoveries and innovations which will take place during the next 50 years for us to perceive it with any degree of certainty. Rather, we must stand aside and, in the normal course of events, have faith in the abilities of our grandchildren to solve the problems of their grandchildren. These are problems of a choice between various types of energy and not a matter of total availability, since we know mankind will never be lacking in energy.

Seen from this point of view, in the decisions we are called on to make or simply the policy orientations we must adopt I feel we can assume that energy reserves which are assured for more than one century are virtually inexhaustible. Those which are assured for a shorter length of time require steps aimed at conserving them and the development of techniques drawing on other energy sources. Today, the typical example is oil. However, the question may arise concerning uranium depending on the way it is used.

I. Uranium resources

Nuclear energy is obtained through the conversion of less stable atomic nuclei into more stable nuclei. It is a universally known fact that changing any system from a less stable to a more stable state releases energy. The more stable nuclei are those of intermediate mass such as iron, copper and zinc, to mention but a few. There are two main sources of nuclear energy. The first is the splitting or fission of heavy nuclei into two lighter nuclei whose atomic weight is closer to the average; hence, they are more stable than the nucleus which has been split. The second is the uniting or fusion of light nuclei to form a heavier nucleus, whose mass is also closer to the average; hence, it is more stable than the initial nuclei as in the case of fission.

Whereas in theory there is a certain similarity between these two sources of nuclear energy, in practice fission has reached the stage of full industrial development, although controlled fusion is but a hope whose feasibility remains to be proven.

As a result, I will primarily devote my attention to fission and simply try to put the outlook for fusion in perspective.

The primary source of energy obtained by fission is uranium. On the average the earth's crust contains four parts per million of the element. In the first kilometer of the earth's surface this represents roughly 1 trillion tons of uranium. It is only economically practicable to exploit deposits with heavier concentrations, however, exceeding one part per thousand to use a round figure. This greatly reduces the tonnage accessible.

Figure 1 shows the predictions appearing in the OECD/IAEA report for December 1979 for countries with a free-market economy. As we can see, reasonably assured reserves total 2.6 million tons and estimated additional resources 2.4 million tons. We can in fact count on 5 million

WORLD URANIUM RESOURCES
(FREE MARKET COUNTRIES ONLY)

- Thousands of tonnes -

Cost	Reasonably Assured Resources	Estimated Additional Resources
< 80 $/kg U	1850	1480
80-130$/kg U	740	970
Total <130 $/kg U	2590	2450

TOTAL KNOWN RESOURCES : 5040

Speculative resources : 6600 to 14800

Energy equivalence of 1 tonne of uranium :

10 000 TOE current reactors
1 000 000 TOE fast breeders.

FIG. 1

tons with a reasonable degree of confidence. Speculative reserves, whose existence is yet to be proven, could total 6 to 15 million tons; we will use a figure of 10 million tons to simplify things.

These numbers are minute in terms of the total quantity of uranium contained in the earth; unfortunately, it is too widely scattered to be usable.

In terms of actual energy requirements, these resources are either rather small, if their yield is based on use in the reactors most commonly found today, or rather sizeable, if used in breeder reactors. In the former, 1 ton of uranium is equal to approximately 10,000 TOE (tons of oil equivalent); this figure varies with the type of reactor. Reasonably assured reserves thus represent some 26 billion tons of oil and will be able to supply the world's foreseeable nuclear power until the beginning of the next century. Estimated additional resources of 24 billion TOE are not quite as certain but very probable; with increasing consumption, they can be expected to add another 10 years. However, even assuming the speculative reserves mentioned earlier were drawn on (some 100 billion TOE), supplies of uranium would run out in 50 years' time, and the first signs of a shortage would probably be seen at the start of the 21st century.

When comparing these figures with those for oil, it must be remembered that proven reserves of oil are on the order of 100 billion tons — some four times more than the reasonably assured reserves of uranium — and that a similar ratio applies for the estimates of different types of less-assured resources for both uranium and oil. Of course, uranium consumption is lower today than oil consumption. However, if, in the decades to come, nuclear power is to satisfy an important share of world needs, given the reactors currently in existence we can expect to see a series of events similar to those accompanying today's growing awareness of the limitations of petroleum resources. On the other hand, breeder reactors use uranium some 100 times more efficiently than present-day reactors. When used to fuel a breeder reactor, 1 ton of uranium represents the equivalent of approximately 1 million TOE and no longer 10,000 TOE, and breeders can utilize the depleted uranium not consumed by our current reactors. Consequently, the reasonably assured reserves of uranium alone attain the equivalent of 2.6 trillion TOE, thus erasing any concern of a shortage within the reasonably foreseeable future.

It is perhaps worth examining the reason for the difference in performance between current reactors and breeder reactors in terms of uranium use. Figure 2 indicates the composition and properties of natural uranium. It contains less than 1 percent fissionable uranium-235 and can directly

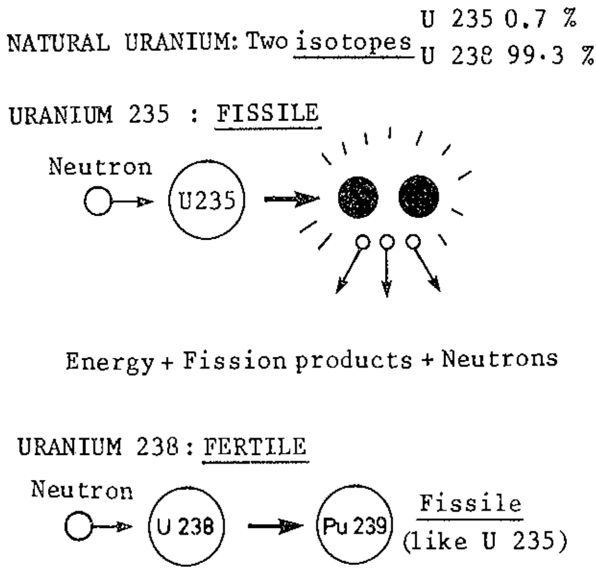


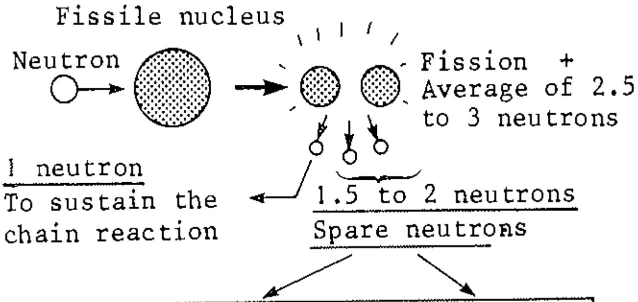
FIG. 2

sustain a chain reaction. Figure 3 illustrates the breeding process which gradually converts nonfissionable uranium-238, which makes up virtually all natural uranium, into fissionable plutonium-239, similar to uranium-235. The intermediate step of creating plutonium-239 makes it possible to consume all the uranium-238 and consequently multiply the energy potential of natural uranium by a factor of roughly 100 compared to its yield when used in current reactors.

Today, world nuclear power programs primarily employ light-water reactors using slightly enriched uranium. The heavy-water reactors employing natural uranium, mentioned by Prof. Chauncey Starr, use uranium some two times more efficiently than the former. Other types of reactors could perform even better; however, there is some doubt they will be brought on stream in sufficient numbers in the world's programs to modify the preceding projections substantially. Of these types, only heavy water reactors have been built in any quantity, primarily in Canada. However, they account for but a very small share of world programs now in progress or being planned.

With the exception of possible, but probably limited, modifications to the above predictions by the development of this reactor type, we can

BREEDING PRINCIPLE



	Wasted neutrons	Neutrons converting U 238 to plutonium
Current reactors	Appreciable →	Less than one : more fissile material consumed than produced
Breeder reactors	Limited →	More than one : more fissile material produced than consumed = breeding

Fig. 3

expect the future of fission-based nuclear energy extending beyond a few decades to turn on the use of breeder reactors. In any event, during their lifetime, estimated at roughly 30 years, the reactors now in service, under construction or on the drawing boards will consume roughly half the world's reasonably assured reserves of uranium. Breeder reactors are in an advanced state of development and have now entered the pilot phase. However, they can only be introduced gradually, and their advent will raise problems I will discuss later.

Earlier, I spoke of the utilization of uranium. A few words are now in order about thorium. This element is unlike natural uranium but similar to uranium-238. Like the latter, it is not fissionable but can be used in breeder reactors with a similar energy yield. Hence, thorium can be viewed as a supplement to the uranium reserves we assume will be used in breeder reactors, and it is available in equivalent quantities. However, uranium reserves are already considerable in terms of use in breeder reactors. Consequently, there is little impetus to exploit thorium. However, thorium can also be used in certain reactor types mentioned earlier. Nonetheless, no plans have been made for power programs based on thorium, and there is little reason to believe its use can substantially modify projections founded on available uranium supplies.

Figures 4 and 5 illustrate two scenarios for rapid and slow growth in nuclear power programs and the effect on uranium consumption in free-market countries to 2025. The influence of the possible use of breeder reactors is also shown in these charts.

To return to near- and medium-term considerations, world programs are primarily organized around light-water reactors using slightly enriched uranium. It is these reactors which will draw on world uranium reserves with the help of enrichment plants.

The map in Figure 6 illustrates current distribution of these reserves. The main reserves are located in the United States, Canada, Australia, South Africa, Niger and Namibia. However, generally speaking they are less unevenly distributed than oil reserves. In Europe, France and Sweden they are in a favorable position. Paradoxically, if we look ahead to the shortage expected to develop in this market at the start of the next century, today's uranium market can be viewed as soft. This can be attributed to the current stagnation in the world's nuclear programs.

It should be pointed out that, at the present time, the cost of natural uranium only accounts for 10 percent of the cost of nuclear-generated electricity, whereas the respective figures are 65 and 80 percent for coal and oil in France. Consequently, the cost of nuclear-generated electricity is relatively unaffected by the price of uranium. In France, the cost of 1 kWh obtained from nuclear energy, coal and oil is respectively 13, 24 and 36 centimes. (See Fig. 7).

II. The fuel cycle

The fuel cycle is the series of steps which goes from extraction of the uranium ore to storage of the nuclear waste. It is illustrated in Figure 8 for both light-water reactors and breeder reactors.

The most important steps in the cycle from a cost and policy point of view are enrichment of the uranium, reprocessing of the spent fuel and nuclear waste management.

These are the operations on which I will focus. First, however, I would like to emphasize one important aspect of uranium extraction. Despite the low concentration of the ore, its energy content is such that, for a given energy potential extracted, the total quantity of rock actually

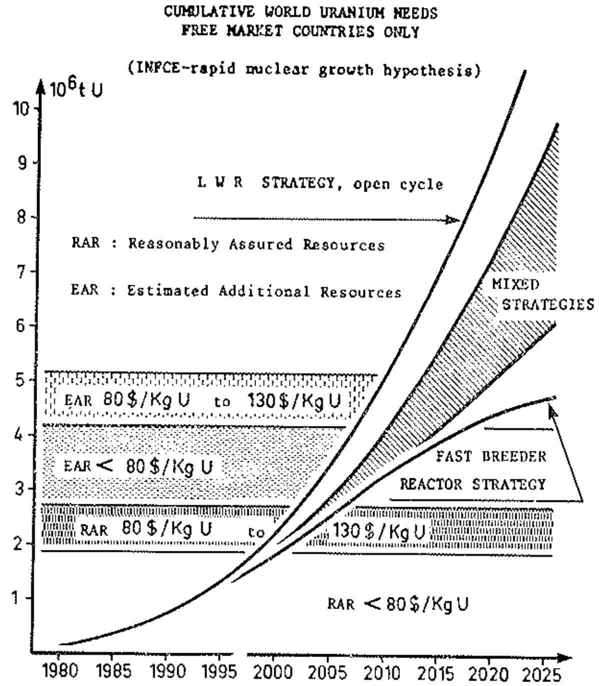

CUMULATIVE WORLD URANIUM NEEDS
FREE MARKET COUNTRIES ONLY
(INFCE-rapid nuclear growth hypothesis)
10^6 t U
L W R STRATEGY, open cycle
RAR : Reasonably Assured Resources
EAR : Estimated Additional Resources
MIXED STRATEGIES
EAR 80 $/Kg U to 130 $/Kg U
EAR < 80 $/Kg U
FAST BREEDER REACTOR STRATEGY
RAR 80 $/Kg U to 130 $/Kg U
RAR < 80 $/Kg U
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025

Fig. 4

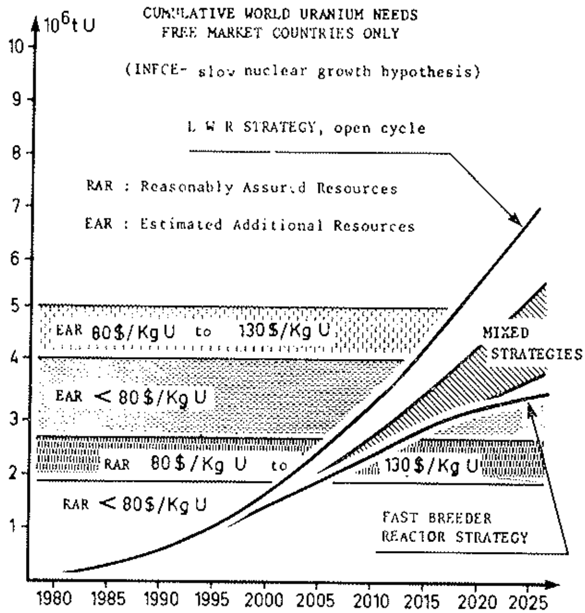

CUMULATIVE WORLD URANIUM NEEDS
FREE MARKET COUNTRIES ONLY
(INFCE- slow nuclear growth hypothesis)
10^6 t U
L W R STRATEGY, open cycle
RAR : Reasonably Assured Resources
EAR : Estimated Additional Resources
EAR 80 $/Kg U to 130 $/Kg U
MIXED STRATEGIES
EAR < 80 $/Kg U
RAR 80 $/Kg U to 130 $/Kg U
RAR < 80 $/Kg U
FAST BREEDER REACTOR STRATEGY
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025

Fig. 5

KNOWN WORLD URANIUM RESOURCES

(Free market countries only)

(Thousands of tonnes)

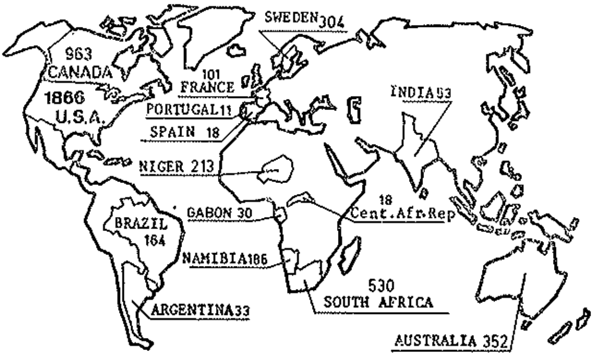


FIG. 6

Per-kWh COST OF ELECTRICITY
IN FRENCH CENTIMES

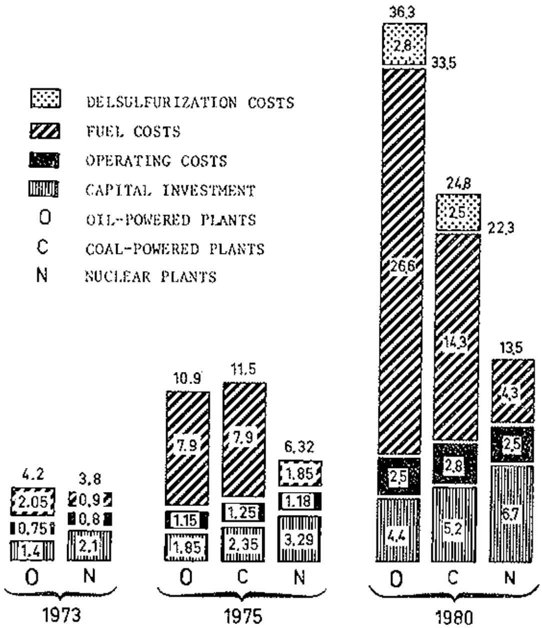


FIG. 7

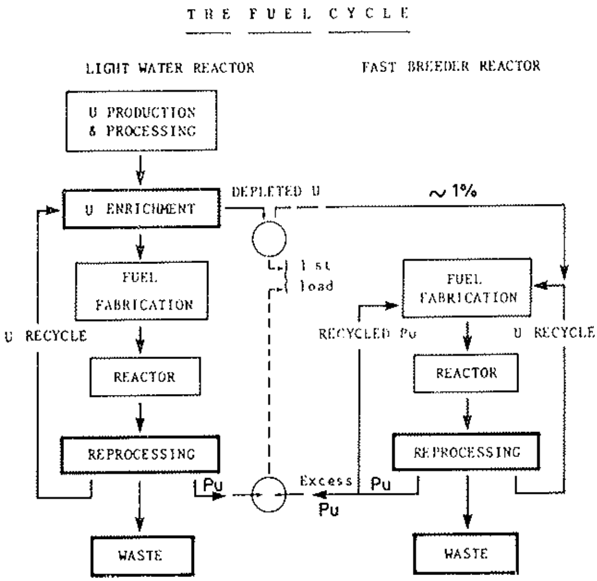


FIG. 8

removed by mining is several times smaller than for coal. This reduction naturally means fewer mining accidents and less impact on the environment. This point can not be emphasized too strongly.

Enrichment

This operation consists of increasing the proportion of fissionable uranium-235 in the uranium used. It is necessary for light-water reactors which constitute over 80 percent of today's programs. This step is not required, however, for units using natural uranium such as heavy-water reactors and the graphite-moderated, gas-cooled units originally developed in France and England.

To circumvent dependence on enrichment, many developing countries have become interested in natural-uranium reactors. However, such units can produce military-grade plutonium more easily than reactors using enriched uranium, thus raising the problem of the proliferation of nuclear weapons.

Enrichment is a very expensive procedure requiring complex installations. Today, to be cost-effective the capacity of an enrichment plant must be greater than the needs of a typical European country. Two thirds of the enrichment capacity now on stream or soon to enter service in the Western world is to be found in the United States and one third in Europe. (See Fig. 9).

Enrichment services in the USSR add 8 percent to the total; however, the country's global capacity is unknown. The slowdown in world nuclear programs has made total world capacity adequate and even excessive at the present time. However, it must be expanded with the upturn in program activity, probably toward the end of the decade.

The low enrichment needed by nuclear power programs entails no risk of proliferation. This is because the uranium they require, only enriched several percent, is unsuited for military applications. Instead, it is the enrichment techniques themselves which are a threat to proliferation. Depending on the case, it is relatively easy to divert this technology to the production of highly enriched uranium for use in nuclear weapons, hence the term "sensitive technology". The guidelines of the London Club, whose members include all leading countries possessing nuclear know-how, oppose transfer of such technology by these countries. Other countries, however, tend to view these restrictions as the institutionalization of a monopoly held by the former which threatens their source of supply, even for civilian needs. This explains their interest in

WORLD URANIUM ENRICHMENT CAPACITY

AND FORESEEABLE NEEDS FOR 1985

(millions of SWUs)

	Capacity	Needs
UNITED STATES	27,3	12,9
EUROPE	12	13,8
WORLD EXCLUDING USSR CHINA & EASTERN BLOCK COUNTRIES	39,4	30,8

1 million SWUs per annum

supports nine 1000 MWe light

water reactor plants

FIG. 9

natural-uranium reactors which are more dangerous in terms of proliferation from the point of view of plutonium production. An enrichment process using chemical methods is now being developed. It is unsuitable for the high enrichment required for nuclear weapons and could provide a solution to this problem.

Reprocessing

Reprocessing of fuel after its stay in the reactor is also a very costly operation, one requiring high technology and considered "sensitive" in terms of the London Club's guidelines. It is a chemical procedure, in theory rather simple, but disturbed by the action of radiation on the reagents. Above all, however, the high levels of radioactivity present require sophisticated, ultrareliable automation of the reprocessing plant. Hence, successful use of this process depends on engineering skill.

Reprocessing isolates three main components. (See Fig. 10). These are the uranium not burned up, the plutonium formed during its stay in

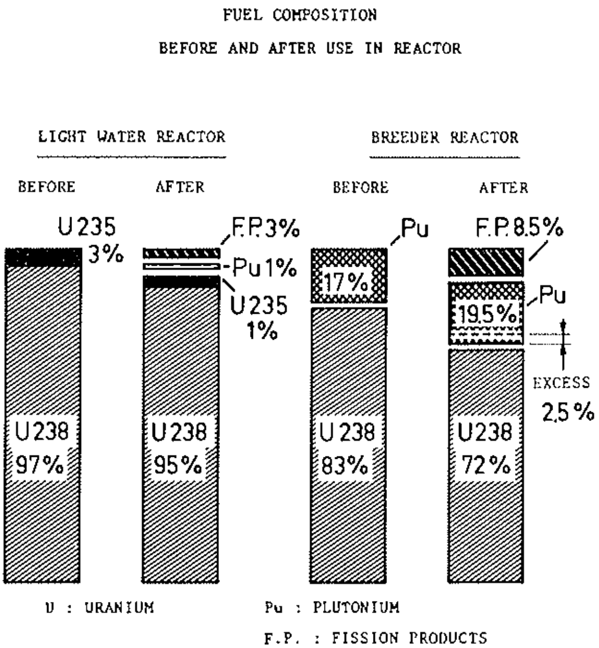


FIG. 10

the reactor and the fission products also formed during this time; the latter constitute highly radioactive waste.

These highly radioactive fission products are only present in small quantities equal to 1 ton per year for a 1,000-MWe reactor. They are contained in certain inactive products which increase the tonnage tenfold. After the fission products are removed, uranium and plutonium can be used with no further precautions than those normally required.

Special attention should be given to two aspects of reprocessing. First, most experts feel reprocessing is necessary for good waste management. When isolated, concentrated and suitably packaged, it is obviously easier to manage the waste in an organized fashion and ensure its long-term innocuousness than if it remains in unprocessed fuel. Here, the volume is far greater and the structure complex, making it unsuited for waste management.

Second, reprocessing permits the recovery of plutonium. Taken together, plutonium recovery and reprocessing, by implication, are crucial to the existence of breeder reactors which require plutonium for their operation. Recovery of this metal, however, obviously permits the manufacture of plutonium-based weapons.

Reprocessing, on the other hand, is not a necessary condition for the operation of existing reactors. Since this step comes later in the chain, it can be postponed to varying degrees. In terms of these reactors, the purpose of reprocessing is primarily one of good waste management.

The recent American policy on nonproliferation is aimed at prohibiting plutonium. It bas led the country to propose the indefinite suspension of reprocessing, even if this means similarly postponing the processing of radioactive waste and the advent of breeder reactors.

The United States, however, has uranium reserves which allow it to operate its present reactors longer than other countries. It should be observed that a prohibition on plutonium is not a foolproof means of preventing the manufacture of nuclear weapons. The production of highly enriched uranium, for example, is probably a far easier means of gaining access to these weapons. Consequently, the question now focuses on the enrichment techniques themselves and the ability to divert them to military applications.

The plutonium produced in the light-water reactors used in today's major power programs is of very poor military quality. In addition, nonreprocessing of the fuel does not present a permanent obstacle to access to plutonium. This is because the radioactivity of the fuel, wbich "protects" the plutonium it contains by preventing access to it, decays over time. After a few dozen years, extraction of the plutonium from this fuel becomes easier than during the first years following its removal from the reactor. Consequently, the storage of unreprocessed fuel would create plutonium "mines" which will become more and more accessible over time.

In the final analysis, reprocessing is a determining factor in the breeder cycle and, hence, in the development of this type of reactor. The reprocessing of breeder fuel is more difficult than for current fuel, since the former is more heavily irradiated. However, reprocessing can now be considered to be reasonably perfected in technical terms and capable of implementation on an industrial scale.

Reprocessing of fuel from existing reactors, however, is equally necessary to bring the first breeder reactors on stream. Twenty to 25 of today's reactors are required for 1 year to produce the plutonium needed by the core of a breeder reactor having the same output as but one of the current type. Hence, the replacement of current reactors by breeders will take dozens of years. Figures 4 and 5 speak for themselves in this respect. Given the maximum limitation of some 50 years on the world's uranium reserves used in reactors of the present type, we can see there is little leeway for the introduction of breeder reactors.

Like enrichment, reprocessing is a sensitive technology whose transfer is not authorized by the London Club's guidelines. I will return to this point later.

Nuclear waste management

The ultimate fate of nuclear waste is the subject of great controversy. However, its importance has been blown out of all proportion, since we now possess all the necessary technology to handle this problem.

We must not forget that we live in an environment characterized by natural radioactivity, whose level varies widely with the location, altitude and nature of the materials surrounding us, among other factors. Despite this fact, we have never been able to prove even the relative effect on health of these different types of exposure to natural radiation.

The various categories of waste are always treated in such a way that their environmental impact is very small not only with respect to natural radioactivity but also relative to variations in this radioactivity.

It is necessary to distinguish between very high-level waste from the reactor core, which is isolated by reprocessing, low- and intermediate-level waste generated by day-to-day operation of power plants or other facilities using radioactive products and very low-level liquid and gaseous effluents. After processing, the effluents are released into the environment in accordance with very strict standards.

Low- and intermediate-level waste is packaged in suitable containers stored in repositories located aboveground or just below the surface. The waste is generally mixed with large quantities of inert matter. This makes it bulkier than very high-level waste which is concentrated into the smallest possible volume. The waste loses its activity over 100 years, leaving but a few specific problems. Only a small amount of area is required for waste storage. In France, the storage center in La Hague, designed to store the waste generated by 20 years of operation of the nation's various nuclear facilities, covers 12 hectares of land.

It is very high-level waste which by far contains the largest share of radioactivity resulting from the use of nuclear energy. It contains the fission products in concentrated form and a small proportion of transuranic elements formed during reactor operation from uranium. Some of these remain radioactive for long periods of time.

The overall radioactivity of this waste decays very rapidly at the beginning, requiring various phases for its management. The following are currently used in France:

— storage in liquid form for several years after reprocessing of some 15 m^3 of solution per year of operation of a 1,000-MWe reactor

— vitrification, by evaporation of the solution and incorporation of the waste in glass, producing approximately 3 m^3 of glass under the same conditions

— interim storage for several years with ventilation to remove the large amounts of heat produced by the radioactivity

— interim storage without ventilation and

— ultimate storage.

With the exception of the last stage, all these phases have been fully developed and are operational. The interim repository in Marcoule covers an area 15 by 15 m in size. It can store the glass from 100 reactor-years of operation. Clearly, the area involved is minute.

No decision concerning the phase of ultimate storage has yet been made by any nation. Perfectly suitable solutions have been developed, including storage in deep salt mines, granite and other formations. However, the decision is not pressing, and policy in this area is to wait and see which methods prove to be the best.

It is this phase, however, which has aroused the greatest public concern, and I would like to review it in greater detail. The radioactivity of the products decays very quickly for the first few hundred years and more slowly thereafter reaching a far lower level roughly comparable to the activity of the uranium ore from which the waste is descended. In actual fact, after a few hundred years the nature of the problem of waste management changes. Before this time, the radioactivity level is substantial, and it must be confined. We know how to build facilities whose integrity we can assure for this length of time. Beyond this horizon and for periods for which we are unable to guarantee this integrity, we must be sure that leakage from the repositories will keep the dispersal of products into the biosphere below the levels set to ensure their innocuousness. Such low-leakage conditions are generally found in nature for deposits of uranium ore.

Figure 11 illustrates the relative hazards over time of waste from nuclear power plants and of the uranium ore from which it is derived.

It should be remembered that waste management is an important problem in the use of nuclear energy, and it has led to detailed research and the development of new technology. Further studies are required,

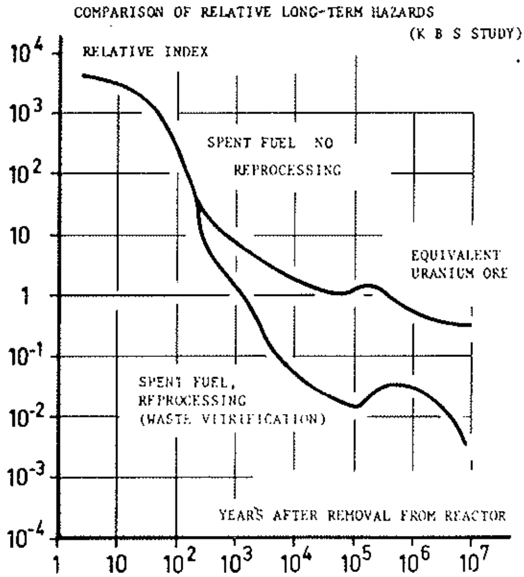


FIG. 11

in particular to determine the best methods of ultimate storage. However, the nature of the problem of waste management does not call into question the development of nuclear energy.

III. Controlled fusion

The industrial use of fission energy is based on the chain reaction caused by the neutrons. In the final analysis, this is a relatively flexible phenomenon which is easy to control.

By comparison, for controlled fusion to take place the temperature of the medium in which the reaction occurs must be raised to 100 million degrees Celsius. The difficulty of controlling the fusion phenomenon is obvious, and this explains the lag in developing this technique relative to fission power.

Fusion power has not truly advanced beyond the stage of basic research. A major step remains ahead, that of reaching the break-even point at which the plasma, where the reaction takes place, will yield more nuclear energy than is absorbed in heating it.

Figure 12 shows past and future progress in the characteristic parameters of the plasma toward the values required for industrial use.

A possible timetable for the development of fusion power appears in Figure 13. Here, it can be seen that, while controlled fusion power is a hope in the long term for mankind, no projections for the near or medium term can be made concerning its contribution to energy needs.

I will not go into detail about the various fusion techniques now under study but will rather focus on sources of fusion power.

The reaction which is easiest to obtain and which yields the largest amount of energy is the deuterium-tritium reaction. This can be envisaged, but a temperature of 1 billion degrees Celsius is needed instead of just 100 million degrees.

Deuterium is present in virtually unlimited quantities on earth; it exists as one part in 6,000 in the hydrogen in water. Tritium, on the other hand, does not occur in nature and must be made from lithium by neutron irradiation. Lithium reserves are far smaller than deuterium reserves. However, all things considered, in terms of energy they are at least equivalent to the reserves of uranium when used in breeder reactors. Hence, like uranium reserves tritium reserves are virtually inexhaustible to any humanly reasonable horizon.

FUSION REACTOR DEVELOPMENT

PLASMA PARAMETERS

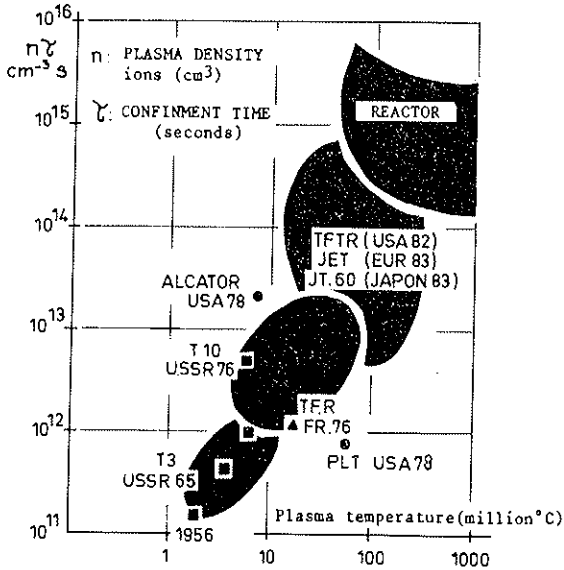


FIG. 12

CONTROLLED NUCLEAR FUSION: A TENTATIVE TIMETABLE

1985 — DEMONSTRATION OF SCIENTIFIC FEASIBILITY (JET, TFTR)

1990 - 2000 — DEMONSTRATION OF ENGINEERING FEASIBILITY (NET, INTOR) without power generation

2000 - 2010 — DEMONSTRATION POWER PLANT

2020 ? — FIRST COMMERCIAL POWER PLANTS

FIG. 13

Consequently, should controlled fusion power become an industrial reality, fusion reactors can be expected to compete with or complement breeder reactors directly, since they offer the user the same overall characteristics. These are:

— resources assured for a long period of time

— large stationary installations requiring the distribution of power from generation plants and

— negligible cost of the raw materials serving as the energy source.

Combined fusion-fission systems are, moreover, a possibility and could be of interest.

Controlled fusion power is often considered to be clean, in other words it does not produce radioactive waste; however, this view must be qualified. Fusion will not produce waste such as the fission products over whose characteristics we have no control. However, it will be a source of very large quantities of various radioactive products with shorter half-lives. It will also require the handling of large quantities of radioactive tritium. The overall balance sheet would appear to be in its favor over fission, but it must not be considered to be devoid of radioactivity problems.

Fusion research has led to close collaboration between industrialized nations. The participation of other nations, however, is very limited and virtually nonexistent.

IV. Conclusions

I have attempted to present an overview of sources of nuclear energy and of the implications of their use. For the purposes of this conference, however, we should ask who will use these sources and where they will be used.

The question of technology transfer between developed and developing nations is one of the major problems of our time. It is particularly touchy in the nuclear field, since this very high-technology industry raises the problem of the proliferation of nuclear weapons.

It must be recognized that, once a certain level of knowledge and technical expertise has been acquired, a country's development of nuclear weapons is primarily determined by political considerations. We must not avoid taking steps to prevent access to these arms. At the same time, however, we must not bar the way to the development of nuclear energy out of fear of the proliferation of nuclear weapons. Quite the contrary, the tensions caused by a major energy crisis would most likely give governments added reason to turn to them.

The development of nuclear energy, however, is keyed to the acquisition of a high level of scientific and technical know-how and the existence of diversified, high-level industry.

The transfer of know-how alone is insufficient to put nuclear energy to work in quantitative terms. A high-level technical and industrial infrastructure is also needed but takes far longer to acquire than the technical knowledge. Failing this, the construction of power plants in developing countries and the transfer of nuclear technology will remain heavily dependent on foreign countries for many years and will probably be accompanied by a smaller local contribution than in other energy fields. Hence, it is likely that nuclear energy will only enter the Third World very gradually. In these countries, moreover, the relatively high output of nuclear power plants will be difficult to couple to poorly adapted energy grids. On the other hand, the use of nuclear energy by industrial nations which have the necessary experience produces savings of oil better suited to the needs of other nations.

* * *

Provided the appropriate techniques are used, sources of nuclear energy are largely assured beyond any humanly reasonable time horizon.

However, the very use of this energy has led to anxiety and debate throughout the world which have seriously impeded its development. As we know, in the near and medium term the substitutes for oil are primarily coal and uranium.

A strong movement back to coal is taking shape, but is it wise to rely on coal alone? A major effort is also under way throughout the world to develop new energy sources. Given this context, it would be unreasonable to reject the very source which has reached the highest level of development and is now capable of providing an industrial answer to the need for diversification.

At the same time, however, we must answer the questions being asked by the public. The acceptance of nuclear energy by public opinion is crucial to its development. I believe these questions can be reduced to a small number. Despite the many facilities already in service throughout the world, they still focus on the reliability of the nuclear technology used to produce energy and on their cost-effectiveness. They concern the consequences for mankind and the environment. And, lastly, they center on the relationship with nuclear weapons. (See Figs. 14 and 15).

I personally feel that none of the objections put forward is reason to abandon nuclear energy, and I feel equally strongly that the development of nuclear energy is not only possible but also desirable in those countries which can put it to use. This can only help shorten the duration of energy imbalances, by reducing them to the near and medium term, and will not compromise world supplies in the long term.

ARGUMENTS IN FAVOUR OF NUCLEAR ENERGY

1 — PROVEN, RELIABLE AND SAFE
2 — ASSURED RESOURCES
3 — LIMITED ENVIRONMENTAL IMPACT
4 — REDUCED OIL (AND COAL) CONSUMPTION - CONSERVATION OF RESOURCES
5 — CHEAPEST ELECTRICITY - REDUCED FOREIGN CURRENCY OUTFLOWS.

FIG. 14

OTHER ASPECTS OF NUCLEAR ENERGY

1 — USE TIED TO MASSIVE PRODUCTION AND CONSUMPTION OF ELECTRICITY
2 — INVOLVES VERY SOPHISTICATED TECHNOLOGY
3 — NECESSITATES AN EFFECTIVE NON-PROLIFERATION POLICY

FIG. 15

DISCUSSION

Chagas

I have some doubts about the use of the slide of Swedish origin (fig. 14) presented by Dr. Starr. I believe that the permissible dose of ICRP must be corrected following new data and I believe that these data should be related to the background radioactivity.

Starr

The ICRP limit is related to drinking water. This is so because people are concerned by deep storage of nuclear wastes and by the leaching of these wastes by ground water.

Sanchez-Sierra

I have two questions to Dr. Starr: first, talking about 1,000 MW nuclear plants, what do you mean with low levels of waste disposal if you accept that it'll produce 160 kg of plutonium and 400 kg of fission products every year? and second, will the price of Fast Breeder Reactors stay constant during 30 years? (2005-2035).

Starr

There are different kinds of wastes and plutonium is not included in the waste disposal. The price of FBR's quoted in my paper is in constant 1990 dollars without taking in account the inflation.

Pasztor

I comment on the same subjects:

a) on the graph 1, you showed a once-through fuel cycle. Then, this does not include reprocessing and thus the plutonium is still in the fuel. You just said that you would not put plutonium in the ground. So, what do you do with it?

b) The real question is whether the cost of the FBR's will not rise over and above that of inflation, as we have seen with the price of Light Water Reactors in the past.

STARR

a) The spent fuel with plutonium would be put in temporary pool storage. As I wrote in my paper, the spent fuel will have ultimately to be disposed of, either by encapsulation and burial, or by reprocessing and recycling.

b) The cost increase of nuclear reactors in the past was due to factors such as increase of regulatory requirements, regulatory delays, etc. We assume this will not be the case in the future. For instance, construction of a nuclear plant in Taïwan takes only 5 years.

SANCHEZ-SIERRA

I point out that, because of your internal opposition, you can easier sell and build nuclear plants in developing countries than to build them in your own country!

SALVETTI

I want to comment shortly on the two papers presented by Dr. Starr and Prof. Teillac.

There is a point which I consider very important for the future of nuclear energy, i.e. the availability of uranium as a function of the time for various nuclear strategies.

In particular, I refer to figure 10 of Dr. Starr's report and to figure 4 of Prof. Teillac's report, on cumulative uranium requirements, for different deployment options, compared with the reasonably assured and estimated additional uranium resources. Considering that from the moment of the decision to build a nuclear power station to its full operation, it takes in average ten years and that the life-time of a nuclear power station is about 30 years, toward the end of the century the electric utilities willing to install a nuclear plant must consider the problem of assurance of fuel supply and have to look for fuel commitments up to 40 years ahead.

Now, in the light of the aforementioned figures, the decisions to be taken in the late '90's or early 2000's will fall in a critical period because of the risk of non-availability of uranium for the whole of the plant life-time.

At that moment, as the fast breeder reactors do not raise this problem, the countries well advanced in the development of these breeders will undoubtedly have a tremendous advantage.

STARR

The basic point is correct — as Prof. Salvetti points out — that, by the turn of the century, those who are watching the uranium availability issue will have to make decisions and the operating utilities will need to decide on building fast breeders or light water reactors.

I believe the rising cost of uranium ore will lead the large nuclear power countries to choose breeders — which need a very high technology with a chemical reprocessing plant — so that the developing countries can continue with light water reactors.

TEILLAC

Je suis tout à fait d'accord avec les conclusions du Prof. Starr et du Prof. Salvetti. Je voudrais ajouter que non seulement il est nécessaire, si l'on fait de l'énergie nucléaire, de passer, à l'avenir, aux surgénérateurs, mais, de plus, que le temps pendant lequel on peut faire ce passage est relativement court. Pour pouvoir mettre en fonctionnement un surgénérateur, il faut en effet que 20 à 25 réacteurs ordinaires aient travaillé pendant un an. Si on attend trop longtemps, la consommation d'uranium sera trop importante et le passage aux surgénérateurs rendu plus difficile à réaliser. Quand on étudie la dynamique du système « énergie nucléaire » dans son ensemble, on s'aperçoit donc qu'il est tout à fait important d'utiliser aujourd'hui le nucléaire sous la forme des réacteurs à eau ordinaire et indispensable, au début du siècle prochain, de faire très sérieusement des surgénérateurs, faute de quoi le nucléaire ne sera pas utilisé dans des conditions convenables. C'est une conclusion générale qu'il me parait important de souligner.

COUTURE

What are the possibilities of other types of reactors than Light Water and Fast Breeder Reactors?

Notably, is it possible to expect any future for the High Temperature Reactors?

What are the possible development of nuclear energy outside the production of electricity?

STARR

The development of High Temperature Reactors is being slowed by the absence of strong industrial support in its development. Technically, this type has a better conversion ratio than the Light Water Reactors. In Germany, process heat is expected from High Temperature Reactors with a different design. However, it takes a long time to settle a reactor system of a new design.

COLOMBO

I should like to congratulate Prof. Teillac for the excellent presentation on nuclear power. His paper was indeed most comprehensive and, I believe, quite convincing to all of us. I was, however, unable to find in the paper (I do not say this in a critical way, but just to remark the different situations of France and Italy about social acceptation of nuclear power) arguments that would allow me to answer satisfactorily to the doubts and questions of the man in-the-street in Italy, who is exposed to an endless bombardment of alarm cries by the anti-nuclear movements.

This is the problem I have to face, as Chairman of the Italian Atomic Energy Commission.

Let me, first of all, state my position on nuclear power, because it may be not identical to that of several of my good friends and colleagues here. I am pro-nuclear on a rational ground, but not by faith.

In other words, if I were at all convinced that our society (and my country in particular) could go along well without nuclear power, I would be happy to accept the idea of a non-nuclear energy system. I believe, however, that we must accept nuclear fission as one of the sources which can contribute, now and for a few decades, to make the transition from the age of petroleum to the age of the definitive energy sources. By "definitive" I mean solar energy and/or nuclear fusion energy, because the first is renewable, the second promises to be based on a practically infinite resource supply. As far as breeders are concerned, my position is that I should like to keep this option open, but

I am not ready now to say that breeder reactors provide an optimal solution to our energy problem.

I strongly support a research and development program on breeders, because this type of reactor may be, ten or twenty years from now, necessary as I believe thermal reactors are a necessity today.

Let me now briefly list the main objections that the anti-nuclear groups make about nuclear power:

1) The risk of proliferation of nuclear weapons. This is a most complex subject, which should not be treated in a simplistic way. We keep telling our opponents that proliferation can be avoided by strict international agreement at multilateral level, that the Vienna Agency (IAEA) handles the matter in an adequate way, and that it would be unfair to get undue limitations to the pacific applications of nuclear power because of the proliferation problem.

We are, however, all aware of the position that President Carter's administration has taken in the last four years on the non-proliferation issue, and of the hard battle that the major European countries had to carry on — during the International Nuclear Fuel Cycle Evaluation — in order to convince the American representatives that their most restrictive views about reprocessing and fast breeders were unjustified. But we cannot ignore that, in spite of all international agreements, the problem of the connection between the pacific and military applications of nuclear power is a real one, and that it may in turn pose questions of rather complex nature on the criteria to be followed for deciding the conditions for the admission of individual countries, particularly in the third world, in the nuclear "club".

2) The problem of radioactive waste management and disposal. We keep telling the public that there is a menu of technically satisfactory solutions, and that we have plenty of time to do more research with the purpose of identifying the best solution according to technical, economic and safety requirements.

Our opponents reply that this is simply not true, and that we cannot affirm to have a safe-enough solution to this problem. We have available recent studies reporting convincing analyses of this problem (let me just quote the CONAES report, dated December 1979), but here again, the arguments that are able to reassure technically knowledgeable people are not convincing for the man-in-the-street, whose appreciation of risk is more emotional than rational.

3) The capital-intensive nature of nuclear power. This is becoming less serious, as a problem, than it was a few years ago. In fact, if it is true that nuclear power plants are very expensive, coal-fired plants are almost as costly

if one considers the cost of pollution-preventing installations and of all infrastructures related to a coal-based energy system. However, if we are to succeed in convincing people (and political decision makers first of all) that nuclear energy is convenient from an economic point of view, we must produce credible cost figures and be sure that all costs have been included, and that, for example, the costs assumed for decommissioning the power plant after its useful lifetime are realistic and not just rough estimates.

4) The centralized nature of nuclear plants is another issue which finds many opponents.

However, if we take, as I believe we should, the attitude that a plurality of energy technologies and sources should be used in the transition away from oil, we could easily admit that the space of nuclear power is within centralized sources, thus assuming that other sources, not necessarily as centralized, will coexist with it.

5) The issue most frequently advanced by the antinuclear movements is that of the risk of accidents from nuclear power plants or other nuclear installations. Our answer to this question is that peaceful nuclear technologies have been developed, since their beginning, with extreme attention to the need of preventing accidents, and that there is such a redundance in terms of safety, to make the likelihood of a major accident exceedingly low.

But the layman, who is not accustomed to think in quantitative terms does not understand the meaning of 10^{-5} reactor x year.

He only understands that there is a risk, that the risk is very small, but not absent. The fact that emergency plants have to be publicized, and people educated to simulate emergency situations makes, in the mind of the man-in-the-street, the risk appear much more consistent than it actually is. We must therefore work actively at educating people to learn to accept a technology, such as nuclear power, which our society is capable to control. In doing this, we should make all possible efforts to remove the subconscious association that frequently is made between nuclear energy and the bomb. Some of our elementary school textbooks tend to associate to hydro-power a good image (that of "white coal"), but when they explain the energy that can be created as a result of transformation of matter in the nuclear fission process, they almost invariably give the example of the bomb. So, we must start by educating the educators, and by making people understand that no energy source or technology is completely safe, and that a comparative analysis of the different types of risks must be made before taking a position on which energy future to choose for our countries. Yesterday, for example, M. Desprairies mentioned in his eloquent lecture that it would be sufficient to have a big accident in one of the main oil terminals in the Gulf, to be in a serious danger as far as the availability of petroleum in Europe is concerned. But people are accustomed to consider oil and oil products as ever-present commodities, and hardly realise the nature of the risk they are running.

Let me therefore conclude that only with a deep action of information, leading to public awareness through an open confrontation with the anti-nuclear movements, we can hope to convince our citizens that they should accept some nuclear power, in the context of a pluralism of sources. This is, at least, the conclusion I have reached in almost two years of hard work at the head of the Italian Atomic Energy Commission. In congratulating once again Prof. Teillac for this brilliant exposé, let me express the hope that in my country we shall be able to make a concrete progress in our nuclear program, which has gone in the last decade through a long and dangerous standby period.

DESPRAIRIES

Je souhaiterais que M. Teillac et M. Chauncey Starr nous disent leur opinion sur le prix futur du Kwh produit par un surgénérateur, par rapport au prix produit par un réacteur à eau légère.

TEILLAC

Nous sommes en train de construire la centrale Superphénix à Creys-Melville. Le coût de l'électricité que produira cette centrale est estimé devoir être voisin de celui de l'électricité produite par une centrale à charbon. Pour les futurs surgénérateurs français, la condition mise par Electricité de France est d'atteindre, grâce à l'effet de série, un prix d'énergie qui ne soit pas plus de 15 pour cent supérieur à celui des réacteurs à eau légère.

STARR

The target for a Fast Breeder Reactor is a cost equal to 1¼ that of a Light Water Reactor.

DANZIN

Quelles sont les ressources et l'avenir du thorium?

TEILLAC

Elles sont moins bien connues que celles de l'uranium mais sensiblement équivalentes avec une marge d'erreur plus grande. Mais le thorium n'est pas fissile naturellement et doit être utilisé dans les surgénérateurs. Tirer parti du thorium demanderait un gros effort.

SALVETTI

I want to comment on the question of M. Danzin on the possible use of Thorium: we have in Italy some experience on Thorium since we have processed the spent fuel coming from the Elk River Reactor (USA), made by mixed Thorium-Uranium oxydes. The difficulty with Thorium comes from the conversion of Th^{232} into U^{233}, which is a fissile material but unfortunately is gamma-active and this fact creates problems for the utilization of U^{233} particularly for the fabrication (or refabrication) of fuel elements: it requires a very sophisticated technology based on completely remote-controlled fabrication plants. So, I see little commercial future for Uranium-Thorium cycle, at least in the next decades.

VAN OVERSTRAETEN

I am surprised and puzzled by fig. 7 of Prof. Teillac's paper:
— do we expect a doubling in the cost of nuclear energy every five years?
— why did the cost of coal energy double during the last five years?

TEILLAC

Les prix indiqués sont en francs courants. Ce sont les comparaisons entre nucléaire, pétrole et charbon relatives à une même année qui ont un sens. L'inflation rend compte approximativement des variations du prix du charbon.

SCHMITT

1. Capital intensity is not an objection against nuclear energy but an advantage at least from the standpoint of industrialized countries.

If the supply of the energy needs of less developed countries is a crucial condition for their economic and social development and if this demand will concentrate to high degree on oil, then it is absolutely necessary for developed countries to conserve energy to develop capital intensive systems (like electricity and nuclear) to reduce the pressure on oil markets.

2. I wonder if our knowledge about the resource base of uranium is only very preliminary.

The cost figures that are the basis to estimate proven and additional uranium reserves (130$/kg) correspond under the assumption of a usable energy content of 10.000 tep/100 kg uranium to only 9$/tec. That is much less than we would assume as a probable long range coal price.

If the energy price level increases, it makes sense to invest in new search for uranium and I am sure more reserves will be found. In this connection, I want to quote the Central German Institute for Geophysical Sciences (BGR) according to which the total estimated amount of economically recoverable uranium reserves is ten times higher than the actually published figures.

3. If proliferation is a very serious problem, which I would like to agree, I wonder why we did not make efforts up till now in the direction of an international solution of this problem (for reprocessing, storage, etc.). Perhaps this Study Week could give some helpful recommendations in this direction.

KONAN

Je voudrais poser une question à propos du transfert de technologie, une question prospective. A l'origine de l'énergie nucléaire pour la production d'électricité, vous avez commencé en France, si mon souvenir est bon, avec 60 MW à Marcoule.

A un moment, on nous a fait espérer des projets nucléaires dont la puissance installée allait jusqu'à 300 MW ce qui, pour l'Afrique et le Tiers Monde, est une taille raisonnable lorsque peut aboutir un effort de regroupement régional pour les pays situés dans les zones éloignées de possibilités hydroélectriques importantes. Peut-on connaître où en sont ces études? Nous savons naturellement qu'il faut beaucoup de temps pour la formation des hommes et ceci pose un problème préalable. Mais je pense qu'il ne faut pas perdre de vue les applications au Tiers Monde. En effet, certains de ces pays produisent de l'uranium; c'est le cas, en Afrique, du Niger et du Gabon. Il serait donc souhaitable que l'on pense, dès à présent, aux possibilités d'accès des pays en développement à la technologie nucléaire, afin d'éviter un jour une confrontation entre pays producteurs et pays consommateurs d'uranium, comme celle que nous connaissons avec les combustibles liquides.

TEILLAC

Merci de poser cette question qui est effectivement très importante, d'abord en ce qui concerne la puissance des réacteurs: il est vrai, que dans les pays industrialisés, un réacteur plus puissant peut conduire, par un effet de taille, à un coût de production moindre de l'électricité. C'est donc dans ce sens que, dans un pays comme la France, on a construit des centrales de 900 MW, puis de 1300 MW. Super Phénix fera 1200 MW et les surgénérateurs de la génération suivante feront probablement 1500 MW. Il est évident que de tels réacteurs ont une puissance installée trop importante pour les pays qui n'ont pas en particulier une infrastructure électrique suffisante. Mais, il est tout à fait possible de fournir à un prix intéressant des réacteurs dont la puissance est seulement de 300 MW et même peut-être moins si c'est nécessaire.

La France peut faire et a fait de telles propositions lorsqu'un pays le lui demande, comme peuvent le faire aussi d'autres pays fournisseurs dans le monde.

BLANC LAPIERRE

Je suis également très heureux de la question posée par le Président Konan et je le remercie. J'ai insisté, le premier jour, sur la nécessité qui s'impose à nous de ne pas rester toujours « à l'échelle du monde » et de porter une attention particulière aux problèmes qui se posent aux différentes régions en fonction de leurs situations économiques particulières.

NUCLEAR ENERGY: SOCIAL, ECONOMIC AND POLITICAL IMPLICATIONS

CARLO SALVETTI
Rome

Introduction

« Quam ob rem culpa eius non naturae fiat accepta. Aliquot experimentis probatum est posse innocens esse ferrum. In foedere, quod ex pulsis regibus populo Romano dedit Porsina, nominatim comprehensum ne fero nisi in agri cultu uteretur. Et tum stilo osseo scribere institutum uetustissimi auctores prodiderunt » (1). (Pliny the Elder - Natural History, XXXIV, 39, 139).

Such was — according to the historian Pliny the Elder — the ambivalent nature of iron, in his age both a basic instrument for human progress and, at the same time, a so deadly arm as an A-bomb could be nowadays. Iron, in fact, represented the deciding step forward, as compared to the bronze era: as a matter of fact, the exclusive control on iron-making meant the achievement of wealth, power and security.

As it is well-known, the attempt made by Porsena was unsuccessful despite the measures taken to ensure the observance of the agreement: 20 hostages chosen among the members of the most influential Roman families and the Janiculum garrisoned to control the Tiber.

In few years the Romans were able to wipe out the traces of the Etruscans' power, while the latter had believed the going on of history

(1) So its crimes should not be ascribed to Nature. A certain number of experiences show that iron can also be harmless. The Treaty Porsena imposed on the Romans after the expulsion of their kings included a formal clause forbidding the use of iron, except in agriculture. According to the ancients, the habit of writing with a bony stiletto started in this era.

and the development of the society could be stopped simply by means of a treaty. This event creates a historical precedent to major developments of nuclear energy: the International Non-Proliferation Treaty, which provides for controls and inspections on peaceful activities — always suspected to be a cover-up for armament development — as well as pressing recommendations for the use of other energy sources, just to "keep the temptations away", exactly as the bony stiletto of 25 centuries ago was to prevent a peaceful iron point from becoming a dangerous arm.

In this connection, even older, more authoritative and meaningful historical testimonies exist.

The following passages, for instance, are quoted from the Bible:

Disarmament of Israel

Not a single smith was to be found in the whole land of Israel for the Philistines had said: "Otherwise the Hebrews will make swords or spears". All Israel, therefore, had to go down to the Philistines to sharpen their plowshares, mattocks, axes and sickles. The price for the plowshares and mattocks was two-thirds of a shekel, and a third of a shekel for sharpening the axes and for setting the ox-goads.

And so on the day of battle neither sword nor spear could be found in the possession of any of the soldiers with Saul or Jonathan. Only Saul and his son Jonathan had them. (Samuel 1°, 19-22).

Samson defeats the Philistines

Then Samson said:

"With the Jawbone of an ass
I have piled them in a heap;
With the jawbone of an ass
I have slain a thousand men". (Judges, (15) 16).

David fights Goliath

"David put his hand into the bag and took out a stone, hurled it with the sling, and struck the Philistine on the forehead. The stone embedded itself in his brow, and he fell prostrated on the ground. Thus David overcame the Philistine with sling and stone: he struck the Philistine mortally, and did it without a sword. Then David ran and stood over him; with the Philistine's own sword which he drew from its sheath he dispatched him and cut off his head". (Samuel 1°, (17) 49-51).

The first passage implicitly explains the somehow incredible stories of David and Samson. It was not a mere chance or a free personal choice if the heroes of Israel fought with jawbones of asses and slings against the Philistines armed to the teeth. The truth is that they were kept completely disarmed and could not even sharpen their plowshares at home. The Philistines ended like the Etruscans: after a hundred year struggles, they disappeared both as a people and as a power without leaving further historical traces of their existence throughout the following 30 centuries.

These historical precedents may be useful to frame into a long-run outlook the present contrasts of interests, the evaluations about the advantages nuclear energy offers for peaceful utilizations, as well as the preoccupations for the military, social and moral consequences of its use for different aims.

On the other hand, even 30 centuries ago plowshares were indispensable for agriculture; yet, they could be used to hit or kill a neighbour. From these two historical events, we can draw a second and major conclusion necessary to trace out the general lines of our meeting subject: *mankind and energy.*

The almost 5 centuries separating these two events — dramatically similar to each other — show that it is impossible to talk in the abstract about "mankind and energy"; on the contrary, we do have to refer to a specific time and to specific segments of society.

In fact, the problems the Hebrews and Philistines were confronted with about 30 centuries ago were not the same the Etruscans (who were not living in Italy yet), or the Romans (who were not even existing at that time) faced later on.

On the other hand, the "Iron-Non-Proliferation Treaty" conceived by Porsena could no longer have any interest for the Palestinian peoples, who had already gone beyond the transition phase between bronze and iron.

Hence, also the debate on mankind and energy should be focused on the problems of those peoples who, because of their own peculiar historical evolution, are facing today an energy problem that has undoubtedly a technological origin, but also involves social as well as political consequences. Of course, this does not mean that the developing part of mankind should not be taken into consideration, or that the industrialized countries may be allowed to make their own choices without taking into account the requirements of the rest of the world.

What I want to stress here is that the responsibility to solve the energy problem falls on the ones who caused it by requiring always increasing primary energy sources; the ones who also have adequate intellectual, economic and managerial means to work out the problem, but are not willing to do it.

Impact on man and society

The great scientific and technological innovations of the past have always touched off a reaction of refusal in the public opinion because of their innovatory — and therefore revolutionary — meaning. The story of mankind provides ample evidence of this: the grudging acceptance of the invention of the steam engine; its harnessing to marine propulsion and the opposition to the first railways are but a few examples.

Man, both as an individual person and as a member of society is influenced in his own behaviour and way of thinking by the cultural models of previous generations.

Only a very small part of the society — that is, opinion- and culture-makers — is in the position to live in keeping with the evolution of society, while the majority of it, even accepting the more superficial aspects of modern life, proves to be deeply conservative when it faces innovations: in this situation, the individual person's appraisal is always influenced by his own inherited culture, which of course, does not include "novelties".

Therefore the appraisal is always given on an ethical basis and involves the acceptability of an innovation according to the individual or collective ethics.

The present reactions before the development of nuclear energy reflect this inertial human behaviour and should therefore be analyzed in the light of the inherited patterns of behaviour.

The terrifying associations of nuclear energy's first appearance in history, at Hiroshima and Nagasaki, perhaps explain the hesitations and the fears that it calls forth; yet it is equally true tbat the average cultural formation at the moment of its arrival on the scene was certainly backward or at least at a level incapable of assimilating rapidly all that was novel in nuclear science. Again, the individual person's average cultural endowment does not include the perception of the costs and benefits accruings for the individual himself as well as for the society as a whole — from every major innovation, such as nuclear energy. Not being in a position to evaluate costs and benefits and then to draw conclusions, the individual person tends to be "rigourist" and to believe that bis own appraisal should be independent from any costs-and-benefits analysis or from the present specific political, social and economic circumstances.

As a consequence, the individual person tends, firstly, to widen the range of his so-called "indefeasible rights", considered as a part of the very nature of the human being, and then to found his negative appraisal of a specific innovation on a presumed incompatibility between it and the individual rights.

According to this line of reasoning, the Governments should ban every innovation — without considering the actual social and economic requirements — in order to ensure the respect of the citizens' rights; theoretically at least, hence, every Government's decision should not subordinate the individual interest to the will or the advantages of the different parliamentary majorities. On the contrary, what Governments and Parliaments actually do is to follow a utilitarianism that often conflicts with the guarantee of the indefeasible individual rights: their aim is the highest availability of goods and services for the largest number of persons, rather than the guarantee of equal rights to every citizen.

Utilitarianism is — obviously — based on the principle of utility, according to which a risk for a few persons is acceptable when the interest of many is at stake. In this way, ethics becomes dependent on expedients, evaluations, compromises and political coalitions. So, the individual person will tend to take up a questioning attitude vis à vis large institutions which, on the basis of overall costs-and-benefits analysis, support specific developments, such as, for instance, the introduction of a new technology. This is how a conflictual situation comes into being between the man in the street and the centres of power (governmental, industrial and trade union circles) represented by the institution referred to — a situation where the matter of contention comes to be identified with those selfsame institutions, as the individual enters into confrontation with these and may contest them, for this very reason.

It is equally evident that the costs-and-benefits analysis and the balance sheet emerging from these will differ from one segment of society to another and will be a consequence of the different tasks and responsibilities assigned by the society itself to the segment in question. No one doubts that at governmental level the introduction of nuclear is not only accepted, but considered essential as an alternative to other primary sources of energy, if a country is to be energy-independent and its supply sources are to be differentiated. But it is precisely because the State deems it to be in the interest of the community to choose the nuclear option that the "natural defences" of the common person are called forth and induce him to oppose such a decision as an example of the State smothering the individual. It is to attitudes of this kind that anti-nuclear publications such as Robert Jungk's "Atomstaat" make their appeal.

But are civil rights and nuclear energy actually incompatible? Is nuclear energy, by its very nature, in contrast with ethics? We cannot answer but a flat no.

Let's briefly examine the main anti-nuclear issues:

1) The radiation emission, even if small, produced by nuclear plants, represents for the inhabitants of the surroundings an *additional risk* which does not affect the ones living farther away. So the *civil rights* of the former *might be prejudiced.*

2) The emission of radioactive products is definitely not negligible and, especially in some rare but catastrophic cases, may jeopardize the life of several thousand persons.

3) The production of highly-radioactive wastes, that should be kept for several hundred thousand years, gives rise to an incalculable risk for the health of future generations. In this case, the *civil rights* of the latter *might be prejudiced* as well.

4) The worries that nuclear catastrophes might result from terrorism attacks to nuclear plants or from thefts of fissionable material for explosive-making, will sooner or later give rise to limitations of the individual freedom and, as a consequence, to the abolition of democracy.

5) Nuclear energy is not economical; quite the contrary, it is much more costly than other energy sources when all the different factors — completely neglected by nuclear supporters — are taken into account.

A huge amount of experience accumulated and the research carried out throughout 40 years in different countries allow us to refute all these anti-nuclear issues, not on the basis of sophisms but on the basis of facts.

Briefly, these are our answers:

1) The nuclear choice *does not widen the range of the existing risks, but replaces some of them.* If a nuclear plant is built, it means that a need of electric power exists; if the nuclear option is chosen, what can realistically be required is that the problems it causes be not more serious than with other options.

A nuclear plant does not affect the environment more than a corresponding coal or fuel-oil power plant; the contrary is true as proved by the experience of nearly 250 nuclear power stations now in operation.

Considering that the settlements surrounding a nuclear plant are more threatened than the rest of the population is a mystification, used to prove that the nuclear option is the *only risk* existing for the inhabitants: hence, the respect of their individual rights only depends on whether a nuclear plant exists in the surroundings. As a matter of fact, every human activity involves a given amount of risks, that regulations and controls try to keep within acceptable margins. Road traffic, chemical plants, farming and building are but a few examples. One who lives near a nuclear plant hence does not undergo an *overall risk* higher than the people living near highways, or chemical plants or working in farms or construction fields.

2) The likelihood of catastrophes that might take place in connection with nuclear plants has been a highly-exploited argument at the beginning of the anti-nuclear campaign. Today it has become a negligible issue, as no one believes any longer that reactors might go up like bombs (of course, like A-bombs!) or that reactor cores might melt in few seconds killing masses of people, and so on.

The 1979 Harrisburg accident helped to dispel these doubts much more than research and experts had ever managed to do. In fact, despite the serious damages to the equipment, the lack of core refrigeration, the series of mistakes made by the operators, the health of the surroundings' inhabitants was never in danger.

The several hundred journalists rushed to the scene of the accident to transmit dramatic reports could only speak about the strong psychological stress, which did not result from the fear of the reactor itself, but from their own doom forecasts of impending explosions.

3) The problem of radioactive wastes is another anti-nuclear issue exploited to prove the intrinsic immorality of nuclear energy. It is true that the wastes remain radioactive for a very long time: therefore special care must be taken so that they do not spread to the human environment. But it is equally true that very advanced technologies have been worked out to ensure the maximum of safety for the present as well as the future generations.

In this connection I want to draw attention to the following points:

— both weight and volume of higher radioactive wastes are very small; if a country like Italy were to produce the whole amount of the required electric power by means of nuclear power stations, the wastes would still amount to just a few hundred cubic meters per year. Supposing that all the Italian plants were coal-fired, the wastes volume per year (ash + calcium sulphate produced by the desulphurization of fumes) would come to several million cubic meters.

Because of their small volume, the process through which the radioactive wastes are made innocuous is not too expensive. Many other industrial activities produce greater volumes of much more dangerous wastes that can be isolated or reduced only at prohibitive costs.

— The radioactive wastes decay rapidly; it is false — as some people maintain — that they remain radioactive for 100.000 years: as a matter of fact, after a hundred years their harmfulness is reduced by a factor 20 as compared to the initial one; after 500 years it is already negligible (about 1/1000) and after 2000 years it becomes practically the same as some rocks, for instance the ones containing pitchblende.

The length of these time lapses should not be a worry; many industries are normally producing wastes containing highly-toxic chemical elements and compounds, that will remain forever exactly as toxic as they are today.

4) Nuclear energy, undoubtedly, does not help the constitution of undemocratic organizations: the experts' reliability and high-level professional skills are not likely to be reconciled with the utopias and foolish ambitions of certain absolutist political parties. Equally groundless is the thesis that nuclear power stations might be chosen as a preferential target by terrorists: whoever knows how such a plant is organized, also knows that it would be much easier for them to poison for example a town acqueduct, or to mine a bridge or a railway station. I believe the criminals would not be very satisfied with the poor results of a nuclear-plant sabotage.

5) Another argument to be refuted is that nuclear energy is more costly than other energy sources. The anti-nuclear maintain that the official figures of nuclear costs appear to be very low because they take into account neither some specific expenditures nor the social costs. What they say is false: complete data on direct as well as indirect costs of nearly 250 nuclear plants operating in 20 countries are available and provide ample evidence of the contrary.

According to this line of reasoning then, all the Governments of countries owning nuclear reactors were plotting against the world public opinion: and so the Russians, Americans, Canadians, French, Germans, English, Swedes, Argentines, Koreans, Bulgars, Swiss, Italian, Spanish and so on were all plotters interested in maintaining that nuclear energy is more economical!

If the anti-nuclear thesis seems to me to be groundless, on the other hand we cannot disregard that the siting of a nuclear power station has a different impact on the different segments of society, and is much stronger on rural than on urban settlements.

The activity of a construction field involving the work of 2000-3000 workers, moving to the building site and living there for years, would undoubtedly put to the test the social infrastructures of a small community: houses, schools, roads, transports as well as water supply and so on, risk becoming insufficient for the inhabitants, unless the authorities in charge take adequate measures.

Of course, the same problems are faced for any large industrial settlement — be it nuclear or not — and in this connection Governments and local authorities have specific intervention methods and plans.

From a "utilitarian" point of view, nuclear energy is very economical and hence acceptable, while from the "rigouristic" point of view it cannot be proved that it necessarily entails, by its very nature, a threat for the individual inalienable rights and that it should be prohibited for this reason.

Although nuclear energy — like any other human activity — involves some problems at a practical level, it can be ethically accepted. Is it more moral to accept nuclear energy, thus allowing the future generation to live and prosper without being troubled by a too-fast-growing population, or on the contrary, were it better to ban the nuclear, thus stopping (or reducing) the population growth and making birth-control methods be accepted by larger shares of society? Is it more moral to make a developing country be short of energy, thus risking to give rise to wars between hungry peoples for the control of the residual sources of fossile fuel, or to allow it to develop naturally by means, among other elements, also of nuclear energy?

Throughout the Middle Ages, before the building techniques achieved acceptable safety standards, the construction of the large cathedrals involved a heavy cost in terms of human lives, and still nowadays the building industry is one of the most dangerous human activities: yet no opinion movement against it has ever existed. Fire too, both in its domestic as well as industrial or agricultural use, involves a large amount of risk and has always given rise to serious accidents: nevertheless, lighting a fire is not considered immoral. These are but examples of the fact that it is not the risk itself involved in any human activity that should be marked as immoral, as the main moral dangers derive from the irresponsibility or from the superficiality of those who aim at preventing or delaying the orderly and peaceful development of mankind.

Impact on the political and economic structures of society

Nuclear energy is nowadays undoubtedly much more economical than other energy sources, as far as the production of electric-power is concerned.

Table 1 shows the comparison between fuel-oil- and coal-fired power plants: this analysis has been carried out in France, but a similar situation exists in many European as well as non-European countries.

Table 1 — *Electric Power production costs in France as to 1990* (FF cents - 1980/KWh).

	Nuclear	Fuel Oil	Coal
Capital	6,70	4,44	5,16
Fuel	4,27	26,56	14,28
Running Costs - Operation maintenance	2,55	2,52	2,85
	13,52	33,52	22,29
Desulphurization of Fumes		2,8	2,5
Total	13,52	36,32	24,79

So, it can be observed that the costs of nuclear energy amount to about 50% as compared to coal-produced energy, and total about 1/3 of the expenditures for oil-produced energy; therefore the economic advantage of a country choosing the nuclear option is undoubtedly very large.

But does it actually favour all the different sectors of society? No doubt that the availability of low-cost electric power furthers the newly-launched industrial activities and increases the competitiveness margins of the traditional ones.

Every single citizen will draw economic advantages, while the country as a whole will be in a position to cut its foreign currency expenditures for oil or coal.

On the other hand, nuclear energy has considerable — and not always appreciated — economic and political consequences; it entails, if not actual damages, at least revenue losses due to the new events taking place at political and economic level. For instance, replacing fuel-oil or coal by nuclear energy gives rise to a decrease in the land and sea transports of goods and through this in the activity of shipyards and industries manufacturing railroad equipment.

If a country goes nuclear — and stops buying fuel-oil and coal — large saving will result: in Italy, for instance, every 1000 MWe nuclear power station would cancel a 300 million dollars/year oil bill from the country's balance sheet. As a consequence, of course, an equivalent loss will appear in the balance sheet of another oil or coal exporting country or an Oil Multinational.

The capitals channelled towards more modern and productive technologies — such as nuclear energy — reduce, of course, the financial availabilities for more traditional and less efficient economic sectors, whose decreasing power vis à vis of new developing industrial groups may cause far-reaching changes in the political equilibria. Furthermore, the option of going nuclear necessarily cuts the country's monetary outflows, thus causing large financial damages to oil and coal-exporting countries.

If, on the one hand, such a change in monetary flows helps to strengthen the currencies of the energy-dependent countries, on the other hand it entails by force of circumstances large readjustments in the commercial — i.e. import-export — flows, both in terms of amount and of type of goods exchanged.

Lastly, it should be observed that politics too — that is political stances as well as official institutions — will have to consider the long-time spans typical of nuclear planning and to try to cope with them.

Impact on international politics

The first industrial revolution brought great advantages chiefly to the countries that had plenty of raw materials and energy sources, like Great Britain, the United States of America, etc. So a political equilibrium came into being, that was to last until the first world war.

No doubt that the whole range of advantages (low costs for fuel and transports, greater autonomy and energy independence) offered by nuclear energy opens new prospects for the countries lacking raw materials, in particular oil and coal. A massive introduction of nuclear energy on a world-wide scale may give rise to new political equilibria and entail in this process serious international tensions, as the countries exporting the traditional energy raw materials will try to protect their own interests and so will all the economic sectors whose fortune is bound to the present situation. The coming of nuclear energy may well ensure the developing countries a greater share of traditional energy sources, thus enabling them to take off from both an industrial and a technological point of view and attain the level necessary if they themselves are — autonomously — to benefit from this novel source of energy.

Due to the inherent ambivalence of the use — civil and military — to which nuclear techniques and materials can be put, a worldwide use of nuclear energy would create problems related to those potential military applications, with the consequent threat that this would imply to present equilibria.

Particularly aware of this potential danger for existing equilibria are the States owning nuclear weapons. This is how the Non-Proliferation-Treaty (N.P.T.) came into being — to provide an international instrument to ensure that the status quo will be maintained.

Large scale controls on nuclear activities and international trade of nuclear materials (the latter also subject to the limitations contemplated in the London Club Guidelines) are a novel feature on the international political scene in that these controls imply precise limits to national sovereignty.

The historical precedents for limitation agreements such as the NPT are, frankly, not very encouraging, for they give rise to so many illusions short-lived or long-lived as they may have been — from Lars Porsena, as we already mentioned at the beginning of this paper, in the sixth century B. C. imposing on Rome his prohibition against the use of iron for arms production, to the Treaty of Versailles denying Germany the rearmament. Moreover, new restrictions have recently been adopted

— notably by the USA — in order to prevent (or at least to delay) the proliferation of nuclear weapons, and this even in contrast with the NPT (Article N. 4) explicitly enjoining upon the signatory countries the free transfer of nuclear technologies among themselves.

Here again, there is no lack of historic failures in attempts to prohibit the export of new technologies: Chinese gunpowder and silkworm rearing are classic examples. The fears associated with the dissemination of the so-called sensitive nuclear technologies have been particularly felt in recent years in the United States of America.

Diametrically opposed to the Eisenhower "Atoms for Peace" policy, more recent administrations (Ford, Carter) have become the mouthpiece for these fears, widely shared by US Congress circles. So the International Nuclear Fuel Cycle Evaluation (INFCE) was instituted at the Washington Conference in October 1977 and is now over after two and a half years' intense activity. In the meantime, despite the statements of the Washington Conference binding the countries not to alter the existent status quo, new limitations on international trade of nuclear materials were introduced, especially by the USA following the approval of the Non-Proliferation Act of April 1978.

It is true that nuclear technologies and their associated materials may be used for both civil and military targets: nevertheless it is necessary to dispel the misunderstanding that gave rise to INFCE: that is to say, the fact that the nuclear option at a military level must of necessity be preceded by an option at a civilian level.

The most glaring example of the contrary is China. As early as 1964 this country owned its own nuclear weapon; nevertheless, its civilian nuclear option is only extremely recent.

INFCE has proved that a non-proliferating nuclear fuel cycle is a pure utopia as all fuel cycles are potentially equally proliferative, to a greater or lesser degree; and the Conference has also shown that non-proliferation is chiefly a political problem and only marginally a technical one. To sum up, after two and a half years' work and lively debate, the experts have made sure that the ball is now back in the politicians' court.

Conclusions

Every major innovation has always given rise to deep ideological contrasts and often also to wars aimed at barring the neighbours' development.

The XIX century Romantic Movement can be interpreted as a reaction against the scientific and technical culture furthering the industrialization process in Western Europe.

From a historical point of view, the present anti-nuclear opinion movements are fully comprehensible as far as both the international relationships (and the problems connected with the absolute control on nuclear weapons), and the specific reactions of the people directly concerned by the siting of a nuclear plant (referring to the XIX century romantic, anti-scientific tradition) are concerned.

Of course, any major technological innovation gives rise to a greater or lesser amount of risk: we might even say that the more threats it entails for the status quo, the more it can be considered important, and this involves political and economic aspects as well as safety and protection for mankind and so on.

The introduction of any new technology — exactly as the start of any new activity — has always entailed the rise of new risks: even building cathedrals during the Middle Ages involved a heavy cost in terms of human lives before the achievement of advanced building techniques allowed to keep the risks within acceptable margins.

This is the case for any other major innovation; at the beginning mankind hesitated but then always chose to go ahead.

The same will undoubtedly happen with nuclear energy.

Janos PASZTOR presents the part — devoted to the nuclear issue — of his paper intitled

"ENERGY FOR THE FUTURE

as seen by the World Council of Churches, in the light of the MIT Conference on Faith, Science and the Future"

(The other parts of this paper will be presented in the last session entitled "Prospects and general discussion"). He begins his talk by these words:

J. PASZTOR

As said, I represent the World Council of Churches and I would like to thank Mr. President, in the name of the World Council, that I could represent this organization. We do many things at the World Council of Churches and our little group on energy is just a small part of the big thing, but anyway I would like to say a few words about our thoughts specifically on nuclear power and although I find it difficult to separate our discussions on nuclear power from the rest of the energy debate.

ENERGY FOR THE FUTURE

JANOS PASZTOR
World Council of Churches
Sub-unit on Church and Society Energy for my Neighbour Programme

I. The Basis of the Concern of the Churches [1]

The Christian churches have an authentic and inescapable concern with the energy problem world-wide. Energy is essential to human life. Its modes of production and consumption, which influence the conditions of life and social relations, require ethical decisions. Many seemingly technical debates rest on ethical assumptions, implicit or explicit, and have ethical consequences. They even provoke questions about the very meaning of human life.

There is today a rising demand for energy in the world. In part the churches must endorse this demand: it represents relief from poverty and freedom from external economic domination. In part the churches must criticize this demand, insofar as it represents extravagance and the notion that rising consumption always means a higher quality of life. In any case, the rising demand meets dwindling supplies of traditional forms of energy: firewood, coal, natural gas and petroleum.

The combination of increasing demand and increasing scarcity means that major social, political and economic changes must come. These changes have significance for the efforts of the churches in improving the human condition.

Every individual and organization working on the improvement of social conditions must have some idea or vision of the kind of society they would like to reach. This will change constantly depending on the social, political and technical conditions. The WCC has such a vision; we call it the Just, Participatory and Sustainable Society.

Justice in this context means criticism of the vast inequalities in access to energy, between rich and poor, at the international and intra-national levels. The sharing of energy tecbnologies and resources is a moral demand. Justice requires also the sharing of risks. It is unjust to maximize cheap energy by imposing exorbitant risks on some groups. Justice also requires attention to the socio-economic context within which energy systems work. It is the social management of energy, rather than energy in isolation, that determines the issues of justice.

Participation requires attention to the way in which people share in the decisions that affect their lives and their welfare. People should be able to participate in decisions concerning energy, to ensure that these serve their interests as members of the community as well as individuals. The churches have a responsibility to encourage such public participation, so that society as a whole may responsibly control these energy technologies. Without such participation it will never be possible to achieve a just society.

Sustainability reinforces the demand for justice, that is justice not only for our sake, but also for the sake of those who are not yet born. Our wasting of the earth's energy capital these days will deprive further generations of that resource in the future. In addition some of the technologies we are using extensively are creating irreversible ecological impacts, which will only become apparent in the future. In order to achieve sustainable energy policies, the energy needs of the present generations must be balanced with those of generations not yet born.

II. History of Ecumenical Activity in the Area of Energy before 1979

In June 1974 the WCC held a World Conference on "Science and Technology for Human Development" in Bucharest, Rumania; at this meeting the churches were drawn into the growing controversy over the use of civilian nuclear power [2]. To clarify the issues the sub-unit on Church and Society was mandated to hold an international hearing on the risk and benefits of nuclear power, eventually convened in Sigtuna, Sweden, in June 1975, with the participation of a number of distinguished nuclear energy experts and others concerned with energy policy [3]. This marks the beginning of the WCC concern with issues of energy.

These preliminary discussions helped the churches see that they had to deal with some very basic technical and economic questions; it was also realized that the question of nuclear energy posed some very important ethical dimensions as well: e.g. who uses the energy produced? For what purpose? Who pays for the energy? What are the hidden costs? etc. etc.

Another critical issue emerged: the energy needs of the developing countries. As a result, in the summer of 1976 the WCC launched the Energy for my Neighbour Programme (ENP) [4].

This programme was designed to take up, in a very practical way, the energy problems of the Third World, and especially the huge disparities in energy consumption between rich and poor countries. Generally speaking, high energy use countries are affluent, while the low energy use countries are poor and the churches' task should be to help the poor. The basic aim of the ENP was therefore to sensitize the churches and their members in the rich countries about this problem. By conserving energy in their homes, by driving less, etc., there would be savings which could be collected through churches and used for developing practical energy projects in the Third World.

Meanwhile the ecumenical contribution to the energy debate continued when the WCC officially participated in the discussion of "The Public Acceptance of Nuclear Power" at the International Conference on Nuclear Power and its Fuel Cycle, sponsored by the International Atomic Energy Agency, at Salzburg, Austria, in May 1977 [5].

A further ecumenical discussion on "Nuclear Power and the Churches" was held in Switzerland in the Spring of 1978 [6]. Here the costs and benefits of nuclear energy were examined further, though the meeting was unable to reach conclusive agreement. I will return to the results of this meeting later. At this point, it suffices to say that up to the 1979 Conference on Faith, Science and the Future, the WCC activities in the area of energy were focussed on two major areas:

i. The question of nuclear power;

ii. The question of injustice between the rich and poor countries in terms of energy use.

But the Bossey Consultation showed that it was not possible to limit the discussion to these two specific questions; energy issues had to be seen in a much broader context.

III. Activities of the WCC Churches in Energy Conservation and in the Sharing of Energy Resources

During the second half of the 70's, many churches in the rich world started taking up the energy issue in one way or another. The WCC booklet on the purpose of the ENP became quite popular, and was translated and used by groups like "Bread for the World" in the German Evangelical Church. They launched a programme, "Aktion-E" along the lines of the ENP, which has been successful in alerting churches to the issues. Many churches, especially in the Netherlands, USA and in Sweden held hearings on nuclear power, and produced policy statements against nuclear energy (i.e. NCCC/USA). In addition these churches have been actively engaged in programmes to conserve energy, at family and parish levels. Hence by the time of the MIT Conference (July 1979) the issue Energy was on the agenda of a large number of churches.

IV. The World Conference on Faith, Science and the Future at MIT

The 1979 World Conference on "Faith, Science and the Future" at the Massachusetts Institute of Technology in Cambridge, USA, was the first world ecumenical meeting on this theme. Half the delegates were scientists (both natural and social) while the other half were theologians, pastors, political leaders, businessmen and others. It is not possible to discuss this Conference in detail here, but only to refer to the discussions of the energy issues.

"Energy for the Future" was the theme of one of the ten sections into which the Conference was divided. This section tried to pull together the past work of the WCC on nuclear energy, on energy problems in the Third World, etc., and attempted to look at the question of energy in a broader perspective than before. The work of this Conference, together with the results of past meetings provides the basis for my own attempt to outline the churches' view of energy problems today.

The idea, "energy crisis" is very fashionable these days. What is the nature of this crisis? Are we really short of energy? The answer to that question is of course no. We are not running out of energy as such. Even though certain fossil fuels are running out, there is still a lot of coal, oil shale and tar sands to be found. Uranium reserves are also very large and Thorium can be found just about anywhere. The hydro-electric potential of this globe has yet to be exploited. In the developing countries only 8% of the hydro-electric capacity has been realized. In addition to these conventional energy sources, the amount of solar power intercepted by the earth is thousands of times larger than what humanity uses at present. The total heat available inside the earth is again many magnitudes larger than the total global consumption per year. The energy crisis cannot really be a shortage of energy as such. There is plenty around and the problem is a little more complex than that.

Energy has to be in the form of a useful fuel, which can then be used in a machine or in some other process to achieve useful work. Most of the time it is possible to convert one fuel into another, although often with very high losses. Thus coal is a fuel, which can be directly burnt, to produce heat energy, which can do work. It can also be turned into a liquid fuel (at a rather high energy cost) which can than be burnt in a thermal plant to produce electricity, a fuel able to energize electrical appliances.

These different fuels are used for different purposes, depending on their quality. Electricity is high quality fuel, since almost any process can be made to run on electricity. In addition, most other forms of energy can be produced when starting from electricity, such as low or high temperature heat, mechanical energy, chemical energy, etc.

The ideal situation would of course be if we had unlimited supply of some high quality fuel such as electricity. This is, however, not the case, and therefore we have to economize. High quality energy should not be used for a process which could run on some available lower quality energy. In other words, it is very important to properly match the fuel and the activity. High quality fuel like electricity should be used for running TV sets and computers, while household warm water should be produced with a lower quality fuel, like the sun or some chemical fuel, such as coal or biomass.

Looking at the energy crisis from this point of view, it is clear that it is not really a problem of lack of energy, but of *lack of certain fuels* in certain regions. In the industrialized countries there seems to be a shortage of liquid hydro-carbon fuels, while in some African countries the most serious problem seems to be the shortage of firewood for cooking.

It is however not sufficient to only talk about the shortage of fuels — a certain *technology* will be necessary to utilize that fuel. In Burma for example, there is a very serious shortage of electricity, in spite of the fact that the country has a huge potential of hydro-electricity. The country lacks the necessary technology to tap that source of energy. Fusion energy could theoretically supply humanity with unlimited amounts of energy, but we do not yet have the technology to make fusion work.

A combination of human and financial *capital* is necessary to acquire the required technology. In the case of a very simple wood burner only human capital is needed to collect the wood and a few stones. Very complex energy technologies, such as nuclear fusion or solar power satellites are more capital intensive.

With the capital, the fuel and the technology it is possible to construct some kind of a unit providing energy which can do useful work. This was the point at which classical energy policy stopped. There are, however, a number of other important issues which have to be dealt with. The *environmental impacts* must be assessed. The construction of a nuclear reactor in a certain neighbourhood might produce fear in the people living in the area. We now know we cannot ignore this kind of *psychological impact.* The large demand of certain countries for liquid hydro-carbons is making that fuel unavailable for a large percentage of mankind, which raises a question of *social justice.* The interests of minorities might easily be sacrificed for the good of the majority, as in the case of Western coal in the US. These kinds of decisions require *moral consideration.* In some countries the existing civilian nuclear programmes are closely related to the military nuclear programmes. Either can be an offshoot of the other, raising *geopolitical considerations.* Often people oppose nuclear power, not only because it might be dangerous or uneconomical, but also because they see nuclear energy as the major cornerstone of an increasingly energy-intensive society, where the role of human labour will be very different than in our present societies. This poses the question of *life styles,* now an important issue in the debate between different energy options.

This list is incomplete and many more could be mentioned. The point is that the energy crisis is a very complex societal problem, with very many, often inter-connecting, dimensions.

Traditional energy policy has tended to look only at the economic and technical considerations; today a more interdisciplinary approach is obligatory.

The churches do not have particular expertise in the technology or the economics of energy — and should not claim it. On the other hand they do have some expertise in the analysis of the socio-ethical dimension. We at the WCC have attempted to work along these lines when dealing with energy issues.

1. *Technical Criteria*

The churches have inevitably been drawn into the debate about appropriate energy technologies. Energy technologies range from very simple to very complex. A wood fire surrounded by four stones is a simple way of providing heat for cooking. Cooking with electricity from a nuclear reactor obviously requires some of the most complicated technologies humanity has ever developed. Not only is the technology complex, but this kind of a technology can only be produced in those societies, which have the necessary social and industrial infrastructure capable of supporting that level of technical development.

Simple energy technologies are usually based on some renewable fuel such as wood. In addition they also require some minimal input of other materials for the construction of the burners. Complex energy technologies are usually based on non-renewables, such as coal, but even if they run on a renewable fuel, such as the sun, they still require a very large material input, which of course depletes the non-renewable resources. For example, photovoltaic electricity is based on a renewable source of energy, the sun, but it also requires materials for the collectors, such as aluminium, various crystal oxides, plastics, etc. Some of these are mined directly, while others have to be produced. Necessarily more factories will be needed, which need workers, who need consumer goods, which necessitates the production of more electricity.

As technologies get more complex, they require not only factories producing them, but a complex energy-intensive society.

This division between simple and complex technologies corresponds more or less to the "soft-hard" division often used in the jargon. Of course, there is no such thing as a completely soft, or completely hard energy technology. Hot water, for example, can be produced in many different ways. A rather soft technology would be to use a direct solar heater. One could also produce methane or ethanol from some kind of a biomass and that in turn can be burnt to heat the water. This would be a "harder" way, but still not as "hard" as heating the water with nuclear electricity.

The churches today feel that we must challenge the trend towards a more and more complex society based on highly energy-intensive activities.

2. *Socio-Political Issues*

At the MIT Conference on Faith, Science and the Future, the guiding theme for all our deliberations was the Just, Participatory and Sustainable Society. In the section on energy participation was emphasized, since without full participation of everybody concerned it would not be possible to achieve either just or sustainable energy policies.

However, as energy technologies and societies become more and more complex, people find it ever more difficult to participate in decision-making. Lay persons cannot understand the intricacies of complex systems like the nuclear fuel cycle — to mention one example. Even the experts have problems, since they are often only expert in a particular profession and not of the whole system. People feel overwhelmed in our societies when they are faced with the possibility of a nuclear or solar satellite economy. People still try to participate, but the tendency is to become passive users of energy — whether by plugging into the walls for electricity, or filling up at a nearby gas station. But this kind of blind reliance can be very dangerous. People in the industrialized countries are reluctant to face up to the fact that the gasoline, which is peacefully pumped into their cars each day comes from the most volatile region in the world. People who just plug in their electric appliances often forget or just do not understand the social and environmental costs of producing the electricity probably far away from their homes.

As energy technologies become more and more complex, they tend to become more centralized. This is very clearly happening in the case of electricity. Tremendous economic and political power is concentrated in a few hands as a results of such trends. It may be in the hands of national governments or private groups; wherever it is, it takes power away from the people. Recently the French Government announced plans to increase police security around nuclear installations, and to limit the right to strike for workers in those installations. This affects only a few thousand workers now, but the trend is clear. The new wave of youth protest in Europe is just another one of the reactions against such trends.

Participation in decisions concerning energy is not just for the sake of getting energy at a lower price and higher quantity in your home. Participation involves the development of our political and social institutions which will keep up with the kinds of technologies being produced. A recent study in the US, the Kemeny study of the Three-Mile Island accident, shows that unless some fundamental changes are made in the

US federal legislative system nuclear energy will not be successful in that country. This report is not an anti-nuclear report as such, but it does say that the present political institutions are simply unable to cope with the public demands for responsible political control of this technology.

3. *Time Perspectives*

In most countries at the present time there are only two time perspectives which are important when making decisions about energy policy. The first is that period during which economic returns are possible on any particular investment; this is influenced mainly by the prevailing discount rate. Many of the available solar technologies have not gained wide acceptance, because their pay-back times are typically more than 15-20 years.

Second is the political time perspective, — in the US and in many other countries only about four years. In the socialist countries it is determined by the five-year economic plans. These are relatively short time horizons and if the returns from a certain policy only come after ten years a present administration may not find it useful politically, so another policy might be favoured, which could bring quicker results irrespective of the long-range benefits.

There are, however, many other time horizons which have to be considered in any responsible energy policy. The present economic and political time horizons simply are inadequate to deal with such a situation. Yet in 40 years or less, our children will be dealing with the results of our present day energy policy, and we do have a responsibility towards them as well.

As Herman Daly put it at the MIT Conference, the material resources of this globe belong to everybody, that is including those generations which are not yet born. If we really claim to have a democratic system, and would have a referendum on the further use of these resources, we would also have to count the votes of those who are not yet born. The democratic system believes that the majority should decide. In such a scenario of course, the present generation would be in a very clear minority. In some cases technological change may be able to provide new and different energy sources. It may be possible to construct a nuclear plant in Greece today, but the forests which have been cut out by the Greeks and the Romans are now gone.

Our churches have repeatedly stressed that stewardship in this context means responsibilities to all people, including to those who are not yet born.

4. *The Environment*

Every time work is done, energy is degraded from a higher to a lower quality state. Eventually all the energy will be degraded into low quality energy or low temperature heat. As energy is degraded, entropy is said to increase. This is a fundamental law of thermodynamics and in a closed system it is not possible to reverse it except by increasing the entropy even more outside the system, so that overall the entropy change is still positive.

We are of course very far from the time when all energy will have degraded into low temperature heat and when no further activity will be possible. This kind of analysis, however, does have some very important implications for our present energy policy.

As more and more of the easily available energy (low entropy state) supplies are being used up man has to invest increasing amounts of energy and technology to exploit the less available (high entropy state) resources. The difficulties of extracting North Sea oil or solar electricity from satellites are good examples. Correspondingly, ever larger amounts of energy have to be produced so that the even less available sources may be extracted. Our churches feel, that this is just another trend towards a more complex, more energy-intensive society, which has to be resisted.

The technologies extracting the energy sources and making them into useful fuels need large energy and material inputs themselves. This in turn necessitates large industries, which also need large inputs of energy. Nuclear energy and solar electricity may look like very clean sources of energy, but when one looks at all the pollution produced in the production of the *whole* nuclear and solar electric cycle (including the supporting industries), the picture is quite different.

It is often claimed that large centralized sources of energy are much less polluting than small dispersed ones. This statement may be true in the sense that many small coal-fired thermal plants are more polluting than one big one. However, the difference between soft and hard energy technologies is much more than just small vs. large of the same technology.

Hard, centralized energy sources work on the principle of maximum production of as high quality energy as possible, such as electricity. Only a small fraction of the primary energy input is eventually distributed to users due to the very high conversion and transmission losses. The consumers can then use this high quality energy for just about any purpose.

Soft energy technologies, however, work on a very different principle. First of all the specific activity is considered and then a particular energy technology is matched to that, which can supply the right quality of energy for the right purpose. Direct solar energy is a good way to heat water, while electricity is the appropriate energy source to run computers. This way, by matching the right source with the right end use, the total turnover of energy is much smaller, for the same amount of activity.

Most of the soft energy technologies are less polluting by nature than some of the hard ones, but even if they are not they will be less polluting overall, since much less of them would be necessary.

This is not to say of course that soft energy technologies cannot and do not have serious environmental impacts. I have already mentioned the disappearance of the Mediterranean forests which were cut forever by the Greeks and the Romans. Today, deforestation rates in the tropical zones are so high that if present trends go unchecked there will not be a single tree in that area by the year 2000. Although use of wood as a fuel is only number three reason (1. is agricultural clearing, 2. is industrial use of timber) it still is a major one. The deforested areas are unable to support proper agriculture, and after a few years they completely erode, and end up as silt in the rivers downstream. No wonder that they are having bigger and bigger floods every year in N. India, Burma and Thailand.

These impacts are, however, not inherent in these technologies. With the proper management of natural resources, it is possible to replant those trees which were cut. China is a good example of this, where total forest area is actually increasing in spite of the extensive use of timber and fuel wood.

Stewardship for nature means in this context an environmental policy which deals with these issues. It will not be possible to achieve a sustainable society unless some of these environmental impacts are reduced while others are totally eliminated.

5. *The Nuclear Issue*

This is the area where the WCC has done most work, in so far as energy is concerned, but it is here that I have the greatest difficulty in conveying to you what we think about it. We represent a large number of different opinions on this issue, and it is not easy to come to a conclusion.

As I mentioned before, we organized and took part in a number of international conferences on this topic. It took us a long time and a lot of work to get where we are now, which is a call for a five-year moratorium on the further development of nuclear energy world-wide. This call was just recently endorsed by the Central Committee of the World Council of Churches (in a narrow vote!).

First at the Sigtuna Hearing we learned a lot about what nuclear energy is all about; how it works and how it does not work. We also began to understand the broader implications of what the use or non-use of nuclear power would mean in so far as the other energy options are concerned. We also began to see some of the societal problems underlying debates about nuclear energy.

At the 1978 Bossey Consultation some kind of a coherent thinking about nuclear power began to emerge. The report summarizes four major points in the thinking of the group as follows:

"In briefest summary, we find:

1) The nuclear debate cannot be addressed, in an absolutist sense, without consideration of other energy options, including especially energy conservation and the possibility of technologically less complicated societies. In this respect, the issue is for many governments and peoples not as clear-cut ethically, as is for example that of racism. Failure to recognize this complexity, has contributed significantly to the present dishevelled state of the debate.

2) More specifically, energy consumption and more rational use of energy deserve much more attention than they generally receive, especially in the industrialized countries. This matter is germane to the nuclear debate because reduced (or less rapidly growing) energy demands change both the desirability and availability of the various energy supply options, including nuclear power, its chief present alternative (coal), and its chief future alternative (solar).

3) Most of the nuclear debate is but symptomatic of a much deeper societal debate about more technology or less, about centralized versus decentralized, appropriate (versus inappropriate?) with many groups defining these terms to suit their own social aims. At this time there is no ecumenical position on this much broader debate which will be one of the major issues before the World Conference of 1979.

4) No grounds exist for *rejecting* nuclear power categorically. On the other hand, it cannot be accepted categorically; it is a conditional good, subject to reasoned acceptance under some circumstances and subject to reasoned rejection in others. Even where accepted there may be a point when we may have to say, 'Thus far and no further'. The particular circumstances relate to need for energy, availability of alternative sources, the likelihood of increasing or decreasing the danger of proliferating nuclear weapons, and whether nuclear power in any particular case contributes to a more just, participatory and sustainable society, or to its opposite. Certainly the scale of possible dangers and benefits exceeds that which society is accustomed to consider, and choices to proceed with or renounce civilian nuclear power should be made in each case only after profound deliberation".

It was this conditional acceptance of nuclear energy which served as a starting point for discussion at the MIT Conference. The nuclear debate was undoubtedly the most controversial part of that Conference. After long hours of discussion and many amendments, the final text of the moratorium resolution, which passed 3:1, was as follows:

> "We recommend to all national governments that they immediately introduce a moratorium on the construction of all new nuclear power plants for a period of five years; the purpose of this moratorium is to encourage and enable wide participation in a public debate on the risks, costs and benefits of nuclear energy in all countries directly concerned".

Is this an anti-nuclear statement? Is it in continuity with past WCC statements on nuclear energy? Why was it adopted in this way?

Although we did not carry out any study on who voted for what and why, it is possible to make a few generalizations. About a quarter of the people present were strongly pro-nuclear (many of them nuclear engineers) and they clearly did not support any resolution which would stop nuclear development for any period of time. Another quarter of the participants were people with very strong anti-nuclear feelings. Some in this group abstained from voting (because the action was not strong enough), while most of this group supported the moratorium recommendation only as a compromise. About half of the participants however had some well thought out reasons for halting nuclear development for a period of time. Hence the moratorium is not anti-nuclear in the sense that it rejects the nuclear option. In fact, the Conference report says explicitly: "For the long term we believe that no option should be excluded *per se* ...". The moratorium resolution calls for a halt to any further developments in nuclear energy for a period of five years, so that all the public's problems and questions can be studied fully. If at the end of the five years it is agreed that nuclear power is unacceptable, the churches would so decide. If, however, this energy option will be found to have more benefits than risks and costs the churches will act positively. In this sense the moratorium recommendation is in continuity with the past WCC position. The major change is that the conditional acceptance has turned into a conditional rejection. It is clear to us that the nuclear option will be maintained only if the critical problems are solved. For the time being the risks and overall costs of nuclear energy seem to outweigh the benefits, so a considerable group of our constituency thinks that it is worthwhile to have a "breathing space" before going ahead with any further development of this energy option.

Why did this change of attitude occur at MIT and not at the Bossey Consultation a year before? I am sure that the accident at the Three-Mile Island reactor coming just a few months before the MIT Conference, had a great impact on opinions. However, there were some more important considerations.

The growing difficulties of the nuclear industries in the industrialized countries were well known to the participants of the Conference. Even before the TMI accident, in most industrialized countries there were practically no new orders for reactors, and even some existing ones were cancelled on economic grounds, or as a result of pressure from the public. Most of these countries also reported over-capacity in the electric sector, while at the same time it was liquid hydro-carbons which were in short demand — mostly for transportation and heating.

In addition, a number of studies appeared before the Conference, like the Leach and the Harvard Reports, claiming that much more energy conservation could be achieved in the industrialized countries, without a drop in the GNP. It is also claimed in these reports, that new non-conventional energy sources can be implemented faster than hitherto thought.

These points show that in the next ten to fifteen years, it will not be necessary to build any additional electric capacity in the industrialized countries. The participants at MIT argued that in this case a temporary halt in the further development of nuclear power would not have any bad effects on the overall supply of energy, therefore this was the time to stop — say for five years. This would give us time for public discussion of the overall risks, costs and benefits of nuclear power.

Moreover the question of nuclear power in most of the developing countries is just emerging as an issue. They also need more time to study this new option, whether it will be beneficial to the development of their societies or not.

6. *Global Concerns*

In most countries there exist institutions whose mandate is to correct some of the social disparities within the society. There are pension funds for the old, medical insurance for the sick, environmental agencies for a better ecology and there are civil laws which enforce the written rules of any particular nation. Imperfect as these systems may be, they do function and those people who are being served by these institutions usually would find it very difficult to live without them. They exist however only at national levels, and possibly in some cases at regional levels. This was viable 30 years ago, but today when transnational companies operate in dozens of countries at a time, often being more powerful than the national governments themselves, and when mass communication brings the world together these are not sufficient any more. International institutions are required. This is especially true in the case of energy, where just about anything that happens, happens at international levels. To mention just a few things: the international petroleum trade, the acid rain produced over Sweden by the coal plants of the U.K., international nuclear proliferation, etc.

7. *The Energy Crisis in the Developing Countries*

In the next two years the WCC wants to give specific attention to the energy problems of developing countries. The existence of substantial social disparities in these countries complicates discussion of the energy crisis. In some urban areas one finds a minority of élites living according to Western energy-and-consumer-goods-intensive styles, while literally hundreds of millions are unable to secure basic needs of water, food and clothing.

In rural India (where 70% of the people live) 95% of all the energy consumed goes for domestic cooking, and about 90% of this energy comes from wood, cow dung cakes, rice husks and coconut shells. Clearly this pattern of energy consumption requires a very different energy policy than the energy needs of the upper class suburbs of Delhi and Bombay, or for that matter of the Indian aerospace industry.

In fact, a large percentage of the rural and urban poor in these countries are so poor that they do not have any "spare" purchasing power at all. This means that it is almost meaningless to talk about any kind of new energy technology be that a simple wind mill, biogas plant or rural electrification, since the poor simply cannot afford it — and they will not be able to do so in the near future.

Therefore the question of energy in such a context must be a part of an overall development strategy, which is concerned with improved food production and improved small-scale employment opportunities. This must be achieved with the resources they have now, because as mentioned before they are unable to afford any "new" technology.

Industrialization will be necessary in those areas, but by itself that will not solve the problem of poverty. Just recently I spent six weeks in South and South-East Asia. There was only one country I visited which did not have any visible signs of real misery and hunger — and this was Burma, although their state of industrialization is minimal. Industrialization may be necessary, but it must be supplemented with the kind of social policies which definitely favour the poor. At present the rural poor do not have any energy costs in the usual economic sense. Even though it may be difficult and time consuming to collect the firewood and the cow dung cakes, it is still "free", costing no money. Most of the "appropriate technologies" people talk about cost money — and thus are not available to the poor. It is only the well-to-do farmers who might be able to build a biogas plant or a windmill — thus increasing the disparities even more. In order for the poor to be able to change to other energy technologies (as the traditional sources run out, as well as to increase their per capita energy use in time), the first essential step is to create such employment as will enable them to earn enough to purchase those technologies. No government or voluntary agency is prepared to build about 100 million biogas units in India. So the poor themselves will have to be able to buy these.

On the other hand, industry is necessary and for that some of the energy technologies at this time have to be imported from the more industrialized countries. Since the production of more complex or hard energy technologies in general needs an extensive industrial base, developing countries in general have to import them. Such a transfer of technology usually results in technical, economic and, ultimately, political dependence of the receiving country on the donor country. The supply of nuclear fuel for the Indian Tarapur reactor is a good example for this kind of dependence, although India has a very extensive industrial base capable of producing nuclear reactors, space rockets and modern electronic circuits just to name a few.

The "Energy for my Neighbour Programme" of the WCC is presently involved in a major study of the ethical and social dimensions of the energy crisis in the developing countries. We will be holding consultations in Africa, Asia and the Middle East to see how they look at the energy crisis and what they hope to do about it.

8. *Selective Inattention*

The energy problem is more than just the lack of a certain resource or technology. It has many dimensions. Selective inattention is the art of emphasizing one or two of these dimensions and neglecting the others. To a certain extent we must be selective in order not to lose our way in a sea of detail. It is not possible to solve all the dimensions of such a complex problem.

The important issue is to be conscious of *which* dimensions of the problem will be neglected and which ones will be emphasized. When I was a student of nuclear engineering at a very prestigious technological institute, I was amazed that during my five years in the Department of Nuclear Engineering none of the socio-political problems of nuclear power were ever discussed, either formally within a course or informally between students and staff. We only discussed the technical detail, and although these are very important, we neglected these other equally important dimensions.

In the rich affluent countries if we have to wait more than ten minutes at the gas station or if we have to switch to a smaller car, because we cannot afford to run big gas guzzlers, we talk about energy crisis. Here again, we are neglecting other sides of the problem altogether. For just about half of mankind, that is about two billion people, the energy crisis is threatening not their ability to buy consumer goods and to live luxurious lives, but to produce sufficient food, to cook it and to receive some minimal transportation. While we are preoccupied with our problems of perpetuating our energy-intensive life styles by introducing solar satellites and fusion power, the poor are dying in the Third World, because they are unable to cook their meal and unable to irrigate their lands because of the lack of energy for pumping. Their energy crisis is different from the one we have and we think that the churches as well as people outside them should start to pay serious attention to this problem.

9. *Future Action for the Churches*

We have not found answers in the churches to all these problems I have raised here. We did not expect to do so. Nevertheless, we feel we are on the right track by asking these kinds of questions. The best we could do so far was to work out a set of guidelines, which our member churches could use and discuss as a guide to action in matters concerning energy. The Conference thus made recommendations to the member churches as well as to the respective national governments, as follows:

Recommendation of Section VI of Energy for the Future [7]
(as approved by the Conference at MIT)

A. We recommend to the churches that they:

1) give high priority to the development of strategies for full participation in discussions and decisions regarding the energy issues within their membership, in ecumenical councils and in public;

2) insist that such participation include all classes and groups of the population with full access to relevant information and real involvement in the discussions and decisions through fair and open procedures;

3) arouse concern and conscience regarding energy decisions with specific consideration for the responsibility people bear as citizens, consumers and workers in all aspects of the energy sector;

4) identify ethical criteria by which the social impacts of energy technologies must be assessed and insist that in setting energy policy such criteria be given equal weight along-side technical and economic factors;

5) identify and utilize members with special knowledge and responsibility in the energy field who can help one another and others to be equipped for informed participation;

6) involve such experts, along with those who have insight in the theological and ethical issues, in equipping church members for participation in critical and informed deliberations and decisions;

7) develop a climate of trust and critical self-awareness in which biases can be acknowledged and corrected, differences of opinion and

conviction can be faced and conflicts be dealt with, thus facilitating a continuing programme of education, participation and choice;

8) develop education materials about the energy issue for different levels of church life which give people a chance to acquaint themselves with the discussion thus far, enter a process of honest and open dialogue and so make up their own minds about opinions to be chosen and decisions to be made;

9) engage in a constructive and critical analysis of the national and international energy policies of their own countries, engage wherever possible in open discussion with their governments about these policies and keep each other informed of both progress and problems in these efforts;

10) engage with people at the local level in projects which enable them personally and together to experiment with a life style which makes appropriate use of the available energy sources;

11) endorse, promote and support the use of the WCC 'Energy for my Neighbour' programme through their agencies and congregations.

B. We recommend to all national governments that they:

1) study the actual use of all forms of energy in their countries and not only the consumption of commercially traded fuels;

2) base the forecasts of future energy demand on the real needs for different forms of energy in the different sectors, rather than on extrapolation from aggregates of past fuel consumption;

3) provide incentives for the most rapid possible transition to the just, rational and efficient matching of energy sources to energy needs;

4) ensure that scarce resources of capital and skills are allocated in the first instance to the development of systems that will, as soon as possible, efficiently provide energy in the forms really needed from renewable sources;

5) mitigate any severe injustices between different sections of the population which may develop during the transition to efficient and renewable energy systems;

6) limit the growth in combustion of fossil fuels as much as possible, using these fuels, especially coal, as bridging fuels in the transition to renewable energy sources over the medium and long term;

7) meanwhile, use existing nuclear power plants only to the extent, for the purposes, and for the time, that there is no better alternative;

8) immediately introduce a moratorium on the construction of all new nuclear power plants for a period of five years; the purpose of this moratorium is to encourage and enable wide participation in a public debate on the risks, costs and benefits of nuclear energy in all countries directly concerned;

9) not reprocess spent nuclear fuel to extract fissile material such as plutonium — except for separation of small quantities for research and medical applications — and not construct plutonium-fuelled reactors;

10) devise short-, medium- and long-term national energy strategies designed to achieve these objectives and which are mutually compatible;

11) at all stages of the devising and carrying out of such strategies, keep people fully and honestly informed, and encourage the widest possible public participation through fair and open procedures;

12) cooperate with other governments in order to ensure that:

a) rates of consumption of the world's remaining non-renewable fuels are reduced as quickly as possible;

b) injustices between countries caused by the unequal distribution of the fuels over the earth's surface and by market mechanisms are mitigated through international agreement;

c) pollution of the environment by excess carbon dioxide, radioactivity and other by-products of the consumption of fuel is substantially researched and kept to the minimum that is technically feasible and ecologically sustainable;

d) all countries move, with all possible speed, towards the efficient use of energy from renewable sources;

e) the trend to destruction of the earth's forests be reversed;

f) there is international support to aid the autonomous capacity of developing countries for energy research and development and for self-reliant energy projects in the poorer areas of the world.

REFERENCES

[1] For more, see "A Statement by the Working Committee of Church and Society", *Anticipation* no. 26, p. 51, Geneva, June 1979.

[2] Report of the Conference "Science and Technology for Human Development", *Anticipation* no. 19, Geneva, November 1974.

[3] Preparation for and Findings of the Sigtuna Hearing. See *Anticipation* nos. 20 and 21, Geneva, May and October 1975, and Francis and Abrecht (eds.), *Facing up to Nuclear Power*, WCC, Geneva, 1976.

[4] *Anticipation* no. 23, p. 7, November 1976, and "Energy for my Neighbour — an Action Programme of the WCC", Geneva, 1978.

[5] *Anticipation* no. 24, Geneva, November 1977.

[6] *Anticipation* no. 26, pp. 32-79, Geneva, June 1979.

[7] *Faith and Science in an Unjust World.* Report of the MIT Conference, Vol. 2. Report and Recommendations, pp. 101-103. WCC, Geneva, 1980.

DISCUSSION

In presenting the nuclear part of his paper, J. Pasztor adds the following comments:

PASZTOR

If you are interested by the nuclear debate which happened at the M.I.T. Conference, I brought with me a transcription of it. You can have an idea what feelings people had about it. Some things I would like to mention, things you probably will not like, and to tell you what some people are saying about you, about scientists, energy policy makers and so on.

People, especially in those countries which have a democratic tradition, want to participate in decisions concerning energy just as well as in any other decision, but, as energy technologies become more and more complex — and this is of course very much the case with nuclear power —, they find it very difficult. Things are so complex that they cannot grasp it. There were the days when people trusted scientists, engineers and policy makers; they do not do it any more. People have been lied to, especially about nuclear power. They do not trust scientists any more. You can tell them beautiful prospect about nuclear energy, they do not believe it. They have good reasons for that. They see how the experts among themselves do not agree. There were very distinguished people sitting there who were discussing data about nuclear power, about oil and gas, and they did not agree with each other. When the public sees that, they say: "Look, even them they do not agree. How can we decide?".

People are worried about that. People are worried about civil liberties too. When I was preparing this paper, there was an article in the French newspaper "Le Monde" that, in France, they increased police forces around nuclear reactors and are reducing the possibility of strike for nuclear workers. Whether it is true or not, they read it, and they are worried. They are worried about terrorism, and maybe it is easier to poison a water supply than blow up a reactor, but it surely makes a much bigger headline if you try to blow up a reactor than poison a water well. And that is what terrorists want to do.

I think that we need time. Our technologists have advanced a great deal and our institutions have not. For example, take the Kemeny Report [1] after the Three Mile Island accident in the United States. It is clearly not an anti-nuclear report, but it does say that unless the Federal Control system changes insofar, nuclear power will not have a future in the United States. We need newer institutions which are capable of providing the infrastructures for such technologies as nuclear and others which may come. And finally, there is one point which I would like to mention. We have heard this morning two very interesting articles about nuclear energy, but these were purely technical and they completely missed what I would call, and many people would call, the issues about nuclear power.

There are other dimensions which we must not forget. There was the question of the TMI accident, which I am sure influenced many of the people, and, in addition, there was a number of reports which appeared, which said that if you conserve more energy, you can have more renewable energy sources, you can have all these things without losing GNP.

So people said: "Look, if that is true and there is an overcapacity of electric supply in many of these countries, why not stop now for a while? We will think a little more about nuclear power, we will not hurt the electric supply, so why not halt, think about it, and then if we find that it is O.K., we will go ahead later?".

One more additional comment I would like to make concerns developing countries. We have had a number of participants from the developing countries at this meeting and I do not think we really know enough about the situation there. I think that nuclear power is becoming an important issue; then it is important to really think it over: is this the right way to go, or is it not?

(1) The Commission headed by Prof. Kemeny was asked by President Carter to report on the accident of Three Mile Island.

DISCUSSION

CHAGAS

I am very skeptical about any sort of "moratorium". I am against inhibition of scientific research. Remember tbe moratorium on DNA recombination. If it would be upheld we would not have the new insulin and the producing of interferon which have so great expectations.

TEILLAC

Je suis absolument d'accord avec ce que vient de dire le Prof. Chagas. Je l'ai exprimé dans une conférence à Stockholm il n'y a pas si longtemps. Le moratoire est un non-sens technique, il arrête les expérimentations, il ne permet pas de progrès.

LEPRINCE-RINGUET

1. Je suis contre le moratoire. C'est toujours une démobilisation complète dans la science et les techniques correspondantes. C'est, en fait, un arrêt définitif que l'on n'ose pas demander.

2. Parmi les antinucléaires, il y a ceux qui rejettent la civilisation de la consommation et du gigantisme. Pour eux, l'énergie nucléaire, fer de lance de notre civilisation, doit être complètement rejetée, quels que soient les progrès. Je les comprends. Mais je réagis vivement contre les tracts apocalyptiques, faits pour affoler l'opinion avec des motifs pseudo-scientifiques (par exemple: « il y aura en 1981, autour des centrales nucléaires, 100.000 à 1 million d'enfants monstrueux ». Or, il n'y en a pas).

3. Lors de l'accident de Three Mile Island, l'évêque de Harrisburg a ordonné aux curés de son diocèse, de donner l'absolution générale à leurs fidèles. On devine l'affolement qui a suivi! Lorsque les ecclésiastiques se mêlent d'énergie nucléaire!...

COUTURE

I will take two minutes of your time to tell you a story which I borrow from La Fontaine:

In a big oak tree, there lived three families, consisting of a mother and a few small ones:

— at the top, there was an eagle's nest

— on a hole, in the middle of the tree, there was a she cat and her little ones

— a boar family was established at the bottom.

Now, one day, the cat climbed to the top and said to the eagle: "Look at the wild boar down here: she is digging the ground to make the tree fall down!".

Afterwards, the cat went down and said to the boar: "Be careful, if you get away, the eagle told me she will fly down and kill your family!".

So, both mothers decided a moratorium in their energy programs and did not dare to move any more and get food. And, after some time,

"Il ne resta personne
De la gent marcassine ou de la gent aiglonne,
Qui n'alla de vie à trépas..."

Nobody survived in both families.

WILSON

I am very sad about nuclear energy. We need all sources: coal as well as nuclear, but there is a loss of public confidence about safety of nuclear reactor, chiefly after the shock of Three Mile Island (cf. the film *China Syndrome* which remains in public mind).

Can public confidence be regained? This is uncertain and a clear evidence is needed that safety, not economy, is governing factor in design and operation of nuclear reactors.

These are possible steps towards this goal:

1. Shut down 10% of reactors, those of the worst safety records; no restart until major evidence of change.

2. Set up insurance with steeply graduated premiums based on safety record.

3. Reorganize selection and training of operators.

4. Develop and build control systems with best experience from modern chemical plants, aircraft, airline, marine and space vehicles on man-machine system with safety as paramount factor.

5. Aid utilities financially. Charge new safety review board with monitoring position and progress.

Will it be successful? I don't know without such steps if there is any hope of success.

We need public association: *safety* must be the overall overriding governing principle in reactor operation.

STARR

The largest ethical issue is the provision of energy to support improving the material status of the poor of the world, a growing population whose health and welfare are at a bare subsistence level now. This must be balanced against other risks and social costs.

Although the more efficient use of energy (conservation) is essential, only coal and nuclear provide the options to meet our future needs of the world with confidence.

PARIKH

There are great problems of technical, political and economical nature facing the nuclear development within the developing countries. But the use of nuclear energy in the developed countries makes an important contribution for us, by reducing oil consumption. We watch, with great anxiety and uneasiness, not only the oil price rise, but also the level of oil consumed by the developed countries. The oil market is so tight that 5% to 10% increase in oil consumption can mean considerable rise in oil prices.

So, I think that whatever oil can be saved either by nuclear or conservation or solar, is most welcomed by us.

DANZIN

Je voudrais faire quatre commentaires sur l'énergie nucléaire.

1. D'abord un témoignage: J'étais en Juillet dernier en Chine et j'ai rencontré une équipe de l'Institut de Prospectives et de Planification de Pékin. La Chine doit résoudre un énorme problème de nutrition et de mise au travail en raison du passage de sa population de 1 milliard en 1980 à 1,2 milliard en l'an 2000. Pour cela, il lui faut des disponibilités en énergie. La réponse concrète vient d'être donnée par une politique qui comprend le développement simultané du charbon, du pétrole et du « nucléaire » (achat d'une Centrale de 1300 MW à la France en Octobre 1980).

2. La prudence conseille de tester en vraie grandeur les différentes techniques de production d'énergie, de manière à reduire les dangers de guerre ou de rupture de l'activité économique qui pourraient résulter d'un arrêt des sources traditionnelles (huile, gaz) pour des raisons politiques.

Tester la sécurité veut dire expérimenter en vraie grandeur, c'est-à-dire construire des centrales expérimentales. Etant donné qu'il existe une crainte concernant l'ensemble du système nucléaire de production d'électricité, la seule manière de parer ces dangers, c'est de les mesurer et de les combattre expérimentalement. C'est d'autant plus vrai dans le domaine du nucléaire que les délais de réalisation sont longs. Or, une pénurie profonde de pétrole pourrait entraîner une décision grave si elle était prise sans préparation, de compenser la rupture des fournitures de pétrole par la construction précipitée de nombreuses centrales nucléaires.

3. Le danger de « prolifération militaire » est lié à la « prolifération de la connaissance ». C'est là un fait acquis; il faut examiner comment répondre à ce fait et ne pas relier la prolifération à la production d'énergie électrique.

4. Les dangers liés au charbon (pollution de l'air, accumulation de CO^2 dans l'atmosphère, etc.) me paraissent techniquement beaucoup plus grands, en tout cas, beaucoup plus « inconnus » que les dangers nucléaires.

TEILLAC

Je voudrais intervenir personnellement sur une question qui n'a pas été discutée jusqu'à maintenant de façon à susciter des discussions. C'est le problème de « public acceptance » comme on dit en anglais.

Certaines objections au nucléaire sont émises dans le public et on peut se demander ce qu'il faut faire.

Pour ma part, je vois deux choses; la première c'est d'accroître l'expérience et les résultats techniques. Il s'est accumulé, jusqu'à présent, l'équivalent de deux mille années-réacteurs dans le monde sans inconvénient majeur, et chaque jour qui passe apporte plus de force à cet argument. Le deuxième point qui me paraît important à dire actuellement, c'est que la contestation cherche à discréditer la confiance dans les techniciens qui travaillent sur les problèmes du nucléaire de façon à jeter le doute dans l'esprit du public. Ces techniciens ont, pourtant, en général, la même honnêteté et les mêmes qualités professionnelles et morales que dans les autres professions. Dans ce contexte, il est essentiel que les pouvoirs publics de nos pays, les gouvernements, manifestent leur confiance dans ces techniciens. C'est, je crois, ce qui se passe en France, où le gouvernement a pris clairement position en faveur du nucléaire en expliquant qu'il pensait que les risques étaient suffisamment faibles pour qu'on puisse procéder à un développement industriel. Dans les pays où les gouvernements prennent cette position avec suffisamment de force, le public ressent une certaine confiance dans la position des techniciens et c'est un antidote à l'action des contestataires.

Enfin, je voudrais discuter le bénéfice qu'on peut attendre de grands débats publics. On pense souvent que les grands débats publics permettent d'améliorer la compréhension des problèmes. Personnellement, je pense que débattre devant le public des questions techniques puis demander au public de se prononcer par référendum est un non-sens. Le public ne peut pas juger de questions techniques qu'il ne comprend pas. Il sera tenté de prendre des positions subjectives en fonction d'experts qui, sur un problème déterminé, ne sont jamais complètement d'accord. Chacun de nous ici qui travaille dans le domaine scientifique sait bien qu'il y a une marge d'appréciation des résultats. L'essentiel c'est que cette marge d'appréciation soit suffisamment faible, mais les discussions entre scientifiques devant le public sont sans intérêt. Je ne voudrais pas qu'on interprète mes propos comme ceux d'un adversaire de l'information au public. Je suis, au contraire, tout-à-fait convaincu qu'il est nécessaire de donner régulièrement au public une information aussi complète que possible sur tous les problèmes techniques qui se posent et de faire cette information en termes compréhensibles. Je suis donc très favorable à une information du public, mais non à des débats contradictoires qui dégénèrent en querelles de spécialistes.

Angelini

Je me propose de vous faire part de quelques considérations sur les questions concernant l'énergie nucléaire evoquées ce matin par le Professeur Blanc Lapierre et à propos des éxposés et des discussions sur ce sujet que nous avons écoutés aujourd'hui.

1. Au cours de la Conférence sur la sûreté nucléaire organisée tout récemmement à Stockholm par l'Agence Internationale pour l'Energie Nucléaire j'ai présenté une communication concernant la comparaison, au point de vue des risques, des moyens de production d'énergie. A cette occasion j'ai insisté sur la nécessité d'établir une évaluation globale de toutes les phases du cycle, de la recherche de la source primaire à la livraison de l'énergie à l'usager.

Je reprendrai dans la suite quelques observations que j'ai exprimées lors de la Conférence de Stockholm.

Il est bien connu que les sources renouvelables d'énergie utilisées pour la production de l'électricité sont généralement acceptées:

il s'agit de sources *d'origine solaire*, c'est-à-dire de l'hydraulique, des vagues de la mer, de la radiation solaire, du vent et des sources *d'origine différente*, en particulier les marées d'origine gravitationnelle et la géothermique d'origine endogène.

A l'exception de la géothermie, ces sources sont tout à fait « propres » dans le sens que leur utilisation ne comporte aucune émission d'effluents; leur conversion en électricité n'implique aucune diffusion de chaleur dans l'atmosphère ou dans les eaux.

Leur incidence sur l'environnement n'est pas négligeable surtout dans certains cas. La construction et l'exploitation des installations entraînent des risques modestes, mais non négligeables.

Etant donné que pour la production d'électricité, et sauf certaines exceptions parfois même importantes, il faut renoncer à utiliser le pétrole et, aussi, parce que nous devons réserver le pétrole et le gaz naturel pour les utilisations dans lesquelles il ne peuvent être remplacés, (industrie chimique et pétrochimique, transports...), le problème se simplifie et le choix est limité au charbon et à l'énergie nucléaire.

Il faut porter son attention sur les facteurs qui ont une influence significative dans ce choix, eu égard aux risques et aux problèmes de sûreté dans le sens le plus étendu de ces termes *en vue d'une évaluation globale comprenant non seulement les centrales, mais le cycle de production tout entier et les problèmes qui s'y rattachent.*

Le cycle de production auquel nous nous référons comprend toutes les activités, à partir de la recherche de la source primaire jusqu'à la livraison de l'électricité à l'usager.

Les points suivants que nous allons examiner sont placés dans l'ordre naturel d'exploitation des deux sources.

La recherche minière ne présente aucun problème particulier en vue des objectifs à atteindre: les risques sont modestes et les problèmes de sûreté n'existent pratiquement pas pour les deux sources faisant l'objet de la comparaison.

L'exploitation des mines de charbon présente des risques bien connus d'après l'éxperience du passé. Les victimes sont nombreuses et résultent des statistiques officielles. Un indice du risque relatif à l'extraction du charbon pourrait être exprimé par le nombre de victimes par million de tonnes de charbon extrait.

Du point de vue du risque, l'exploitation des mines d'uranium ne pose pas de problèmes: l'extraction de l'uranium comporte des exigences pour la protection des travailleurs vis-à-vis des radiations, ces exigences peuvent être satisfaites sans difficulté dans l'état actuel des connaissances.

Le traitement des minerais d'uranium comporte aussi des exigences de protection, mais pratiquement pas de risques.

Le traitement du charbon après l'extraction ne comporte pas d'exigences spéciales.

Une phase obligatoire du cycle du combustible pour l'alimentation des centrales nucléaires à eau légère ou à graphite est celle de *l'enrichissement* de l'uranium. Cette opération comporte un coût — qui ne compromet pas la compétitivité de l'énergie produite — mais n'implique aucun risque particulier.

L'enrichissement de l'uranium n'est d'ailleurs pas nécessaire dans l'alimentation des réacteurs modérés à eau lourde.

Pour ce qui concerne la sûreté, il est notoire que, dans les *centrales conventionnelles*, on n'a pas enregistré d'accidents graves, et que le plus important d'entre eux, survenu dans une *centrale nucléaire* — celui de Three Mile Island — n'a causé ni victimes ni blessés.

Pour ce qui concerne les *résidus de la combustion*, des problèmes se posent pour les centrales nucléaires; ils concernent

— les effluents radioactifs;

— le traitement des combustibles irradiés;

— le stockage du plutonium;

— le dépôt des résidus radioactifs.

Par contre, pour les centrales à charbon il y a des problèmes concernant:

— les effluents gazeux de la combustion: en particulier le CO_2, le SO_2 et les oxydes d'azote;

— les résidus solides, c'est-à-dire les cendres, qui soulèvent des problèmes de stockage, de dispersion et, d'utilisation quand celle-ci est possible.

Ces problèmes concernent le voisinage immédiat et parfois lointain des centrales thermiques.

Des experts ont soulevé des préoccupations au sujet de la diffusion dans la haute atmosphère de l'anhydride carbonique qui, à long terme, pourrait déterminer une augmentation de la température de la surface du globe avec des conséquences négatives très importantes. Suivant certaines évaluations, la contribution des centrales thermoélectriques brûlant des combustibles traditionnels y compris le charbon serait importante à ce sujet.

Il s'agit donc d'un risque à long terme comme celui qui est souvent évoqué pour les déchets des centrales nucléaires contenant des isotopes radioactifs à vie très longue.

Les problèmes de démantellement — decommissioning — ne se posent que pour les centrales nucléaires.

Notre but n'est pas celui de nous arrêter sur l'analyse des ces questions, mais d'en solliciter un examen objectif en vue d'une évaluation globale concernant toutes les phases des cycles de production confrontés, et considérant les problèmes dans leur intégralité dans l'espace et le temps et surtout en toute objectivité.

Il est superflu de souligner que les considérations qui précèdent n'ont pas la prétention d'être complètes; elles visent à attirer l'attention sur la nécessité de baser les choix fondamentaux en matière d'énergie sur des comparaisons indépendantes de toute prise de position préconçue.

2. Le Président et moi, avons évoqué *le risque de graves complications internationales*, et même de guerre, à cause de la dépendance vis à vis du pétrole de la production d'énergie. Dans toute comparaison, il apparait indispensable de tenir compte de ce risque majeur.

Il ne faut donc pas mettre de limite aux efforts à poursuivre pour remplacer le pétrole par le charbon dans toutes les utilisations où le pétrole n'est pas indispensable et, en particulier, dans la production d'énergie électrique; tout renoncement et renvoi de la solution du problème énergétique par cette voie, pourrait avoir des conséquences très graves.

Il est tout à fait injuste d'exagérer les risques du nucléaire et d'en sous-estimer les avantages. En calculant l'apport possible de l'énergie nucléaire on ne peut pas faire abstraction des conséquences extrêmement graves d'une possible aggravation de la crise du pétrole.

Je voudrais rappeler ici que le coût des retards dans la réalisation des installations nucléaires dépasse largement celui mesurable par des évaluations économiques. Pensons seulement à la quantité de matières premières énergétiques nucléaires qui, en cas d'abandon des programmes nucléaires, resteraient inutilisées. L'uranium disponible dans le monde occidental, y compris les gisements connus et présumés et les estimations sur des zones probables, atteint 5 millions de tonnes, pour un coût d'extraction ne dépassant pas 50$ (1979) par livre d'U_3O_8. Je parle des ressources « raisonnablement assurées » et des « ressources additionnelles » selon les définitions OECD-IAEA, Organisations qui ont régulièrement mis à jour et amélioré les évaluations globales des ressources nucléaires. Celles-ci, si elles sont utilisées suivant les technologies des réacteurs aujourd'hui éprouvées à l'échelle industrielle, représentent une disponibilité énergétique du même ordre de grandeur que celle des réserves mondiales de pétrole. Par ailleurs, si l'uranium est utilisé dans les surrégénérateurs, l'équivalent énergétique de ces ressources devient alors si élevé que la ressource nucléaire deviendrait presque illimitée.

Je voudrais conclure sur ce point en évoquant que tout renoncement à l'augmentation de la production nucléaire signifie l'extinction définitive de quantités équivalentes d'une matière première de plus en plus précieuse telle que le pétrole, du fait que: I) ce dernier est absolument indispensable dans des utilisations essentielles autres que la production d'électricité; II) il devient de plus en plus insuffisant; III) il est sujet à de considérables augmentations des coûts; et IV) il pose des problèmes, bien connus, de caractère international en raison aussi des difficultés d'accès résultant de la forte concentration des réserves dans des zones politiquement instables.

3. Il apparait utile de souligner la grande importance — par rapport à la possibilité de complications internationales — en ce qui concerne *l'accès*, le transport des combustibles et la constitution d'importants *stocks* d'énergie.

L'accès aux sources primaires pose aux pays importateurs des problèmes de transport qui, à égalité de potentiel énergétique, sont très modestes — presque insignifiants pour l'uranium, mais très importants pour le charbon, non seulement pour ce qui concerne les transports terrestres (en particulier chemins de fer et carboducts) qui sont très coûteux, mais aussi pour les transports maritimes qui comportent la réalisation d'infrastructures souvent très onéreuses.

Aux problèmes des transports peuvent être associés ceux du *stockage*. Le stockage du charbon, comparé à celui des combustibles nucléaires, implique des coûts considérables et comporte des limitations très importantes; la quantité de charbon constituant la réserve d'une centrale thermique ne peut en effet dépasser les besoins de quelques mois d'alimentation de l'usine.

Les combustibles nucléaires permettent de constituer des stocks correspondant à quelques années de production, à un coût relativement modeste et sans avoir à résoudre des problèmes d'environnement.

Quand le cycle surrégénérateur sera devenu une réalité industrielle, les quantités d'uranium appauvri provenant des usines d'enrichissement et de traitement des combustibles irradiés, pourront constituer une réserve stratégique d'une durée de quelques dizaines d'années.

Il est superflu de souligner ici l'importance de ce facteur, eu égard à la réduction des risques d'interruption de courant dûs aux difficultés de transport qui peuvent provenir de complications internationales, voire de la guerre.

4. Cette considération nous amène à la conclusion qu'au point de vue

— de l'indépendance énergétique ainsi que

— de l'économie de la production

la production nucléaire

— *par les centrales à neutrons thermiques* est à mi-chemin entre la production hydraulique et la production thermique traditionnelle

— *par les centrales surrégénératrices* est tout à fait comparable à la production hydraulique.

5) Enfin quelques mots sur la propagande antinucléaire pour souligner qu'elle a utilisé largement une pollution de l'information basée sur des images de centrales nucléaires qui n'ont rien à voir avec la réalité: example le « China syndrome ».

Cet appel à l'objectivité a sa raison d'être: en effet, c'est surtout à partir du début de la dernière décennie que l'on assiste à une campagne qui semble avoir pour but de désorienter l'opinion publique sur les problèmes de l'énergie, dont l'importance pour le développement économique et social des populations est vitale.

Elle a utilisé aussi une arme fallacieuse en attaquant la crédibilité des savants, des ingénieurs et en général des experts qui ont réalisé des progrès substantiels dans le domaine de la science et de la technique nucléaire, de même que dans le domaine de la sûreté.

En particulier, à la suite de l'accident de Harrisburg, quelqu'un a envisagé l'adoption d'une moratoire dans la construction et l'implantation des unités nucléaires dans certains pays.

Nous ne reviendrons pas, ici, sur les conséquences ultérieures désastreuses d'un retard dans le recours à l'énergie nucléaire pour les pays dont les ressources de combustibles fossiles sont très limitées ou nulles.

Nous allons considérer ce problème aussi sous un autre point de vue et précisément sous l'aspect du chemin vers une sécurité et une fiabilité toujours plus grande des installations nucléaires. Le progrès pour la réalisation de ces objectifs se base sur l'expérience dans la construction et l'exploitation des nouvelles centrales qui découle à son tour de l'expérience acquise avec les réalisations précédentes y compris, en particulier, les défauts constatés, l'analyse de leurs causes et de leurs conséquences.

L'interruption pendant quelques années de ce flux d'expérience et de connaissances ne pourrait avoir que des conséquences négatives surtout pour ce qui concerne le progrès dans le domaine de la sûreté et de la fiabilité des installations et cela d'autant plus que les experts et les spécialistes qui travaillent dans ce domaine auprès des constructeurs et des exploitants finiraient, dans les années de moratoire, par abandonner la technique nucléaire pour orienter leur activité dans d'autres directions.

La situation actuelle d'immobilité du nucléaire ne peut que conduire au choix entre deux alternatives:

— recours à la source nucléaire

— renoncement à l'apport de l'énergie nucléaire, avec les conséquences qu'on peut prévoir.

Ceux qui considèrent que l'utilité sociale du recours au nucléaire est grande ou même essentielle, devront prodiguer leurs efforts pour s'adresser à temps aux secteurs les plus divers de la vie sociale et, en général, à l'opinion publique; parmi les différentes actions possibles, je cite, en premier lieu, la nécessité de mettre en évidence le sens des responsabilités et la crédibilité de ceux qui soutiennent le recours au nucléaire en ayant examiné de manière exhaustive les avantages et les désavantages et constaté objectivement que le bilan est positif. En deuxième lieu, l'opportunité de rétablir efficacement la vérité à l'égard de tous ceux qui entravent une information correcte et objective et qui la polluent en répandant des nouvelles alarmantes et injustifiées à partir de positions discutables et partiales.

TABOR

Most of the discussion so far on nuclear energy and, in part oil and coal, has been in regard to the enormous needs of energy of the highly-developed countries. Clearly, solar energy is not yet mature enough to offer the immediate answers for more energy. And the problem of energy in the world today is not the availability of energy sources but a question of timing. The intensive energy sources such as oil, coal and nuclear will have to be exploited, at least in the the next future.

I feel a certain inferiority complex and it is probably shared by some of my friends from the developing countries, because most of the discussion on nuclear energy and coal energy has been concerned with the giant nations of the world, but though they have tremendous resources and capabilities, they have tremendous problems, and these are the ones we are talking about. But, I believe that it is one of the functions of this meeting to talk about the problems of the smaller countries.

The discussion we have had is hardly relevant to the smaller countries for which power stations of 600 to 1000 MW — which is where the cost of conventional and nuclear stations flattens out — are simply too big. Thus the question of transfer of nuclear capability to such countries is hardly relevant. Solar installations — about which I will talk tomorrow — flatten out in cost about 20 MW for solar pounds, and at much smaller sizes for photovoltaics, they have much more relevance to developing countries.

As regards the problems arising in the nuclear debate, my only contribution will be a quotation from C.P. Snow. He writes: "The only weapon we have to oppose the bad effects of technology is technology itself. There is no other. We cannot retreat into a non-technological Eden which never existed. It is only by the rational use of technology to control and guide what technology is doing that we can keep any hopes of a social life more desirable than our own or in fact of a social life which is not appalling to imagine". The message is quite simple: we are faced with problems created by technology, we must find a technological answer.

PASZTOR

There are a number of criticisms which were given about my report and I would like to reply to some of them. Let me emphasize that my paper is not the official position of the World Council of Churches. The recommendation is found at the back, in the summary that you have read.

1. My paper is *based* on the official position of the WCC as well as discussions at our meetings and conferences. Thus some issues I have brought up here are not part of the WCC official position, nevertheless I brought it up here, because those have been mentioned at our meetings.

2. Let me emphasize that over half of the participants were scientists and engineers. The people who made these comments were not only theologians and church-men.

3. Again the moratorium does not call for a scrapping of the nuclear industry altogether. It is only calling for a stop in the further construction of nuclear plants for a period of time, that is a slow-down if you like, so that all the problems may be fully studied by the public during this period of time. We did not deny the nuclear option to anybody by this action, neither to the rich nor the poor countries.

4. And finally to the question: "Why the WCC is mixing science and values"?

We, at the WCC, agree very much with the view of the Roman Catholic Church, that science is part of culture. If this is true, then it is impossible to talk about science without bringing in values.

ENERGY AND ENVIRONMENT

Chaired by Professor A. BLANC-LAPIERRE

ENERGY AND ENVIRONMENT

G. PUPPI

Man is demanding from the earth's system more and more energy from various sources: sun, fossil fuels and minerals, wood and hydro.

In terms of mean power over the year the primary demand is now of the order of 10 TW and will certainly increase by the beginning of the next century, probably by another factor of 2. At this level it is comparable with the global power demand for photosynthetic processes in the biosphere which is estimated actually around 40 TW. The species "man" is therefore a major component of the biosphere in terms of energy demand.

It is interesting to note how the actual and projected mean power primary demand by mankind compares with the one relative to a natural phenomenon like global geothermal heat flux estimated at 32 TW, and how it is far superior to the one dissipated globally in tidal phenomena estimated at 3 TW. It is also greater by about 2 order of magnitude in comparison with those relative to earthquakes, volcanoes and hot sources.

Only solar energy in its direct and indirect forms, as renewable source, and fossil chemical and nuclear fuels can be therefore the long range answer to the request of energy by man.

Primitive societies did indeed utilize renewable sources, burning wood, exploiting hydropower and wind. Hydropower did bridge the transition to modern societies which are now dominated by fossil fuel utilization in form of coal oil and natural gas. Modern societies are also characterized by the increasing use of energy in the form of electricity.

There has been no real energy policy in the development of modern societies for the choice of the type of source to be exploited with a conscious look at the future, except for the new form discovered some 40 years ago of producing heat through nuclear fission. Choice has been dominated by only one element until the recent crisis; the current cost.

The proof is quite simple: the main motivation in the 50's for developing nuclear energy, for civil use, despite the foreseen technological difficulties and the bad outlook of the economy, was the prediction of the inadequacy of oil and gas reserves to meet the demand at the turn of this century or at the beginning of the next one; but the same argument did not work for coal whose reserves were already at that time estimated to be at least one order of magnitude greater.

It is a matter of fact that very little money has been devoted to develop advanced technologies for coal, until recently, when coal has been rehabilitated as a fundamental option for bridging the future, together with nuclear energy, the final option of solar energy and perhaps fusion.

The recent energy crisis has shown the necessity of an energy policy hopefully on a worldwide basis, or at least inside large geopolitical ensembles in the world, characterized by serious studies and rational decisions, putting into the picture also the problem of the sources to be exploited, but also the problem of a better utilization of energy by final users, the problem of conservation of energy and the problem of environmental impact of energy production. The last one is precisely the subject I am supposed to deal with in this report; a very hot subject indeed judging from the interest and the emotion it is causing in different milieux from the scientific to the political one.

Man's impact on the environment is in principle localized: the local changes in the environment is what we call normally pollution: I am not going to discuss this point which will be covered by other contributions: I shall concentrate my contribution on those widespread effects of pollution which can be relevant, on a global scale, for systematic drifts in the earth system and/or triggering mechanisms.

These effects can be roughly grouped in the following categories and defined as:

a) an additional source of heat coming from the burning of fossile and non fossile materials (both chemical and nuclear burning);

b) an additional source for the atmosphere of particulates and various gas (in particular CO_2);

c) an alteration of the physical and chemical properties of the various interfaces between the fundamental subsystem: atmosphere - hydrosphere - criosphere - soil - biosphere.

The first effect, an additional source of heat due to any process which produces energy by burning wood, coal, oil, gas etc., or by using nuclear fission or fusion processes, is not relevant on a planetary scale. Even at the level of 40 TW of mean power, which is a figure on the pessimistic side being eventually reached half a century from now if other factors are unchanged, the increase of the mean temperature of the earth will be negligible of the order of a few percent of a degree.

Heat production by man on the other hand tends more and more to be concentrated in limited areas where the amount of heat released per unit surface can reach very high values polluting, locally, waters and air and in extreme cases, modifying local meteorological conditions.

Because the only concern with heat production is related to local effects, the sole recommendation which is important refers to the best utilization of heat as a means to improve exploitation of local resources (Energy conservation, utilization of heat at low temperature, co-generation are the known instruments to be used).

The second effect, the introduction into the atmosphere of an additional amount of particulates and gas, as a result of fuel burning, represents in the medium term, decades to centuries, the most important issue and the one of greatest concern on a global scale. As a matter of fact any variation in the content of gas and particulates in the atmosphere changes the magnitude of the "greenhouse effect" or the value of "albedo" in it and consequently the set-point for the thermal equilibrium of the earth.

The climatic system is very complex, but a qualitative idea of its behaviour can be obtained following the so called "balance models" where the balance between incoming solar energy and outgoing infrared radiation is regulated essentially by two modulating factors i.e. *the albedo for the incoming radiation* and the *"greenhouse effect" for the outgoing radiation.* Particulates floating in the upper atmosphere and stratosphere increase the albedo, particulates in the lower atmosphere contribute to greenhouse effect.

The main interest has recently been focused on CO_2 as the leading factor which regulates the earth's mean global temperature through greenhouse effect. CO_2 is present in the atmosphere and in the upper layer of the oceans and there is a dynamic exchange between the two systems. On the other hand the atmosphere is coupled with the biosphere for exchange of CO_2 and the upper layer of the oceans is coupled with deep waters which act mainly as a sink for CO_2, through the formation of carbonates.

Release of CO_2 in the atmosphere from fuel combustion (wood, oil, gas, organic matter) is a non negligible contribution already today and gives way to accumulation, given the limited efficiency of the upper layer of the oceans in connecting the atmosphere with the deep waters. Doubling of CO_2 content in the atmosphere from today's value would mean an increase in the mean global temperature between 2° and 3° in a time interval of the order of a century at the present immission rate which is around 5 *P* tgC/year.

There are extreme scenarios (where the foreseeable increase in energy demand is assumed to be satisfied completely by fossil fuel in the next century) where the increase of mean global temperature can easily be more than 5°. At this level there is little doubt that the climatic system is going to experience sensible modifications both with regard to the latitudinal distribution of wet and dry weather, and to the reduction in volume of the criosphere. Flooding of coastal civilizations, and marked dependence on latitude of agriculture are the most obvious consequences. There are still many incertitudes in the scheme described, and first of all to what extent other natural causes of systematic or random character can modify the behaviour of the system. It is therefore too early to draw conclusions of political nature on a world wide basis.

A deeper understanding of the physics of a climatic system and a more refined simulation of its behaviour are badly needed before reliable statements can be formulated. On the other hand I cannot ignore the circumstance that, if there is any truth in what has heen worked out by many people up to now, the threshold for a possible significant climatic change due to CO_2 accumulation in the atmosphere can be only a few generations ahead of us.

If CO_2 concentration in the atmosphere is such a leading parameter for the control of the climate, we can play with it to some extent because of the hysteresis shown by the system controlling the intensity of the source.

If the earth is getting hotter, which seems by the way not to have been the case in the last 40 years, after the optimum reached in 1940, the way of producing energy, now committed almost entirely to burning wood, coal, petrol and natural gas, can be modified in favour of the obvious substitutes: nuclear energy and renewable sources. Due to the already mentioned hysteresis present in the CO_2 cycle the change should be a drastic one and most probably irreversible for many decades or a century. For this reason the new energy system should point to the more advanced technologies where the fuel problem is not a problem- like on one side breeder reactors and hopefully fusion reactors for the nuclear, and solar power collected both on earth and in space on the other side.

The problem of energy production from nuclear or solar sources on earth is developed by other colleagues in this meeting, but the coming into the picture of space-based systems for providing more services to man needs a comment. There is little doubt that man, by the beginning of next century will be able to build large systems in space, if he wishes to do so.

The revolution in the space transportation system marked by the coming into operation next year of reusable launchers — the shuttles — in place of expendable launchers — the rockets, is the first step for an enlarged capability to bring in orbit much more weight at much lower cost.

The successive steps for a real industrialization and colonization of space are already clear: assembly in orbit of artefacts brought from earth, manufacturing in orbit of structural elements from raw material coming from earth, extraterrestrial mining for providing raw materials, transition from remote control to automation and robotics, organization of an outer space logistic system, colonization of neighbourhood space. Autonomous development along this avenue of space-based systems is bound to availability of large amounts of energy, and the obvious solution is solar energy harnessed in orbit. At this point what has appeared up to now as a mean for developing space system, the large availability of energy locally produced, can be considered also as a motivation for developing space systems if huge amounts of energy can be transferred from space to earth for the benefit of the earth system.

In principle the space solution to the energy problems has many features of an ideal system: energy can be sent to earth where it is needed and when it is needed; beginning and shut down of irroration are both operations with non-intrinsic delay; energy can be transferred in form of light (and in some case of shadow) or in space form of microwave beams; the building in space of a power station is an almost linear process as a function of dimensions and consequently of power output; power not conveyed on earth can be used in orbit for increasing the system and for manufacturing goods of high energy content to be transferred to earth.

If you start to walk along this avenue you find that power from space can be used not only for feeding electrical networks but for a variety of hard intervention on earth systems. Among others let me list the following: softening and steering of hurricanes; a variety of local minor weather modifications like fog dispersal or accelerated evaporation, hailstorm prevention and furthermore: acceleration of upwelling in coastal regions, illumination of critical spots during night or shadowing during day; anticipation of dawn or postponement of the growing dark; finally modulation on a global scale of sun power hitting the earth.

Recourse to space means not only availability of energy in substitution of energy produced on earth but also a powerful tool for intervention in natural phenomena and consequently on climate. Where this avenue is approaching to an end is not possible to see today; the technological problems we can foresee today do not look insuperable; the building of a large system is fundamentally a linear one and can proceed by successive additions which can follow both the market demand and the maturity of technology in order to satisfy the economics.

But there is in this exciting scenario a big question mark. Systems like the one sketched here, are for their proper nature worldwide systems or are certainly doomed to develop into worldwide systems; as a matter of fact regionalization with respect to geopolitical areas of the exploitation of space is very hard and limited to very peculiar orbits under strict rules. A worldwide agreement is therefore a basic necessity for the very existence of these systems, an almost desperate noble deed as we can see it today. Do you believe that the idea of being prepared to counteract a climatic change at its beginning with a worldwide effort could be a sufficient motivation for a better understanding among nations, for an unprecedented endeavour like the one quoted before, which also provides a strategic reserve of energy for the future? I have no answer to this question, I can only say that I will not miss any opportunity, as I am doing today, to raise the question.

The possibility to use space systems for solving terrestrial problems of an unprecedented scale is not proposed by science fiction writers; scientists all over the world are certainly working on this subject as I can judge from my personal knowledge of the activity of two working groups, one named "The Imaginators" set up jointly by NASA and ESA and one in USA named "The Innovators", and from my knowledge of feasibility studies under way of some basic elements like a large solar power station.

After this faithful excursus into the future possibilities of mankind in space let us go back to earth.

The next question deals with the possibility to intervene in controlling CO_2 accumulation in the atmosphere by other means than the drastic decision to stop burning fossil fuel. The only possibility to do it on a worldwide scale seems to reside in a better control of the exchange of CO_2 between the atmosphere and the biosphere.

Between these two reservoirs of carbon, estimated for the atmosphere at 700 PtgC for land biota something of the same order (600-1000) PtgC, plus a detritus pool even greater but more difficult to estimate (700-3000) PtgC, there is a continuous exchange whose order of magnitude is estimated ~50 PtgC/year due to the two inverse processes of photosynthesis from one side and respiration on the other side. It is clear that new or accelerated photosynthesis from one side and deforestation from the other side can change the equilibrium; due to large incertitudes in the data available the balance cannot be now defined better than ± 2 PtgC/year so we do not know if the biota represent a source or a sink for atmospheric CO_2. It is interesting to note that the quoted incertitude compares in magnitude with today's rate of injection by burning fossil fuel ~ 5 PtgC/year and with the actual yearly increase of CO_2 content in the atmosphere which is roughly one half of the last figure. Release of CO_2 from land biota to tbe atmosphere is caused mainly by burning due to shifting agriculture, to deforestation due to population increase, to wildfires in forest, burning of agricultural wastes etc.

In a possible future general policy for reassessment of energy sources, the question of shifting the equilibrium in favour of more CO_2 uptaking by land biota from atmosphere, through appropriate measures for land use, could be an important issue.

About the other links of the atmosphere with the ocean the crucial point is the dissolution of CO_2 in the mixed layer, the metabolic processes in the marine life, the transit of organic matter through the thermocline to the final reservoir of marine sediments in deep water. Carbon dioxide injected below the thermocline is a possibility already suggested, other versions of accelerating the transit through the mixed layer could be invented.

There is certainly room for new ideas on this matter.

Impact of man on the environment is not limited to CO_2 accumulation in the atmosphere; many other alterations due to injection in the atmosphere, on land and in the waters of residues of human activity have been introduced whose immediate effects of pollution are partly known but whose long term influence on the earth system is largely unknown. It is clear that we are just at the beginning of a serious investigation of the problem and progress will be achieved in the future also in the understanding of the long range behaviour of the alterations we are building up in the earth system. But the real problem is not only this one. We know from past history, when man was a negligible entity in the economy of the earth's system, that climate did change very often and we know that the last glaciation ended only 10.000 years ago, and that climate did fluctuate in historical time, and that the so-called "little ice age" happened only a few centuries ago, when still the impact of man on nature was a negligible one.

The reasons for such minor climatic changes are not yet understood; only the great ice ages have a possible explanation in terms of variations of the orbital parameters of the earth's orbit.

A new "little ice age" or a "warm climate" more pronounced than the one we enjoyed in the first half of this century can have serious consequences on the human life support system, as it is organized today. The question is to understand to what extent man's impact on environment, which has now a non-negligible weight, can trigger or accelerate fluctuations in the climate system which are an intrinsic property of the system itself, not yet understood.

The final assessment of this impact and in particular any judgement on its beneficial or not beneficial nature should be approached with great caution because of the great incertitude, not to say ignorance, we have in predicting even the sign of the possible variations due to natural causes. We have not solved the problem but we have understood that we have a problem for the future, perhaps one of the most relevant to the preservation of life.

Two extreme ways are open to mankind for the future.

The first way is to try to reduce the impact of our activities on the environment by a more intelligent handling of our operations, and try to repair some of the damages present and future; this option means essentially that we select a definite set-point, we try to keep it as far as possible undisturbed by our activities, and remain only with the incertitudes connected with natural causes.

The second way is to forget about a particular set-point and develop the capability to control the systems at least natural causes; this option is toward harder and harder technology and increasing availability of energy including eventually a large utilization of resources from space.

The extreme pathways are normally quoted for clarifying the discussion but are never a real solution and compromise will probably be the road to be taken. But how and when the elements of the two extreme options will combine together for the compromise is too early to say.

ENERGY AND HEALTH

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1. Introduction

In recent years the processes of energy production have been regarded all over the world, as mainly responsible for the deterioration of the environment and a harmful effect on human health.

The damages to health are due to the pollution of air, water and soil by the by-products formed in energy production and affect the exposed population. Also the workers in the plants where energy is produced are subject to occupational contamination.

Moreover a limited number of dramatic events in various parts of the world, whose effects were amplified through the emotional reaction of the mass media have aroused deep concern regarding the health effects of energy production, mainly in the case of nuclear energy.

This fact has induced populations and even administrations to oppose the establishment of new power plants. Therefore as there is insufficient energy for development many countries now face energy shortages.

In effect the increasing concern over industrial plants, and especially power plants, as a source of pollution and thus as a menace to health, has developed into an international movement which may take the name of anti-technological and/or ecological, and which reflects the preoccupation of thousands of people that our biosphere may become irreversibly contaminated.

This concern is indeed justified because in many countries until a few years ago the planning of an industrial plant never took into account the problem of the disposal of the by-products and wastes, gaseous, liquid or solid, except for a few very toxic substances.

The Alkali Act (1904) represents the first step in legislation regarding respect for the environment and thus for the health of the people.

Some particular devices developed by modern technology may reduce the discharge of toxic or harmful substances formed in the production of energy; but beginning immediately, old and obsolete technologies should be replaced by others which reduce to a minimum the discharge of any harmful product, e.g. closed cycle plants.

Moreover, it should be clear that every form of human activity may involve a risk and that this risk may be also a health risk. The question now is to evaluate in the field of energy production the ratio of risk, i.e. disease and even death, against the benefits of the supply of energy.

Nevertheless, although the concern is only partially justified, the impact of fear on the public is very strong, primarily because there is confusion between the problems of *technological safety* and those of *health protection.*

Technological safety is most important and all efforts should be made to provide maximum safety, but accidents can occur and should be recorded for their statistical incidence on health.

The present report examines the effects on health of the main processes of energy production, and of the systems used.

The evaluation of these effects includes generally also the unexpected and unforeseeable accidents, i.e. the so called *residual risks.* In my opinion the figures of the risks should be considered separately. They should be eventually compared to the health effects due to operation and maintenance of the power plant.

— Energy may be produced by conventional means:

a) through thermochemical processes using as fuel: oil; coal; biomasses: wood or other organic materials including new fuels (ethanol, hydrocarbons from plants);

b) through hydroelectric systems using water power;

c) using the heat from geothermal sources.

— Energy can also be produced from alternative sources:

d) by other systems related to the side effects of solar or other cosmic energy factors on the earth, such as the use of wind, waves and tides.

The production of energy through conventional and nuclear systems accounts at present for 98% of all the energy produced in the world.

2. Production of Energy in Power Plants

In order to evaluate the impact on health of the different systems of energy production the main technological processes used at present for this purpose will be here briefly summarized.

2.1. *Thermochemical processes*

The highest percentage of energy produced in the world at the present moment is thermochemical, that is, based on the energy developed in the oxidation reaction of a certain number of carbon derivatives; such as *coal, liquid* and *gaseous hydrocarbons, wood* and other suitable organic matter (biomasses).

In this reaction combustion not only carbon dioxide (CO_2) and water (H_2O) are formed and in certain conditions also carbon monoxide (CO) but also minor products, mainly gaseous or particles which are dangerous to health. The small percentage of sulphur compounds present in coal and oil gives rise in combustion to SO_2 and to dusts, the so-called particulate matter, which affects health.

2.1.1. *Oil:* The sulphur content of oil, as an example, if it is of the order of 3%, means that in burning one ton of oil 60 kg of SO_2 are formed.

This fact has been clearly established; therefore the sulphur percentage in oil to be used in burners has been limited. The oil is submitted to chemical treatment, in order to reduce its sulphur content. Low sulphur oils are used in regions with particular meteorological conditions in order to avoid the rise, in a steady atmosphere, of SO_2 concentrations which may go over the safety limits.

The effects of SO_2 in the air on the health of the population is well known, and its effects in causing bronchial diseases and severe respiratory problems in aged persons have been demonstrated.

The historical "smogs" of London and other towns in the 20's and 30's with the high number of casualties have promoted all over the world new strategies for heating and new regulations in the use of fuels, not only in power plants but also for domestic purposes.

In the emissions from combustion of oil the particulate matter should also be considered as substances harmful to man.

Although difficult, the partial elimination of SO_2 is possible in big power plants; the same applies to particulate matter.

This is impossible in small plants, mainly in single houses. This fact has led in London to a concentration of heat and power supply in big power plants with a great reduction of SO_2 and particulates in the atmosphere.

2.1.2. *Coal*: The use of coal poses the same problems, with the difference that coal sulphur content cannot be economically reduced, and thus better abatement systems should be provided for power plants. Coal combustion also gives rise to a larger amount of particles. The disadvantages of coal with respect to oil (independently from the mining stage) are well known and have therefore oriented energy production towards the use of oil.

For all the above reasons the establishment of a power plant in a particular area is not accepted by the neighboring inhabitants although, it should reduce the percentage of contaminants in the atmosphere substituting a capillary system of thousands of burners producing energy (Table 1).

2.1.3. *Energy from Biomasses*

It may sound preposterous to consider here wood in the world balance of energy production, in an era of oil and nuclear energy, but if we consider the figures and the use of these materials in the developing countries we may change our mind.

In recent years the problem of utilization of biomasses has been examined with great attention in industrialized countries in a program of alternative energies.

The *Comes* in France (1979) made a study from which in the year 2000 the contribution from solar energy to our needs would be the equivalent of 17 million tons of oil Mtep, of which 7 Mtep from wood and 3-5 Mtep from agricultural wastes.

To look at our present situation even in states like France, the use of wood and charcoal produces about 50% of the energy used in the country and in agriculture.

In the developing countries of Africa and in the Indian region, wood is largely used for the production of energy for domestic uses. According to M'beche (1980), each African uses 400 kg of wood per year. This causes a number of problems: e.g. deforestation and desertification, mainly in subdesert regions like the Sahel.

In India tons of dung from animals are burnt for the same purpose, but in this way materials which are important for the natural fertilization of soil are destroyed.

Biomasses can be directly exploited by thermochemical systems, (e.g. combustion pyrolysis, gasification, and hydrocracking) and even give rise to gas which can be utilized for the synthesis of methanol and hydrocarbons; or by biochemical procedures through hydrolysis and fermentation to methane or other *biogas* and ethanol (Chartier and Mériaux, 1980).

The limits to some of these processes are mainly economic.

In rural areas of developing countries the use of biogas is now being considered for many purposes, with the use of special engines to transform biogas into electric power (e.g. Totem).

Presently there are some difficulties at the microbiological stage because it is not easy to have microbiological conditions standardized for different types of substrates.

Gazogens, which use wood and other materials have also been utilized in the past for trasportation during periods of oil shortage, as in World War II.

2.2. *Hydroelectric energy*

Hydroelectric energy is based on the possibility of converting the power of a waterfall — that is the potential energy of water — into electric energy through the use of an electromagnetic device (dynamo).

For this purpose water should be collected in particular basins, generally obtained artificially with dams.

The impact of this system on health, considering only operation and maintenance, should be minimum. The effect of the creation of artificial lakes on the environment is quite evident: changes of climate may affect the health population.

A certain risk to health is represented by accidents of the dams. In the last twenty years all over the world the figures of casualties due to dams have been rather high, so that, contrary to the general opinion, also hydroelectric power may represent a residual risk to health.

2.3. *Geothermal energy*

So far the use of geothermal energy, that is, the use of geothermal heat tranformed into electric energy, is limited to few areas in the world (Italy, Japan, U.S., Central America) and is not of great importance in the overall production of world energy, but may be increased and developed in future years.

The data so far available are not sufficient for the moment to draw any conclusion about the impact on health, except for the occupational health of the workers.

The reuse of water for chemical exploitation (boric acid and other products) and the closed cycle make this system, with the exception of accidents, one of the safest.

2.4. *Energy from alternative sources*

Nuclear processes of energy production which we may consider between conventional and alternative systems, will be examined separately.

We should now consider other non-conventional alternative systems, which are actually in development.

2.4.1. *Synfuels*

One of the most important challenges of chemistry in the next years will be the use of coal to produce energy. It is not possible, after and in the "oil era" to think of using coal as was done in the last century and even in the first decades of this century.

The usefulness and the advantages of a liquid fuel for transportation and for utilization in engines indicate that the return to coal for the producing of energy should be mainly to obtain liquid fuels.

At present the systems for converting coal into liquid fuel which are now in operation or under advanced study are about twenty, based on different principles, i.e.:

1) *gasification*: in order to obtain gaseous fuels;

2) *gasification for the production of liquid fuels*: the gas obtained from coal, a mixture of CO and H_2 is catalytically transformed into hydrocarbons on the pattern of the Fischer-Tropsch process;

3) *hydroliquefaction*: that is, the treatment of coal under pressure with hydrogen and the separation of the liquid products formed;

4) *solvent extraction of coal* (SRC solvent refined coal);

5) *pyrolysis*.

All these systems lead to a number of products called in an oversimplification "synfuels", — but it would be advisable to call the oils "syncrudes" because they must be submitted to further refinenment — and the gases *syngas* (Josephson, 1980).

Except for World War II experience in Germany there is so far little experience in large-scale production with these systems.

The improved techniques of gasification, mainly the German Lurgi system, and the use of new catalyzers indicate great flexibility of these systems.

The first practical applications in these years were made in South Africa with the commercial production of SASOL, where a production of 40,000 barrels of liquid fuels per day is scheduled as well as great amounts of ethylene, sulphur and tars.

Gasification implies, as above reported, the preparation of a gaseous fuel principally constituted by CO and H_2 or methane and in a second stage the synthesis to methanol or that of hydrocarbons along the Fischer-Tropsch line (Casa, 1980).

It is not possible to go into technical details of these processes, which are very important to assess the impact on health of the different synfuels. A recent report by ES & T (1980) of the Synfuels Industry Seminar held in Arlington this year illustrates the number of methods for the preparation of fuels from coal and the details of the various processes which are so far not all completely developed.

It can be pointed out here that for the year 2000 a production of 6 billion bbl/daily from coal of syncrudes in the United States alone can be predicted (E. Donley, 1980).

Surely this means a great change, new technologies and the creation of a number of new products which so far are not known for their biological properties.

2.4.2. *New fuels*

New fuels must also be considered if *shale oil* and *bituminous sands* are to be used as raw materials for the preparation of liquid fuels.

Although this problem may be limited to certain areas of the world where conditions exist which permit the development of industries for the preparation of new fuels, as in the U.S.A. and Canada, its impact on health is rather important both for the techniques of separation of the carbonaceous organic matter from the inorganic support, and for the use of these oils in power plants.

In effect in both stages it may be an important factor in the health both of the workers and the population living in the neighborhood, that is, in the preparation stage of the fuel and in its use in power plants.

2.4.3. *Solar energy*

So far the practical utilization of solar energy in power plants is based on two different processes:

1) Thermal utilization of solar energy through the use of special devices reflecting solar rays at a single point in order to heat water or other liquid which is used to generate power.

2) Photovoltaic conversion, that is, the direct transformation — through the use of special solid state cells, generally of Silicium — of solar into electric energy.

The first system has been studied for a number of years but only in the present oil shortage has it been reconsidered for larger applications.

The second system implies the use of delicate materials which are rather expensive, and its use has so far been limited to producing energy for spacial devices but experimental stations are now operating in various countries. At present a number of pilot plants are under test in several countries in order to establish the practical feasibility and the economy of the system.

Only a limited amount of information is available about health effects of this system which should be "clean" from a certain point of view.

3. Nuclear energy

The production of nuclear energy involves transformations of the nuclear fuel, generally enriched Uranium which gives rise to radioactive isotopes (some of which are gaseous or volatiles (Ar^{41}, Kr^{85}, Xe^{133}, I^{131} etc.) and to α, β, γ radiation and may cause severe health effects in man if in high concentration.

The psychological impact of the use of nuclear weapons in warfare has produced a number of strict rules for the construction of nuclear power plants in order to avoid through very accurate planning the leakage of any radioactive material and the exposure of workers to radiation.

Radiation protection rules are also applied to whole populations. In these conditions concentration of radioisotopes and thus the effects of the byproducts of nuclear plants on health do not influence the level of radioactivity and should not affect man.

Exposure of workers in plants is strictly controlled under international rules. The same applies to nuclear engines on mobile vectors, such as ships and submarines.

The protection devices in this case should also avoid any contamination which would have harmful effects on the health of man and wildlife (Prodi, 1977).

A still debated, but partially solved problem, is that of nuclear waste disposal in order to prevent radioisotopes from contaminating the soil and through the soil the food chain which affects the health of man.

3.1. *Production of energy by nuclear fission*

Nuclear energy, probably because of its dangerousness, is the best controlled of all energies, and even the different systems of production are very well known.

Because of these reasons we shall not go into detail on the systems of producing energy from nuclear processes which have been discussed at a great number of meetings and whose analysis has been elaborated in various countries; a large bibliography can be found in many books and papers (Villani, 1977).

In order to establish the effect of nuclear energy production on health, the whole cycle of production of nuclear energy must be taken into account although it is only the localization of a nuclear power plant in an area which causes the strongest opposition in neighboring populations.

In the case of nuclear energy different stages must be considered:

1) Extraction of minerals containing fissile substances.
2) Preparation of the nuclear fuel.
3) Transportation of the nuclear fuel.
4) Nuclear power plant and fission.
5) Reprocessing of the nuclear fuel.
6) Transportation of nuclear wastes.
7) Waste disposal.

The possibility of contamination or accident may occur at the various stages. The sites where operations 1, 2, 3, 4, 5 and 7 occur may be very far from one another and affect different groups of population.

Energy production can take place in a power plant utilizing different systems, i.e., PWR (pressured water reactor) or BWR (power plants), but also in mobile systems such as ships and submarines, where the engine uses thermal energy produced in a nuclear reactor.

In both cases it should be borne in mind that there may be contamination and thus health risk from normal activity of the nuclear reactor, and health risk due to an accident with the nuclear reactor.

It must be clearly stated that there is a difference between safety of the reactor and the hazard due to the presence of an operating reactor, although in the overall evaluation both data concur to form a single figure.

The operating of a nuclear reactor, according to the studies made all over the world, do not affect the populations of the nearby sites more than 1/3 of the natural background, since the emission of radioactive gases and water-soluble radioactive compounds is extremely low (0.003—0,4 mrem/year) in comparison with 102 of the average world natural radioactive background.

In Rome because of particular geological composition of the materials used in buildings this figure is practically double the world average.

A comparative analysis of the effects on health of conventional and nuclear systems of producing energy will be discussed later.

The major problems in the production of nuclear energy may arise in the other stages of the cycle, i.e. production of the fuel, transportation, and recycling.

Highly sophisticated technology make it possible even at these stages to reduce the impact on health of populations and even of the workers: the available figures of the effects on workers all over the world indicate that the risk is less than that of other power plants.

Accidents or sabotage due to terrorism may cause effects on populations: but although this case implies the technological safety of a reactor, it has been demonstrated that nuclear plants are less exposed to sabotage than other plants.

The effects of the dispersion of plutonium in an inhabited area have been studied and indicate a heavy risk, but this "scenario" is only postulated in case of a terrorist attack or war and cannot be considered in the normal running of a nuclear power plant (WHO 1979).

The systems of reprocessing and the disposal of nuclear waste constitute another important and delicate stage of the nuclear energy cycle. The very strict regulations and the experience of about twenty years indicate that exposures for workers and populations are under the limits.

The waste disposal has created a number of problems in order to avoid leakages or radioactive contamination.

The problem in this case, more than health protection, is environmental protection for a remote future because so far the present systems allow the control of wastes for many centuries.

4. Energy for transportation

4.1. *Hydrocarbons* - The effects on health of the production of energy for transportation can be evaluated through the following figures: it was calculated that in U.S.A. in 1970 42% of the air pollutants were produced (CO, NO_x, SO_2) by engines used for transportation.

To these pollutants we must add the minor products such as aldehydes, unsaturated hydrocarbons, polycyclic hydrocarbons and metals in traces like lead (Pb).

In certain areas, characterized by special meteorological conditions, also secondary pollutants, which are formed by the reaction of the above substances under the effect of sunlight may be present as, e.g., nitrosyl derivatives of hydrocarbons, epoxides, etc. which are very irritant and dangerous for man. The engines most evidely used to produce energy for transportation are:

— *internal combustion motors* which use mainly light hydrocarbons;

— *diesel motors* which use high heavy hydrocarbons;

— *jet propulsion motors* heavy hydrocarbons.

The normal products of combustion are, as above reported, CO_2 (carbon dioxide), CO (carbon monoxyde), NO_x (nitrogen oxydes), hydrocarbons, polycyclic hydrocarbons, particles and SO_2 (sulphur dioxide).

The effect on health of these substances will be discussed further on.

The presence of lead in urban areas and even on the highways also constitutes a great problem for health as the effects of men's absorption of lead causes a number of diseases.

The presence of a high level of polycyclic hydrocarbons such as benzopyrene, which are known to be topic carcinogens, is another great problem.

Aldehydes are also produced in internal combustion and give rise to further reactions, with the formation of secondary products.

In the field of alternative energy sources, the use of methanol and ethanol has heen envisaged.

Methanol can be easily produced by direct synthesis from $CO + H_2$

$\rightarrow CH_3OH$, but its use as a fuel in transportation has not been carefully studied.

The combustion of methanol in the internal combustion engine may give rise to CO_2 and CO plus water but also to formic aldehyde which is quite toxic and irritant. Ethanol has been studied more and even largely used so that there is a direct experience in this field.

4.2. *Ethanol*

The use of ethanol pure or added to gasoline has been recently considered for internal power motors.

A certain experience with mixtures of anhydrous ethanol and gasoline was acquired during World War II. This showed that ethanol is a good fuel: its disadvantage is represented by the cost in obtaining anhydrous ethanol and the difficulty in avoiding hydration of the mixture.

At present in some countries the possibility has been envisaged of using a 10% ethanol-gasoline, the so-called gasohol.

Another line is followed in Brazil, where the use of alcohol that is 96% ethanol is studied as the unique fuel for internal power engines.

The source of ethanol is fermentation of carbohydrates from sugar cane, manioc, cereals and agricultural byproducts. This involves in countries like Brazil a huge investment in the cultivation of large areas (C & EN, 1980).

The impact of alcohol exhausts from motors on health cannot for the moment be evaluated for lack of experimental data, but it may lead beyond CO_2 and CO to a certain number of aldehydes and condensation products, of which we do not know the biological activity.

5. Methodologies for the assessment of the impact of energy production processes on health

Although we now have a complete knowledge of the present technologies for the production of energy, and thus of the pollutants, it is not so easy to establish the criteria for the assessment of the impact of energy on human health.

Apart from the figures, which can vary according to the parameters used, the people consider only the fact of the construction of a power plant in a certain area independently of the fuel used.

5.1. *Global impact on health*

Let us first consider the figures reflecting the global impact on health, calculated on the basis of the following factors:

Material acquisition and construction.
Emission caused by production.
Operation and maintenance.
Energy back-up.
Energy storage and transportation.

This global evaluation considers a health risk distributed over a very wide zone, not affecting just a single area and its population. For example, in conventional energy coal is produced in the U.S. and may be burned for producing energy in a power plant in the Mediterranean area; according to this parameter the health risk must be distributed among the miners in Pennsylvania or Dakota, sailors for the transport and the people living near the power plant, to say nothing of the workers who build and operate the power plant.

This global approach, although generally followed, introduces too many variables and covers too large an area which in my opinion goes far beyond the direct impact of energy production which depends on *"operation and maintenance"*.

5.2. *Local effect*

I should also like to mention the data regarding the direct effect of the *operation and maintenance* of a power plant on the health of the people living in industrial areas.

The fact that a great number of administrators and citizens oppose the building of power plants in their area is rather common in recent years even as regards conventional plants using oil as fuel.

In operation and maintenance there must also be considered the number of accidents, which may lead to casualties.

This element of risk, through not actual, is usually taken into consideration in estimating the potential danger to health from the various systems of energy production. For example, the operation of hydroelectric plants has caused considerable damage to health and some casualties in the last twenty years.

However the number of casualties for populations living near hydroelectric power plants is not comparable to the actual damage caused in the same period by power stations run with coal, oil or nuclear energy.

5.3. *Mathematical models*

In order to estimate the possible effect on health from the establishment of a new power plant, mathematical models have been elaborated to study the distribution and concentration of the various pollutants; also various devices such as high smoke stacks, different weather conditions and use of various type of fuels have been considered.

These models, are used to evaluate the effects on health of the most common pollutants produced burning coal or oil.

Recently other types of mathematical models have been proposed (Budianski, 1980).

As an example I might mention the study of an oilburning thermoelectric power plant made in Italy by ENEL in connection with the building of a such a power plant on the Adriatic coast in the Marche region (Angelini, 1972).

A complete account of this study based on mathematical models, elaborating data from different sources: geology, seismology, meteorology, morphology, demography, land use, land planning, as well as hydrology for lakes and rivers, thalassography for factors related to the sea, to the landscape and even to tourism, produced figures regarding the concentrations of pollutants in the different areas where power plants might be located.

These figures indicated no effect on health even in the worst meteorological conditions. This approach is now indispensable in selecting sites for new power plants; and even when results indicate no danger, some local authorities do not permit the establishment of new power plants, thus leading to energy shortages. It is known that several new power plants, both thermoelectric and nuclear, have not been allowed by local administrators, and in some countries law has been passed requiring that any site for a new power plant must be approved by Parliament or Referendum.

Notwithstanding the difficulties opposition to new power plants is always very strong.

This is an example of over sensitization due to the past misuse of environment.

Now even when the most sophisticated technologies and a thorough study of the effect on health and environment, indicate that a new plant involves no risk, its establishment is openly refused.

5.4. *Energy from mobile sources*

Another aspect less considered by those who study the effects of energy production on human health is the energy produced by mobile systems: automobiles, trucks, airplanes, trains, ships etc.

In this case the studies of pollution in towns can be of substantial help. It is necessary to consider, beyond the nature of the contaminants, their concentration and their effect on health.

Therefore the impact of energy production on health will be evaluated, when possible, considering both the *global* and the *local* effect on populations and workers.

6. Health effects of pollutants from energy production

6.1. *Health effects of coal and oil combustion*

Air pollution due to the production of energy in power plants and mobile engines, has been throughly studied, generally in a complex system (such as that of a town or an industrial area), where different sources contribute to the overall contamination.

Nevertheless, a direct relationship has been established between the concentration of several pollutants and a certain number of diseases.

It has been estimated that air pollution in a town can be attributed: 21% to power plants and 42% to transportation emissions. Thus on an average 63% of the total air pollution of a town can be considered to be due to energy production, whereas industrial processes account for only 14%. The maximum permitted concentration for the main pollutants has been established by various countries. These are continuously under revision because of their complexity. These figures take into account not only the concentration but also the duration in order to calculate the exposure of populations; they also establish a maximum "instant concentration".

In some cases a maximum concentration is established for the site point of immission.

These methodological details indicate that the problem is rather complex, but although the approach is not strictly scientific, a direct relation can be established between the overall quantity of immissions and the health of tbe population.

When coal is used, being a complex heterogeneous material it may give rise in combustion to a number of products. The smoke beyond the normal combustion gases contains about thirty different elements, some of them even radioactive, such as Beryllium, Mercury, Arsenic, Cadmium, Lead, Nickel and Vanadium.

Ridker (1969) considers the following diseases in the evaluation of the effect of pollution on health:

Tumors of the respiratory tract.
Bronchitis.
Acute bronchitis.
Emphysema.
Pneumonia and bronchopneumonia.
Asthma.

Serio and Spaziani (1969) and Serio (1969) have developed a model for the evaluation of impact of pollution on health, using a more complete list of diseases, where also the cost of premature deaths and absence from work are calculated.

These models are rather complicated and the input data attributable to energy production processes are not always exact, so that the results obtained cannot be completely representative of the actual situation.

However, they do indicate the long-term effect of the most important pollutants from power plants (burning coal or oil), especially sulphur dioxide and particles (Liu *et al.*, 1980).

(SO_2) at a concentration of 0,15 ppm may cause severe harm to man (bronchitis, dispnea etc.). Therefore when meteorological conditions (thermal inversion, lack of winds, etc.) do not allow dispersion of SO_2, levels dangerous to health can be reached (Governa and Paoletti, 1975).

In order to control the discharge of great quantities of SO_2 into the atmosphere, special systems are now used or envisaged (Marini-Bettòlo, 1970a, 1970b, 1972).

These considerations are of great importance for the control of power plants, but coal and oil also produce energy in mobile systems.

Other products are formed which may affect health: particulate matter, as well as lead, when additives for antiknock are used.

Devices for the abatement of these pollutants are complicated and expensive.

The contaminants produced in the exhaust of power plants, domestic heating, vehicles, etc., that is in all the forms of energy production for power, heating and transport are known (Table 1) and constitute the primary pollutants; the interaction of these substances with the atmosphere in the presence of light may give rise to secondary pollutants, constituting, according to the meteorological condition, the "oxidizing" and the "reducing smog" (Pitts *et al.*, 1978).

The nuisance of these compounds is directly proportional to their concentration.

Although it is quite clear that some of these substances cause health hazards it is very difficult on a pure epidemiological basis to establish

TABLE 1 — *Emissions in tons/year per 1000 MW from power plants.*

	Annual emission in 1000 tons	
	Coal	*Oil*
CO	0.52	0.0084
CH	0.21	0.67
NOx	21	22
SOx	139	53
Particles	4.5	0.7
Aldehydes	0.052	0.12

TABLE 2 — *Average composition of air pollutants from motor exhaust.*

CO	47 %
NOx	10 %
Particles	13 %
CH	15 %
SOx	15 %

direct correlations. Perhaps in the near future a greater number of data may make it possible to draw better conclusions. But emergency situations such as the rapid increase of the concentration of some pollutants, like SO_2, undoubtedly show the increase of about 20% of casualties among people suffering from respiratory diseases (Marini-Bettòlo, 1971).

The effects of particulate matter are very important both for its physical and chemical impact on the respiratory system of man, but there is no evidence that the tars containing polycyclic hydrocarbons cause an increase in lung cancer.

The evaluation of this cause of hazard is made difficult by the fact that many people smoke, and with a single cigarette levels of polycyclic hydrocarbons many times higher than that of air contamination in town are reached.

6.1.1. *Health and Energy for transportation*

The presence of high percentages of CO, carbon monoxide in car exhausts, causes in cities a concentration of 10-15 ppm of that gas. The acute toxicity of carbon monoxyde is very well known and causes a diminution of the capacity of blood in transporting the oxygen; when certain levels are reached death occurs. The long term toxicity of CO seems to affect cardiovascular systems and thus cause a number of diseases. Also here an assessment of its effective contribution to diseases is difficult if we consider tbat smokers inhale smoke with 400 ppm of CO.

NOx are very irritant to all the mucosa and are mainly due to motor exhaust, a catalytic process of combustion in the presence of air (Pitts *et al.*, 1978).

The techniques proposed to reduce the content of CO and NOx from motors use catalytical beds in the escapement tube. This implies also the reduction of lead in gasoline for anti-knock purposes but at the same time the necessity to increase through technological processes the quality of the gasoline with a notable increase of energy consumption (Dartnell, 1980).

The lead presence in the exhaust of cars as particles suspended in the air in the form of various derivatives has become quite a problem in recent years, even in the country because of highway traffic (Tab. 3).

Table 4 shows the amount of lead released into the air (Harrison and Laxan, 1980).

Lead pathology is well known: it may affect to some degree the

TABLE 3 — *Lead derivatives present in particulate matter.*

$PbSO_4$ $(NH_4)_2SO_4$
PbBrCl
PbBrCl $(NH_4)_2SO_4$
$PbSO_4$
α—PbBrCl, NH_4Cl

TABLE 4 — *Emissions of lead in 1975 in U.S.A.*

Origin	*Tons*
Oil combustion	100
Coal combustion	228
Auto exhausts	127.500*

* This figure represents 90% of the overall lead contribution to environment.

development of the brain in children and cause other severe diseases. The health effects of diesel engine exhausts have recently been discussed in an International Symposium, where the importance of this source of pollution for health was emphasized.

An increase of the number of diesel engines is forecast in the coming years and has been evaluated by the Symposium as 25% of the cars now on the roads.

That means an increase of 400,000 tons of particulate matter (ES & T, 1980).

The main factors of diesel exhaust which affect health are the particulate matter and the NOx. The particles in the Ames test show mutagenicity. The interpretation of tbe results and their transfer to man are not yet clear because of the lack of standardization of the methodology of the assay depending on the type of solvent used in the extraction of the particulate matter.

Although laboratory tests give evidence of the biological effects of diesel exhausts on animals, only a limited number of epidemiological data are available to draw a more definite picture.

6.2. *Health and synfuels*

The possible toxicity of synfuels has been studied by Clark (1980) at the Oak Ridge division of Fuel Chemistry in comparison to petrol, crude oils and shale-oil derived substitutes.

The tests made on the acidic, alkaline and neutral fractions, submitted to further chromatographic separation indicate in the Ames test, that not only polycyclic hydrocarbons from neutral fractions are responsible — as petroleum crude for mutagenicity but also the alkaline fractions.

These results, according to Clark, may pose a problem of safety just for synfuels. The responsible agents of the mutagenicity being azaarenes and aromatic primary amines, and even polycyclic aromatic primary amines.

This fact may cause a certain concern in the use of Synfuels, but the work is just beginning. Actually it has been shown that SRC-II (solvent refined coal) liquid reduces its mutagenicity if submitted to hydrotreating which removes nitrogen, sulphur and oxygen compounds responsible for the mutagenic effect (C. and EN April 14, 1980, pag. 32).

A rather complete study recently investigated the health and environmental effects of coal conversion technologies (Morris *et al.*, 1979) using a rather sophisticated elaboration (i.e. the Brookhaven Energy System Network Simulator, ESNS) of a number of analytical data of different supply technologies. The end use applications of central station electricity generation indicate that the following systems of health damage increase in this order:

Direct combustion of natural gas and oil.
Direct combustion of synthetic gas and oil.
Central-station electric power produced from synthetic gas.
Central-station electric power produced from coal.
Central-station electric power produced by the combustion of synthetic liquid fuels.

Moreover a number of occupational health effects specific to coal hydrogenation indicate that the major hazards, i.e. lung and skin cancer and bronchitis, should be attributed to polycyclic hydrocarbons. It must be observed that carcinogens become more concentrated in residual oils.

These latter hazards may be considered common for the old gaswork and coke-oven workers.

The present knowledge in this field is not sufficient to fully understand all the aspects of the problem, and further research is necessary to avoid hazards to the population and the workers. This is a very important point because these technologies may in the near future become the main system for the production of fuel all over the world.

6.3. *Effects of radiation on health*

It is well known that radiation produced in nuclear processes may act on the cells and on the whole body causing severe damages and even death.

Radiations in a nuclear plant may be produced in the form of rays α and β particles or accelerated beams of neutrons.

The interaction of ionizing radiations with living systems is quite complex and causes the formation of free radicals and thus the alteration of tissues.

Very strict rules have been established by the *International Commission for Radiation Protection* (ICRP) prescribing the maximum concentration of the various radio isotopes that can be tolerated in the air.

The *Maximum admissible concentration*, MAC, for radioisotopes has been proposed in various legislations, and is essentially described from the data established by ICRP.

There is a difference between the exposed workers (30 times higher because of the time of exposure) in respect to population in the limits established in 5 rem year and 0.18 rem year respectively. The cycles of the nuclear reactor are so designed that no leakage of radioisotopes or exposure to radiation is possible so that the limited emissions do not influence the background level of natural radiation.

Therefore theoretically there should be no possibility of health hazard caused by a nuclear power plant in the local environment. On the other hand, a certain risk may be calculated for professional workers in the *global* health impact assessment, where operation such as extraction of radioactive material, transportation, recycling and disposal are taken into account.

Nevertheless, the fear of an unexpected accident, the so-called *residual risk*, causes populations to oppose the construction of nuclear power plants in their neighborhood.

As an example the MAC for Ar^{41} is 4.10^{-7} in the air (microcurie per ml), for Kr^{85} it is 3.10^{-6}, for Xe^{133} it is 3.10^{-6} and for I^{131} it is 2.10^{-9}.

7. New technologies for the protection of health in energy production

As above reported a number of chemical substances are produced in power plants when burning coal or oil, and even from nuclear plants.

On the basis of experience a knowledge of acute and long term toxicology of these substances has been acquired.

This enabled legislators to establish limits of emissions from industrial power plants.

In order to respect these limits a number of devices or systems have been adopted in modern plants: i.e. the use of fuels which have been treated in order to reduce their sulphur content, the long range control of discharges in the atmosphere (e.g. the Rhine delta system in Holland with automatic monitors) the tall stacks, the chemical treatment of gas and fumes, etc.

These systems have succeeded in some area, (e.g. Tokyo, Los Angeles), in reducing to acceptable levels the pollution and thus the risk for health.

The pollutants from transportation can also be reduced by adequate technologies, although at a certain cost. Regulations in various countries establish the progressive reduction in tbe exhaust from vehicles of carbon monoxyde, nitrogen oxydes and lead (added to gasoline as tetraethyl-lead to improve its octane number).

New technologies have been recently reviewed (Felder *et al.*, 1980), which are available for reducing the health risks from "operation and maintenance" in power plants.

In the case of nuclear energy in all countries because of the particular character of nuclear fission which produces radio-isotopes of bigh specific activity, the strictest regulations have always been applied even since the first constructions of nuclear plants. These regulations have provided the maximum protection for health of the workers and of the population. The regulations are continually modified in order to provide maximum safety. If we recall some accidents from that of Windscale 19 . . to that of Three Mile Island in 1979, these caused great emotional reactions but the safety measures avoided effects on the health of populations.

* * *

It is rather difficult to establish an acceptable limit of the concentration of pollutants from power plants. A zero concentration is not realistic, though it would be the optimum for health. It is thus necessary to establish the most acceptable figure for both health protection and economy. In effect the reduction of health hazards implies considerable investment which raises the price of energy.

The problem of health protection costs was first studied by Commoner (1972). Recently Jacobs (1979) has analyzed environmental health hazards from an economic point of view. Although referring to environmental pollution, the figures are parallel to those for energy pollution, which as shown before, constitutes statistically 2/3 of the environmental pollution.

The analysis and comparison of analytical and epidemiological data show that there is a direct relationship between the degree of pollution and health costs due to diseases caused by pollution. As it is impossible to eliminate completely the presence of pollutants in the air it was suggested that a limit be found on an economic basis where *marginal abatement costs* and *marginal health costs* are in equilibrium.

Although it is doubtful whether it is possible to submit health to an economic limitation this approach is a further demonstration of the direct impact of the pollution from power plants on health.

8. Comparative evaluation of the effect on health of different systems of energy production

It is not easy to compare the impact on health of the different systems of energy production, even if limited to thermoelectric, hydroelectric, nuclear and non-conventional, because there are many different factors to consider:

1°) *the object*: that is *workers* in the plant or in other stages of the system producing energy, and the *population*, not only people living in the neighborhood of the plant, but also those affected by the long-range fall-out. (It has been demonstrated that the effects (such as acid rains) may occur hundreds of miles from the sites of the power plants);

2°) *the effects*: which are sometimes difficult to correlate with the presence of a power generating plant or pollution due to traffic. These effects are mainly long-term diseases. An epidemiological approach to this problem would require years of investigation, the mathematical *model* being quite complicated;

3°) *the risk*: in addition to short and long term health effects there is the factor risk, which involve casualties, due to accidents occurring in one of the stages of the system e.g. collapse of a dam, accidents in transportation of the fuel, both conventional and nuclear, explosion of heating vessels, uncontrolled emission of radioisotopes.

Although limited in time and dispersed in space, these factors have to be taken into account in a more detailed analysis of the effects of energy production on health and welfare.

Results of these epidemiological and statistical investigations may sometimes lead to discrepancies depending on the use made of the input data. However they cannot change the overall character of the phenomenon which thus can be considered valid as an indication of the tendency of the system (Oudiz *et al.*, 1980).

The only reliable guideline at the present time is the concentrations of different pollutants in the air during a certain time, period of e.g. 24 hours. These figures appear in national and even international regulations as maximum limits allowable and concentrations compatible with health both in confined areas (such as factories and power plants) and in open areas.

As regards radioactive emissions the limits are theoretically zero, because there is no threshold for radioactivity exposure, but also in this case a limit has been established by the ICRP (International Commission for Radiological Protection) as the maximum tolerable dose for each person (30 rem per lifetime). Over this maximum dose due to ionizing radiation-producing machines or to radioisotopes — there is a danger for health because, as we know, ionizing radiation even in low doses may affect the blood and the reproductive organs and induce mutations which may cause cancer (Prodi, 1977). We might here recall that the population of the world is subject daily to ionizing radiation from the overall natural background, which has been evaluated at 102 mrem yearly. X-rays for health control expose humanity to a further number of rem calculated as 73 mrem/year.

The radioactivity from the discharge from nuclear power plants does not perceptibly change the natural background; it has been calculated that it contributes for 0,003 mrem/year plus 4 mrem for the fall out.

For all the above reasons it is difficult to find authors or collective reports who dare to establish a direct relation between the effects of a steady or mobile source of pollution and the population health. This is much easier to establish for workers in a power plant. In this case, taking into account the number of casualties — and not environmental conditions — nuclear energy appears the safer.

This uncertainty of evaluation appears also in an excellent Report by WHO (1979) on Nuclear Energy and Health, where, in *78* pages, *only one* analyzes comparatively the effects on public health of nuclear energy and other systems of energy production.

And even in this analysis there are no figures (which may be inspiring) — but only research data of single groups. The general philosophy is that the effect on health of a source of energy, depends on the quality and the concentration of the products (or radiation) generated and released in the atmosphere. This means that we must in each case measure the concentration and calculate whether the limits are surpassed. In that case we should correlate the concentrations with the known clinical data on biological effects of radiation. Here I believe that the quotation of a few sentences by the WHO Report could be very useful for a better understanding of this problem.

"On a fixé des normes correspondant à toute une gamme de concentrations de polluants qui *semblent* produire des effets nuisibles sur la santé. Ces effets nuisibles vont de la simple gêne à l'invalidité totale et à la mort, en passant par les écarts physiologiques par rapport a l'homme, l'apparition de symptômes, les maladies déclarées, la perte de temps oeuvré et la retraite prémature". This means that much of the work is questionable.

The number of casualties reported by Comar C. L. and Sagan (1976) (Table 5) indicate that Nuclear energy is safer than Oil or Coal and thermoelectric power plants: if we compare here the data for hydroelectric plants, where in twenty years the casualties were about 5.000 in comparison to the 11, of nuclear, we will come to the conclusion that so far the most dangerous form of energy is the hydroelectric!

TABLE 5 — *Number of accidents per year during the functioning of a power plant of 1000 MW(e)* (WHO, 1978).

	Numbre of casualties
Coal	0.54 - 5
Oil	0.14 - 1.3
Nuclear	0.001 - 0.86

Maybe this is a distortion of statistics, but the figures should be fully elaborated and all the implications evaluated.

Regarding these results we must appreciate the work of H. Inhaber of the Atomic Energy Control Board of Canada (1978), who made a complete analysis of all the available data in order to establish the risk of energy production and thus to ascertain how to reduce them.

As already mentioned the study considers only total risk which includes the six components we have above mentioned.

The technologies examined are the conventional (Coal, Oil, Natural gas, Hydroelectric) the nuclear, the non conventional such as solar (thermal, photovoltaic, space heating) the use of wind and Ocean temperatures, and methanol.

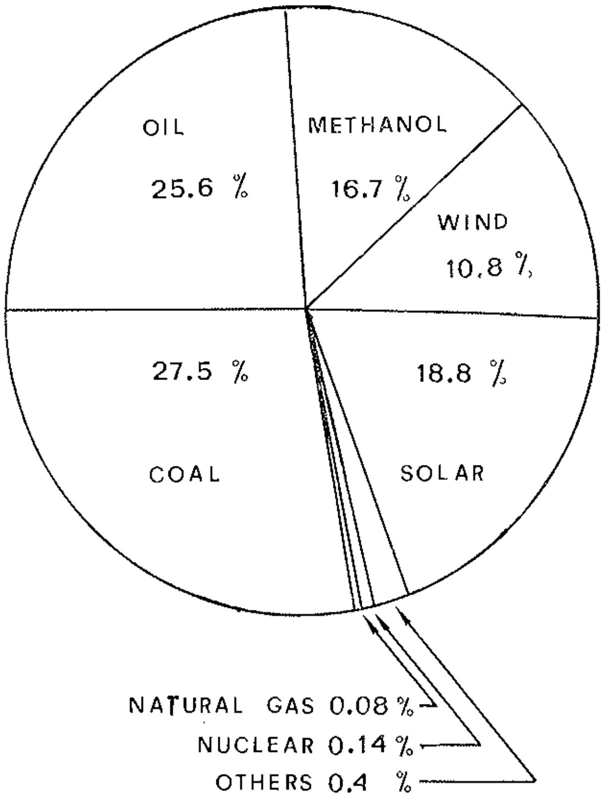

FIG. 1 — Proportion of total risk for seven conventional and non-conventional energy sources (Inhaber 1978).

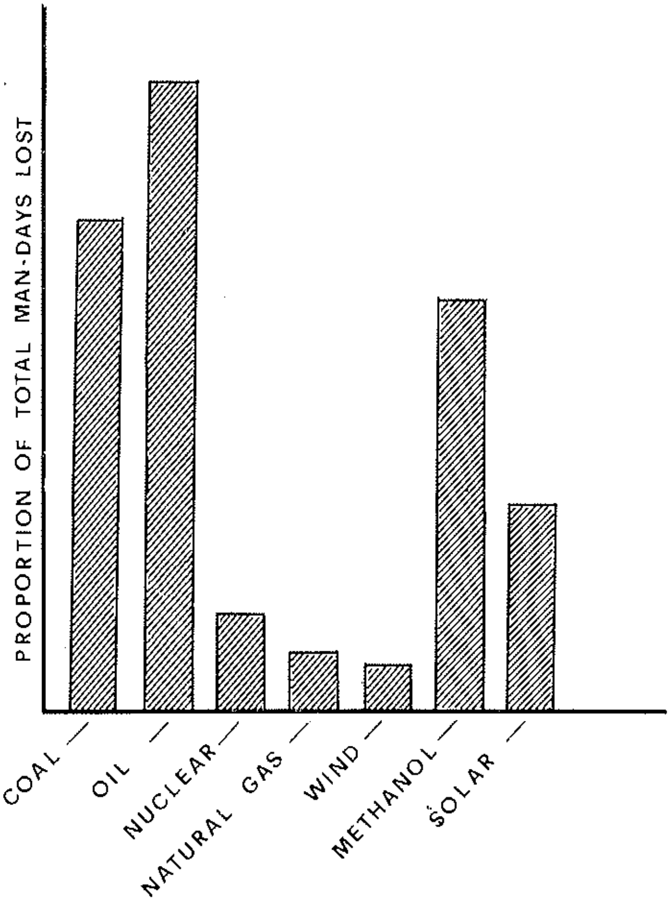

Fig. 2 — Local impact on health of energy production.

The methodology considers all the five components as factors of the health risk in a very thorough analysis of the different systems contributing to the final figure. A number of graphs point out the relationships of occupational death, occupational man-days lost on the one hand and on the other public deaths and public man-days lost. These data have been combined into one, which accounts for both occupational and public deaths and diseases (Man days lost) per Megawatt-year. This shows that the least dangerous system is natural gas, followed by nuclear energy, whereas alternative energy systems — contrary to what one might think — affect health much more than other systems (Fig. 1).

In figure 2 is represented the local impact of operation and maintenance for a Megawatt-year power plant with different systems.

An overall graph of the situation gives the proportion of total risk for these conventional and non conventional sources. Of course this system is a global one that takes into account the production and transportation of fuel. Thus the health hazard may be spread to different areas of the world (see the petrol produced in the Middle East, refined in the Mediterranean, transported to northern Europe and there consumed) but it provides a first basis for discussion and a better interpretation of the policy to be followed in protecting the public and the workers and the population.

9. Conclusions

In the presently available systems of energy production involving both chemical and nuclear changes, certain products and or radiations are produced.

Thus the impact on health and quality of life from energy production is due to the nature and concentration of these products in the human environment.

A house chimney may produce, in case of bad combustion, concentrations of carbon monoxide which in a closed area may cause death. This does not happen in power plants using tall stacks: in tbat case controlled combustion avoids the formation of carbon monoxide, which even if formed will be diluted together with other substances produced in combustion. Its effects therefore will not cause locally any harm (CEE-1973).

According to WHO, health is not only a state without illness but also a condition of well being; this should be borne in mind in order to eliminate not only toxic emissions but also smoke and bad odors.

Technology is at present able to reduce the concentration of harmful substances in the human environment to acceptable levels. The example of London, where single house heating was replaced by a number of well controlled power plants, has shown an improvement in health and air quality.

If adequate measures and technological systems, such as those mentioned above, can reduce the contaminants to levels not harmful to man, it is also possible — by the use of a modern approach such as analytical automatic devices and mathematical models for the elaboration of the power plants — to forecast, the distribution and concentration of harmful substances in the various areas.

At this point a risk/benefit balance can be drawn. The presence of a power plant, either conventional or nuclear, may involve at any site a certain health risk and even a residual risk in case of accident. It may be here pointed out that even the least contaminating form of energy, i.e. the hydroelectric, may involve risk if we consider the accidents which may occur and have occurred to dams.

The risk exists wherever there is human activity and production of energy. Therefore all available technologies should be used to prevent or reduce to the minimum all possible causes of risk. The ratio risk/benefit should be the object of study not only by economists but also by public health administrators.

The same risk/benefit analysis should be made for contaminants released in the production of energy for trasportation: here harmful substances may be produced by air, land and sea traffic. The great multiplicity and the mobility of the sources make necessary the adoption of technical measures but their control is difficult except by legislative means and strict enforcement.

Energy production is the main factor not only in the development but also in the survival of mankind, represented by more than its 4 billion persons.

Every effort should thus be made to protect the health of man.

The recent advances in research and technology indicate that this possibility exists. Reduction of immissions is possible although at a certain cost, and this cost should be supported by all countries for the health and welfare of mankind.

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DISCUSSION

Tabor

Measurements conducted on solar constant on Mt. S. Catherine in the Sinai desert (where there is no industry), showed a reduction of 10-15% on measurements done at the same site 40 years earlier (by the late Dr. Abbott) with the same instruments. This decrease is about the same as that recorded at the Smithsonian Institution in Washington D.C. I do not attempt to state the exact cause of this decrease (which is certainly *not* a reduction in the sun itself) but the moral seems to be that when we pollute the atmosphere in one place you really pollute the entire atmosphere of the globe.

Hall

Just two comments: 1) The previous estimates of CO_2 in the atmosphere due to biomass are probably five times too high. 2) If the CO_2 concentration increases to 600 p.p.m., this will be beneficial to the photosynthetic capability of plants to increase or biomass. Of great importance is the change in species distribution due to increased CO_2 concentration.

Sassin

It is not at all clear on which basis to judge the seriousness of certain pollutants: there are local effects on human beings or bio-organisms but there are also effects on global systems. CO_2 increase of a few percent over and above the natural level has no direct negative health effect. But it interferes significantly with the radiation balance. A climatic effect with all its indirect effects on bio-organisms cannot be excluded.

The fluorocarbons used in spray cans and their potential influence on the ozone layer is an other example, illustrating the conflicting assessments of a pollutant with respect to local or global impacts.

It appears that we need an ad hoc observation of the energy production methods. A major fraction of man's environments' impact depends on a rather arbitrary method of accounting. With better information on all environmental systems, we have to revise this judgement.

DÖBEREINER

A comment to Dr. Hall's observation that increased CO_2 concentration will increase plant growth. This aspect is still debatable because initial excitement of the possibility of increasing plant growth by artificially increasing CO_2 concentration has been proven to be transitory. There was an immediate response of the plant to increase CO_2 but, later, the plant responds with reduced leaf area because other limiting factors in most cases restrict growth and not CO_2 concentration.

SCHMITT

I just want to ask if there exist studies about the correlation between health and well being of man and level of energy consumption.

MARINI-BETTÒLO

There is surely a direct correlation between standards of life and public health.

CHAGAS

In analysing, in the relations between health and standard of life, I would like to remember that not all diseases or states of non health are of organic origin. The present affluence in certain nations has brought an amount of anxiety, of neuroses and other psychosomatic diseases which make it difficult to clear out the present situation.

STARR

In considering the pollution effects of energy production on health, one should also consider the health benefits of a more developed energy using society which provides better food, medical care, and prevention of endemic disease.

CHAGAS

I think that energy is also expressed in form of anxiety, of non organic damages.

COUTURE

I am aware of some dissymetry in what has been discussed this afternoon. While the disks and disadvantages of energy production and use are the subject of very detailed and numerous studies, matters tend to be much more indistinct when it comes to the advantages and benefits which human beings can derive from abundant energy. Would it be possible to have a better balance between the two opposite aspects of the relations between energy and the well-being of humanity?

PORTER

The more we have pollution the more we are evolved. I don't understand, Prof. Puppi, what is meant by a solar power satellite. The collector on earth needs a lot of land. The system will be extremely capital intensive, the system will have an enormous cost.

PASZTOR

Could you explain what kind of imports would result in the atmosphere as a result of all the Shuttle flights and their effects in the ozone layer necessary for the solar satellites?

PUPPI

The motivation for the Sun Power Satellite (SPS) stands on the following points among others.

1. Allow collection of an extra amount of solar energy otherwise lost by the earth.

2. Flexibility in the use by many customers simultaneously with multibeam antennas, at the place, the amount, the time they want.

3. Turn on and shut down almost instantaneously, providing an inherent safety of the system.

4. 24 hours duty cycle.

The above points refer to utilization for final immission in an electric network. SPS beams can be also used for hard intervention in some natural phenomena on earth like hurricane softening, steering hailstorm dissolution, etc.

Today with the technology at hand the system is too costly and requires too many flights, and cost in energy for building equals energy output in tbe lifetime of the system. Therefore major technological advances are necessary before developing the system, mainly in the reduction of the ratio weight/power of the structure and development of a more efficient space transportation system (unmanned cargo).

If so, the disposal of large amounts of energy in orbit may eventually allow the manufacturing of valuable goods in orbit and the amplification of the system itself by successive additions.

MARINI-BETTÒLO

I agree that the effects of energy production may be more than those generally considered i.e. on respiratory and cardiovascular diseases as well as on tumors.

But the problem of anxiety here mentioned, — a psychosomatic effect — is not to ascribe it to energy production but to high concentration of population and its activities in limited areas such as towns.

At this point, one should bear in mind to put clear limits to the concept of energy production and thus to their effects on environment and on health.

Otherwise, we could also have mentioned biological and animal energies which are beyond the scope of the present meeting.

SOLAR ENERGY

Chaired by Professor G. Porter

INTRODUCTION

GEORGE PORTER

In discussions of this kind there is a tendency to class solar energy with those novel possibilities for the future which can make only minor contributions at the present time. Yet, it has always been, and still is, by far the greatest source of man's energy. Even excluding its fossilised forms, oil, coal and gas, it remains our principal energy source when one remembers that these fuels are used only to "top up" the energy received from the sun so as to maintain more comfortable temperatures. Furthermore, renewable fuels such as wood, dung and vegetable oils provide the principal sources of additional heat and light for a large fraction of mankind.

Primary energy is needed in three main forms; as low grade heat, as electricity and as chemical fuels, in roughly equal proportions. These are, of course, interconvertible one to another within the restrictions of the Second Law of thermodynamics, but there is a price to pay for the conversion unless the end product is low grade heat. Solar energy can be converted directly into each of these forms and the papers of this part of our discussion deal with each form of conversion. The highest efficiencies are attainable when heat is the final product, the second highest with electricity from photovoltaic cells and the least efficient is the conversion of solar energy into chemical potential as biomass. However, biomass is *stored* energy and, in fact, chemical potential is the only form of long-term energy storage, since electricity cannot be stored in significant amounts and heat can only be stored for relatively short periods. The main disadvantage of the sun as an energy source is that it is intermittent and out of phase with our requirements so this storage over long periods is of immense importance, as nature discovered three billion years ago.

Each form of solar energy will, in the end, have to compete with non-renewable sources on economic grounds. Since the first forms of energy to be depleted will be liquid chemical fuels, the production of these from biomass is of immediate importance. Soon afterwards biogas will become important as natural gas is depleted; the main competitors being liquid and gaseous fuels derived from coal. Coal itself will be rapidly depleted when it substitutes for oil and gas; biomass will then become our principal chemical feedstock and source of stored chemical potential. Along with biomass I include purely photochemical methods of solar energy storage which, although in a very early stage of development, may eventually prove to be the most effective of all.

Although the cost of photovoltaic cells is falling dramatically, it seems likely that electricity from nuclear power will be more cost effective (except for small-scale special applications) until fissionable materials are depleted. This will probably occur over about the same time scale as the depletion of fossil chemical fuels. Thermal applications of solar energy are already cost effective, especially if one includes passive heating of dwellings.

It is very difficult to predict exactly how prices of these competitive sources will move over the next few decades but it is clear that within the next century we small become largely dependent on renewable sources, as fossil and fissionable fuels are depleted. Amongst renewable sources I include nuclear fusion since, if it can be successfully developed, the fuel supply will be so large that we may consider it almost inexhaustible. So, in the longer term, our options are very few; in fact our choice will be largely between the two forms of nuclear fusion . . . reactors which might be developed on earth and the reactor ninety-three million miles away which already works very well. We are now projecting our thoughts beyond any immediate requirements but, when one is concerned with a problem as large as the future energy supply of mankind, the necessary adjustments will require many decades, even after the research is completed.

The time when one form of energy replaces another, when solar energy replaces fossil fuels for example, will be determined on economic grounds and, in a more temporary way, by political situations. But, with so few options open to us, it would be wise to pursue each option energetically — to carry out the necessary research and pilot development so that, when the need arises, the lead time for introduction of the energy source most appropriate to the time and place is not unduly prolonged.

It is often argued that solar energy will be useful in special areas and situations but can never make a major contribution to the world's energy needs because of the large areas of the earth's surface which would be required. If one compares the area required for a solar collector with that of a coal or nuclear power station of the same power, the former is, of course, far greater. But our thinking should be on quite different lines. The essential needs of man are food and fuel with fuel becoming more and more important as we move into a technologically-based civilisation. We do not think it strange that, of the 14 billion hectares total land surface of the world, 10%, or 1.4 billion hectares are cultivated and devoted to the production of our food. It is not unreasonable therefore, that another large area of the earth's surface should be devoted to producing our second need, energy, in a similarly renewable and benign way. In fact, if the solar collection efficiency were 10%, a reasonable objective, the land area required to provide the present world energy consumption would be only one thirtieth of that devoted to agriculture, or 0.05 billion hectares. Furthermore, if the method used were photovoltaic cells or photochemistry the most suitable places would be in the 2 billion hectares of desert which have high insolation and are useless for conventional agriculture or other purposes.

The long term prospect for solar energy therefore gives us cause for the optimistic view that our energy-hungry and increasing population can be supplied with all its reasonable energy requirements. In the shorter term, each form of solar energy will develop, in competition with other forms of energy, being successful at first in those special applications and regions where it has particular advantages. Of these regions, the largest impact over the next few years is likely to be in the developing countries.

THERMAL CONVERSION OF SOLAR ENERGY

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ABSTRACT — The paper describes the collection of solar radiation in the form of heat, the different types of collector used, the optical and thermal losses which lead to efficiency equations and the relative merits of concentrating and non-concentrating collectors. Many thermal applications of solar energy are already practical and viable despite the two intrinsic difficulties of solar energy i.e. the low intensity — which calls for large collection areas — and intermittency — that calls for some form of energy storage or back-up from other sources.

A simple economic analysis provides a first approximation to economic viability for any proposed application (always providing that the necessary is available). Applicability in developing countries is sketched. A special section is devoted to solar ponds because of their potential in harnessing solar energy on a large scale.

1) INTRODUCTION

In this paper, we concentrate on thermal conversion. Apart from the age-old use of solar energy in photo-synthesis processes, the thermal conversion methods of using solar energy are currently the most widely used, being practical and viable in many cases. But there are difficulties and constraints. We thus examine these in order to see the practical applications and potential in their proper perspective.

Like the other conversion processes, thermal conversion suffers from two of the basic characteristics of solar radiation, namely, the relatively low energy density and the intermittency and time pattern of availability.

The low energy density — ranging from, at best, 1 kW/m^2 to a small fraction of this even during daytime, means that the collector areas have to be large in relation to the amount of energy they can deliver: this involves a large investment in apparatus and space.

The intermittency means that the time pattern of availability is usually quite different from that of the energy demand. Some form of energy storage is thus generally required and the equipment has to be designed to handle *peak* inputs rather than the mean. These are complicating factors that invariably increase costs still further.

Thus the paper, in addition to discussing how solar energy is collected and used, discusses also economics and the storage of heat.

2) Thermal conversion processes

A. *General*

All solar energy conversion processes are hampered by the two intrinsic characteristics of solar radiation already referred to i.e. low energy density and the irregularity of supply. As an example of the effect of low intensity, taking a mean incidence of 200 w/m^2, we would need an area of ca. 500 m^2 of collector — operating at 50% efficiency — to provide the same heat as would be provided by burning 1 barrel of oil a day. If the solar heat were used to generate mechanical power — at usually much lower thermodynamic efficiencies than when using fuel (as shown in Section 2G) — the area of collector to replace one barrel of oil a day would be even larger than the 500 m^2 quoted.

The prohlem of irregularity in the supply is covered in Section 2E on storage. Suffice it to say here that whilst technical solutions for short-term storage are available, the problem of long-term storage i.e. from summer to winter — is extremely difficult and viable solutions are not currently available (1).

The conversion apparatus itself has to contend with a number of intrinsic difficulties:

(i) All solar thermal conversion processes are based upon the absorption of solar radiation — either in its natural form or concentrated by lenses or mirrors — by a black absorbing surface. As the surface heats up, it begins to lose energy to the surroundings by conduction through supports, by conduction-convection through the air and by thermal radiation. The higher the desired temperature of use, the greater the heat losses. Thus the challenge to the solar apparatus designer is to build a

(1) A possible exception is the solar pond, discussed in Section 6.

low-cost solar "trap" i.e. a system which allows solar radiation into an enclosure but inhibits the loss of thermal energy from it. Special black surfaces — known as "selective" surfaces — and vacuum enclosures to achieve these goals are discussed later. An alternative method of reducing heat losses is to reduce the physical size of the absorber i.e. to use optical concentration to bring solar radiation over a large area on to an absorber of smaller surface area. For large concentration ratios, the system must track the sun which introduces a new set of difficulties.

(ii) In addition to the thermal losses, there are optical losses. The absorber does not absorb quite all the solar radiation incident upon it. Windows used to prevent cooling of the absorber by the wind, are never 100% transparent: the transmission can be improved by selecting non-absorbing windows as far as possible [2] or by treating the glass to reduce reflection losses. Optical concentration devices — mirrors or lenses — if used, will have their own optical losses.

(iii) The windows tend to become covered with dust or dirt which demands periodical cleaning unless a reduced performance is acceptable.

(iv) For large collector systems, the transport of energy, collected over a large area, to a central point of use, can involve serious losses of energy, though two systems discussed later — the power-tower and the solar pond — provide elegant solutions to this ploblem.

B) *Thermal Losses*

The rate of loss of heat q_ℓ from a heated surface of area A sqr meters is given by:

$$q_\ell = UA \Delta T \text{ watts}$$

where ΔT = difference between the surface and ambient temperatures
U = heat loss coefficient in watts per m^2 per °C or °K.

If we consider an absorber surface that has "transparent insulation" — in the form of a glass window and an air gap between the glass and the surface — on the upper side, and solid insulation — such as rock-wool or fibre-glass on the rear side — then the upward loss has two

(2) Ordinary window glass usually contains a small percentage of iron and results in an additional loss of transmission of the order of 5%.

major components:

(i) conduction-convention across the air gap;

(ii) thermal radiation across the air gap.

One method of reducing the air conduction-convection loss is to evacuate the space between the surface and the window. This is not considered practical for large flat absorbers — since the window would tend to collapse — but it is possible for absorbers inside cylindrical glass tubes. Such collectors are described later (3). However, even if a vacuum is used, the thermal radiation loss remains and, in fact, is generally larger than the conduction-convention loss. Thus it is even more important to reduce the radiation loss than the convection loss.

For a given geometry and temperature, the loss is proportional to the emissivity ϵ, a property of the surface, which can range from a value of unity for the most highly emitting surfaces to as low as 0.02-0.1 for polished metals. Most black paints and most non-metallic surfaces have $\epsilon \sim 0.90-0.95$. If the absorbing surface were a polished metal instead of being painted black, the radiation loss could be reduced by a factor of ten or more: unfortunately, polished metals are poor absorbers of solar radiation.

At the first World Solar Energy Symposium — held in Arizona in 1955 — it was demonstrated that it is possible to treat a polished metal surface in such a way that it absorbs solar radiation like black paint but emits like a polished metal. Such surfaces are known as "selective black" surfaces. Provided the cost of producing such surfaces is not excessive, they are cost-effective since they increase the thermal efficiency of collectors. For evacuated collectors, selective black surfaces are mandatory because reducing the convection loss without reducing the radiation loss would only result in a small improvement in performance.

(A short statement on the theory, practice, significance and literature of selective surfaces is given in Appendix III).

(3) An alternative to vacuum for reducing convection heat transfer — but not air-conduction heat transfer — is by dividing the gap into small cells — square or rectangular — in which the short dimension across the cell is of the order of a centimeter. This is referred to as a "honeycomb" or "egg-separator" structure. The walls of the cells must he transparent or very highly reflecting so that solar radiation entering the honeycomb will travel down to the bottom to strike the absorber. Despite the apparent attraction of this system cf. an evacuated system, there are considerable difficulties in making a practical viable system. (Tabor, 1969).

C) *Optical Concentration*

As already indicated, one method of reducing the effect of thermal losses — whether conductive, convective or radiative — is by reducing, relatively, the size of the absorber i.e. by optical concentration using lenses or mirrors. Although lenses can be used, they have not been considered practical: thus optical concentration, particularly in larger devices, is generally by mirrors. (See ASE 1956a and Butti & Perlin 1980 for description of early concentrators).

Very high concentrations are used in solar "furnaces" yielding temperatures of up to 3000 °C. These are essentially research tools. For most practical purposes, lower concentrations are adequate.

Because of the (apparent) motion of the sun in the heavens, optical concentrating devices have to be positioned continuously to "track" the sun — and many such solar devices have been built — and are currently under development. Tracking systems present considerable difficulties in design, control and maintenance and many engineers have doubts as to their viability except for special applications. The question arises, is optical concentration possible without the need for continuous tracking i.e. either completely stationary or perhaps a very occasional adjustment of position?

It has been shown that a cylindrical parabolic mirror with its axis horizontal in the east-west direction need not, in fact, track the sun during the day: such systems, requiring a slight tilt adjustment — say once a week — have been demonstrated in practic (Tabor, 1958) having concentration factors of the order of 3 to 4. Recent developments are referred to in Section 3B(c).

D) *The Efficiency of Thermal Solar Collectors*

Appendix I shows that efficiency E of a thermal Collector may be written as:

$$E = a - b \Delta T$$

a is the optical efficiency i.e. is a measure of the optical losses and b is a measure of the thermal losses. Since b is proportional to U/P where P is the optical concentration factor, the fall-off of efficiency with rising temperature is less steep for high values of P, which is why designers seek to increase the concentration factor P if they want higher operating temperatures. Reduction of the heat loss coefficient U — for example, by use of vacuum — has a similar effect to an increase in P.

E) *Heat Storage*

In general, the time pattern of energy demand does not match the pattern of supply. In very rare cases, such as solar distillation, it is possible to store the product — in this case distilled water. In most other cases, because of the wide fluctuations of solar radiation, either some means of storing solar energy must be incorporated, or an auxiliary source of energy must be available to provide the demand when the sun is unable to do so. In many practical systems, both heat storage and an auxiliary energy source (standby) are used since the storage may be adequate for short periods but not for long.

Short term storage is usually either sensible heat or latent heat of fusion storage. In sensible heat storage, a mass of liquid or solid enclosed in a well insulated container is allowed to rise in temperature during the charging stage i.e. when heat is put into the store, the temperature falling when heat is withdrawn. For temperatures below 100 °C, water is the most common material used, though rock-piles are often used when the heat transfer medium is air — for example, in the heating of buildings. For temperatures a little above 100 °C, water is sometimes used but the container must be designed to stand the pressures developed. For higher temperatures, oils and other fluids are used instead of water. Heat stored Q is given by the simple equation:

$$Q = MC_p \cdot \Delta T$$

where M is the mass of storage material, ΔT is the range of temperature swing and C_p is the specific heat of the storage material. For $\Delta T = 20°C$, water stores 84 kJ per litre: almost all other materials store considerably less. As a consequence, all sensible heat systems involve large volumes which lead to expensive container and heat losses therefrom. Also, the sensible heat systems give an output of variable temperature, which complicates controls and can lead to considerable loss of efficiency when the heat is used to operate a thermodynamic machine such as an absorption refrigerator or a heat engine.

Latent heat storage is based upon the fact that when a material melts, a large amount of heat is absorbed — which can be regained when it freezes. A major advantage of this system is that, for most materials, the melting takes place at a clearly defined temperature (or at least a very narrow range): the heat storage Q is given by:

$$Q = M(L + C_p \cdot \Delta T)$$

where L is the latent heat of storage and ΔT is the swing in temperature which is allowed, and which gives rise to some additional sensible heat storage.

The values of L lead to storage capacities in the region of 40-400 kJ/litre (which is equivalent to heating water over a range of 10-100 °C in sensible heat storage) and Goldstein (1961) in a classical paper, pointed out that it was unlikely that some new material would be discovered with much higher L values.

There are many practical problems in this type of storage and the types of materials proposed are not very cheap (e.g. water or rocks) remembering the large quantities that may be needed.

Long-term storage. For applications such as house heating — and to a less extent, cooling — a break-through in long-term storage would greatly improve the picture of viability of solar installations hy raising the utilisation factor u (Section 5 - Economics) to near unity. But the problem is extremely difficult. This is because the storage material is only "cycled" once a year so that the quantity needed is very large. Apart from the solar pond (see Section 6), there do not appear to be, at present, viable solutions to long-term storage based upon sensible or latent heat processes though there are some investigations on using the earth — or aquifers — as large-volume, long-term, sensible heat storage media. The alternative is chemical storage. Here, solar energy is absorbed in a chemical reaction producing say two products that can be stored separately, the energy being regained when the components are physically brought together. The splitting of water into hydrogen and oxygen is the classical example (this can be done either by electrolysis or by some high-temperature processes), the energy being regained as heat by direct re-combination or as electricity by means of re-combination in a fuel cell. Unfortunately, the storage of hydrogen in large quantities presents a new set of problems not entirely solved at this time.

(A special form of chemical storage is bio-conversion which, however, is not covered in this paper).

F) *Production of Power*

A mechanical heat engine — of one form or another — may be used to convert heat to mechanical power — which can be converted to electricity using a generator (4). It is a fundamental characteristic of all forms of heat engines that their maximum possible efficiency is limited by Carnot's Law (5) i.e. increases with increasing temperature of operation. Thus when such engines — which include piston engines, turbines and some less well-known types — are operated from fuel, the fuel is burnt at the highest practical temperature possible.

However, when operating a heat engine from a solar collector, we are faced with a contradiction: as the input temperature of the engine (i.e. the output temperature of the collector or heat store) is raised — in order to improve the engine efficiency — the efficiency of the collector falls as indicated in Section 2D: an optimum has to be chosen.

Appendix II shows how the optimum is established. The conclusions, as shown in the Table in the Appendix, are rather discouraging: except for solar collectors having a high degree of optical concentration and capable of reaching temperatures of 1000 °K or higher, the overall efficiency is quite low — usually less than 10 percent — and for non-concentrating collectors, usually less than 4%. (For solar ponds discussed later, the efficiency may be less than 2%).

Despite these low figures, thermal solar power plants have been built, especially for small local power sources such as water pumping: the question is not one of efficiency but of cost per unit of energy produced, in comparison to alternative energy sources available at the site.

In an attempt to obtain high efficiency, very high-concentration collectors have been proposed, of which the "power tower" or "central receiver" is an example. In this system, a large field is covered with "heliostat" (6) mirrors (substantially flat and of the order of 10 m^2 area

(4) Thermo-electric and thermionic devices convert heat directly into electricity: their efficiency is low but may find applicability in small systems where, however, solar cells are becoming increasingly competitive.

(5) Carnot's Law states that the maximum efficiency E of any heat engine for converting heat to power is $\dfrac{\Delta T}{T_t}$ where $\Delta T = T_t - T_c$ i.e. the difference between the hot source absolute temperature T_t and the cold sink absolute temperature T_c to which the waste heat is rejected. For ΔT small, $E \sim \Delta T/300$.

(6) See Section 3 Ba.

each) each of which is automatically oriented to direct solar radiation on to a "boiler" mounted on a high tower on the south (7) side of the field. High-temperature steam is produced and used to operate conventional steam turbo-generators. This concept is proposed for large systems — in the megawatt class — and several demonstration units are currently being built: costs appear to be high and the system can only be considered for very sunny areas.

Direct production of electricity from the sun using photovoltaic cells is discussed in Prof. Overstraeten's paper: we will not compare the two approaches, except to note that the smaller the size, the more attractive the photovoltaic approach appears because the cost per unit of power produced is almost independent of size whereas for thermal plants, the unit cost decreases with increasing size.

3) Types of collector

Solar collectors can be divided into four main classes:

(A) flat-plate;

(B) concentrating collectors;

(C) flat-plate with booster mirrors: this is a stage between (A) and (B);

(D) evacuated tubular collectors.

(Special types of collectors — such as solar cookers, distillers and solar ponds — are dealt with separately).

(A) *Flat-plate collectors.* These comprise a flat-plate usually of metal, though recently plastics have been proposed for low-temperature applications, having channels or tubes in which flows a fluid to be heated. (For air heaters, the channels may be omitted, the air passing across the back of the plate). The plate is suitably blackened to increase the absorption of solar energy to a maximum. A few cm above the plate is a glass or transparent plastic window — to prevent chilling of the plate by the wind — and the back of the plate is insulated with a few cms of suitable insulation to reduce heat loss from the rear. The plate,

(7) In the northern hemisphere.

window and rear insulation are mounted in a water-tight box. Unit size is usually of the order of 1-2 m^2.

The collector is mounted to face the sun (i.e. facing south in the northern hemisphere) tilted to the horizontal by an angle about equal to the site latitude: often the tilt is set some 10° more than the latitude angle in order to help the collection in the winter period, sacrificing some collection in the summer.

The flat-plate collector will not easily surpass the 100 °C level so that its application is limited to water heating, house heating and perhaps for absorption cooling: it is, however, the most widely used form of collector.

Because the collector must be durable, it is not as low in cost as one might expect: as a water heater, it almost invariably competes with electric water heating and usually with oil or gas heating unless the local cost of these fuels is particularly low.

A special form of flat-plate collector ([8]) uses a horizontal plastic bag containing a few cms depth of water: there is insulation at the rear and sides and a transparent cover above the bag. One advantage of this system is that the bag can be made very long so that a large area is obtained with a minimum of plumbing. However, the temperature of operation is severely limited and the lifetime of the plastic is, in general, far less than that for a metal absorber.

(B) *Concentrating collectors.* As indicated in Section 2C, higher temperatures can be obtained by concentrating a large area of solar radiation on to a small area absorber. Concentrating collectors are in three classes:

(a) High-concentration types, with concentration ratios in excess of 50 and as high as several thousand. Such systems require continuous tracking of the sun both altitude (i.e. north-south) and azimuth (i.e. east-west) movement and are referred to as two-axis concentrators. The classical form is that of a paraboloidal mirror and, when the main purpose is to obtain high temperatures, the unit is referred to as a solar furnace.

Rotating a large paraboloidal structure is difficult and one solution — used initially for the solar furnaces in France — is to have the

([8]) Sometimes referred to as a "shallow solar pond".

paraboloid stationary and use a very large flat mirror — referred to as a heliostat — that, following the sun, directs the reflected beam to the fixed mirror. Moving large heliostats is also a problem so that the next stage of development has been to use a large number of small heliostatic mirrors each separately commanded to follow the sun (9). Pioneer work was done in this direction by the late Prof. Francia (1961) in Italy: the concept has been taken over by the U.S. and other solar groups in the development of the central tower power concept referred to in Section 2G. The economics of these systems is still questionable. Furthermore, operation that depends upon the solar beam, is poor in cloudy areas: a few hours storage capacity seems mandatory; viable long-term storage appears remote.

(b) One-axis tracking collectors. For many applications particularly in industry — or for power production on a small scale — the complexities of two-axis tracking systems are unnecessary and a simpler form is possible. These are based upon the cylindrical parabola — or optical variations there-on — which concentrate the solar beam on to a *line* focus, the cylinder being rotated about its cylindrical axis so as to keep the solar beam on a linear absorber at the focus. The cylindrical parabolic mirrors may be mounted with the axis north-south and horizontal — as was done with the famous 50 HP Shuman-Boys plant in Egypt in 1913 (ASE 1956 b) — though it is better (though not convenient for large units) to tilt the axis to the latitude angle. In theory, such systems could provide a concentration ratio of about 200: in practice, 50 appears an upper limit. As with the two-axis systems, the mirror may be split into a series of strips each separately oriented, in order to avoid movement of a large unit structure.

Linear tracking concentrators have frequently been proposed for small power plants (a few kW up to 50 kW) and some units have been built. High initial and maintenance costs seem to have inhibited widespread use of these collectors though R & D is continuing in many laboratories.

(c) Stationary or semi-stationary concentrators. In Section 2C, we have already indicated that it is possible to buid a linear concentrator mounted horizontally in an east-west direction — having a moderate

(9) Archimedes is said to have used this principle in 212 B.C. to set fire to the enemy fleet off Syracuse, using the polished shields of his soldiers as mirrors.

degree of concentration — that does not have to track the sun continuously, though periodic adjustment of the tilt (a few times a year) is needed if a concentration factor more than 1.7 is required. Winston (1974), in a very elegant generalised treatment, showed that the limiting value of the concentration ratio P is given by:

$$P_{max} = 1/\sin \Theta$$

where 2 Θ is the angular limit of the heavens over which the mirror can concentrate. (For a mirror, stationary the whole year, Θ would have to be about 36° and $P_{max} = 1.7$: if the mirror is adjusted twice a year — at the equinexes — $\Theta \sim 18°$ and $P_{max} \sim 3.2$: for weekly adjustment, Θ would be about 6° and $P_{max} \sim 10$). Practical concentration factors are usually less than P_{max} because economic optimisation suggests truncating the mirrors, resulting in some loss of concentration (Tabor, 1977).

The focus, heing a line, suggests the use of evacuated cylindrical absorbers (discussed in the next section): this low-loss absorber — and the moderate concentration factor possible with a CPC — provides an elegant answer for intermediate temperature collectors — say to 200°-300° C.

All this is not to suggest that all the problems have been solved: costs are still high and problems in the field still persist.

(C) *Flat-plate collectores with mirror boosters.* Where only a very small concentration is required — and the problems of continuous tracking are to be avoided — flat-plate collectors can be used with flat mirrors added on one or more edges to provide a small boost of energy. The system appears to have been first demonstrated by Shuman in 1911 (ASE, 1956c). The mirror is usually cost-effective if the lahour of occasional, but mandatory, tilt adjustment is free. Some examples of booster systems are given by Tabor (1966).

(D) *Evacuated tubular collectors.* These have already been referred to in Section 2B. The evacuated envelope is a glass tube 1-2 m in length and 5-10 cm in diameter. Performance is good but costs are still high because the area per unit is necessarily limited, and glass-metal seals, where used, are expensive and fragile. The cost becomes less significant when tbe unit is used with a concentrating mirror, but the dangers of overheating are increased.

4) Applications

A) *Water heating*

This is by far the most widespread non-agricultural application of solar energy, probably because of its basic simplicity and because it is usually more viable economically i.e. a shorter-period payback — than most other solar applications. (In Israel alone there are 3-400,000 domestic hot water installations ([10]) i.e. about one in three families use the sun for water heating: all new buildings will incorporate solar water heating by law).

There are two main types — the thermosyphon and the pumped. In the former, a storage tank is mounted above the collector (which is almost invariably of the flat-plate type as described in Section 3A) and heated water circulates between collector and tank without the aid of a pump. Such systems are trouble-free and work for a decade or more without any maintenance. However, they are limited to warm regions where frost is not expected. In colder climates (or in areas where the storage tank cannot he on the roof) pumped systems are used: the collector may use an antifreeze solution that passes its heat to the storage tank via a heat exchanger: an electric controller activates the pump. Such systems are less efficient and somewhat more costly than the thermosyphon systems.

A storage tank — of usually about one day's capacity — is invariably employed: an auxiliary source of heat is needed to allow for prolonged sunless periods. The collector area for a family is a few square metres. As a substitute for electric water heating, the payback time in most areas is a few years unless very low-cost electricity is available. Payback time against fuel oil is usually longer: where cbeap natural gas in available, the solar water heater has difficulty in competing.

B) *Air heaters*

Air heaters — used usually for house heating or drying purposes discussed below — are generally of the flat-plate type hut are lower in

([10]) This corresponds to approximately 2% saving in oil imports.

cost, as liquid-carrying pipes are not needed and their associated corrosion problems avoided: freezing is also not a problem. Efficiencies (i.e. the amount of heat delivered per m^2) are lower than for liquid heaters and large ducts and fans are needed to circulate the air. Nevertheless, it is claimed that solar air heaters are economically viable in many cases.

C) *Drying*

Primitive drying of fruits and other agricultural products in open trays is unhygienic and can lead to excessive spoilage. Solar air heaters can be particularly valuable as a replacement for such primitive systems, as well as for fuel used for drying in more advanced societies.

Two practical problems appear: (i) the drying season may not extend over more than a fraction of the year: thus the use factor u (see Section 5 on Economics) is low; (ii) in primitive societies there may not be power available to operate the blowers.

It is to be expected that, as the primitive methods are forcibly displaced (because of minimum quality standards demanded by the customers), more and more development in solar drying techniques will take place. Kilkis (1979) presents an interesting account of some such developments in Turkey.

D) *House heating and cooling*

The developed countries use as much as 30% of their primary energy sources for the heating and cooling of buildings, most of which, having been constructed at a time of cheap and plentiful supplies, are very wasteful from a thermal point of view. Thus improving the insulation and other conservation methods is a first step: a second step (easier for new buildings than for old) is to design the building — orientation, windows, natural ventilation, thermal mass, etc. — to "match" the local climate: this approach is now referred to as "passive design".

In many countries — in particular the U.S.A. — a great deal of work has been and is being carried out using "active" solar systems for the heating and cooling of buildings and several thousand such buildings have been constructed. Economic viability is still questionable: the absence of a viable seasonal storage system means that, for the heating of buildings, the available solar radiation is low during the season it is most needed and the energy gained by the collectors in summer has to be jettisoned. For summer cooling, the match between solar availability and energy demand is better but by no means ideal. Furthermore, absorption cooling calls for higher temperatures than the simplest flat-plate collectors can provide efficiently so that more sophisticated collectors (such as the evacuated-tube type) are needed. A further reason for high cost is that the control system is generally more complex than for a non-solar house and auxiliary heating and cooling facilities are almost invariably needed, as a solar installation would be over designed if it could — by itself — handle the most extreme weather conditions that can occur.

The author's view is that, in selected areas, a case can be made for viable heating and/or cooling of buildings: as experience grows, the area of applicability will grow also.

E) *Solar cookers*

In developing countries where cooking in the villages is done using wood — and deforestation is occurring — the idea of using solar cookers is attractive. In the last 30 years, solar cooker designs have been reported from India, the U.S.A., Canada, Israel and other countries and some, at least, have operated quite effectively.

There are two types — the "hot-box" type which produces a moderate temperature for slow baking operations and the focusing type (an ultra-simple two-axis concentrator) that produces higher temperatures for boiling of water, roasting, etc. ([11]).

Yet solar cookers have not "caught on" — even in a country like India where, in the absence of wood, cow-dung is burnt, thereby further impoverishing the local agriculture. The reasons appear social and economic: social in that the device requires a change in habit, and economic in that, for poor communities, governments and other local agencies (agricultural banks for example) have not been prepared to finance the acquisition of solar cookers by the peasants even if this would have helped the overall economy (in preventing deforestation or the burning

([11]) See Butti and Perlin (1980) for description of early hot-boxes, starting in 1767, and early focussing types from mid-eighteenth century. The Brace Institute at McGill University, PQ, Canada, has prepared working drawings to assist developing countries to build their own cookers.

of cow-dung). The market is too poor and dispersed to attract private entrepreneurs.

The author feels there is a place for solar cookers but their use would have to be promoted by a central or local agency.

F) *Distillation (desalination)*

In arid areas having access to saline wells or sea water, the ability to desalinate such water can make the difference between survival and extinction of communities. The sun may be used either directly, in a solar still, or indirectly as a source of energy for a conventional desalination plant.

The solar still is a simple device, usually in the form of a glass-covered tray: a large unit (5000 m^2) was built in Chile in 1872 (ASE, 1956d) and was in operation for about 40 years. Attempts to use transparent plastics instead of glass (which is difficult to ship to remote areas) has not been too successful as experience in some Greek installations has shown. There is nothing "wrong" with the simple still except that the cost of water it produces is high — of the order of \$ 6/m^2 according to Tabor (1978a). Thus the solar still — with an output, in round figures, of 3 litres per day per m^2 — can be very useful for supplying small quantities of potable water for domestic needs, where other fresh water supplies are not readily available: the water is too costly for agricultural uses. In such cases, a conventional distillation plant is needed, preferably of the new low-temperature multiflash types as developed in Israel that need input temperatures in the region of 70 °C, which are readily obtained from solar collectors. Since such units are designed to produce *large* quantities of desalinated water, a large collector is needed and the solar pond seems a natural choice (Tabor 1975). For such large units, the cost of desalinated water can be an order of magnitude lower than for basin-type stills.

An important general document on solar distillation was issued by tbe UN (1970).

G) *Pumping of water*

This is a special case of solar power and is important because, in many arid areas, the pumping of water is more vital than any other power use. Pumping in remote areas, when windmills or water mills are not available, is usually carried out using small diesel or gasoline engines. Maintenance has proven very difficult and fuel, delivered to the site, has become very expensive. Thus the solar pump — with its own local replenishing source of energy — is very attractive and numerous efforts have been made to produce successful small solar power units for pumping. The very small use of such units to date indicates that the problem is not simple. First are the economic difficulties: the units require capital which is generally not available to the local community. Then there are the technical difficulties. Most of the units to date have been piston-engine types of low efficiency and which frequently break down. If more sophisticated collector systems are considered (to improve efficiency), there is often a lack of skilled personnel to install and maintain them. Completely sealed vapour turbines, which require no maintenance, have been proposed and actually used in one or two applications: with the development of collectors tailor-made to this application, many more solar pumping units can be expected to go into the field in the next decade — if the necessary financing is made available.

5) Economics

The decision to use solar energy for any particular purpose will be decided — apart from the technical questions of whetber it can be delivered in the form needed — by its cost *relative to alternative sources of energy available at the site.* But "cost" for solar energy is primarily the cost of capital: thus many poor countries or communities may be obliged to continue to buy fuel — on a pay-as-you-use basis — instead of switching to a solar source which, on life-cycle cost basis, may be more economically viable.

The determination of the true cost of solar energy vis-a-vis alternative sources is an extremely complex process, which will not be attempted in this paper. Faute de mieux, we will omit all sophistication from the calculations and treat the collected solar energy as an economiser of fuel (or electricity) ([12]). No allowance is made for saving of installed capacity

([12]) The treatment given is suitable — as a starting point — for individuals, and for companies that are compensated in the accounting procedures for substituting a fuel expense by a plant investment.

i.e. we assume the generating equipment or furnaces for heat production needed without solar energy are still needed.

By equating the annual cost of one m² of a solar installation with the cost of fuel to produce the same number of joules as the collector produces, we obtain at once, for the condition of economic viability:

$$K < 0.25 \times 10^{-10}\ QuFYE_c/E_f \text{ or } 0.25 \times 10^{-10}\ QuFE_c/E_fJ$$

where:

K = maximum permissible investment in the solar collector system (collectors, storage, converters installation costs, etc.) in $/m².

J = total annual charges on capital i.e. interest plus amortisation — expressed as a fraction of the investment ([13]). (It is convenient to add in here the annual maintenance costs expressed in the same form).

Y = 1/J = payback-time in years.

Q = total annual insolation *in the plane of the collector* in Joules/m².

F = cost of fuel, *delivered to the site*, $/ton.

u = utilisation factor i.e. how much of the energy delivered by the collector system is actually used during the year.

E_c = mean annual efficiency of the collector system.

E_f = efficiency of the fuel-burning system. The fuel is assumed to have a calorific value of 4×10^{10} Joules per ton.

If the cost K of the system is given, the pay-back time Y is given by inverting equation (10):

$$Y = \frac{4 \times 10^{10}\ E_fK}{QuFE_c} \text{ years.}$$

If the value of Y obtained is greater than 1/J where J is the *actual* total annual charges, then the system is simply not viable from an economic point of view.

([13]) The writer here assumes that the cost of capital is based upon a fixed interest charge and ignores inflation. This is founded upon the assumption that inflation will affect fuel and electricity prices to the same extent as it affects all other prices and the value of investments. This assumption is not necessarily correct but the economists are by no means agreed as to what would be a more correct calculation method.

In competing with electricity, instead of equation (10) we use equation (11).

$$K < 0.278 \times 10^{-6}\ QuYcE_{cc}$$

where E_{cc} is the efficiency of the collector system *together with any heat engine used.* (For photovoltaics, E_{cc} would be the solar cell efficiency including losses in batteries, diodes and control systems).

c = cost of alternative electricity at the site, in \$/kWh. (The constant converts kWh to Joules).

Or, inverting equation (11) when K is given, the payback time Y is

$$Y = \frac{3.6 \times 10^{6}\ K}{QucE_{cc}} \text{ years.}$$

If the solar installation is used to heat a building in the winter, the value of u can be quite small (assuming no seasonal storage): this can have a profound effect on economic viability. A similar argument occurs if the solar energy is used solely to cool a building in a climate with a short hot season, though the match in this case is generally better than in the heating case. (It is for this reason that, in the U.S., in areas having a climate requiring heating in winter and cooling in summer, accent has been placed on using solar energy for both purposes).

In the case of domestic solar water heating, there is a year-round demand — which may actually be larger in summer than in winter — so that the value of u can be high — unless the collector is oversized.

Note that where solar *heat* is used to replace *electrical* resistance heating, the value of E_{cc} in equations (11) is the same as E_c used in equations (10).

If the solar installation is intended to produce power for injection into a grid, the value of c is the same as in the previous case, but E_{cc} is now much lower than E_c.

For a solar power installation in a developing country — to replace a diesel or other local generator in a remote place — the value of c can be very high indeed: costs of over a dollar/kWh are reported in some cases though 15-30 cents is more usual. These high values of c give the solar plant a good chance of being economically viable.

6) Solar ponds

The solar collectors discussed in Section 3 are all small units of a few m² area: even the large central receiver concept is made up of many small units. By comparison, a solar pond is a large-area collector in the form of a mass of water which is probably the lowest-cost, large area collector system conceivable. The ocean is also a large-area solar collector and attempts have been made — and are still being made — to harness this heat for power purposes. But the temperature differences available (of 20 °C max) make exploitation difficult.

Normally, a pond or lake exposed to solar radiation will not heat up more than a few degrees above ambient. This is because, when solar radiation penetrates the pond and reaches the bottom, the water there becomes heated and rises to the surface by convection, where the heat is rapidly dissipated to the atmosphere.

Convection can be suppressed by the imposition of a density gradient — by the dissolution of salt in increasing concentration with depth ([14]): water heated at the bottom remains there — and is insulated by the non-convecting water above. As a result, temperatures of over 100 °C have been recorded at the bottom of such ponds, though 90 °C is a practical working upper limit. The top of the pond is nearly at ambient temperature. Thus, for power production purposes, there is available a hot source and a cold sink — with a temperature difference of 50-60 °C before the heat-exchangers — that falls to 40-50 °C after the heat-exchangers.

The development of very high-reliability, low-temperature turbines ([15]) makes it practical to convert solar pond heat to power even though an even more economical use is for heating, where the Carnot limitation does not apply.

(i) the low energy density of solar radiation calls for large collection areas: solar ponds can be made very large with negligible amounts of constructional materials;

(ii) the intermittency of solar radiation. This calls for some form of energy storage if a continuous supply of energy is mandatory. The

([14]) The depth is normally 1-2 m.

([15]) For example, the ORMAT Company has reported having installed several thousands of such turbines in over 40 countries with accumulated experience of many millions of operating hours.

solar pond — because of its mass of water — has "built-in" storage. For the normal depths — of about 2 metres — the pond is insensitive to isolation variations over a week or more i.e. the output can follow the demand with little consideration of the supply: indeed the plant can be designed to provide peaks of power many times the nominal capacity. (Deeper ponds can be designed to provide seasonal storage i.e. from summer to winter);

(iii) the problem of dirt — that collects on the windows of classical collectors: a non-convecting solar pond has no windows;

(iv) large solar insrallations raise the problem of transport of energy from a large collection area to a central zone of use. In the solar pond, transport of heat is particularly easy using the "decanting" method. It is known that, where a density gradient exists in a fluid, it is possible to move a layer horizontally without disturbing the layers above or below. It is thus possible to "decant" the hot zone of the pond, and transportation of this heat, over a distance of a kilometer or more, is feasible.

The cost figures given later show that a solar pond is a very low-cost source of calories at temperatures up to about 90 °C: indeed they are so cheap that conversion to power, even with the low thermodynamic efficiencies, is feasible.

It is necessary to record that there are site-limitations to solar ponds i.e. they cannot be set up viably in all places. These limitations are:

(i) the pond, being horizontal, the sites should not be far from the equator i.e. they should be within about ± 40° latitude, though a case has been made for the heating of buildings at even higher latitudes;

(ii) a source of cheap salt or brine should be available locally;

(iii) the site should be reasonably flat — to reduce the earth-moving work to a minimum;

(iv) unless complete sealing of the pond is assured, it would be inadvisable to construct a pond where there is underground fresh water near the surface;

(v) a cheap source of water (sea-water may be used) must be available to make up for evaporation losses;

(vi) it is not considered practical to make very small ponds, as the efficiency and economics improve with increasing size. The smallest practical size has not yet been established but is probably in the region of a hectare — for heat production — and several hectares for power production.

Where these site limitations do not apply, solar ponds appear to be an attractive method of harnessing solar energy on a large scale.

Efficiency of collection. Because half of the solar radiation is infra-red, which is absorbed in the first few cms of the pond i.e. does not penetrate to the bottom, — and allowing for other losses — the collection efficiency of a solar pond will — in practice — be of the order of 20%: this is lower than for other collectors but the unit area cost is an order of magnitude below that of flat-plate collectors.

The estimated thermal yield and costs are shown in Table 1 (A). The pond cost assumes the use of an expensive elastomer lining: the pond cost would drop about 40% for those sites where the lining could be omitted.

Electricity generation. A 5% thermodynamic conversion efficiency has already been achieved in a 150 kW solar pond power station (SPPS) inaugurated in December 1979 at Ein Bokek, on the shores of the Dead Sea. It is expected that the thermodynamic efficiency in later units will be raised to 8% but, taking the lower figure of 5%, gives an annual yield of 20 GWh(e) per km^2 equivalent to 5 MW installed at an annual load factor of 46%.

Table 1 (B) shows how bus-bar costs of power are estimated at from 13.5 US cents/kWh for a lined pond to a low of 5-6 cents for an unlined pond and expected improved efficiency.

The SOLMAT and ORMAT companies, that jointly designed and executed the 150 kW power station, estimate a final cost of about \$ 3000/kW installed for 5 MW unit, levelling off to \$ 2000/kW for units of 40 MW or larger.

It is hoped that the first 5 MW plant will be "on line" by 1982 and 20 MW plants before 1990. It should be noted that, for a large central fuel-fired power station consuming, say 270 gms of oil per net kWh produced, the *fuel component* of power cost is 0.2C cents where C is the cost of a barrel of fuel oil delivered. Thus, with oil costs — at the time of writing — of \$ 30-40 per barrel, the fuel component cost is 6-8 cents: this does not include the cost of the generating plant.

Thus solar pond power may compete with central power production using fuel oil at current and expected fuel prices: it seems highly competitive with small local diesel generators, where power costs range between 15 and 30 cents per kWh.

A rather unexpected bonus, for developing countries, is that the cost of solar pond power stations — which decreases with increasing size — reaches an asymptote at around 20-40 MW. This means that small countries can increase their installed capacity in small steps as the demand develops, rather than in the large steps — of 600 MW or more — that is recommended for nuclear or fossil-fueled stations.

Summarising, for those areas where solar ponds are practical, this represents an extremely interesting possibility as an energy source in place of oil or other fossil fuels. For thermal applications — and a large amount of primary energy in many countries goes for low-temperature thermal processes — the solar calories provided by solar ponds appear lower in cost than calories from almost any other source. District heating is one application, provided the limitations of the site, including availability of cheap land ([16]), are taken into account. Central air-conditioning in warm climates is another possibility.

7) Applicability to developing countries

One of the conclusions of an ad-hoc advisory panel, organised by the U.S. National Academy of Sciences in 1972 (NAS, 1972) was that a first necessary step was for developing countries to delineate clearly what their energy needs were, as specifically as possible. A second step was to acquire and collate the climatological data needed for effective solar energy utilisation.

It was also recognised that the application of solar energy in developing areas requires capital that is not always available. Thus massive support by governments and international agencies is needed if solar devices are to be introduced on a significant scale.

Thermal applications of solar energy in developing countries are seen to be mainly in the following areas:

(i) Agricultural applications, such as for the trying of products and the production of salt. As already discussed in Section 4C, here is a

([16]) A new development under study is the construction of ponds that "float" in the sea — or in lakes. This could avoid the use of land where this is expensive.

place for the technology of air dryers to be applied. As regards salt production, it is surprising that some countries having a seaboard are importing salt when they could produce it locally. For salt production on a *large* scale, solar pond technology could be applied.

Refrigerators for the preservation of agricultural products and the fish industry have frequently been quoted as a need in the developing countries. The principle of solar heat-operated refrigerators is known but the technology has never heen developed: the market here — as for solar cookers — is not attractive to private entrepreneurs. It seems that, if solar refrigeration is to penetrate these potential markets, the easier (though perhaps less logical) route will be via standard refrigerators (electrical or mechanical) — that require no development — that are driven by a solar power source.

(ii) Domestic applications. Solar hot water is an obvious application though the demand — and therefore the priority — in developing countries is usually lower than in the developed. Since the developing countries are mostly in the temperate or warm climate areas, space cooling would be attractive but the capital cost is high and may be beyond the capacity of the community to pay. It is to be hoped — and encouraged — that local architects will apply passive system design principles to the local buildings thereby avoiding the cost and complexities of the active systems.

Desalination can be of great importance as a source of potable water for the population and their cattle: there would appear to be room both for the simple type solar stills and for the more sophisticated solar-operated conventional desalination plants for regions where a potable water distribution network exists. The former can be locally built: the latter would almost certainly need to be imported. As indicated in Section 4F, the recent development of multi-flash distillation plants operating at the low temperatures obtainable from solar ponds opens very interesting possibilities for developing areas needing centralised supplies of potable water in quantities of say, 100 m^3 a day or more.

(iii) Power sources. Life, even in the poorest communities, is today considered virtually untenable without some form of power, either mechanical or electrical (at least at the village level if not at the individual level). Solar devices can replace the diesel engine. In very small sizes, photovoltaic plants, even at present prices, would provide the simplest answer — and the price of solar cells is expected to drop in the coming years. As the power rating increases, solar-thermal plants will take over, as indicated in Section 2F. At this moment in time, the thermal units would appear more economic in sizes above a few kW — perhaps at even lower ratings.

Solar power units would have two major functions: as isolated units to pump water i.e. the solar system is built near the well; as central (village) units to provide power for refrigeration machines and electricity primarily for lighting. Solar ponds can be expected, in a decade or so, to be able to provide solar electricity to a regional (as distinct from village) grid.

8) Credo

There is no single magic solution to the energy shortage: in each area, the energy needs will be met by a *mix* of energy sources: solar energy, as a non-polluting and renewable source, provides an additional option for the decision makers, and each advance in solar technology will increase the solar share.

TABLE 1 — *Estimated costs in sunny climate (1977 US$)*
(Solar input: 2000 kWh/m², yr: 1 km² pond area)

A) *Thermal Energy* (20% collection efficiency)

Annual Yield:	400 million kWhr
Annual Pond Cost:	$1,521,000 ([a]) (for lined pond costing $13/m²)
Make-up water:	200,000
Maintenance:	40,000
Total:	$1,761,000 = $4400 per million kWh(t) ($1.29 per million BTU)

Competes with fuel oil at $41 per ton.

B) *Power Production*

	Lined Pond US$13/m²		*Unlined Pond* US$8/m²	
Power-plant ([b]) cost $/kW installed	1,500	1,000	1,500	1,000
		Annual Costs		
Pond	1,521,000	1,521,000	913,000	913,000
Water	200,000	200,000	200,000	200,000
Maintenance	100,000	100,000	100,000	100,000
Power-plant	877,500	585,000	877,500	585,000
Total $	2,698,500	2,406,000	2,090,000	1,798,000
		Bus-Bar Power Costs ([c])		
At 5% thermodynamic conversion: annual yield = 20 GWH				
Cents/kWh	13.5	12.0	10.5	9.0
For power plant conversion efficiency raised to 8%				
Cents/kWh ([d])	8.1	7.2	5.9	5.3

([a]) Salt and land are assumed to be free. Charges taken as 11.7% i.e. 8% interest, 15 years life.
([b]) Plant refers to turbogenerators, heat-exchangers and all auxilliaries.
([c]) Excludes station operating costs.
([d]) Includes allowance for reduced size heat-exchangers.

APPENDIX I

EFFICIENCY OF THERMAL SOLAR COLLECTORS

The useful energy q_u from unit area of the absorber is the difference between the absorbed energy and the heat loss

$$q_u = \alpha\tau I - U \Delta T$$

where α is the absorbtivity and τ is the optical transmissivity: I is the incident intensity: U is the heat-loss coefficient and ΔT the temperature rise of the surface above ambient. U is normally treated as a constant, but is a weak function of the temperatures. If a concentrator is used, the absorbed energy is increased by a factor rP where P is the concentration factor and r is the reflectivity (optical transmission) of the concentrator i.e.

$$q_u = \alpha\tau\, rPI - U \Delta T$$

Dividing by the input solar energy, PI yields the efficiency E

$$E = \alpha\tau\, r - \frac{U \Delta T}{PI}$$

which, it may be shown, should be written with an efficiency extraction factor F when T is in terms of the fluid temperature rather than the surface temperature i.e.

$$E = F \left[\alpha\tau r - \frac{U \Delta T}{PI} \right] \qquad \text{(Ii)}$$

$$= a - b \Delta T \qquad \text{(Iia)}$$

where $a \equiv F \alpha\tau\, r$, usually called the collector optical efficiency factor

$$b \equiv \frac{FU}{PI} \qquad \text{(Iii)}$$

Since b contains the solar intensity I, E will vary during the day. It may be shown that, for clear days at least, an equation of the same type as (Iia) may be used to represent average efficiency by using some modified constants, for a and b, for b expressed in terms of the mean intensity I.

APPENDIX II

OPTIMAL TEMPERATURE FOR COLLECTOR - HEAT ENGINE SYSTEM

The average efficiency E_c of the collector operating at an output temperature T can be written (see Appendix I):

$$E_c = a - k\ (T - T_a) \qquad \text{(IIi)}$$

where a and k are taken as constants, though k is a weak function of temperature. $T_a \equiv$ ambient temperature. Putting the efficiency to zero gives the maximum "no-flow" temperature $T_m = T_a + a/k$. If the condensing temperature T_c for the heat engine is not the same as ambient, it is convenient to write IIi as:

$$E_e = c\ \frac{T - T_c}{T} = c\ \frac{y}{1 + y} \qquad \text{(IIiii)}$$

where c is the departure from a true Carnot engine (and is a weak function of T). The overall efficiency E is then:

$$E = E_c E_e = c\ (a^1 - by)\ \left(\frac{y}{1 + y}\right) \qquad \text{(IIiv)}$$

The optimum value of y is:

$$y_o = \sqrt{1 + a^1/b} - 1 = \sqrt{1 + y_m} - 1 \qquad \text{(IIv)}$$

where y_m ($= a^1/b$) is from IIia, the "no-flow" limiting value of the temperature rise ratio $(t_m - T_c)/T_c$.

Note that equation (IIvi) can be written:

$$y_o = \tfrac{1}{2}\, y_m\, (1 - y_m/4 + \quad)$$

i.e. the optimum y or optimum Δ T is a little less than half the maximum y or maximum Δ T. We note that the optimum collector efficiency is also about half the efficiency at zero temperature rise for all cases except for systems having very large values of y_m i.e. high-concentration systems.

Substituting (IIv) in (IIiv) gives, for the optimal overall efficiency,

$$E_{opt} = \frac{y_o}{y_o + 2} = \frac{1 + y_m - 1}{1 + y_m + 1} \qquad \text{(IIva)}$$

Ex. For T_c = 300 °K = 27 °C.

T_m, °K =	375	450	600	750	900	1200	1800	2700
$y_m = \frac{T_m - T_c}{T_c}$ =	0.25	.50	1.0	1.5	2.0	3.0	5.0	8.0
y_o =	0.118	.225	.414	.581	.732	1.00	1.449	2.0
$T_{opt} = T_c(y_o+1)$°K =	335	367	424	474	520	600	735	900
T_{opt}, °C =	62	94	151	201	247	327	462	627
$\frac{E_{opt}}{ca^1}$ =	0.056	.101	.172	.225	.268	.333	.420	.500

For a typical case where c ~ 0.6; a^1 ~ 0.667, i.e. ca^1 ~ 0.4

E_{opt} % =	2.22	4.04	6.88	9.00	10.7	13.3	16.8	20.0

The table accentuates the low overall efficiencies to be expected, except for collectors having no-flow temperatures above about 1000 °K and working temperatures above several hundred degrees C.

APPENDIX III

SELECTIVE BLACK SURFACES

Early solar absorbers were painted black in order to absorb the maximum of solar radiation: such surfaces — when heated — are also strong emitters of thermal radiation. However, it is possible to design a surface which, whilst a good absorber to solar radiation, is a poor emitter of thermal radiation (at least to temperatures up to a few hundred degrees C). This is because the spectrum of solar energy is in the range 0.3-2.0 micrometres whilst thermal radiation is of much larger wavelength. It is therefore possible to construct surfaces that, like optical filters, have different properties at different wavelengths.

A number of methods are available to achieve this effect: the most common is to start with a polished metal surface. Such surfaces have low thermal emittance but are also rather reflective to solar radiation. The metal surface is then coated with a thin dark layer of a semi-conductor — such as a sulphide or an oxide — that makes it highly absorbing to solar radiation, but the added layer chosen has very low thermal emittance of its own i.e. it hardly changes the low emittance of the base metal. The absorbtance α is defined as the ratio of the solar radiation absorbed to that which would be absorbed by a perfect absorber for which $\alpha = 1.0$. Similarly, the thermal emittance ε of a surface — at a given temperature T — is the ratio of the heat emitted by the surface to that which would be emitted by a perfect emitter. Thus black paint has a value of $\alpha \sim 0.95$ and a value of ε about the same. However, in a selective surface, it is possible to reduce ε to about 0.1 i.e. the thermal radiation is reduced by a factor of about 10, whilst the absorbtance α is maintained at above 0.9.

The significance of a selective black surface is illustrated by the following example. In a flat-plate collector, with a black painted absorber, the heat losses are approximately 60 parts by thermal radiation (R), 30 parts by convection across the airgap (C), and 10 parts from the rear (B). If a selective surface is used with $\varepsilon = 0.1$, we get $R = 6$, $C = 30$, $B = 10$, total 46 i.e. less than half the original value of 100: if convection were suppressed, the loss across the airgap could be reduced to about 10 parts giving a total of 26 or a quarter of the original. (With high vacuum surrounding the collector, the losses will be even less). The effect of reduced losses is similar to having some optical concentration but without the complication of tracking.

Selective black surfaces are produced commercially by such processes as electro-plating, dipping in chemical solutions, vacuum deposition and chemical vapor deposition (CVD).

Two survey papers — including over 80 references — on selective surfaces are to be found in Dixon & Leslie (1979) and a similar paper in Tabor (1978b): a basic description is given in Jordan (1967) and 1977).

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DIRECT GENERATION OF ELECTRICITY FROM SOLAR ENERGY

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1. Introduction

The two most widely used methods to convert solar radiation into electricity are the thermodynamic one and the photovoltaic one.

In the thermodynamic method, an array of sun-tracking mirrors focus solar radiation into a centrally located receiver, usually at the top of a tower. The heat transmitted to the receiver is transferred to a fluid which through a heat exchanger, produces steam to run a conventional steam engine, producing electricity. This method of electricity generation will probably be important for central power plants in countries with large direct solar radiation.

Photovoltaic conversion is the direct generation of electricity from solar radiation. This method is based on the use of solar cells.

Although the power density of photovoltaic conversion is low (of the order of 10-30 MW per km^2) compared to the one for thermal power stations (400-800 MW/km^2) and to that of a nuclear power plant (2000-4000 MW/km^2) an area of less than 1% of the total land area is usually sufficient to generate all the electricity needed in a country.

2. Operations and properties of photovoltaic modules

A solar cell is a semiconductor diode with the active part, the p-n junction, close to the surface. The most widely used material for solar cell fabrication is monocrystalline silicon. A cross section of a solar cell and a top view are given in figure 1.

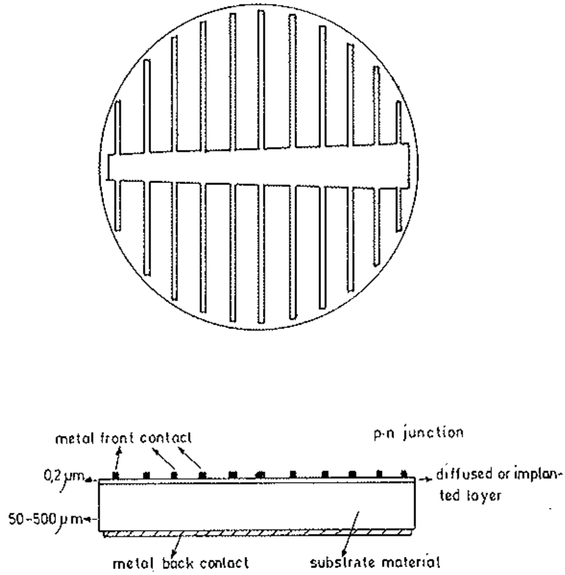

FIG. 1. Cross section and top view of a solar cell.

The incident light is absorbed by the solar cell and creates mobile electrons and holes, which are collected by the p-n junction. These mobile carriers constitute the current which is then collected by the metal front and back contacts. Metal layers usually are not transparent for light. The metal front contact therefore is given the typical finger structure. The metal coverage is typically only 7 to 8%. To minimize the light reflection, an antireflective coating is deposited on top of the cell.

A typical electrical output characteristic of a cell is shown in figure 2. Important quantities are the short circuit current I_{sc}, the open circuit voltage V_{oc} and the maximum power P_m. They are usually given for normalized irradiation conditions, referred to as AM1 (incident power of 1000 Watt/m^2 and a temperature of 28°C). Under these conditions, a typical silicon cell generates on the order of 30 mA/cm^2 at a voltage between 500 and 600 mV. The peak power, expressed in peak watt is the power generated by a cell under these normalized AM1 conditions. The price of photovoltaic conversion is always expressed in a price per peak watt.

The efficiency is defined as the ratio of the electrical output power and the incident power. Silicon solar cells typically have an efficiency between 12 and 18%.

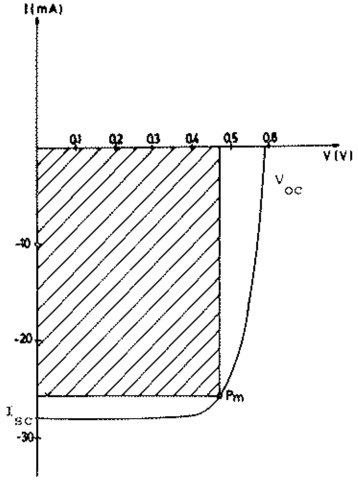

FIG. 2. Typical current-voltage characteristic of a solar cell.

Photovoltaic conversion has a modular nature. The output voltage is determined by the number of solar cells, in series, each having a voltage of about 0.5 Volt, and the output current is determined by the number of cells in parallel. A photovoltaic module consists of a number of solar cells in series and in parallel. They are interconnected by metal strips and are encapsulated in plastic or in glass. The encapsulation is important to increase the resistance against corrosion, sandstorms, hailstorms ... The lifetime of photovoltaic modules will have to be 20 years. A picture of a photovoltaic module is shown in figure 3.

Although silicon is the only material used for the industrial fabrication of solar cells, other materials are very promising and are studied intensively in the laboratory. The most interesting candidates are gallium arsenide, amorphous silicon and cadmiumsuphide — cupper sulfide.

3. PRICE PREDICTIONS

The photovoltaic module price goals of the D.O.E. (Department of Energy - U.S.A.) and the achievements are shown in figure 4 for the period 1975-1986.

After 1986 the price will still go down further, but new technologies, eventually using other materials than silicon will have to be used.

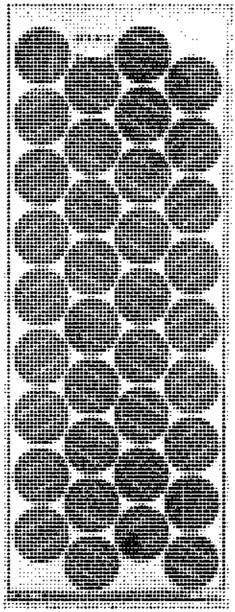

Fig. 3. Photovoltaic module.

The price for large quantities, today, is 6 dollars per peak watt, and will according to the predictions decrease below 1 dollar per peak watt in less than 10 years from now. This goal is realistic and can be achieved by continuing the research on refining of quartz, on silicon sheet formation, on module production processes, on module encapsulation i.e. on all steps of the production technology and on testing and automation.

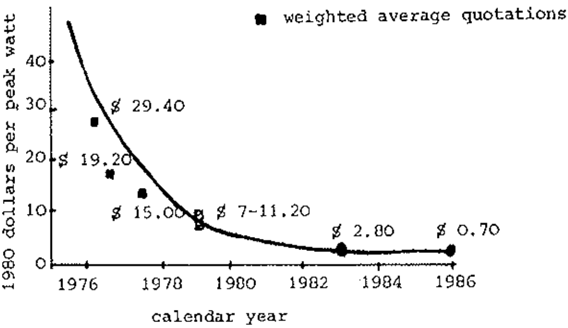

Fig. 4. D.O.E. Price goals and achievements.

Important is also the energy payback time, i.e. the time during which photovoltaic modules will have to operate to gain back the energy required to fabricate them. This time is still several years but will be reduced to 6 months to 1 year for the production process yielding 1 dollar per peak watt. This time is very reasonable compared to a life expectency of 20 years.

The price of photovoltaic conversion and the energy payback time can also be reduced by concentrating the incident light. This procedure is economical as long as the concentrator per unit area is much cheaper than the solar cells per unit area. Since only direct radiation can be concentrated, this alternative approach will be of interest only in countries where the ratio of direct to diffuse light is high. A concentrator system usually requires suntracking, resulting in a more complex system which for some developing countries could be a problem. It is also too early to predict to what extent concentration will be used. Hybrid systems where both the electricity and the heat are used, look promising for some applications. A lot of research is done also on systems with higher efficiency, where a larger part of the total energy spectrum is used. This can be done either by using beam splitting and solar cells made of different materials, or by using stacked cells. Figure 5 shows a simple concentrator.

A photovoltaic system usually consists of a solar cell array, energy storage, regulation and control devices. Batteries (usually lead-acid) are normally used for storage. The size of the batteries depends on the application. It is interesting to study the decomposition of the cost of photovoltaic systems. As an example we take a realistic evaluation from H. Durand (H. Durand, 1979) for a photovoltaic system of medium importance (10 to 100 kW peak) located in a sunny remote area (3400 h sun per year). The cost decomposition is given in Table 1.

The prices given for 1979 are realistic for a remote area, where transport, installation and infrastructure are very expensive. For 1985 it is assumed that a certain infrastructure already exists and that local workers are already formed and take over part of the work.

From this table, it can be concluded that the efficiency of the panels is very important, because several cost factors are proportional to the area. These factors are: encapsulation, frame, structure, land area and transport. It also can be concluded that although the panel price reduces with a factor 7.5, the total price reduces only with a factor 5. This is due to the fact that several costs can not be reduced as easily as the one of the photovoltaic panels.

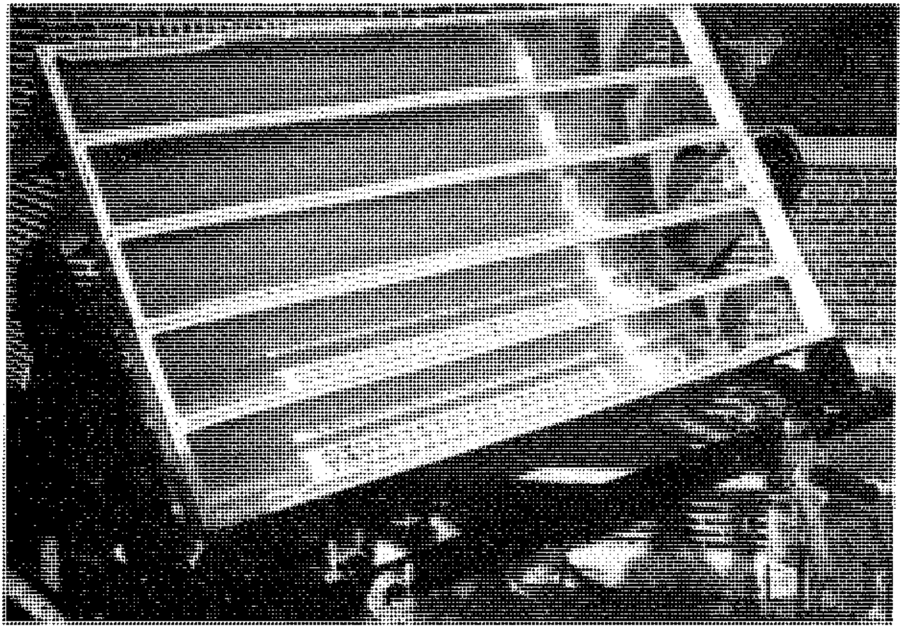

FIG. 5. Concentrator for photovoltaic conversion.

The most important conclusion is that the price per kWh for this stand alone system with storage already in 1985 will not be more than 40 dollar cent, and that this cost can still be reduced further. For a remote location, this price is lower than is usually obtained with a Diesel generator.

4. System applications

Photovoltaic conversion can be used in applications from a few milliwatts to several megawatts as needed for central power plants. The applications can be listed in categories according to the economical prospects.

a. *Independent small power*

For a large number of mini power applications, solar cells can be an economical solution due to the high price of dry batteries. Examples of

TABLE 1 — *Decomposition of the cost in U.S. dollars of a P.V. system in 1979 and 1985.*

Price of kW-peak	1979 (10 m²)	1985 (8 m²)
Encapsulation	10 × 450 = 4500	8 × 100 = 800
Silicon	8 × 400 = 3200	6 × 60 = 360
Fabrication	8 × 300 = 2400	6 × 30 = 180
Overhead, profit	5100	660
Total panel	15200	2000
Batteries (24 hrs)	1000	800
Structure	3000	500
Converter	2000	300
Installation	1500	300
Transport	2000	1000
Profit	5500	1100
Total	30200	6000

Price per kWh (interest 6%, lifetime 20 y., lifetime batteries 10 y.):

Price	2500	500
Maintenance	500	100
Total	3000	600
Pricep er kWh	2	0,40

this application where solar cells are used to recharge a rechargeable battery to replace a dry battery are: digital watches, calculators, small telemetric systems, transistor radios, walkie-talkies . . .

Belonging to the same category, but having a somewhat larger power, are: road call boxes along the highways, railroad signalling, school TV in developing countries, auxiliary motor of a sailing boat, light buoys, radio transmitter stations . . .

These applications are already economical now either because of the lack of conventional electricity at the location or because of the high price of dry batteries or because of security.

Many examples already exist for school TV in developing countries. The importance is enormous because photovoltaics in many remote locations is the only way to supply electricity. Some special TV sets with low power consumption and working on direct current were developed and are on the market. Important is the reliability of the system, which after several years of field experience now is remarkably high.

b. *Remote applications*

Throughout the world there are still about one million villages without electricity. These villages in developing countries have a need for water pumping (drinking water and irrigation) and for electrification (for refrigeration in hospitals, for illumination . . .). Due to the location of these villages, remote from the cities, a conventional power plant would be too costly because of the length of the transmission lines. Diesel generators are now often used. The drawbacks of these generators in developing countries are the difficulty of maintenance and the problematic transportation system for the fuel. For most of the locations, photovoltaic conversion therefore will be the most economical method, once the price of the modules is below 3 to 4 dollars per peak watt. Already now photovoltaic conversion is economical at several locations. This application offers the largest near term opportunity for solar cells. Their reliability, their low maintenance cost and their modular nature are important advantages. Storage of batteries which in general is very expensive, can either be avoided (ex. for water pumping) or can be limited to one or two days due to the locations in sunrich areas. It is often stated that Diesel generators are a reliable source of electricity and that the cost is rather low. A study (L. Rosenblum *et al.*, 1979) done by the Lewis Research Center of the NASA in the U.S. learns that the cost ranges from 2700 $ for a 3 kVA generator to 5500 $ for a 10 kVA generator, plus 1000 $ for installation. The cost per kW of capacity installed thus ranges from $ 1200 to $ 650 kW^{-1}. The maintenance costs and the fuel costs at maximum capacity usually exceed the first cost of the generator. It is also recommended practice to provide a second diesel generator on-site as a back up to ensure power availability. Consideration of the only initial cost of a Diesel generator can thus be misleading. Fig. 6 shows the energy cost versus the annual energy consumption for a photovoltaic system and a 3 kVA diesel in 1978 and 1981.

The following assumptions were made: a fuel cost of 2 $ per gallon in 1978, a system life of 5 years, an annual interest of 10% and a fuel escalation of 7% per annum. From fig. 6 it may be concluded that the cost breakeven point for photovoltaics in 1978 and 1981 is 4200 kWh and 17000 kWh annual energy consumption respectively. A reduction of the photovoltaic kWh to 0.40 $ in 1985 will make this system more economical than the Diesel generator for every consumption.

c. *Residential applications and transportation*

Photovoltaic conversion is not limited in use to developing countries, but can play an important role in generating electricity in the Western world.

Once the price of photovoltaic modules gets below one dollar per peak watt, their use in residential applications becomes economical even in industrial countries. In order to limit the expensive storage of batteries to a few days, a connection to the grid is necessary. This application can, less than ten years from now, be the start of an important contribution to the electricity generation. Special photovoltaic shingles already exist in the United States.

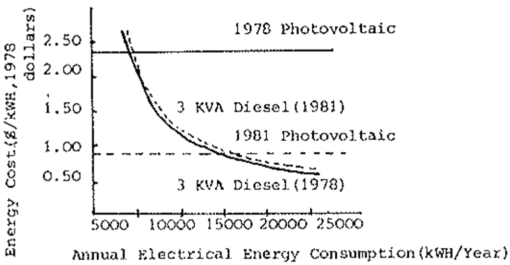

FIG. 6

The policy in the United States is different from the one in Europe. In the United States, the excess power generated by the photovoltaic generator will be sold to the utility and no storage is required. The system generally will reduce the utility peak load. Residential applications are considered as the most important applications in the next 10 years. In Europe, several countries rely heavily on nuclear power and it will be hard to convince the utilities to accept photovoltaic residential systems.

The way photovoltaic generation can be introduced will be different. A reasonable scheme is to limit the contribution to 25% of the electricity consumption (this requires approximately 10 m^2). No selling back of electricity to the utility is then required when a 24 hour storage is provided. This system would be economical already at a panel module cost of 1 $ per peak watt. Due to the limited storage, a good management can provide a reduction of the utility peak load.

The use of solar energy for transportation is related to the breakthrough of the electric car. Parking lots covered with photovoltaic modules can be used to charge the batteries of the car during day time. This solution is of special interest to people going to work with their car, and will be economical when the price is of the order of one dollar per peak watt.

d. *Central power stations*

Solar energy will have a large impact on the energy production of a country, only if it is used in central power plants. The break-even prices lie below one dollar per peak watt, because large areas will be needed due to the low energy density. The problem of energy storage can be eased by combining a solar energy plant with a complementary energy source, as a wind mill or a hydro-electric plant. The break-even price can be reached before the year 2000.

An interesting idea is to launch a Solar Power Satellite which could turn continuously in the sun. The electric energy can be transmitted to a central receiver station by microwaves. The advantage certainly is the independence from climatological conditions.

5. Pilot Projects

As shown above, photovoltaics is going to play an important role for the energy production in the future. A lot of research and of development has still to be carried out. Although photovoltaics today is still too expensive to compete with conventional energy sources for many applications, it is time now to set up pilot projects. The Commission of the European Communities, in the second 4 year R & D programme is going to fund pilot projects with a total installed power of 1 M Watt.

The decision about which projects will be financed will be taken at the end of the current year. Already now we can conclude that the operation will be very successful. The large interest from industry, regional authorities, national governments and users is shown by the following data:

— there are more than 30 proposals in total for more than 3 M Watt coming from all the European member countries;

— the E. C. finances up to a maximum of 50%. The other 50% financing involves users, utilities, non governmental bodies, local and national authorities;

— all the projects are proposed by international consortia. Several member countries are involved in every project.

The pilot projects are different from demonstration projects, in that they include research. Emphasis in research is on the system aspects and on the structures (materials, protection . . .). The R & D cost lies between 5 and 30% of the total cost, which is on the average about 20 $ per peak watt. The system cost is between 10 and 40%.

The power ranges covered are: 1 for 300 k Watt, 4 larger than 200 kW, 8 between 100 and 200, 3 between 50 and 100 and 19 between 30 and 50.

To ease the storage problem, several combinations with other energy sources are proposed: 7 with a wind generator, 5 with Diesel groups, 2 with a hydroelectric plant, 23 with the grid, 7 stand alone.

Examples of applications are: electrification of isolated villages on islands, hospitals, pumps for solar heated pools, rural applications, industrial applications, fresh water pumping, T. V. studio . . .

Most projects propose a small storage (a few hours to 2 days) on lead acid batteries, but also hydrogen storage is proposed.

Almost all proposals use flat silicon panels; 2 use mirror boosters; 2 use CdS/Cu_2S, and 3 use concentrating systems.

The installations bave to be completed before mid 1983. There will be at least one project per member country, and one will be in Sicily next to Eurelius, the European 1MW heliostat.

Also in the United States, a large number of pilot projects are carried out and are plaaned. Examples of new installations for 1981 are: a Florida residence, a Phoenix house, Hawaii residences, the Natural Bridges National Monument, schools, hospitals . . .

6. Conclusions

Photovoltaic conversion can play a major role in providing electricity in developing countries. The modular nature allows a gradual expansion of the installation. The decentralized power generation is ideal for rural sites. Once stabilized the photovoltaic technology can also be transferred to developing countries.

A few decades from now, photovoltaic generation will also give an important contribution to electricity generation in industrialized countries. Use in residential applications will start less than ten years from now.

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BIOMASS: SOLAR ENERGY THROUGH BIOLOGY — FUELS NOW AND IN THE FUTURE

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1. Introduction

Hardly a day goes by without there being a news item warning us of the impending shortage of oil and what it is going to cost us — if we can get it! This belated realisation that non-renewable liquid fuels are going to increase in price, and possibly even be rationed, is one of the main reasons why biomass is being looked at so seriously by so many of the developed countries. Possibly even more important, for the developing countries of the world, is the so-called "woodfuel crisis" which may be even more serious since the problems of deforestation have such long-term detrimental agricultural, social and economic consequences.

The oil/energy problem of the last five years has had three clear effects on biomass energy use and development. Firstly, in developing countries there has been an accelerating use of biomass as oil products have become too expensive and/or unavailable. Secondly, in a number of developed countries large research and development programmes have been instituted which have sought to establish the potential and costs of energy from biomass. Estimated current expenditure is approaching $ 100 million per annum in North America and Europe. The work is still at the early stages but results look far more promising than was thought even two years ago. Demonstration projects and small-scale commercialisation are being rapidly implemented. Thirdly, in at least one country, viz., Brazil (which currently spends over half of its foreign currency on oil imports), large scale biomass energy schemes are being implemented as rapidly as possible — the current investment is over half-billion dollars per annum.

There is no doubt that the majority of the people in the world live by growing plants and processing their products. The main issue in developing countries is that of scarcity and the problem of trying to maintain, or possibly even to increase, the present level of use without harming agriculture or forestry and ecological systems. More efficient use of existing biomass and possible substitutes for biomass use, e.g., solar and wind based technology, should be considered and implemented as quickly as possible to reverse the trend of excessive biomass use, as is already occurring in many countries. In the developed world the expertise exists and is already being used to implement biomass energy programmes from the point of view of potential technology and economics. Biomass can provide a source of energy now and in the future; just how much it can contribute to the overall provision of energy will very much depend on existing local and national circumstances and thus it is imperative that each country establish its energy use patterns and the potential of biomass energy. This is not very easy to accomplish quickly, but needs to be done as soon as possible.

Not many people need reminding that our fossil carbon reserves, whether for fuel or chemicals, are all products of past photosynthesis. Photosynthesis is *the* key process in life and as developed by plants can be simply represented as

$$H_2O + CO_2 \xrightarrow[\text{solar energy}]{\text{plants}} \text{organic materials} + O_2$$

In addition to C, H and O, the plants also incorporate nitrogen and sulphur into the organic material via light-dependent reactions — this latter point is often not appreciated. Thus the basic processes of photosynthesis have determined life as we know it (dependent on organic materials and oxygen) and will continue to play the major role in the integration of bioenergetic systems in tbe future.

In the past photosynthesis has given us coal, oil and gas, fuelwood, food, fibre and chemicals. The relative use of these fixed carbon sources has varied over the years and will undoubtedly do so in the future. It seems necessary now to look at how photosynthesis fits into the biosphere and how we could possibly use biological solar energy conversion in the future as a source of raw materials — and not necessarily in the traditional ways.

What most people do not realise is the magnitude of present photosynthesis — it produces an amount of stored energy in the form of biomass which is about ten times the world's annual use of energy. Table 1 also shows that the total amount of proven fuel reserves below the earth is only equal to the present standing biomass (mostly trees) on the earth's surface while the fossil fuel resources are probably only ten times this amount. This massive-scale capture of solar energy and conversion into a stored product occurs with only a low overall efficiency of about 0.1% on a world-wide basis but because of the adaptability of plants it takes place and can be used over most of the earth.

It is not widely appreciated that one-seventh of the world's annual fuel supplies are biomass (equivalent to 20 million barrels of oil a day — the same as the USA consumption rate) and that about half of all the trees cut down are used for cooking and heating. Because this use is mostly confined to developing countries it has until recently been sadly neglected and the effects of overuse of biomass are having serious and long term consequences. In the non-OPEC developing countries, which contain over 40% of the world's population, non-commercial fuel often comprises up to 90% of their total energy use. This non-commercial fuel includes wood, dung and agricultural waste and because of its nature is seldom thoroughly considered. Total wood-fuel consumption is probably three times that usually shown in statistics, and about half of the world's population relies mainly on wood for their cooking (four-fifths of total household energy use) and heating. Furthermore, supply statistics of non-commercial energy can be out by factors of 10 or even 100.

In my estimation a rural person in the developing countries uses on average about 15 GJ of biomass-derived energy every year. This is the equivalent of 1 ton or 1.4 m^3 of air-dry wood. Local and regional differences in annual use abound, as do the relative proportions of wood, dung and agricultural wastes. The developing countries have a population of about 3 billion of which about 70% are rural. Biomass energy in rural areas usually supplies more than 85% of the energy — and this is mostly used in the household for cooking. There is also an urgent need to supply more local energy for agriculture and small industry. We calculate an annual worldwide rural biomass energy use of about 3.2×10^{10} GJ. In Africa about 65% of the total energy consumed is biomass-derived, in Latin America the figure is about 45%, while in India and the Far East about 50% is biomass energy. Including the urban population of developing countries, who often use large quantities

TABLE 1 — *Fossil fuel reserves and resources, biomass production and CO_2 balances.*

		Tons coal equivalent
Proven reserves		
Coal	5×10^{11}	
Oil	2×10^{11}	
Gas	1×10^{11}	
	8×10^{11} t =	25×10^{21} J
Estimated resources		
Coal	85×10^{11}	
Oil	5×10^{11}	
Gas	3×10^{11}	
Unconventional gas and oil	20×10^{11}	
	113×10^{11} t =	300×10^{21} J
Fossil fuel used so far (1976)	2×10^{11} t carbon =	6×10^{21} J
World's annual energy use		3×10^{20} J (5×10^{9} t carbon from fossil fuels)
Annual photosynthesis		
(a) net primary production	8×10^{10} t carbon (2×10^{11} t organic matter)	= 3×10^{21} J
(b) cultivated land only	0.4×10^{10} t carbon	
Stored in biomass		
(a) total (90% in trees)	8×10^{11} t carbon =	20×10^{21} J
(b) cultivated land only (standing mass)	0.06×10^{11} t carbon	
Atmospheric CO_2	7×10^{11} t carbon	
CO_2 in ocean surface layers	6×10^{11} t carbon	
Soil organic matter	$10\text{-}30 \times 10^{11}$ t carbon	
Ocean organic matter	17×10^{11} t carbon	

These data, although imprecise, show that (a) the world's annual use of energy is only 1/10 the annual photosynthetic energy storage, (b) stored biomass on the earth's surface at present is equivalent to the proven fossil fuel reserves, (c) the total stored as fossil carbon fuel only represents about 100 years of net photosynthesis, and (d) the amount of carbon stored in biomass is approximately the same as the atmospheric carbon (CO_2) and the carbon as CO_2 in the ocean surface layers.

of biomass-derived energy (say, an average of 8 GJ/year) and the use of biofuels by small scale industries, we come up with a total biomass energy use in developing countries of about 4×10^{10} GJ; this is about one-seventh of the world's total energy use.

In this paper I would like to present some evidence that fuels produced by solar energy conversion are a very important source of energy now and will continue to be so for the foreseeable future — probably even to an increasing extent. We should re-examine and if possible, re-employ the previous systems; but, with today's increased population and standard of living, we cannot revert to old technology, but must develop new means of utilising present-day photosynthetic systems more efficiently. Solar biological systems could be realised to varying degrees over the short and long term. Some, such as the use of wood, biological and agricultural wastes, and energy farming, could be put into practice immediately, whereas others may never become practicable. Photobiological systems can be tailored to suit an individual country taking into consideration total available energy, local food and fibre production, ecological aspects, climate and land use. In all cases the total energy input (other than sunlight) into any biological system should be compared with the energy output and also with the energy consumed in the construction and operation of any other competing energy producing system.

Solar energy is a very attractive source of energy for the future but it does have disadvantages. It is diffuse and intermittent on a daily and seasonal basis, thus collection and storage costs can be high. However, plants are designed to capture diffuse radiation and store it for future use. Hence the serious thought (and money) being given to ideas of using biomass as a source of energy — especially for liquid fuels, but also for power generation and other end uses (Table 7). I am aware of biomass programmes in the UK, Ireland, France, Germany, Denmark, Sweden, USA, Canada, Mexico, Brazil, Sudan, Kenya, Zimbabwe, Australia, New Zealand, India, Philippines, Thailand, Israel, South Korea and China. The biggest difficulty with implementing them seems to be the simplicity of the idea — the solution is too simple for such a complex problem! Fortunately for us, plants are very adaptable and exist in great diversity — they could thus continue indefinitely to supply us with renewable quantities of food, fibre, fuel and chemicals. If the serious liquid fuel problem which is predicted within the next 10 to 15 years comes about, we may turn to plant products sooner than we expect. Let us be prepared!

What I am definitely not proposing is that any one country will ever be able to derive all its energy requirements from biomass — this is highly unlikely except in especially favourable circumstances. What each country (or even region) should do is to look closely at the advantages and problems with biomass energy systems — summarized in Table 2. The long term advantages are considerable but implementation of significant programmes will take time and require important economic and political commitments. The programmes will vary in their emphasis and thus most of the research and development should be done locally. Such R & D is an ideal opportunity to encourage local scientists, engineers and administrators in one field of energy supply. One should always be fully aware of the assumptions involved in any energy cost projections (especially if they are more than 6 to 12 months out of date!) before extrapolating or drawing firm conclusions. Even if biomass systems do not become significant suppliers of energy in a specific country in the future, the spin off in terms of benefits to agriculture, forestry, land use patterns and bioconversion technology are, I think, significant.

TABLE 2 — *Some advantages and problems foreseen in biomass for energy schemes.*

Advantages	*Problems*
1. Stores energy.	1. Land use competition.
2. Renewable.	2. Land areas required.
3. Versatile conversion and products; some products with high energy content.	3. Supply uncertainty in initial phase.
4. Dependent on technology already available with minimum capital input; available to all income levels.	4. Costs often uncertain.
5. Can be developed with present manpower and material resources.	5. Fertilizer, soil and water requirements.
6. Large biological and engineering development potential.	6. Existing agricultural, forestry and social practices.
7. Creates employment and develops skills.	7. Bulky resource; transport and storage can be a problem.
8. Reasonably priced in many instances.	8. Subject to climatic variability.
9. Ecologically inoffensive and safe.	
10. Does not increase atmospheric CO_2.	

2. Efficiency of photosynthesis

Plants use radiation between 400 and 700 nm, the so-called photosynthetically active radiation (P.A.R.). This P.A.R. comprises about 50% of the total sunlight which (total) on the earth's surface has an average normal-to-sun daytime intensity of about 800-1000 W/m^2.

The overall practical maximum efficiency of photosynthetic energy conversion is approximately 5-6% (Table 3) and is derived from our knowledge of the process of CO_2 fixation and the physiological and physical losses involved. Fixed CO_2 in the form of carbohydrate has an energy content of 0.47 MJ/mol of CO_2 and the energy of a mole quantum of red light at 680 nm (the least energetic light able to perform photosynthesis efficiently) is 0.176 MJ. Thus the minimum number of mole quanta of red light required to fix one mole of CO_2 is 0.47/0.176 = 2.7. However, since at least 8 quanta of light are required to transfer the four electrons from water to fix one CO_2, the theoretical CO_2 fixation efficiency of light is 2.7/8 = 33%. This is for red light, and obviously for white light it will be correspondingly less. Under the most optimal field conditions values of 3% conversion can be achieved by plants: however, often these values are for short-term growth periods, and when averaged over the whole year they fall to between 1 and 3%.

Table 3 — *Photosynthetic efficiency and energy losses.*

	Available light energy
At sea level	100%
50% loss as a result of 400-700 nm light being the photosynthetically usable wavelengths	50%
20% loss due to reflection, inactive absorption and transmission by leaves	40%
77% loss representing quantum efficiency requirements for CO_2 fixation in 680 nm light (assuming 10 quanta/CO_2),* and remembering that the energy content of 575 nm red light is the radiation peak of visible light	9.2%
40% loss due to respiration	5.5%
	(Overall photosynthetic efficiency)

* If the minimum quantum requirement is 8 quanta/CO_2, then this loss factor becomes 72% instead of 77%, giving the final photosynthetic efficiency of 6.7% instead of 5.5%.

In practice, photosynthetic conversion efficiencies in temperate areas are typically between 0.5 and 1.3% of the total radiation when averaged over the whole year, while values for sub-tropical crops are between 0.5 and 2.5%. The yields which can be expected under various sunlight intensities at different photosynthetic efficiencies can be easily calculated from graphical data.

3. Implementation of biomass energy schemes

The main factors which will determine whether a biomass scheme can be implemented in a given country are (a) the biomass resource, (b) the available technology and infrastructure for conversion, distribution and marketing, and (c) the political will combined with social acceptance and economic viability. These points are now considered in turn.

(a) *The resource base*

The total annual production of biomass (net primary production), the amount of wood produced (including natural forest and managed plantations), and the harvested weight of the major starch and sugar crops are shown in Table 4. In addition, there is a worldwide availability of crop residues and other organic wastes (Table 5). Although the amount of such wastes has been calculated in some detail for the USA, Canada and some European countries where they have been identified as the major short term biomass-resource, such figures are not generally available for the developing countries. Such data that is available is

Table 4 — *Annual biomass production in tons.*

Net primary production (organic matter)	2×10^{11}
Forest production (dry matter)	9×10^{10}
Cereals (as harvested)	1.5×10^{9}
as starch	1×10^{9}
Root crops	5.7×10^{8}
as starch	2.2×10^{8}
Sugar crops	1×10^{9}
as sugar	9×10^{7}

TABLE 5 — *Sources of biomass for conversion to fuels.*

Wastes	*Land Crops*	*Aquatic Plants*
Manures	*Ligno-cellulose*	*Algae*
Slurry	Trees	Uni-cellular
Domestic rubbish	Eucalyptus	Chlorella
Food Wastes	Poplar	Scenedesmus
Sewage	Firs, Pines	Navicula
	Luceana, Casuorina	Multi-cellular
Residues		Kelp
Wood residues	*Starch Crops*	
Cane tops	Maize	*Water weed*
Straw	Cassava	Water hyacinth
Husks		Water reeds/rushes
Citrus peel	*Sugar Crops*	
Bagasse	Cane	
Molasses	Beet	

often questionable and cannot, at present, form a basis for any energy planning discussions. In addition to established sources of wood and food a wide range of other land and aquatic cultivation systems have been proposed for the future. Both established and future options are summarized in Table 5. Two usually neglected resources must be mentioned, viz. aquatic plants and algae and also arid land plants.

(b) *Technology for conversion*

Biomass as it stands in the field or collected as wastes is often an unsuitable fuel since it has a high moisture content, a low physical and energy density and is incompatible with present demands for a fuel to be used in internal combustion engines — the main power source for transport and agriculture in most countries. Established conversion technology can be divided into the biological and the thermal (Table 6). The great versatility of biomass energy systems is one of their most attractive features — there are a range of conversion technologies already available (and being improved) yielding a diversity of products, especially liquid fuels to which the world seems to be addicted and on which most world economies have recently been based.

Plant materials may be degraded biologically by anaerobic digestion processes or by fermentation, the useful products being methane, ethanol and possibly other alcohols, acids and esters. At present the established

TABLE 6 — *Solar energy for fuels: conversion process and products.*

Resource	*Process*	*Products*	*Users*
Dry biomass	Combustion	Heat, electricity	Industry, domestic
(e.g. wood, residues)	Gasification	Gaseous fuels → methanol. Hydrogen, ammonia	Industry, transport, chemicals
	Pyrolysis	Oil, char, gas	Industry, transport
	Hydrolysis & distillation	Ethanol	Transport, chemicals
Wet biomass (e.g. sewage, aquatics)	Anaerobic digestion	Methane	Industry, domestic
Sugars (from juices & cellulose)	Fermentation & distillation	Ethanol	Transport, chemicals
Water	Photochemical/ photobiological catalysis	Hydrogen	Industry, chemical, transport

(Simplified table: numerous cross-links exist. Agriculture included in industry. Many important final products not listed).

technologies are the anaerobic digestion of cellulosic wastes to form methane or the fermentation of simple sugars to form ethanol. The most suitable feedstocks for anaerobic digestion are manures, sewage, food wastes, water plants and algae.

The most suitable materials for thermal conversion are those with a low water content and high in lignocellulose, for example wood chips, straw, husks, shells of nuts, etc. The most likely processes to be adopted will use part of the material as fuel for the production of the required mixture of carbon monoxide and hydrogen (synthesis gas) for the subsequent catalytic formation of alcohols and hydrocarbons. During gasification oxygen or steam may be introduced in order to enhance the degree of conversion to synthesis gas and to increase its purity.

Two basic routes of catalytic conversion, of synthesis gas to further products can be recognised. The gas may be converted directly to hydrocarbons via the Fisher-Tropsch synthesis, or may be used for the formation of methanol. Both routes are well established in connection with use of gas produced from coal with plants operating in countries such as South Africa and Germany. Some plants using sorted domestic rubbish are operating and considerable research is being carried out on gasification of wood. On a smaller scale commercial wood-fuelled gasification plants have been available for some time, the gas produced being suitable for use in stationary engines.

Hence the technology exists for the production of heat, steam, electricity, gas and liquid transport fuels from biomass. In addition alcohols are the conventional starting point for a wide range of low molecular weight chemicals, plastics and fibres. Implementation of such schemes depends on local requirements, economics, energy balances, etc. This great versatility of biomass conversion technologies is one of its distinct advantages.

(c) *Energy ratios and economics*

In an ideal world the main factors to be considered in adopting a specific biomass route would relate to the energy gain and the economics. The benefit to be derived by converting plant material to ethanol can be expressed in terms of the net energy ratio (NER) which is obtained by dividing the final yield of energy in useful products by the total energy inputs derived from sources other than the biomass itself. In computing the inputs, in addition to fuel, fertilizer and irrigation, a value has to be assigned to the farm and process machinery and to ongoing maintenance. In general a net energy gain is seen where the fermentation and distillation is powered by the burning of crop residues, as in the case of sugar cane, or by burning of wood obtained from close by — as for a cassava alcohol-distillery powered using Eucalyptus wood. Reported NER values for such systems vary from about 2.4 to over 7. For most starch crops and sugar beet the values are close to or below one, i.e., more energy is used than is produced. However, this may still be worthwhile if the fuel source is for instance cheap coal or poor quality, wood or residues, etc., which are in effect converted to a high quality fuel.

For the thermal conversion routes an efficiency can be calculated as the ratio of energy in the end product as a fraction of the energy content of the starting material. Since part of the feed is completely combusted to power the conversion, this value must be less than one. Here the justification is again related to the production of a high quality, higher energy density liquid fuel, from a bulky wet biomass source. At present the efficiency of methanol production from wood is probahly about 25%, however efficiencies of around 60% are theoretically feasible.

The estimates of the cost of producing alcohol by fermentation of biomass vary enormously from US 10 cents per litre to over 60 cents per litre. However, many of these estimates are based on paper studies. Realistic figures from Brazil (1979) are as follows: 30.5 cents per litre for sugar cane alcohol and 31.7 cents for cassava-derived alcohol as compared to gasoline at an ex-refinery selling price of 23 cents per litre and a retail price of 39.6 cents per litre. The alcohol prices are FOB distillery selling prices calculated for alcohol produced by autonomous distilleries computed to yield the investor a 15% annual return on investment calculated according to the discounted cash flow method and on *proalcool* funding of 80% of the fixed investment. Ethanol production, from farm crops, in the USA is profitable at present due to the tax structure. The Federal Government has passed an exemption of gasoline tax on *gasohol* (a 10% ethanol: gasoline blend) equivalent to $ 0.4 per gallon. Various states have further tax incentives so that in Iowa for instance the combined subsidies work out at over $ 1 per gallon. The justification for this lies in the fact that in order to maintain corn prices the government subsidizes each bushel of corn *not* produced with one dollar. A bushel of corn can produce 2.5 gallons (US) of ethanol to be used in 25 gallons of gasohol.

Most paper studies indicate that methanol produced by gasification of wood and catalytic resynthesis will be considerably cheaper than ethanol produced by fermentation. The only problem is that no production plants are operating at present. A detailed analysis for methanol plant in New Zealand can be summarised as follows. At an efficiency of 50% for a 2500 oven-dry tons per day plant at 1977 prices using NZ national cost benefit economics (10% on capital, DCF over 30 years, no tax or depreciation) the product price was $ 214 per ton using wood at $ 55 a ton or $ 146 a ton for wood at $ 25 a ton. These values are equivalent to product costs of between 17 and 19 cents a litre, comparable with those summarised recently by the US Solar Energy Research Institute (SERI) where methanol costs from wastes or fuel crops varied from 11 cents to 35 cents per litre at raw material costs from a negative value for waste to about $ 50 a ton, with assumed efficiencies of methanol production of between 25 and 50%.

(d) *Implementation*

The assessment and implementation of biomass energy programmes in individual countries is an excellent opportunity for a country to develop its own research, development and demonstration capabilities in this area. The types of biomass available for conversion to energy are very much region-dependent, e.g., sugar cane and cassava in hotter climates, cellulose in temperate areas and hydrocarbon shrubs in arid zones. No one country has a monopoly on biomass-for-energy expertise and indeed it is widespread — note the ethanol programme in Brazil, the biogas plants in China and India, gasifiers in Germany, straw burners in Denmark, agro-forestry in East Africa, village woodlots in Korea and parts of India, and so on. It is also an opportunity to develop collaboration between scientists, engineers, foresters, agronomists, sociologists, economists, and administrators within a country, within regions and between countries. Biomass conversion to energy is an "old-but-new" and rapidly developing area which interests many young scientists, engineers, etc., because it has both immediate practical and also longer-term basic research and development requirements. It would be worthwhile recognising and encouraging local talents and imagination and putting them to use as soon as possible in field, laboratory and pilot-scale projects.

It is imperative that good energy assessments be made in individual countries (with or without outside help), identifying the energy flows, limitations in data, and opportunities. The priority needs must be matched with the available resources. The practical importance of biomass energy must be made very clear. Proposals to implement such biomass energy systems must be clearly spelt out. Such data must then be used to influence tbe decision makers, only after the socio-economic and institutional barriers are clearly recognised and proposals are available on how they can be overcome and with the all important, full co-operation of the people themselves and the decision makers — otherwise experience shows that nothing may be accomplished. There is a great opportunity for collaboration and also self-help in introducing and improving the application of biomass energy systems.

4. Status of various biomass projects throughout the world

In Tables 7 and 8 a short summary of biomass and energy costs of some schemes around the world are listed. Further details are given for a number of these schemes in the references cited. Just to be parochial I will refer briefly to some European studies.

TABLE 7 — *Estimated biomass and energy product costs (various countries).*

Country	*Product and Source*	*Costs*
1. Brazil (1977) . . .	Ethanol from sugar cane (ex distillery) Gasohol (retail)	US $ 16.7/10^6 BTU US $ 0.33/litre US $ 13.18/10^6 BTU
2. Australia (1975) . .	Ethanol from Cassava Industrial ethanol	AU $ 250/t AU $ 275/t
3. Canada (1975 & 78)	Methanol from wood	CAN $ 0.35-0.70/gallon
4. New Zealand (1976)	Ethanol from pine trees (500 t/day capacity; credits from byproducts)	NZ $ 260/t (13% return on capital)
5. New Zealand (1977)	Biogas from plants Natural gas prodn. cost Coal gas prodn. cost	NZ $ 3.45-5.57/GJ NZ $ 1.09/GJ NZ $ 6.33/GJ
6. Upper Volta (1976) .	Fuelwood from plantation Kerosene (retail) Butane gas (retail) Electricity	US $ 0.09/kWh (t) US $ 0.13/kWh (t) US $ 0.11/kWh (t) US $ 0.19/kWh (t)
7. Philippines (1977) .	Electricity from *Leucaena* fuel-woodfired generating station (same cost as oil-fired station)	US $ 0.014-0.018/kWh
8. Tanzania (1976) . .	Biogas from dung (for cooking and lighting) Electricity	US $ 0.012/kWh US $ 0.113/kWh
9. India (Tamil Nadu) (1978)	*Casuarina* fuelwood to replace coalfired electricity generating station (competitive with coal: 15-30 year payback)	US $ 12/t (dry)

TABLE 8 — *Biomass energy products costs compared to conventional - USA (1981).*

Product	*Cost from biomass* ($/$10^6$ BTU)	*Conventional cost* ($/$10^6$ BTU)	*Biomass* / *Conventional*
Methanol	8.4 - 15.9	8.4	1.0 - 1.9
Ethanol	15.0 - 36.3	19.6	0.8 - 1.9
Medium BTU gas	4.7 - 7.4	3.0 - 5.0	0.9 - 2.5
Substitute natural gas . . .	4.8 - 7.3	3.0 - 5.0	1.0 - 2.4
Ammonia	5.8 - 11.4	7.4	0.8 - 1.5
Fuel oil	3.6 - 7.9	3.2	1.1 - 2.5
Electricity	0.03- 0.14 ($/kWh)	0.03 - 0.06 ($/kWh)	0.5 - 4.5

Europe (UKISES, 1979; Anon, 1980; Chartier and Meriaux, 1980)

In Europe a number of countries and the EEC are conducting extensive feasibility studies of the potential which biomass may have for supplying a source of energy and fuels in the future. Trial plantings of alder, willows, poplars, etc., are being undertaken in addition to assessing energy yields from agricultural residues, urban wastes, techniques of conversion, waste land and forest potentials and algal systems. Biological and thermal conversion equipment is available and is in great demand for use in Europe and for implementing overseas programmes.

A recent study by the European Commission (Brussels) shows that in the 9 EEC countries biomass could provide 4% of their total energy requirements in the year 2000 (equal to 50 million tons oil equivalent or 2 million barrels of oil per day) — this is the same as the use of energy by the agricultural sector and could be achieved with the use of residues and wastes and utilizing some marginal land with minimal disturbance to conventional agriculture. With a great effort and minimal disturbance to agriculture and forestry the EEC countries could provide 20% of their total energy requirements from biomass, if they so wished. In France, which estimates a biomass potential of 9 million tons oil equivalent in 1990, the large Government R & D programme for solar energy gives priority to biomass for energy schemes. The EEC has a substantial biomass programme and the U.K. also is supporting serious assessment and trial projects.

5. FUTURE PHOTOSYNTHESIS

Whole plants

One of the "problems" with photosynthesis is that it requires a whole plant to function — and the problem with whole plant photosynthesis is that its efficiency is usually low (less than 1%) since many limiting factors of the environment and the plant itself interact to determine the final overall efficiency. Thus a task for photosynthesis of the far future is to try to select and/or manipulate plants which will give higher yields with acceptable energy output/input ratios. We need much more effort placed on studies of whole plant physiology and biochemistry and their interactions with external (environmental) factors. Already this type of research is being increasingly funded by both industrial and government organisations — in marked contrast to the neglect of this type of research in the past.

Examples of the type of research which is being done or needs to be done are: photosynthetic mechanisms of carbon fixation: factors in bio-productivity; genetic engineering using plant cell tissue cultures; plant selection and breeding to overcome stresses (drought, temperature or salinity); selection of plants and algae with useful products such as oil, glycerol, waxes, or pigments; nitrogen fixation and metabolism and its regulation by photosynthesis.

Artificial photosynthesis

Also to be seriously considered is long-term basic, directed research on artificial photobiological/chemical systems for production of fuels and chemicals (H_2, fixed C, and NH_3) and needs for sustained funding if these exciting future possibilities are to be realised.

Since whole plant photosynthesis operates under the burden of so many limiting factors (internal and external) would it be possible to construct artificial systems which mimic certain parts of the photosynthetic processes and so produce useful products at higher efficiencies of solar energy conversion? (A 13 per cent maximum efficiency of solar energy conversion is considered a practical limit to produce a storable product). I think that this is definitely feasible from a technical point of view but it will take some time to discover whether it could ever be economical. Note must also be taken of other chemical and physical systems (light driven) which are presently being investigated and may come to fruition before biologically-based systems do so.

A number of proposals have been made to mimic photosynthesis in vitro or to use in vivo photosynthesis in an abbreviated form in order to overcome the inefficiencies and instability factors that seem to be inherent in whole plant (or algal) photosynthesis. The state of the art is still very rudimentary, but it gives some idea of what may be achieved in the future — the scope is enormous, but it may well take ten years or longer to discover whether any of these systems has any practical potential for the future. Fortunately, the quality of the work, the wide interest, and the wide range of disciplines being attracted augurs profitable results.

Plants perform at least two unique reactions upon which all life depends, viz., the splitting of water by visible light to produce oxygen and protons and the fixation of CO_2 into organic compounds. An understanding of how these two systems operate and attempts to mimic the processes with in vitro and completely synthetic systems is now the subject of active research by biologists and chemists alike.

In vitro systems which emulate the plant's ability *to reduce CO_2* to the level of organic compounds are a very attractive proposition and are being actively investigated by photochemists and biochemists. Recent reports claim the formation from CO_2 of methanol, formaldehyde and formic acid. These are very interesting and important studies since it is the first time that light has been used outside the plant to catalytically fix CO_2. There has also been one report of the photochemical *reduction of nitrogen* to ammonia on TiO powder using UV light.

A recently published idea is the photosynthetic *reduction of nitrate* to ammonia using membrane particles from blue-green algae. This process naturally seems to occur by light reactions closely linked (via reduced ferredoxin) to the primary reaction of photosynthesis, i.e., not involving the CO_2 fixation process. It is an interesting way to produce ammonia! However, it may be possible to use intact blue-green algae (immobilised?) to continually fix N_2 to NH_3 — the cells would have to be genetically derepressed and this is now certainly possible with the recent advances in genetics.

The term *"biophotolysis"* is an abbreviation applied to photosynthetic systems that split water to produce hydrogen gas. This applies to both living systems, such as algae, and to in vitro systems comprising various biological components such as membranes and enzymes. We also discuss the so-called "artificial" systems which seek to mimic the photosynthetic systems by the use of synthetic catalysts. Our bias tends to lean heavily on this last approach.

The great interest in biophotolysis-type systems probably derives from the fact that they are the only energy systems currently known to have the following three attributes: (a) the substrate (water) is ubiquitous, (b) the driving force is unlimited (sun), and (c) the product is stable and non-polluting (hydrogen). At present, the biological system is the only one that is able to use wide range visible light to catalytically split water to H_2 and O_2; we hope that other systems will be found soon.

Photovoltages and Photocurrents

Over the last few years, there have been a number of experiments aimed at constructing electrochemical devices based on the principle of charge separation in photobiological membrane systems. They have been well summarised by Haehnel *et al.* and discussed in detailed chapters in a recent volume. A commonly used approach is to deposit the pigmented membrane onto electrodes (pure chlorophyll, mixtures of chlorophyll and organic redox compounds, chloroplast membranes, and reaction centers of photosynthetic bacteria have been used). Another approach has been to use the biological system with lipid membranes such as liposomes or BLMs (bacteriorhodopsin, photosynthetic reaction centres, and chloroplast membrane extracts have been used); stability has been improved by polymer incorporation into the BLM or by the use of lipid-impregnated Millipore filters. The characteristics of such systems have been described.

6. Concluding statement

Photosynthesis is the key process in the living world and will continue to be so for the continuation of life as we know it. The development of photobiological energy conversion systems has long term implications. We might well have an alternative way of providing ourselves with food, fuel, fibre and chemicals in the next century.

Suggested timetable for biomass-for-fuel programmes

Next 10 years: fuels from residues, trees and existing crops; use of existing biofuels; demonstrations and training.

10-20 years: increased residue and complete crop utilisation, local energy crops and plantations in use.

After 20 years: energy farming; improved plant species; artificial photobiology and photochemistry.

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ENERGY ALTERNATIVES FROM AGRICULTURE

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1. Introduction

Although most people associate agriculture with the production of food many other useful products also come from the land. Wood, paper, cotton, waxes, tannins, rubber, gums, resins, oils, essential oils, tobacco, medicines and dyes, are examples. Little more than a hundred years ago practically all our energy needs also came from the land. Our own physical energy and that of animals like horses and cows that provided transport, operated machinery and pulled ploughs, came from food crops and pasture. Heat came from the burning of wood and charcoal. Light came from fires, from candles made of waxes and tallow and from vegetable oil and spirit (alcohol) lamps. It is easy to forget that such sources of energy are still the most common forms found today in the poorer areas of the world. For example, wood provides at least 20% of Brazil's total energy needs. In more developed areas of the world, these sources have been replaced by cheap coal and then by cheap petroleum. Thus the horse gave way to the car, to the tractor and to the diesel engine; wood and charcoal fires to those of coal and fuel oil, and oil lamps were replaced by kerosene, paraffin candles and oil fired electricity generators.

In fact petroleum became so cheap that it has also formed the basis of an enormous petro-chemical industry providing cheap chemical feedstock for synthetic substitutes, for natural products like rubber, cloth,

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ropes, dyes, alcohol and many others. The sudden and extremely large increases in petroleum prices since 1973 have led to a renewed interest in many of these natural products, especially the production of alcohol as a liquid fuel to replace petrol.

The main advantages of biomass fuels are that one type or another can be grown almost anywhere and unlike petroleum products, they are renewable and relatively non-polluting. Whilst most attention has been given to sugar cane (*Saccharum officinarum*) many other plant species are capable of producing alcohol (*) or other fuels like oil and firewood. Some advantages and disadvantages of many of these species will be considered in this paper. Special attention will also be paid to net energy gains and ways in which these can be raised by energy saving agricultural practices and improved processing. Brazil's Alcohol Programme will be briefly outlined and used as an economically viable example to illustrate the main points.

2. PRODUCING ENERGY

2.1. *Photosynthetic Efficiency*

During the last decade plant scientists have found several additional and more efficient pathways to that of the Calvin cycle. The major discovery has been that of the C_4-dicarboxylic acid cycle, initially in sugar cane (Hatch and Slack, 1970) and soon after in a number of other species, mainly tropical grasses and cereals. Table 1 summarizes some of the characteristics of this photosynthetic pathway and shows that these plants can fix more carbon dioxide with less than half of the water consumption and little more than half of the plant protein content. They are also able to use higher light intensities and temperatures. So the warm climate and high radiation found in the tropics offer the best conditions for maximizing plant productivity (Fig. 1). Nevertheless field efficiences are rarely over 1% of the received energy so there is much room for improvement.

Among the potential energy yielding crops, sugar cane, sweet sorghum and maize are all typical C_4 plants while cassava, although a C_3 plant, has been observed to respond to high light and temperature in a similar way (Black *et al.*, 1977).

(*) The term alcohol in this paper means ethanol except where otherwise stated.

TABLE 1 — *Comparison of the photosynthetic efficiency of C_3 and C_4 plants.* (After Black *et al.*, 1977).

	Photosynthetic pathway	
	C_3	C_4
CO_2 compensation point (ppm)	35-85	0-10
CO_2 fixed/ATP consumed	3	5
Leaf N% for maximum photosynthesis	6.5-7.5	3-4.5
g H_2O consumed/g dry matter produced	450-1000	250-350

Another efficient pathway, known as crassulacean acid metabolism (CAM), can help plants like pineapple (*Ananas comosus*) survive under very dry conditions. The very high yields of certain palms and trees also indicate efficient light energy conversion. This is due to their long leaf area duration in addition to their photosynthetic efficiencies (Black *et al.*, 1977; Newbould, 1971).

2.2. *Energy Crops and their Products*

An attempt to compare the energy yields of different crops can be found in Table 2. Whilst such comparisons are dependent on yields

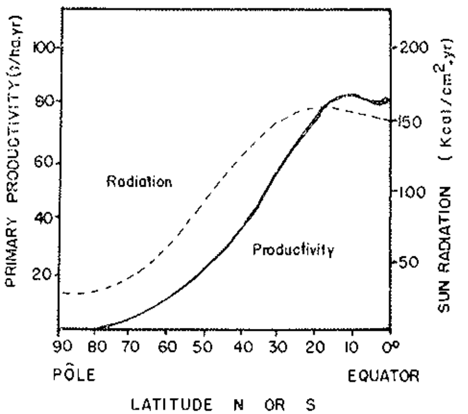

FIG. 1. Effect of latitude on potential primary production (Golley and Leith, 1972).

that can vary enormously, they do help to show the superiority of firewood, wood methanol and oil palm over sugar cane and the advantages of tropical species. These crops will now be considered individually in more detail.

2.2.1. Sugar Crops

Sugar cane is generally considered to be the most promising crop for the large scale production of liquid fuel. Yelds are high because of its C_4 photosynthetic pathway and large leaf area. It can grow on most tropical and subtropical soils in areas receiving over 1500 mm of rain but requires high natural or added fertility and a short, fairly dry ripening period. When plant residues are returned to the land, few nutrients are lost from the system because the primary product, sugar, consists of carbon, hydrogen and oxygen obtained from water and the air. Because of this and the crop's ability to grow well in monoculture without much disease, it has been successfully cultivated on certain good tropical soils for centuries without fertilizer.

One of the disadvantages of the crop is that harvesting costs are high because much labour is generally needed. In fact, this need may be an advantage in poor countries with unemployment problems and little capital to mechanize. Another problem is that a seasonal harvesting period of 5 to 10 months leaves processing equipment idle for part of the year. However, these disadvantages are outweighed by the use of byproduct bagasse for processing energy and the easy and well established fermentation of molasses to ethanol.

Besides sugar cane, sweet varieties of sorghum (*Sorghum bicolor*), and sugar beet (*Beta vulgaris*) also produce large sugar yields. Sweet sorghum, although still economically unimportant, is a promissing alternative to sugar cane in regions with longer dry seasons and lower water supply because of its remarkable drought resistance and shorter growth cycle (6 months). It also can be grown in temperate regions with success (Polack and Day, 1980). The crop bas a large and effective root system and therefore low fertilizer requirements. Besides sugar, which is extracted from the stems by sugar cane mills, sorghum also yields grains which can be used for cattle feeding or, like other starchy products, as an additional energy source. In more humid regions 2 or 3 regrowths can be obtained and then energy yields/year can come close to those of sugar cane (Table 2).

Sugar beet (Austin *et al.*, 1978) is the most important sugar crop in temperate regions. Potential sugar beet yields are balf of those of

TABLE 2 — *The agricultural and energy yields of the most promising crops* (Rosenthal *et al.*, 1978; Menezes, 1979; Serra *et al.*, 1979; Schooley *et al.*, 1979; Austin *et al.*, 1978; Sá Filho *et al.*, 1980; CESP, 1979; CAT/CNPq, 1978; Brito, 1979 and investigators of INT).

	Crop yields t/ha.yr			*Fuel yields* [a]		*Energy yields*
	Actual means	*Estimated potential*	*Type*	*L/t*	*L/ha.yr*	*TOE/ ha.yr* [a c]
Sugar crops						
Sugar cane	60	90	ethanol	67	4020	2.1
Sugar beet	30	56	ethanol	67	2010	1.0
Sweet sorghum (stems)	35	50	ethanol	55	1925	1.0
Starch crops						
Sweet sorghum (grains)	3	5	ethanol	30	1080	0.6
Cassava	13	40	ethanol	180	2340	1.2
Sweet potatoes	15	30	ethanol	125	1875	1.0
Maize	3	6	ethanol	360	1080	0.6
Babassu palm nuts	3 [b]	25 [b]	ethanol	80	240	0.1
Oil crops						
Babassu kernels	0.6	5	oil	37	22	0.02
African oil palm	18	38	oil	210	3780	3.7
Wood crops (25% H_2O)						
Eucalyptus or others	16	30	ethanol	159	2544	1.3
Eucalyptus or others	16	30	methanol	330	5280	2.7
Fire wood	16	30	wood	—	—	4.8

[a] Calculated from actual mean yields.

[b] Actual mean yields are from extraction of naturally occurring trees and potentials are for plantations.

[c] Calculated on the hasis of: ethanol 5120, methanol 5034, oil 9723, K cals/L and wood 3000 K cal/kg and 10^7 K cal = 1 TOE.

sugar cane but actual yields are often similar because of the more advanced technology used in temperate countries. However, such technology with high fertilizer inputs often gives small net energy gains (Austin *et al.*, 1978).

Ethanol is the fermentation product of all sugar crops and can be produced in large quantities by already existing technology. Anhydrous ethanol, mixed in the proportion 1:5 with petrol can be used by standard car motors without any adaptation. It has antiknocking properties and consumption is increased only slightly. The production of anhydrous alcohol requires azeotrophic distillation with benzene or hexane and an additional distillation step and therefore it is preferable to modify petrol engines so that they can use straight 96° GL ethanol even though the consumption/km is 15 to 20% higher.

2.2.2. Starch Crops

Cassava, a photosynthetically efficient and easily grown root crop is currently receiving much attention as a means of expanding alcohol production into areas of Brazil that are considered too dry for sugar cane. Apart from drought tolerance it can be grown on a wide range of poor soils with very little need for fertilizer (Alvim and Maia, 1979). This and other low field requirements for root production (Table 3) compared to sugar cane, have incentivated production in Brazil. Other advantages of cassava are its high concentration of energy (Table 2) which lowers transport and production costs as well as the unrestricted harvesting period which makes all year round processing possible. The crop can also be stored in the soil or as a flour.

Yields of alcohol per hectare are usually quoted as being below those of sugar cane when average yields of 12-15 ton/ha are used (Table 2). This picture is unreal however because much of the crop is grown in a primitive way with yields well below the agricultural potential. Because it is a subsistence crop and grows so easily, it has not received the research it deserves. Experimental yelds of 50 t/ha/year are common and yelds of 70 t/ha in 7 months have been observed in little known varieties (Arkcoll, 1980). However, although yields of over 40 tons/ha can be achieved easily on commercial farms, there is evidence that this cannot be maintained with monocropping. There may be a case for rotating the crop with other energy crops like sweet sorghum, maize and oil crops like castor or with food crops.

TABLE 3 — *Energy needs for the agricultural production of sugar cane and cassava* (Moreira *et al.*, 1979).

	Energy Consumption (Mcal/ha. yr)	
	Sugar Cane	*Cassava*
Labour	118	118
Machines	402	279
Fuel	2 239	1 491
N	887	347
P	89	45
K	96	53
Ca	37	50
Seed	188	118
Insecticide	3	24
Herbicide	55	24
TOTAL	3 914	2 567

Other traditional starch crops e.g. maize seem less promising (Table 2) but sorghum grain, if obtainable in addition to sugar from the stems may have a future. Sweet potatoes (*Ipomoea batatas*) can produce more than 50 t/ha in 6 months under market garden conditions in Taiwan (AVRDC report, 1978). Starch yields from native babassu palms are low but potential plantation yields appear attractive (Table 2).

Starch crop processing for the production of ethanol requires additional investments because the starch has to be hydrolyzed prior to fermentation.

2.2.3. Vegetable Oil Crops

The African oil palm (*Elaeis guineensis*) looks the most interesting crop from the point of view of yield (Table 4). A good modern plantation will yield about 5 tons/ha oil and this could well double within a few years because recently developed tissue culture techniques will now allow the multiplication of the best trees in fields already giving over 8 tons of oil/ha. No other oil crop is able to produce over 2 ton/ha on a regular basis and most give less than 1 ton. The crop is so efficient because, being a tree, it maintains a permanent large leaf area and root system. Moreover, it grows best in the permanently wet tropics where conditions for photosynthesis are greatest (Fig. 1). The high yields of oil palms combined with the higher calorific value of oil give much more energy per unit area than an extremely good crop of sugar cane (Table 2). Apart from high installation costs, harvesting is done largely by hand and with mules and processing fuel is supplied by burning the fibrous residues. Unlike sugar cane the African oil palm can be harvested continuously throughout the year, requires little more than a simple pressing to produce the final fuel and leaves much less effluent to dispose of. It can also be grown on extremely poor leached soil in the wet tropics where few other agricultural alternatives exist and where it represents a desirable tree alternative in forest areas. Unfortunately such areas are often remote and transport costs may be high if processing is not done locally.

The main disadvantages of the African oil palm are the high implantation costs, the 4 years wait until the first harvest and the high world price for edihle oils (U.S. $ 600/ton). This is now about three times that of crude petroleum (Fig. 2). However as the graph shows, these price differences are changing fast and if the tendencies continue vegetable oil will be soon of economic advantage. Palm oil is usually the cheapest vegetable oil and its share of the market is rapidly expanding (Colon and Surre, 1979).

Most other oil crops are restricted by their lower yields (Table 4). However, they might become useful if grown near consumption areas and

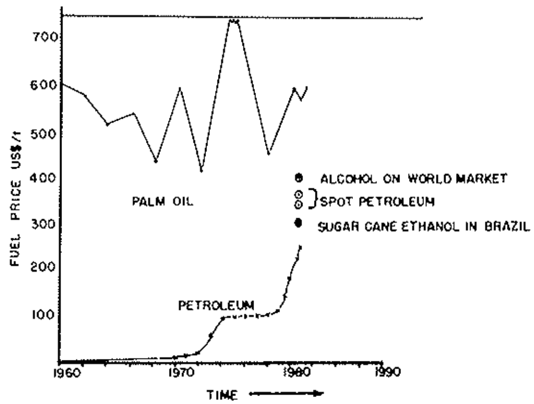

Fig. 2. World prices of palm oil, alcohol and petroleum (Colon and Surre, 1979).

TABLE 4 — *Yields of oil crops t/ha. crop* (Purseglove, 1968).

Crop		Crop Yield	% Oil	Oil Yield	Growth Period (days)
African oil palm (*Elaeis guineensis*)	good yield	25.00	20	5.00	365
	best recorded [a]	38.00	22	8.36	365
Coconut copra (*Cocus nucifera*)	good yield	2.25	67.5	1.52	365
	best recorded	5.00	67.5	3.38	365
Castor seed (*Ricinus communis*)	good yield	1.50	47.5	0.70	160
	best recorded	3.36	55	1.85	160
Groundnuts (*Arachis hipogaea*)	good yield	1.34	45	0.60	120
	best recorded	1.25	50	1.13	120
Soybeans (*Glycine max*)	good yield	2.70	22	0.60	120
	best recorded	4.00	22	0.88	120
Sunflower (*Helianthus annuus*)	good yield	1.57	30	0.47	140
	best recorded	3.36	35	1.18	140
Babassu nuts (*Orbignya speciosa*)		10.00	3.4	0.34	365

[a] best in Purseglove, J. W. (1968) and TPI (1971).

in rotations with other energy crops. Soybeans and peanuts have the advantage of being a legume which adds nitrogen from the air (see 3.3). Crops like castor may have a future because they can be grown in drier regions. Although it is expensive (U.S. $ 1.200/ton), castor oil also has much potential as a lubricant, having a lifetime six times that of mineral oil (Sá Filho *et al.*, 1980).

Many other new oil bearing crops are being studied at present and a few are thought to have interesting futures because of their high potential energy yields. Some examples from Brazil are peachpalm (*Bactris gasipaes*), macaúba (*Acrocomia selerocarpa*) and babassu (*Orbignya* spp). The first grows in the wet tropics and is already exploited commercially for palm hearts and its high yields of edible fruits. Besides oil, the starch meal can be converted into alcohol (D. B. Alkcoll, unpublished results). Both the macaúba and babassu palms are found in natural groves in drier areas of the country. Babassu is exploited for the oil rich kernels and much interest is now developing in ways of using the whole nut as an energy source (Peixoto, 1973; IPT, 1979). Complete dry distillation or the separate use of the starchy mesocarp for alcohol production, the endocarp for high grade charcoal, the endosperm for oil and meal and the fibrous epicarp for process energy, are believed to be viable. Industries are now being set up to exploit the crop. It is particularly interesting to ask what a little selection, fertilizer and disease control might do to the yields of these species that produce so well on very poor soils, and without any fertilization or other treatment.

Vegetable oils are being used to replace diesel, fuel oil and lubricants. The possibility of running diesel motors on vegetable oil has been known since the work of Rudolf Diesel in 1911 and many attempts to stimulate its use have been made since (Sá Filho *et al.*, 1980). Minor technical problems were usually overcome in these early studies on old and slow diesel motors. However, modern and much more efficient models coke up rapidly when run on vegetable oils and mixtures of these with diesel (Ventura, 1980). Because diesel motors are so efficient it may be worth while to modify vegetable oils to suit them. This can be done by interesterification with alcohols, giving glycerol as a by product (Mensier, 1952) or by cracking and catalytic conversion to high grade fuel (Weisz *et al.*, 1979). Unprocessed crude vegetable oil might be better used in fuel oil burners and boilers.

2.2.4. Wood and Charcoal

In general, plant growth is limited mainly by cold in most of the temperate regions of the world, by drought in the dry and seasonal tropics and semi-tropics, and by lack of nutrients in the humid tropics. In all of these situations certain trees are especially good at extending the growth period and using poor soils because of their large and long lasting leaf and root systems. Thus under many conditions, trees are capable of producing much more biomass than annual and short lived crops (Table 2). The yelds of 35 t/ha (50% H_2O) are not uncommon in good eucalyptus plantations and 75 t/ha have been recorded experimentally (Brito, 1979). Trees also tend to be very resistant to disease and pests and rarely need much fertilizer. Furthermore, many are able to use land that is marginal or inappropriate for conventional agriculture because it is too wet, too dry, too cold, too steep, too stony or too poor in nutrients. In this way, trees can be used to produce energy without competing with food crops for good land, a major worry with alcohol projects in developing countries. In addition trees and forests are attractive from an ecological point of view. They help maintain and stabilize the climate, prevent flooding, soil erosion and compaction, desertification and nutrient loss. There are also many N fixing legume tree species especially in the tropics.

Although the principal product from trees is wood, various fruits, nuts and exudates might also become important sources of energy or at least help replace more of the synthetic products (like rubber) currently being made from petroleum. Several oil palms have already been discussed.

Planned selection of fast growing species and those that coppice (King, 1980; Stewart, 1980) is in progress and should lead to shorter delays between planting and harvesting. There is even the possibility of mechanical harvesting on very short rotations. Species unsuitable for pulp will need to be examined specifically as energy sources (Burley, 1980; King, 1980).

The most promising species in the tropics are *Gmelina arborea*, *Pinus caribaea* and *Eucalyptus* spp. (e.g. *E. deglupta, E. robusta, E. alba*). However, there is also much interest in N_2-fixing legume trees like *Leucaena leucocephala* and non-legume nodulating trees like alder (*Alnus* spp.) and casuarina (*C. equisetifolia*). Poplar (*Populus* spp.) and Willow (*Salix* spp.) seem promising for coppicing in temperate climates (Passaris, 1980).

The main advantages of wood as an energy source are that it is freely or cheaply available from natural forests in many places and it is easy to store and use without processing. Consequently it remains the principal energy source for home cooking and heating in many areas of the world where such forest is still found. The loss of these forests is now a subject for worldwide concern and reforestation and the formation of village wood lots are commonly advocated and more and more frequently used as a partial solution (Eckholm, 1975). Both reforestation and a-forestation are practised on a large scale for steel production, for electricity generation, for brick making and as a chemical feedstock in some countries. 60% of Brazilian blast-furnaces use charcoal. Waste wood and sawdust is also widely used in the pulp and sawn wood industries for their own fuel needs. Such industrial uses can be expected to expand rapidly in the future where wood is cheaply available.

The need for large specific wood stoves and boilers is now limiting the rapid replacement of oil fired steam generators in Brazil. Steam engines are also making a comeback and another alternative that is becoming increasingly popular, is the revival of the gasogen motor in which the producer gases from a charcoal (or wood if scrubbed) burner are led directly into internal combustion engines (King, 1980; Chittenden and Breag, 1980). About 2000 units a month are now being sold in Brazil. Charcoal is a cleaner fuel that partially overcomes the major disadvantages of wood: smoke, tar, large bulk and heavy weight per unit of energy. These limit storage and transport and its use as a fuel for transport. A further concentration of energy can be made by converting wood into a whole range of hydrocarbons by gasification, pyrolysis, hydrogenation and hydrolysis (Lowe and Overend, 1978; King, 1980). These have been tried and used industrially in different parts of the world in the past and are now the subject of much renewed interest as they are becoming more economically attractive. Wood hydrolysis to sugar and fermentation to ethanol is less attractive but is almost viable if the lignin waste is fully used as charcoal or as a binding agent. Methanol production from wood is now starting in Brazil (CESP, 1979); however, much development remains to be done, enormous capital investment is needed and royalties must be paid on catalysts. In addition methanol or the original wood could be converted to other gases and liquid fuels, in the same way as coal, by modifying processing conditions and catalysts (Weisz *et al.*, 1979; Lowe and Overend, 1978; King, 1980). The experimental demonstration that diesel motors can be run on wood powder remains another unexploited possibility. High field yields, the low cost and the versatily of wood as a direct or indirect fuel and source of chemical feedstock, guarantee it an increasing importance as a renewable energy source in the future.

2.2.5. Other Crops

Several other plants have been suggested as energy sources. These include pineapples (*Ananas comosus*) which has outyelded sugar cane in Hawaii with lower requirements for water (Marzola and Bartholomew, 1979). However, it is probably more valuable as an export crop than a fuel at the moment. Lesser known species in which interest is being shown include *Euphorbia tirucalli* and *E. lathyris* which contain latexes rich in terpenes that are easily converted to fuel oil. Yields of about 1.5 tons oil/ha are indicated without selection (Calvin, 1980). Although these are low, the crops are attractive because they are able to grow under extremely arid conditions (50 mm rain/yr.). Yields of another latex bearing member of the same family, rubber, have risen from 220 kg before the Second World War to 3.8 t/ha in some plantations, with 5 t/ha now considered possible (Williams, 1975). Although it is too valuable to consider as a fuel, natural rubber is making a considerable comeback at the moment and will save petroleum by replacing more and more synthetic rubber in the future. This illustrates how research, especially selection from the vast reserves of genetic variability, can produce really dramatic improvements in crop yields.

The scope for finding and improving other new energy crops, especially those not previously considered for food, is also especially good in the tropics. There are over-sweet unpalatable pineapples which weigh 20 kg as well as several large toxic roots and hundreds of oil bearing fruits (Pesce, 1941) known in the Amazon region that remain unexamined. Sweet exudates from palms (Duke, 1977), latexes from other *Euphorbiaceae* (Calvin, 1980), oils from trees like *Copaifera multijuga* (Calvin, 1980) and *Ocotea barcellensis* (Alvim and Alvim, 1979), essential oils from *Croton sanderianus* (Carioca *et al.*, 1978), oil from *Caryocar* spp, *Jessenia* spp and *Mauritia* spp (NAS, 1979; ONERN, 1977), *Caryodendron* spp (Martinez, 1970) and *Simauba* spp spoiled maize in the USA (Calvin, 1980) and Jerusalem artichokes (*Helianthus tuberosus*) in France (Passaris, 1980), also have their advocates. Although the yields of most of these are low at present, they should not be prematurely dismissed without proper examination.

2.2.6. Agricultural Waste Products

Is is easy to forget that the majority of agricultural products represent a small proportion of the total plant (Table 5). Thus agricultural efficiency can be improved considerably by the use of many plant residues.

TABLE 5 — *Some Agricultural Wastes from Field and Factories.*

Crop	*Field Waste*	*Solid Factory Waste*	*Liquid Factory Waste*
Cereals	straw	bran	—
Banana	stem	skins	wash water
Sugar cane	leaves	bagasse, molasses, filter mud	wash water & stillage
Cassava	stem & leaves	skins	wash water & stillage
Oil Palm	—	bunch & fibre waste	waste water
Cocoa	pods	pulp	—
Coffee	—	pulp	fermentation water
Soybeans	straw	shells	texturized vegetable protein liquor
Wood	leaves & branches	sawdust, chips	sulphite liquor
Sisal	—	pulp	pulp exudate
Peanuts	straw	shells	—
Vegetable	stem & straw	skins & cleanings	wash water

Unfortunately, most of these are currently considered to be too light and bulky to carry far from the field. At present, they may be best left there to perform a useful service improving soil fertility and structure by returning nutrients and organic matter (Vergara and Pimentel, 1978).

However, many crops also produce one and often several waste products at a processing centre where they create a considerable disposal problem. Hence many are already used to provide processing fuel normally by burning when reasonably dry (e.g. sawdust, bagasse, oil palm residues). This fuel saving gives sugar cane a considerable advantage over energy crops like cassava (Vergara and Pimentel, 1978; Silva *et al.*, 1978). Both crops also produce vast amounts of wet wastes that are much more difficult to deal with. These are the wash water effluents and distillery wastes (stillage). Such wastes are dilute and bulky. They are disposed of as cheaply as possible, and frequently pollute rivers. Each liter of sugar cane or cassava ethanol yields 8-12 liters of stillage as by-product and this stillage contains 1.5% non-fermentable sugar (pentoses) and so has a high biochemical oxygen demand. Alternatives like simple evaporation by sun energy are being tried. Falling-film evaporators are expensive, but glycerine recovery can improve the economy balance. A 50% concentrate can be used to fuel the still.

Stillage can also be used as a fertilizer rich in potash but low in P and N. Rapid multiplication of microorganisms in soil results and can cause problems by tying up soil nitrogen. On the other hand, properly directed microbial activity which may stimulate biological N_2 fixation and phosphate solubilization is possible but not yet used. The fermentation of stillage (producing "biogas"), possibly after mixing it with manure or garbage (Paturau, 1969), is also being considered.

Methane production from fermentations is now widely practised, especially in China and India to recover a fuel from animal and human sewage (NAS, 1977; Barnet *et al.*, 1978). Several small household units have been developed, however; these are still expensive, the production of gas is slow and 5 cows are needed to provide the dung to produce the gas needs of a small family. The process has also come into conflict with the use of free, dried cowdung, the traditional fuel burnt in much of rural India.

Many other microbial conversions to fuels other than ethanol and biogas can be considered for the disposal of liquid agricultural wastes. Some of the most interesting of these produce hydrogen, acetone and various alcohols (NAS, 1976; Smith, 1979).

Beyond the farm and the processing factory, many agricultural and forestry products end up in urban refuse. Energy can be recovered from this as it can from any reasonably dry organic matter, by direct combustion or controlled pyrolysis. The latter can yeld gases, alcohols, fuel oils, charcoal and tar in varying amounts depending on the catalysts and processing conditions used (Lowe and Overend, 1978; Appel and Miller, 1973; Schlesinger *et al.*, 1973; Paturau, 1969; Vergara and Pimentel, 1978).

Many of the processes discussed in this section have proved to be uneconomical in the past. All clearly need reconsidering and feasibility studies must be continuously updated to accompany rising petroleum prices and new technological developments.

3. Reducing Energy Inputs

3.1. *Energy Balance*

So far we have mainly considered the potential of different crops to produce energy and given little consideration to the fossil energy inputs that also determine the all important net energy gain. These inputs are now so large with the modern agricultural techniques used in developed countries that many crops do not in fact produce positive gains (Weisz and Marshall, 1979; Vergara and Pimentel, 1978). This is one of the main arguments against large scale alcohol production from surplus maize in the U.S.A. Lebailly (1980) has shown that the situation has become worse in the last 20 years with the overall energy balance for food crops changing from 0.68 to 0.41 between 1960 and 1975 in Europe.

As mentioned previously, tropical regions offer better prospects for obtaining net energy gains from agriculture than temperate zones, not only because sun energy inputs are obviously larger and constant during most parts of the year and the overall biomass productivity is higher (Fig. 1), but also because there are many more alternative tropical crops. Energy balance data are very variable and reliable estimates are not easy to find. In order to obtain realistic estimates every single item of agricultural production, harvest, transport and industrialization should be considered. Data from various studies are available for sugar cane, sweet sorghum, cassava and wood (Silva *et al.*, 1976; Hopkins and Day, 1980; Serra *et al.*, 1979; Inden and Wagner, 1978) and energy gain/input coefficients are between 0.9 and 2.4 (estimated potential 6.1) for sugar cane, 0.89 - 1.92 for sweet sorghum (stems + grains), 0.73 - 1.45 (estimated potential 4.5) for cassava and 0.66 - 0.87 for ethanol from wood. However, net energy gain per ha. is more important than energy input/output ratios. Some examples for the major crops are given in Table 6. No data are available for oil palms; however, inputs are small. Similarly, fire-wood which produces the highest yields of energy per ha. (Table 2) requires very few energy inputs compared to most biomass fuels.

TABLE 6 — *Energy balance for alcohol production from different crops* (Silva *et al.*, 1978).

Crop	*Crop Yield (l/ha. yr.)*	*Alcohol Yield (t/ha. yr.)*	*Energy (Mcal/ha. yr.)*		
			Production	*Consumption*	*Balance*
Sugar cane	54.0	3.564	36.297	14.952	21.345
Cassava	14.5	2.523	13.261	11.456	1.815*
Sweet sorghum	32.5	2.145	23.113	11.179	11.394

* 9.358 M cals if stems are used as fuel source.

Apart from obvious ways of improving the production of net energy by breeding for higher plant yields and using byproducts as fuel, there are many other means by which agriculture can be made more energy efficient such as the saving of fuel by reduced mechanization and the use of less fertilizer and pesticides. These will now be discussed in more detail.

3.2. *Saving Fossil Fuels*

The highest energy inputs in modern mechanized agriculture are for fuels, for land clearing, cultivation, harvesting, drying and transport. These can account for 50 or 60% of the total energy costs (Table 3). As already mentioned, hand labour may be an attractive alternative for some of these operations especially in countries with unemployment problems. Minimum tillage, or the direct planting of seed in unploughed land, can drastically reduce cultivation costs in some soils (Kaster and Bonato, 1980). This is becoming increasingly popular, especially in the tropics where it helps to control erosion and has even increased root growth and yields by retaining soil moisture and lowering soil temperature (Maurya and Lal, 1980). Additional fuel can be economized in many ways. Some examples are the thorough drying of wood before transport, the use of solar grain driers, the diffusion of sugar out of cane and the separation of alcohol with semi-permeable membranes or zeolites instead of by distillation. Serra *et al.* (1979) have also suggested that trees should be planted on 10-30% of the land on energy farms, to supply processing fuel.

Fuel is also needed for the manufacture and application of herbicides, fungicides, and pesticides. These can be avoided or reduced by breeding for resistance to plant pests and diseases, by the use of biological control and by rotating crops. The need to reduce much excessive routine spraying to only the few applications that are economically justified, is obvious.

3.3. *Saving Fertilizer*

Fertilizers account for the second largest part of the energy inputs (25-40%) (Serra *et al.*, 1979). Nitrogen (N) represents about 80% of the costs (1200 M cal/ha against 250 for PK). Fortunately it is this element which can be fixed biologically from the air. This process needs less than half of tbe energy used by chemical nitrogen fixation and even this part is derived from plant photosynthesis. Legumes can obtain all the nitrogen they need through a sophisticated symbiotic association with nitrogen fixing bacteria (*Rhizobium* spp). Leguminous oil seeds, e.g. soybeans and peanuts and many legume trees have potential as energy crops. These, and others, can also contribute to the N requirements of non-legume crops when intercropped or rotated with them. The 16 million tons of N per year, worth ahout 1 billion US dollars, incorporated in the Brazilian soybean crop give an idea of the importance of biological N_2 fixation. In recent years, several associations of cereals and grasses with nitrogen fixing bacteria have also been found. None of them is as efficient as that of legumes, but even if 10-40% of their nitrogen needs are covered by biological fixation, the economy on a world scale could be very large. Sugar cane is one of the grasses which can obtain large parts of its nitrogen from biological fixation (Döbereiner, 1961; Ruschel *et al.*, 1978). Sorghum and maize also associate with nitrogen fixing bacteria and research to elucidate the mechanisms involved is in progress (Döbereiner, 1979; Neyra and Döbereiner, 1977). Apart from selection and breeding for the ability to fix nitrogen some systems can be stimulated by the return of organic matter to the soil. For example leaving sugar cane tops on the soils, instead of burning them, increased soil N by 440 kg/ha in 4 years and raised yields by 9 tons in the third and in the fourth years (Table 7). The extra crop also contained the equivalent of 90 kg N/ha.year.

Breeding crops for tolerance to low soil pH, aluminium toxicity and low phosphorus content can reduce the need for limestone and phosphorus fertilizers. The cost of soluble phosphate fertilizers can be further reduced by returning crop residues like sugar cane filter press cake and furnace

TABLE 7 — *Effects of handling sugar cane trash on soil nitrogen and cane yield* (Veiga *et al.*, 1961).

Treatment	*N_2 fixing bacteria*[a]			*Cane Yield t/ha.yr*	
	2nd yr	*4th yr*	*% soil N 4th yr*	*1st and 2nd yr*	*3rd and 4th yr*
Trash left on the ground	362	352	0.301	85	69
Trash aligned in alternative rows	278	242	0.270	77	62
Trash burned	92	115	0.257	87	60

[a] n° of microcolonies of *Beijerinckia*/g soil.

ash and by the use of rock phosphate on acid soils for many tropical, especially perennial crops. Sugar cane stillage can also be used to improve the availability of rock phosphate on such soils.

4. The Brazilian experience

The Brazilian economy has been very seriously affected by the sudden increases in world petroleum prices because over 80% of its requirements are imported. This now costs over 10 billion dollars annually and accounts for about 50% of the total imports. The urgent need to solve this problem has led to rapid increases in the price of local petroleum products and the stimulation of an old project to add ethanol to petrol. Brazil has done this periodically since the 1930's, especially when petroleum was scarce during the Second World War. Experience gained during this period and since, has helped the country to rapidly increase ethanol production, mainly by encouraging the large existing sugar cane industry. The project has been so successful that practically all the petrol sold in the country now contains 20% alcohol. Production has risen sharply since 1977 (Table 8, Fig. 3) to over 3 billion litres in 1980. Expansion to

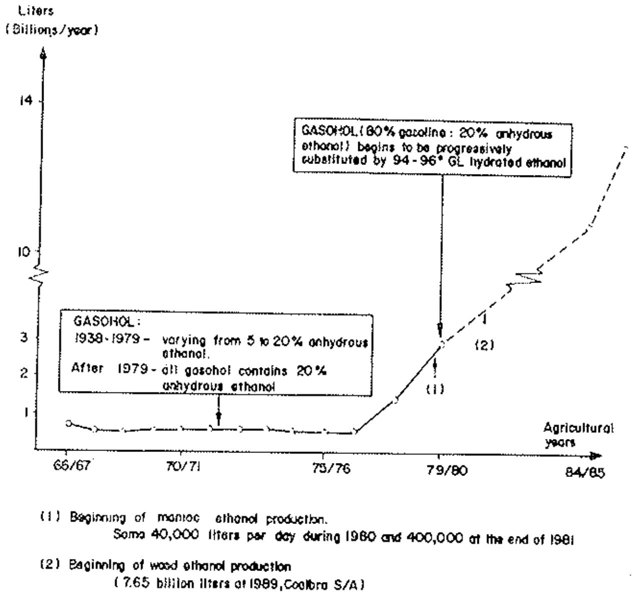

Fig. 3. Estimated scenario for energy alternatives in Brazil.

TABLE 8 — *Alcohol Production and Demand in Brazil* (in Million Litres) (World Bank estimates).

Year	*Production*	*Export*	*Local Consumption* *Chemicals*	*Fuel ethanol* [a]	*Gasoline*	*Alcohol/ Gasoline Average %*
1967	n.a.	n.a.	n.a.	437	7,247	6.1
1968	n.a.	n.a.	n.a.	171	8,216	2.3
1969	n.a.	n.a.	n.a.	32	8,748	0.3
1970	n.a.	n.a.	n.a.	184	9,705	1.9
1971	n.a.	n.a.	n.a.	254	10,617	2.4
1972	n.a.	n.a.	n.a.	391	12,004	3.3
1973	653	44	300	309	13,918	2.2
1974	615	89	336	190	14,322	1.4
1975	579	74	343	102	14,619	1.1
1976	642	33	438	171	14,660	1.2
1977	1,010	4	367	639	14,139	4.3
1978	2,000	10	355	1,635	14,970	9.9
1979	3,300	—	200	3,100	13,017	19.6
1980	3,900	—	300	3,600	13,325	21.7
1985	10,700	—	1,500	9,200	12,314	44.5

[a] Excluding any likely substitution of diesel fuel.

10.7 billion litres is planned for 1985, by which time it is hoped that cassava will account for about 5% and wood ethanol perhaps for another 8%. In addition to the use of gasohol, about 250,000 cars able to run on 95° GL alcohol have already been made and about 100,000 old cars have been converted to accept this fuel (Table 9). Problems of a shortage of pumps on minor roads, water addition and human consumption are now being faced.

In addition to saving imports it is estimated that the project will create 450,000 new jobs between 1980 and 1985 in the interior. However, fears have been expressed about the competition of fuel with food production and prices, especially because car owners have more purchasing power than the very poor (Brown, 1980; CAT/CNPq, 1978). Whilst this could create real problems in many developing countries like India, Brazil is fortunate in having vast areas of unused land whose use the Government is actively encouraging to avoid such a fuel-food conflict.

TABLE 9 — *Conversion of Brazilian Motor cars to pure 95° GL ethanol.*[a]

	New pure ethanol motors 10^3	*Converted Motors* 10^3	*N° of stations with ethanol pumps*
Jan. 1979	0	1	0
Jan. 1980	0.6	5	500
Sept. 1980	50	30	1800
Dec. 1980	250	80	4000
1982	900	240	—
1985	1950	550	—

[a] Projections of the Ministery of Industry & Commerce.

The distribution of the major energy crops in Brazil can be seen in Figures 4 and 5. These suggest that it will be best to use different crops in different areas.

Table 10 summarizes the area of land used for fuel production in Brazil and compares this with estimates (*) for the year 2000 when around 75% of the country's liquid fuels should be coming from biomass. It is estimated that only 2% of the total territory or 15% of the agricultural land will be needed (Goldemberg, 1978; assuming only 8% of Brazil is suitable for agriculture). So the large untapped forest reserves of the Amazon (50% of the country) could remain untouched and there would still be ample land available for food production and export as well as for fuel.

(*) The estimates shown in Table 10 are based on the following scenario:

Estimated gasohol requirements in year 2000 would be 50×10^9 L/yr. If 50% gasohol is replaced by pure hydrated ethanol (pure hydrated ethanol efficiency = 0.8 × gasohol efficiency) 30×10^9 L/yr hydrated ethanol would be required. Anhydrous ethanol requirements (year 2000) for continued gasohol would be 5×10^9 L/yr.

Assuming no use of vegetable oil in Diesel vehicles, estimated Diesel oil requirements in year 2000 in absence of renewable fuels: 36×10^9 L/yr (current consumption plus a 3% annual increase).

If 87.5% diesel oil consumption is to be substituted by a 1:1 diesel oil: Palm oil mixture and 12,5% by ethanol running vehicles, additional requirements would be:

Palm oil - 16×10^9 L/yr; Hydrated ethanol - 5×10^9 L/yr.

Hydrated ethanol requirements (year 2000): 35.4×10^9 L/yr.

TABLE 10 — *Land requirements for the replacement of fossil fuels by biomass derived fuels in Brazil* (Goldemberg, 1978; Colabra, 1980; National Institute of Technology, 1979; Brazilian Ethanol Program, 1980).[a]

	Year 1980 (Current figures)		*Year 2000 (According to the assumed scenario)* [a]	
	Ethanol production $L/yr \times 10^{-9}$	*Land requirement* $ha \times 10^{-6}$	*Ethanol production* $L/yr \times 10^{-9}$	*Land requirement* $ha \times 10^{-6}$
Gasohol replacement (50% in year 2000)				
by sugar cane ethanol	3	1.0	5	1.4
by wood ethanol	0	—	14	6.3
by manioc, sorghum, etc. ethanol	0	—	11	4.3
Diesel oil replacement (87.5% in year 2000)				
by ethanol (12.5% vehicles)	—	—	5	1.7
by Diesel palm oil mixture (1:1)	—	—	16	2.8
To support continued gasohol use	—	—	5	1.7
Total Brazilian territory		850		850
Suitable land [b]		70		120
% of total land to be used for liquid fuels		0.12		2.1
% of suitable land to be used for liquid fuels		1.43		15.2

[a] The assumed scenario is described in the text (item 4).

[b] Land suitable for rainfed agriculture excluding the Amazon forest and the dry North-eastern regions.

The World Bank estimates are that ethanol production from Brazilian cane refineries gives an economic return of between 16 and 30% when the petroleum price is US $ 30 a barrel. This is due to the cheapness with which sugar cane, wood refineries and alcohols can be produced in Brazil (Table 11). Similar projects may not be so attractive elsewhere. For example Vergara and Pimentel (1978) compared the potential for biomass fuel in five countries and concluded that the prospects were promising

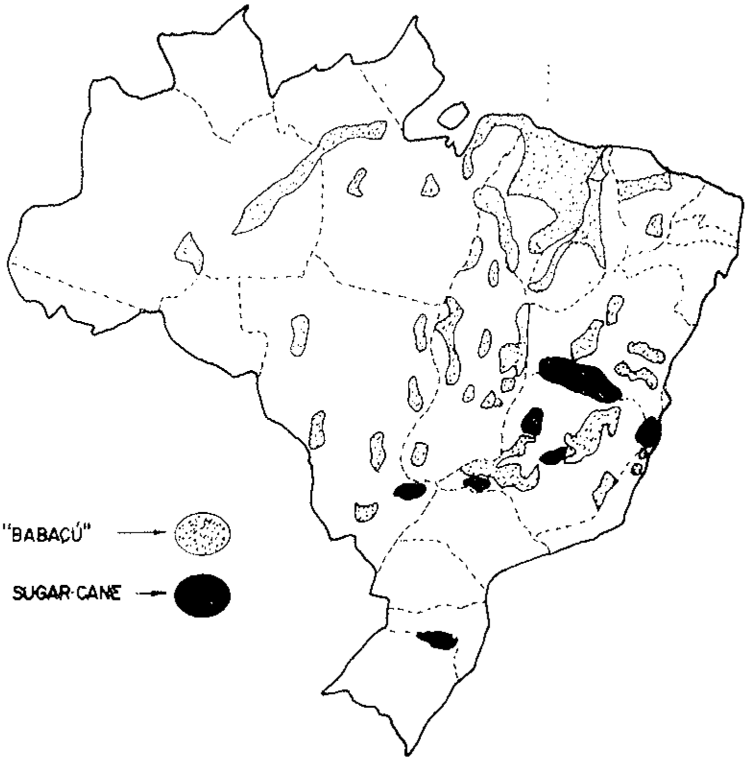

FIG. 4. Regions where sugar cane is grown and where natural babassu occurrence is found (Ministry of Industry and Commerce, 1978 unpublished data).

in Brazil and the Sudan but unattractive in the USA, Sweden and India.

However, the future potential for such fuels will depend on their price compared to that of petroleum, improvements in the yields of net energy and the extent to which it becomes possible to replace diesel and fuel oils. Sugar and alcohol prices are currently high on world markets and may seem too valuable to be used as fuel. Alcohol is an excellent feedstock for the production of ethylene and other valuable chemicals, so Brazil is currently exporting a certain amount for such purposes. However, sudden world shortages of petroleum have emphasized the strategic advantage of developing a home grown substitute, even if it is more expensive at the moment. The rapidly rising petroleum price can be expected to eliminate the difference in the very near future (Fig. 2) and thus provide a further justification of the programme.

TABLE 11 — *Liquid Fuel Production Costs and Brazilian Retail Prices* (October 1980).

Production costs	*Fuel*	*US $/liter*
Sugar cane	ethanol	0.25
Cassava	ethanol	0.33
Eucalyptus [a]	ethanol	0.42
Eucalyptus [b]	methanol	0.10
Retail Prices		
Fuel ethanol (95° GL)		0.43
Gasohol [c]		0.77
Pure Gasoline		not retailed

[a] By acid hydrolysis assuming the use of hydrolytic lignin to produce lignin cake (Araújo-Neto, unpublished data).

[b] After Leite (1979) methanol is not yet part of the Brazilian Alcohol Program and is not available as fuel.

[c] 80% gasoline plus 20% anhydrous ethanol.

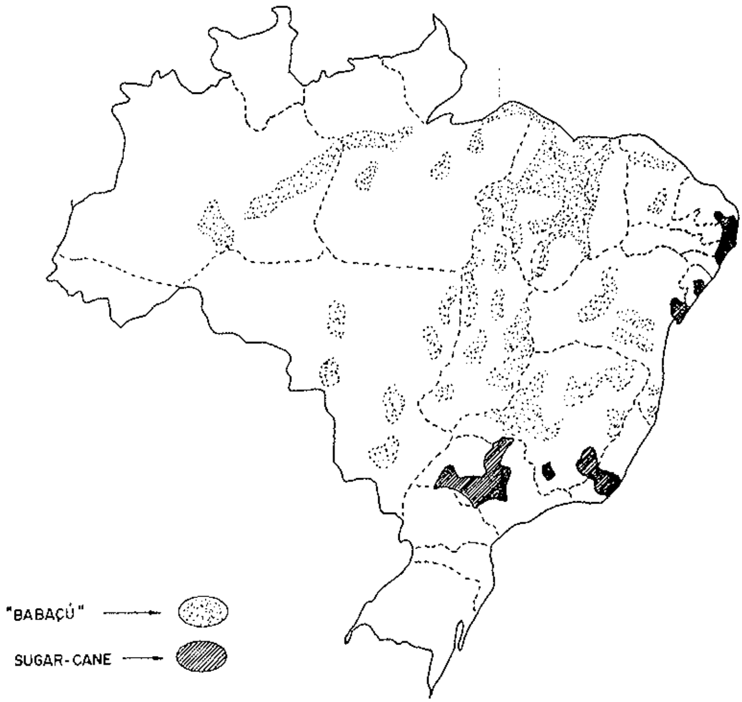

FIG. 5. Regions where cassava and Eucalyptus are grown (Ministry of Industry and Commerce, 1978, unpublished data).

5. Conclusions

1. The possibilities for producing biomass fuels are much better in the tropics and subtropics than in temperate regions because of the greater potential for crop growth.

2. Sugar cane is the most attractive crop for ethanol production because net energy yields can be large and the technology is well known and proven, and can be used immediately.

3. The ability of other crops like sweet sorghum, cassava and Eucalyptus to grow on drier and marginal land may justify their use for ethanol production in some countries.

4. The replacement of diesel and fuel oil by ethanol is not very attractive at present. This limits the potential impact of biomass fuels on the total replacement of Brazil's petroleum imports. Vegetable oils, especially from the African Oil Palm, might become viable alternatives in the future.

5. Firewood produces the highest energy yields per area and is the cheapest source of biomass in most places. It deserves much more consideration than it now receives.

6. Methanol production from wood looks more attractive in terms of yields and cost than ethanol from any source, but development problems restrict this promising source in Brazil at present.

7. Apart from the obvious possibilities of improving yields by agricultural practices and plant breeding, net energy yields can be easily increased by saving agricultural inputs like fuel and fertilizer and reducing processing costs, especially by using waste products as fuels.

8. Few countries are as fortunate as Brazil in having large areas of unused land that can be exploited for biomass production without seriously affecting the land needed for domestic food supplies. In fact only 2% of the country will be needed to replace all its petroleum imports.

9. The use of biomass as a fuel source will depend on the costs and benefits as affected by crop yields in different locations and the development of new technologies to extract energy from different plants. Solutions will obviously vary from country to country.

10. Flexible manufacturing and marketing policies will be needed to maintain domestic supplies of sugar, alcohol, vegetable oil and cellulose whilst taking advantage of favourable conditions for export to fluctuating world markets.

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DISCUSSION

PASZTOR

Just two questions: 1. What is the cost per Kw of electricity produced from the solar pond you have shown? 2. Is there no danger for the salt gradient to mix?

TABOR

The cost now is about $ 4000 per Kw installed and I hope that, for the later ones, it will go down to nearly $ 2000. We want to compete with hydro-electric plants. The cost of Kw is about 30 c. and we hope to take it down to 6 c.

The mixing is absolutely not a problem. What is really wonderful is the storage possibility.

CHAGAS

What is the problem with winds, studying solar ponds?

TABOR

Well, we flow a plastic wind breaker on the surface of the solar pond so to limit the mix. We lose some energy but it is not a big problem.

BLANC-LAPIERRE

If I have well understood the ratio of solar and oil energy is in your country about 2%, is it correct?

TABOR

Yes it is, but in connection with water heating.

PARIS

How many hours in the year can a solar pond operate?

TABOR

Well, in this particular case, it operates just 1/7 of the total number of hours because the pond we are using is a seventh of the size it should be for a 150 Mw plant. The final version full size, will run continuously. By the way, if you build the pond a little deeper, about 4 or 5 meters deeper, you can use it for heating in the winter, because it stores the summer energy. I think this is the first answer for a seasonal storage.

STARR

The estimated price for $ 6 per peakwatt as a 1985 target really becomes $ 24 to $ 30 per average watt, which places it very far above the conventional source competition of about $ 1 per average cost.

VAN OVERSTRAETEN

The price of solar energy is not comparable with the price of conventional sources within the developed countries. We have to compare them in the Low Developed Countries.

PASZTOR

I would like to ask a question about the production of these photocells. Whether it would be possible, one point after the research has been done, to produce this kinds of cells in what I would call a somewhat lower technology environment, than that you will find in Belgium or in other states?

VAN OVERSTRAETEN

Well, I think it is quite possible to do that. In fact, we are looking into the request of several developing countries which are asking for such technonogy. If we do transfer this technology gradually, starting out in developing countries having done firstly the framing, the incapsulation, the interconnections and then go on manufacturing the cells, I think it is possible to do that. Personally, I feel that it would take another five or ten years; it is completely reasonable to do that because the evolution in the technology is still too rapid.

DANZIN

How much could we count in the year 2000 on the contribution of energy coming from these types of generation in proportion of total energy consumption?

VAN OVERSTRAETEN

Thank you for that question. Personally, I am quite optimistic and I also try to be realistic. I do believe that, if the photovoltaic does have a contribution on the order of 2%, that would be probably a right figure. That does not mean, as I mentioned before, that it is not important, because in developing countries that contribution could be quite higher. In comparison of the amount of energy per capita available today in the developing countries, the photovoltaic electricity would have a large impact because I think that, first of all, photovoltaic conversion is also an appropriate way of energy production in developing countries.

PORTER

The contribution of the photovoltaic electricity will be the 2% of total energy or 2% of electricity generation?

VAN OVERSTRAETEN

I would say as 2% of electricity generation.

PASZTOR

I would like to call the attention to the need for institutional change at the levels of government and private industry. Today's local paper has an article about the difficulty of gasohol in the U.S., because of the lack of institutional support.

CHAGAS

If Dr. Döbereiner allows me, I would like to answer the first question because I think that we have to consider two points. First of all, the sugar cane industry is, more or less, 300 years old and it can be improved in scientific terms, I believe. Secondly, here we have not a guess but facts, we have proved facts, and this is quite a different thing. In Brazil, the Government, the Conservatives are conscious and in favour.

DÖBEREINER

When I say that we go into the savannas, this is a government planning, not what did really happen. When this will happen, it is hard to say. In fact, at the moment, we face some serious agricultural problems, not because there is no land and not because the government does not try to have new areas available to the sugar cane production, but because sugar cane gives you more money. And this is something that will be a big problem, against which we have to do something. The farmers now prefer, instead of beans and mais, to grow sugar cane, which will be running into competition with food crops.

PORTER

The Government has helped with price incentives the diffusion of ethanol hasn't it? The actual cost of this fuel to the consumer is very low, it is the result of a positive taxation policy which is getting results, or is it not?

DÖBEREINER

Sugar cane ethanol at any production cost is already quite below the selling price.

SILVA ARAUJO NETO

The only incentive Brazilian Government is giving for ethanol production is related to the low cost of money for investments in sugar cane plantations.

The interest on this money is lesser than the inflation rate of the money itself. This helps sugar cane very much, even now ethanol can be produced with very good prices if compared with those of gas and gasoline.

PORTER

But could I ask, without loans, without tax incentives and making allowance for the energy input into the alcohol production, how is the present cost comparison between petroleum and ethanol?

DÖBEREINER

I think it is the one I showed.

CHAGAS

Cassava for instance has never been evolved in a scientific way. Much can be done to improve crops production using scientific method.

SCHMITT

If compared to gasoline production costs in my country (FRG) quoted ethanol production costs seem to be lower. This should mean that these products are fully competitive.

HALL

I should come on three questions that have just been answered. The first one is about institutional requirements. This problem exists in the United States and anywhere in the rest of the world. The U.S. today is trying to increase biological alcohol oil production from 80 million gallons to five hundred million gallons within the space of two years. This is even impossible in the United States because it takes eighteen months to put up a distillery.

The second question concerns the food versus fuel problem. A problem which has to be resolved locally e.g., how much fuel do you use in cooking, how much does fuel cost in labour; how much food is essentially wasted in storage for distribution, etc.

The last one is about the use of biogas in industrial equipment. This is common in China and more machines are now being constructed to use biogas in many parts of the world.

DÖBEREINER

Gasohol price in Brazil is artificially taxed and high. So the 77 c in Brazil are much higher.

Ethanol price from sugar cane is about 25 c., from cassava 33 c., wood ethanol 42 c., ethanol at gas station is 43 c. About half of the 77 cents is tax.

SILVA ARAUJO NETO

Just two comments on balances. First of all economic balance. We must realize that if Government gives low cost money to the people, the Government is giving money to our colons and this permits a great saving of dollars. We save some 1 billion burning ethanol instead of gasoline and oil. The answers which are given create employment and push the migration from the towns to the country again. We use for producing ethanol wood and manioc, using central Brazil lands which are bad in terms of farmland. Wood and manioc are just the two raw materials which do not compete with food and which are not influenced by climatic effects. Something else about the energy balance that Prof. Chagas pointed out. There are many ways to increase the present energy balance if you are concerned with sugar cane. Actually, we use an old technology, we have low agricultural yields and we invested a lot of money to build new distilleries.

CHAGAS

I am sure that this program has a very interesting aspect because, first, it will be a decentralized one, and, secondly, it will be a way to fix people in the hinterland and so avoid urbanization. This is an aspect which, may be, has nothing to do with energy, but has an important impact on the society and on the social evolution of a nation.

PORTER

Yes, I am sure that it is a very impressive tool. For Brazil, it is surely a solution. I wonder how far can we go elsewhere in the world. I calculate that the land area needed to supply the all world energy needs, at the efficiency we are talking about, taking the energy efficiency into account, would be about the same as the land area we use at present to grow food, which is a very large land area. Brazil is unique. May be part of Africa. It is a very succesful project in Brazil, but I wonder how to do it elsewhere.

SANCHEZ-SIERRA

I agree very much with the Brazilian alcohol program, especially because they have no choice. The alcohol program presents some important problems, land is one of them, but the land structure in Brazil is changing a lot by now. They are going back to the feudal system because, if they want to improve crops in order to build big alcohol distilleries, I mean a one hundred thousand liters a day, they need big extension of land.

Secondly, they have a pollution problem with some technical possibilities, but, in many plants, they are not using any control. Anyway, Brazil, at this moment, is consuming something like a million barrels a day of oil, importing 90% of this amount. They must improve the alcohol program.

HALL

The problem is the reforestation one, not a culture competition problem.

SCHMITT

The availability of fertilizer can become a problem. If such a program, as the one you showed us, takes place, could we imagine then that the demand for fertilizer will increase so fast that also prices will increase too and may damage the competitivity of the product?

DÖBEREINER

We have to consider this from two sides. The first is the sugar cane one. This is a crop which naturally uses fertilizer. We use much smaller nitrogen fertilizer amounts than those used in Holland and U.S.A.

Secondly, you can burn the straw and apply ash to the fields so you give back P and K fertilizer. About nitrogen, we hope that biological fixation can help the sugar cane.

STARR

There are several levels of energy needs. The first is subsistance. There is another need: increase the material welfare of population. Welfare of population rises with incomes, but it requires also more energy than that sufficient for subsistance.

Biomass is surely one of the basic energy inputs. We need also other energy sources.

SILVA ARAUJO NETO

Two comments. The first related to Dr. Starr's comment. This is concerned with material dependence: material dependence as a part of the energy problem. My comment is a new argument to biomass investigation for ethanol production. I think that, in this meeting, we are forgetting an important fact concerned with ethanol production. Ethanol can create an alcohol chemistry, perfectly comparable with petrol chemistry. We must remember that ethanol can give place to 60% of the plastics used today in the world and it is a question of material needs which is related to ethanol production.

About Dr. Sanchez-Sierra's comment on the fear of feudalism: we are forgetting in this case that Brazil is working in two sub-programs, one of them is concerned with one hundred thousand liters-per-day plants, and another sub-program concerns mini-plants to small farms, plants built with simple materials, with wood sometimes, which will be able to produce only 5000 liters per day and which are intended to run there.

PORTER

That is true. Have we to develop an alcohol chemistry?

LESOURNE

Presently — according to figures produced at the last World Energy Conference in Munich, September 1980 — the world consumption of non-commercial energy represents approximately 10% of the total world energy consumption.

This corresponds to the present share of biomass in the world primary energy balance-sheet.

What is not clear to me is the following: If no new techniques of biomass exploitation are introduced, biomass will cover a smaller and smaller share of world energy consumption. With the new development (as described in the paper of Dr. Hall and Dr. Döbereiner), will it be possible to do better than maintain the share of biomass in total world energy consumption?

SANCHEZ-SIERRA

I think it is important to point out that the Latin American Energy Organization, at this moment, is working in a program called "Energy balance for the Latin American Regions" and this program is going to be applied in all the Latino American countries, I mean 25-27 countries. We have very good information, I mean we have about five to seven energy balances and there is very good information about wood consumption in Peru, Costa Rica, El Salvador, Ecuador, in Nicaragua. I would like to say that the wood consumption in total energy balance of these countries could reach 30% of the energy consumption. It is very easy to understand this because, if we think that at least we have 30-40% of the population in the rural areas in Latin America, at least more or less 80-90% of them are just using this kind of energy because, you know, for many people in the developing countries, the only energy tbat they know, that they can use, is wood; it is easy to understand that. Then, I think even the figures of Dr. Hall are conservative. The situation is worse, but how can we change that? We cannot say.

The National Institute of Energy in Ecuador is working very hard but how can you say, I mean how can you go in the rural area and just say,: "don't do it". They have no choice, what can they do? Just use it. We know the very big problem we are going to have with hydropotential. I want to point, to clarify the situation because we, the technical people, usually we love to talk about tecbnical things, but we need to think about social implications of the energy situation and, specially, I think that, in developing countries, tbe situation is very, very difficult because if they want to change the energy and the social situation, we have to change the structure in many of these countries, I mean the social structure, that is not ready, in order to improve changes there.

CHAGAS

I want to give you just an information that, on the first of June, the Pope made a very interesting speech in the UNESCO about the meaning of culture, and you can get the English of French version, if you want to read it.

DISCUSSION ON ENERGY AS POLITICAL FACTOR

CHAGAS

As the beginning of this discussion, some participants agreed to do preliminary talk in order to introduce the discussion. I ask M. Desprairies to present his introductory remarks.

DESPRAIRIES

Since 1973, energy has become a major political factor, as evidenced by a quick scan of newspapers, which carry articles about energy almost every day, giving it headline importance at least two or three times a year.

1. People whose business is energy tend to think that it is the political issue of our times. However, there are other, more serious problems for the future of humanity; uncontrolled population growth and its direct consequences; the hunger experienced by perhaps two-thirds of mankind; the risks of economic and military conflicts between nations; spreading materialism and the resulting moral decline; and nuclear proliferation.

In fact, energy is just one of the four or five major issues facing our generation and that of our children, and is less serious than the others, because *a*) the difficulty is material, and has technical and financial solutions, raising only indirect rather than direct moral problems (e.g., the consequences of energy price levels for sellers and buyers); and *b*) the necessary effort can be measured, and the time-scale for solving the problem is relatively short (10 to 20 years).

2. Even so, energy is definitely a political issue. For the last two centuries or so it has been the motor of our civilisation, and is even more so now than in the past. Economic growth depends on energy, in both the developed and the developing countries, whose growths are linked. With less energy, hunger and misery would immediately increase in the world. Modern, efficient agriculture and industry feed us and produce the goods we share, but consume enormous amounts of energy. Our cities and towns cannot survive without means of transport, potable water, lighting, electric or gas cookers, etc. In the countryside, horses and oxen no longer exist to replace tractors in ploughing the

soil, nor to produce manure to replace artificial fertilisers. If world energy supplies were suddenly reduced by 20 to 30%, this would trigger a global economic recession of the same order, worse than the 1929 slump, and put tens of millions of people out of work.

3. The Middle East currently supplies a quarter of all energy consumed by mankind outside the Communist countries, but this source may tomorrow be reduced hy 30, 50 or even 100%. This is the first political factor. We must replace a significant part of these petrol supplies by other energy sources.

4. The attitude of both the oil exporting nations and the oil consuming nations is unthinking and dangerous. It can only lead to pursual of the present economic confrontation, but it is consistent with their intellectual traditions and their history, and there is little chance of a change for the better. The myth of petrol as a miraculous source of wealth hides the true facts, giving birth to irrealistic hopes and desires. There is a considerable risk that untangling the situation will involve a major crisis.

4.1. The OPEC countries are fully aware that they hold a trump card, and their attitude is much less open to criticism when seen through their eyes rather than as usually presented hy the industrial nations. The OPEC is made up of poor countries possessing an irreplaceable asset, on which we depend for survival. Discovered just before World War II, their petrol was first massively pumped after 1950. It was then sold at a very low price, because produced at a cost ten times less than coal and in large quantities, and because resources were considered unlimited. It made both the producing and the consuming nations richer, but the producing countries now consider that their petrol — their only wealth — was sold too cheaply for too long. They want to recover part of their lost capital and reduce production so as to make their resources last longer and push up prices to the maximum tolerated by the market (i.e., by our civilisation), using the extra money to build factories and a modern agriculture. The most fervent of the OPEC countries have even greater ambitions. They want to persuade the industrial nations to make good their past wrongs and the other OPEC countries to sell their petrol only in return for development of the Third World.

4.2. Almost all the petrol consuming nations refuse to negotiate on the hasis of "petrol in exchange for development" demanded by some petrol exporting countries, and the rich countries consider that such a negotiation could only end in a deadlock, like at Paris in 1975/77.

The OECD countries believe in the regulating action of the market. Their attitude is: "We probably have a difficult period to go through, but we have money, almost unlimited natural energy resources, and the technological capability for their development. The solution to the problem is technical and financial, not political".

The oil producing countries know that this is true, in the long run, and that their present position of force is only temporary. They may well attempt to obtain the maximum while they can, and this could be what was taking shape before the war between Iraq and Iran, in the form of concerned decreases in output, to prevent petrol prices dropping and then push them as high as possible.

Today, it is rather hard to envisage anything but an economic confrontation, with price rises up to the limit of the industrial nations' capacity to pay, accompanied by a halt in world economic growth. The latter would not result just from the increase in petrol prices, as too often suggested, but also from the multiple disturbances that such sharp price rises would indirectly produce in the fragile, imperfect machinery of the international economy, which is so easily thrown out of order by a slowdown in growth.

5. The industrial nations will suffer from this, but the developing countries infinitely more so. Petrol is indispensable to modest daily life in such countries, being used to light houses, cook food, transport goods, pump water for irrigation, plow and fertilise the land, etc., and already takes up 60 to 70% of their export earnings. And yet, the oil exporting countries show no intention of offsetting the effects of price rises, except for a few of the poorest nations, envisaging in most cases just loans compensating only 10 to 20% of future price increases. They consider that petrol is sold at its correct price, and that it is indecent for the rich countries to deplore the fate of the poor countries. Indeed, in their opinion, it is the rich nations which should compensate the major part of the poor countries' increased petrol expenditures.

Only a strong sense of necessity could convince the industrial nations to follow such a path, as this would remove one of the main oil price restraints. In any case, they would only accept witbin clearly stated and agreed limits, accompanied by a multiannual agreement guaranteeing delivery of stipulated quantities of petrol at defined prices.

However, up to now, the oil exporting countries have always refused to negotiate prices and quantities, the fixing of which is seen as one of their sovereign rights as independent states.

The situation would thus seem to be blocked. A temporary solution will in all likelihood be found, based on loans to the poorest nations, increased worldwide inflation and an even less stable international monetary system. But for how long?

Although petrol is an important contrihuting factor to this increasing lack of stability and the consequent dangers, it would he unfair to put all the hlame on petrol and to refuse to admit that the sometimes extreme attitudes of petrol exporting countries hide legitimate demands, and that these will one day form the hasis of a true dialogue.

COLOMBO

First of all I would like to agree with M. Desprairies on the brilliant exposee he made and especially on the consideration of the very high "specific weight" of energy as a political factor.

The energy problem is typically international and must be looked at in the context of the competition between the different raw materials, different technologies and, also, in the context of the related terms of trade, to use a simplified expression.

I agree also with M. Desprairies on the crucial rôle that petroleum is playing in the overall energy prohlem and I would also state very firmly that petroleum may, in the future, originate crises of large dimension, much larger than those that we have been accustomed to in the last few years.

I have attempted to list, in Fig. 1, several types of oil crises to which we must be prepared in the next decades. Some of these crises may arise as a result of deliberate OPEC policies, some others may be unrelated (or only loosely related) to them.

Fig. 1 is self-explanatory, although this a clearly an oversimplified scheme, but it gives an idea of the variety of causes hehind possible crises which may give rise either to a drop in supply, or to distribution problems, or else to drastic price increases, even contradicting market economy principles.

In any case, the major consequences of an oil crisis are:

— high inflation;

— large halance of payment deficits;

— reduced rates of economic growth;

— high unemployment.

Consumer countries are likely to resist to oil crises if their economy is strong and if they defined and implemented energy strategies aiming at a substantial reduction of their oil dependence. France is the best example of a country which has decided to substitute oil as much as possible. Ten years from now, France is likely to be in a much better position than most European

OIL CRISES

Related to	*Independent from or Triggered by Oper Policies*	
Production	Accident Natural disaster Revoluction, War	Production control Production geared to domestic needs Oil embarg
Production capacity	Decline by lack of maintenance Natural depletion Sabotage	Suspension of investments Suspension of exploration activity
Distribution	Incidents, i.e. Hormuz blockade	Suspension or cut
Price	Wild increase in the spot market	Sharp rise in real terms

FIG. 1

countries, with the only lucky exception of the United Kingdom. I wish to note at this point that those countries that are vulnerable to oil crises may be tempted to react by establishing protectionistic policies, which may, in turn, affect international trade.

Oil consumer countries must adopt promptly strategies of oil substitution in the energy system. Coal and nuclear energy are — at present — the alternative fuels which are most promising. Nuclear programs have been delayed in many countries, and there are still problems of social acceptability, which I hope be overcome if the vulnerability of oil-dependent countries is taken into due consideration. As far as coal is concerned, I agree basically with all that Carroll Wilson said yesterday in his brilliant lecture, and wish only to underline here the degree of commitment that re-penetration of coal presents in the international market. Today, as Carroll said, less than ten percent of the coal produced in the world crosses national borders. If we aim at something close to 800 million tons of coal in the international trade, then we have to understand that this means activating over a hundred "coal chains" of the type represented in Fig. 2, which I have taken from the "WOCOL" Study. It is a matter that deserves a lot of attention, commitment

REQUIREMENTS FOR A COAL CHAIN-AUSTRALIA TO NETHERLANDS (1)

COAL FLOW: 5 Mtce/y corresponding to Carried 5.6 Mt	Coal Mine NS Wales Australia	Unit Train Transport	NS Wales Port Australia	Coal Carrier	Rotterdam Port Netherlands	Barge Transport	Power Plants	TOTAL SYSTEM
FACILITIES	7.5 Mt raw coal 3.75 Mt saleable 1.5 mines	80 Km 42 cars 72 t(net)/car 3.8 trains	30 Mt/year 0.2 ports	110,000 DWT 13 ships	25 Mt/year 0.25 terminal	2.8 pusher tugs 28 barges	600 MWe 4.6 plants (2,700 MWe)	
LEAD TIMES (2)	3 years	3 years	2.5 years	3/4 years each ship	2.5 years	3/4 years each pusher tug	5 years each plant	5 years
TOTAL CAPITAL COSTS (3)	310 M.$	50 M.$	60 M.$	350 M.$	40 M.$	34 M.$	2,300 M.$	3,144 M.$

(1) Investments are estimated by Netherlands' WOCOL Group.
(2) Lead times for actual project execution after all permits granted.
(3) 1979 US $ includes escalation and interest during construction.
SOURCE: WOCOL Report, 1980.

FIG. 2

on the side of both exporting and importing countries, and that requires the solution of hard logistical problems.

Such a steep revival of coal implies also the solution of other problems, which range from the protection of the environment to the health and safety of workers, particularly in coal mines. This matter, which is apparently a technical and social one, has serious political implications as well.

In Fig. 3 and 4 I have tried to represent some East-West and North-South issues arising from, or connected with the energy problem. I wish to point out the need, that the industrial democracies of the West have, to avoid situations of dangerous energy dependence from the East.

We should concretely aim at gradually reaching a more equitable world social and economic order. For this aim it is necessary that the less developed countries have access to technologies, particularly in renewable energy sources and in energy conservation. What we should avoid, in other words, is that the developing countries base their industrial and agricultural activities on technologies characterized by a heavy energy use and by high wastes of energy and materials. It is a very critical matter, that requires close attention and a broad cooperation between the North and the South, in research and development and in the adaptation of technology to the specific needs of the countries concerned.

NORTH-SOUTH

- The present energy supply of the North comes mostly from developing countries.
- In turn the North must help the South to built effluent agricultural and industrial structures.
- A more harmonious world grouth process is necessary with a more balanced mix of agricultural and industrial development in the third world to reduce the risk of international crises.
- Renewable energy technologies as well as energy saving technologies must be available to the third world.

FIG. 3

EAST-WEST

- Eastern countries also facing energy shortages thus increasing possibility of East-West conflict over OPEC oil.
- Importance of joint energy research programs (i.e., gasification and liquefaction of coal; oil shales; fusion) and of technology exchanges.
- The issue of energy interdependence between East and West can lead to dangerous situations (i.e. coal importation by the West; electric power produced in the East and imported by the West).

FIG. 4

SANCHEZ-SIERRA

First of all, I would like to say that it is very difficult to talk after Prof. Colombo and M. Desprairies because I think they noised many important points. Then, I just want, in order to enrich the discussion, to give some ideas about energy as a political factor in developing countries.

First of all, we can talk about resources and supply. We know, as Prof. Colombo said very well, that, at least 60-70% of the energy resources — specially oil — at the present moment, are in the developing countries. Then, there are very important political, economical and social factors, between the industrialized and the developing countries. These facts are at the origin of direct and indirect interventions in many developing countries, not only political interventions, but also military and financial interventions. I want to give two examples which, in my opinion, point out the relation between energy and political issues: one is Iran before 1979, with the interventions of some countries and that of the "seven sisters"; the other is the Afganistan present situation.

As far as military, political and financial indirect intervention is concerned, I think that the recent story of Chile and the fall of his President, Mr. Allende, give us a dramatic example of their effectiveness, and you surely know why all that happened.

There is another problem: it is the problem of international treaties in business. We can talk about nuclear centers, about hydroelectric centers, about control centers, . . . We can talk about every important business that is going to developing countries. Just an example: nuclear energy in developing countries. Yesterday, most of us agreed that nuclear energy is not a good alternative for the developing countries. Why, then, is the nuclear industry building nuclear plants in developing countries? There are some important reasons, many concerned with the relations between energy and politics. First of all, it is very difficult to sell nuclear plants in developed countries.

Dr. C. Wilson showed us a very good picture of the history of nuclear plants in the last decade. We could see that it is becoming more and more difficult to sell nuclear plants in developed countries. Secondly, the nuclear energy needs contracts. A 500 Mw nuclear power plant requires, at least, about $ 7 or 800 millions. This is a lot of money in any country and for any industry in the world. Nuclear Industry must sell nuclear plants and they do not care if the plants are appropriate for developing countries or not. Another important issue is that it is easier to deal with government in developing countries, and specially with military or civil dictators. Indeed, it is easier to deal with a government that does not have to discuss with public opinion and to explain democratically why they are going to build a nuclear plant, or a control center, or . . .

Finally, I would like to agree with Prof. Colombo's idea, that a new international economic order is necessary to reduce the risk of international crisis. I completely agree with that. However, we have to recognize that the new international economic order is already "old". We have been talking about a new economic order for at least ten or fifteen years and I think this is a very important point. Now the overwhelming question is the following one: we are talking, and talking looking for a solution; maybe we will have the decision when it will be too late for mankind. Maybe.

WILSON

The change in government in the U.S. last week is an event which will affect energy policy not only in the U.S. but throughout the world because of the size and weight of the U.S. in world energy demand and supply. I can only make a few personal observations on possible effects of this change of government. The real significance will begin to unfold over the months ahead.

The energy picture in the U.S. is not very susceptible to change by a new administration. Oil prices will reach world prices by September 1981. Gas prices are not far behind. A "windfall profits" tax will take the windfall profits of such increases away from the oil companies (8 million barrels/day is still produced in the U.S.). Most authorities expect U.S. oil and gas production to decline even if exploration efforts are increased above the very high present levels.

A number of measures have been taken to increase coal production and use, including financial assistance to electric power companies to substitute coal for oil where it is possible. Some easing of environmental standards may occur and could accelerate the rise of coal use, and the 3-4 fold difference between coal and oil prices provides a strong financial incentive to use coal. Many industries are investing in changes to substitute coal for oil.

A synthetic fuels program has been established with \$ 20 billion initial funding. A new corporation has been formed to work with industry to establish the start of an industry to produce gas and liquids from coal. With each 50,000 barrel/day plant, costing up to \$ 2 billion, the present financing would result in 500,000 b/d production by the late 1980's which, at this time, will be less than 5% of U.S. oil use.

As to nuclear, the Reagan administration may take a more positive position. But, as I remarked yesterday, I believe the main obstacle to increased nuclear power is the loss of public confidence in the industry and in the government. Until such confidence is regained, I see little prospect of a change from the present situation.

As to conservation, powerful forces, arising from \$ 35/b oil, will make greater energy productivity increase faster everywhere.

There are many other unknowns for the world in the change of government in the U.S. Many of the extravagant and simplistic statements made during the election campaign are likely to be modified as the President-elect takes over the responsibility of having daily discussion on critical matters. It is hoped that he will elect a cabinet of men who are knowledgeable about national and world affairs and a Secretary of State who understands the complexity of the world of 1980 and the constraints which must govern U.S. actions in world affairs.

CHAGAS

Opening the floor to discussion, I would like to make some comments.

I want to make very clear my position. I think that we are too severe against OPEC countries. They have the resources which they need to develop the social welfare of their country. Maybe they have used them wrongly but surely they have inflicted in many countries, as mine, serious economic problems. It was a right, that they used in an exaggerated way, trying to defend their welfare, their people.

STARR

National security is the basis of most issues that relate energy sources to international political relationships. If energy prices had increased slowly, the consuming countries would slowly have accommodated to such increase. The sudden and massive price increases did shock the world, but adjustment to these will eventually take place.

VAN OVERSTRAETEN

I would like to add a small comment. In my opinion, in our discussion here, too often some confusion has arisen, due to the fact that not always we pointed out the differences between the three parts of the world which were mentioned by Dr. Starr: industrialized countries, new industrialized countries and developing countries. I think that it is necessary to class them in this way because the solutions we are talking about should be different from set to set.

PASZTOR

I would like to add a different dimension to this discussion, and this is the question of what kind of society we want to live in, that is the question of life styles. This is a topic which we have discussed a great deal at the World Council of Churches and its member churches.

All the discussion so far assumed that the Western kind of society is the good one, and that it is the Western Society which should be spread all over the world. Many comments included statements like: "The Third World will need so much energy to catch up with us", etc.

There are many people in the world and not just in the rich countries, who think that there are other kinds of societies which one could choose. The role of technology in general and of energy in particular would be very different from the present. In some cases these would mean substantially reduced energy consumption per capita. I think it would be a mistake not to deal with these possibilities.

LESOURNE

I think that many of the key points of the discussion have been already made but I would like to stress a few of them.

1. It is important to realize that the energy problem corresponds to *two subsequent transitions* (towards coal and nuclear) and, later, (towards renewable or quasi-renewable sources). Our debate is limited to the first transition although we will have also political issues during the second.

2. Simultaneously, we are faced with *three crises*:

— a progressive depletion of oil

— a limited capacity of oil production due to OPEC policies

— a political crisis in producing countries or between consuming and producing countries.

The last two are essential, because of the delays necessary to react (even if the consuming countries react vigorously).

3. OPEC countries, especially OAPEC countries, are confronted with a difficult situation. They have to replace a source of national income and not only a source of energy.

4. In considering energy as a political factor, we cannot consider the low developed countries as a homogeneous group. Their energy requirements, the kind of energy sources which are adapted to the economy widely differ from one group to another.

5. A new international order in not decided by a conference. It is the consequence of a historical process. Neverthless, the presently developed countries, which have been in the past the "ruling class" of the world would greatly damage their future if they adopted a conservative attitude, refusing the changes which are in process and not marking an effort to enter into a reform process.

DANZIN

Je désire attirer l'attention sur la nécessité de considérer la crise actuelle de l'énergie comme le révélateur d'une crise plus profonde. Dans une certaine mesure, mes paroles feront écho à certaines remarques du Prof. Lesourne. La population du monde s'élève actuellement à presque 4 milliards de personnes. Nous serons 6 milliards en l'an 2000 et 8 milliards vers 2025-2030, c'est-à-dire à relativement brève échéance. Nous n'éviterons pas des tensions politiques exacerbées par les inégalités si nous ne parvenons pas à opérer un rapprochement entre pays pauvres et pays riches. Or, ce rapprochement est impossible si nous proposons une Société où, pour réussir, il faut dépenser environ dix tonnes d'équivalent pétrole par personne et par année. Toutes les discussions de ces trois dernières journées montrent que ces ressources en énergie n'existeront pas aux dates considérées ci-dessus...

Il faut donc trouver un nouveau type de civilisation reposant sur un nouveau modèle de vie et d'emploi, basé sur une réduction drastique de notre consommation en énergie. Seuls, les peuples riches peuvent proposer un tel changement car ce sont eux qui possèdent la clé du développement et parce qu'ils constituent le modèle sur lequel les autres veulent s'aligner. En conséquence, je ne crois pas que les solutions viendront d'une continuité dans la croissance de consommation d'énergie à haut niveau, appuyée sur des moyens de substitution au pétrole, mais d'une conversion profonde de la société des pays développés.

Nous devons accueillir la crise de l'énergie comme un avertissement. La recherche d'une thérapeutique nous oblige à un diagnostic; le monde est malade et la thérapeutique ne peut être apportée que par les pays riches; nous n'avons pas le droit d'empêcher les peuples de préserver leurs avenirs respectifs en préservant les richesses de leurs sous-sol. Et nous n'avons pas, non plus, le droit de reprocher aux pays en voie de développement de demander un meilleur partage de la richesse et de la connaissance.

De temps en temps, l'évolution se trouve en présence de points de bifurcation où l'avenir de la civilisation est fortement engagé. L'homme est, sans doute, capable d'agir alors sur son destin et de trouver des adaptations, s'il s'est aperçu de ses erreurs et a été capable de les corriger. Je pense, et j'espère, que de telles adaptations sont en cours. Je suis fortement convaincu que, si nous ne nous préparons pas à un mode de vie radicalement différent de celui qui est le nôtre actuellement, nous irons de crise en crise, de plus en plus graves, jusqu'à une crise finale dont je ne sais pas la forme, mais qui sera certainement tragique.

HALL

Security of supply for energy at the local level is just as important as at the national level. This is why farmers and business men will pay premium prices for biomass derived fuels, for example. The developing countries need help in "agriculturizing" themselves for food and energy so that they can help themselves in agriculture and in industrialization.

BLANC-LAPIERRE

Merci. Je voudrais ajouter quelques mots. Les perspectives auxquelles vient de faire allusion M. Danzin sont des perspectives qui sont certainement très intéressantes, que nous avons déjà considérées. Je voudrais revenir à quelques mots qui figuraient dans mon introduction. Je crois qu'il faut faire tout ce qui est possible pour désensibiliser, autant que faire se peut, le système économique par rapport à des à-coups sur l'énergie. Je crois que, lorsque M. Colombo a parlé, il y a deux jours, de maintenir une certaine pluralité des sources d'énergie, c'est de la sagesse.

Je crois aussi que, lorsque, dans un pays en développement on se propose d'augmenter le potentiel énergétique, il faut s'efforcer de développer ses possibilités locales, même si cela revient plus cher, de façon à lui assurer une certaine sécurité énergétique.

ENERGY POLICIES IN DEVELOPING COUNTRIES

Chaired by Professor A. BLANC-LAPIERRE

Blanc-Lapierre

Avant d'ouvrir la séance je voudrais dire que nous regrettons que Mr. Gustavo Rodriguez Elizarraras, Secrétaire Exécutif de l'O.L.A.D.E. (Organisation Latino-Américaine d'Energie), ait été, au dernier moment, empêché, par les devoirs de sa charge, de prendre part à nos travaux. Je remercie le Dr. G. Sanchez-Sierra d'avoir bien voulu présenter le rapport sur l'Energie et le Développement Economique en Amérique Latine, et je lui donne la parole.

ENERGY AND ECONOMIC DEVELOPMENT IN AMERICA LATINA (*)

GUSTAVO RODRIGUEZ ELIZARRARAS
Executive Secretary - OLADE

1. Introduction

Latin America is a continent which is not only underdeveloped but also undermanaged, affirmed the President of my country, Mr. José López Portillo, in a recent speech.

Determined to find its way out of the marginal condition that it occupies with respect to the external context, Latin America parallelly lives the dramatic contradiction of not being able to control, within its own frontiers, its own destiny and this great patrimony, the best instrument for negotiating: the possession of humanity's largest volume of available natural resources.

If, indeed, the energy crisis and the subsequent deterioration of the international economic environment are important parts of the setting in which the Latin American economies must respond to the exigencies of development in the immediate future, the end result will finally depend on the region's capacity for strengthening its economic administration and its own autonomy in confronting and resolving all of the wide range of challenges that it is now up against.

The story of this decade is, in general, and particularly for Latin America, the story of this energy crisis, its political, socio-economic, and even cultural effects, and the differential impact that it has had on the economy of each one of the Latin American countries, on their capacity for assimilating and reordering their economies; and, consequently, this

(*) Paper presented by Dr. Sanchez Sierra.

has been produced on a world-wide scale. Due to the extent of the reach and severity of that crisis, it is urgent that the Latin American society reflect and act with decision with respect to the necessary changes that be made in its development models; this is so because we are dealing not only with the adaptation of the region to new economic conditions, but also with profound transformations imposed by scientific and technological advances, the world redistribution of forces and the exhaustion of the current model of accumulation and domination, imposed by the monetary and the prevailing international prices.

Thus, on addressing this vast subject of Energy and Economic Development in Latin America, it must necessarily fall within the framework made obligatory by one of the most immediate problems and one of the most difficult to overcome, the existing rigidity of the energy basis for regional development, its extraordinary dependence on oil and the impact of fuel prices on the economy, the inadequate use of natural resources and its effect on the environment, and the weak capacity for technological innovation, all of which make new orientations for the area's energy structure difficult.

As it has been reiterated in the forums opened up to the regional and external communities by OLADE, the solution to the energy problem in Latin America, as well as in the rest of the Third World will permit the creation of a new international economic order.

If Latin America's socio-economic problem is observed as a whole, an underlying frustration can be visualized, based on wbat the sbaring of the fruits of progress has been, and is: the reservoir and traditional source of raw material destined to the large external centers of power, the story of integral underdevelopment, as it has been called: tbe story of the development of world capitalism.

It is evident that during these last thirty years, Latin America has lived a vigorous process of overall modernization and development. The statistics and analysis of the region's economic reality indicate that its growth during tbis period has meant that the gross regional product has quadrupled, while the per capita income for the Latin American area bas doubled. It also becomes necessary to ponder the installed productive capacity, which has increased nine-fold.

This undeniable economic take-off that the continent has had, and has, nevertheless manifests a negative counterpart, because Latin America has historically been living on the basis of imported models. This fact, which has become more critical in the last thirty years, is closely linked to the region's current energy problem, since the predominant style of development has basically been imitative of that adopted by Europe and the United States.

If indeed, this market economy, fomenting industrialization policies, has made the economy more dynamic, it has not brought with it an equitable distribution of the benefits of regional development, in terms of well-being and higher standards of living for the traditionally marginated.

Behind this style of growth and the technological transformation that sustained it, there has obviously been a pattern of intensive oil use, characterized by its relative abundance, its technological flexibility, and its reduced price.

According to recent information, at the end of 1979, oil covered more than 70% of the total consumption of energy used commercially in the region. Meanwhile, the world average was 45%, and the corresponding figure for developed countries ascended to 50%.

Within the close relationship among economy-energy-development, it can be pointed out that the direct impact of oil prices on the whole of the available energy resources has been relatively slight. It is estimated that, for most of the Latin American countries, energy importations do not reach 5% of the GNP. However, the real dimension of the problem lies in the indirect effects of this impact: how to finance the deficit in the balance of payments and how to confront the growing protectionist pressures derived from the decline in the level of economic activity in the industrialized countries, compulsory markets for the exportation of Latin American manufactured goods.

The foregoing is an alarm signal since the current energy situation and the development of the energy sector in the region can imply serious competition in light of the urgencies of socio-economic development during the next few years, demanded by a continent where, up to now, they have been too marginated from the growth process.

2. Socio-economic aspects

Adam Smith said that the discovery of Latin America had elevated the mercantile system to a degree of splendor and glory which otherwise it would never have reached.

Discovered due to a mistake of great consequence, and conquered in order to serve God and His Majesty and also because of its wealth the New World has been since its historical origins, the fuel for the contemporary productive system.

Between the gold boom and the silver boom, the continent established its social and economic bases, with the structure of an empire organized around the exploitation of precious metals, this being assigned to it during the Conquest period and later made concrete during its long colonial period.

For an analysis and interpretation of the development of the Latin American economy in its regional context, it is useful, in this brief historic preamble, to point out the role that has corresponded to the "encomienda" system. This kind of social organization, which consisted of trusting a nucleus of the indigenous population to a conqueror, with the responsibility of christianizing it, has been considered the fundamental socio-economic pillar of the first 150 years of Spanish presence in Latin America.

On creating a flow of resources destined to be transferred to, and accumulated in, the metropolis, this economic system did not stimulate an interest on the part of the "encomendero" to utilize the surpluses locally. His objective was always to mobilize this surplus in order to discover, produce, and transport precious metals.

The abundant production of these had an important multiplier effect on the economic activities of the conquered territories. And the regions producing these metals, principally Mexico and Peru, behaved as authentic poles for development until the middle of the seventeenth century.

Within the historical evolution of Latin America, this system, organized around producing poles of precious metals, took the form of a progressive decentralization of the economic and social activities, which would convert the ownership of the land into the basic institution of the whole social order, characterized by the domination of the great mass of the population by a small, culturally different minority.

The socio-economic relationships of these large rural domains, of an essentially subsistence economy and almost completely separate from State authority, would fall under the respective terms latifundio indigenous community and latifundio-minifundio, which have, definitively, characterized the Latin American agrarian structure.

In the face of the decline in mining and the penetration of the English colonizers in Latin America, during the next 150 years of Spanish colonization, the internal commercial activities became weaker, thus preparing the way for a tendency towards regional fragmentation and the almost total absence of significant economic links among countries.

On the basis of these antecedents, the structurization of the Latin American national states was produced by happenstance, conditioned by two factors: the lack of interdependence among the landowners and the urban bourgeoisie, formed at the influx of commercial diversification during the last century of the colonial era, around the creation of Europeanizing urban interests, principally English.

In the three or four decades that followed the Wars of Independence, the Latin American countries had to confront serious difficulties in order to open up lines of trade and, consequently, to organize a system of stable power as a result of the Industrial Revolution. This was characterized by the concentration, in England, of practically all of the commerce of primary products, especially the tropical ones, which were provided by the colonies, and also the concentration of the cotton textile industry, whose raw material was produced on grand scale, with slave labor from the United States.

Among the fundamental aspects of the region's economic complex, it is important to point out the human development. Latin America is a continent with an inhabited area of approximately 20 million square kilometers containing merely 10% of the human population. The average density is 15 inhabitants per square kilometer. This figure, however, hides one of the region's principal characteristics: the heterogeneous composition of its nations, from the extensive to the small Central American and Caribbean countries, with population densities on the order of 200 inhabitants per square kilometer (in the cases of Haiti, El Salvador, and the Dominican Republic).

The high rate of demographic growth is a characteristic of this region, its average growth being 2.8% annually, compared with rates of 2.4% and 1% for the developed countries as a whole, and for the industrialized countries, respectively. It is estimated that if this rhythm of expansion is maintained, the Latin American population will reach 400 million in 1985, with 42% being younger than fifteen years old.

Moreover, the region has experienced a radical transformation in the urban-rural distribution of its population, due to the massive and rapid migration from the country-side to the cities. It is estimated that around 63% of the population currently live in the cities, in comparison with the 49% of two decades ago.

The increase, as well as the changes, in the distribution of the regional population have had multiple and complex socio-economic effects.

This situation exerts strong pressure on employment opportunities, the availability of food, and the population's standard of living, especially, health, education and housing.

Among the 350 million Latin Americans, there are currently 50 million unemployed or underemployed, and some 100 million illiterates, while more or less one half lives in minimal housing conditions.

According to statistics from the FAO, about half of the inhabitants of the region, have not yet reached satisfactory (economic) levels of nutrition and a fifth of the total population is affected by serious malnutrition. The percentage of undernourished children younger than five years old, in other words, those with a weight 10% less than the theoretically normal weight, fluctuates between 37% and 40%.

The diagnostic of employment in Latin America is no less alarming, and it is directly related to the size and growth of the work force, which is one of the highest in the world.

Brazil, Mexico, Argentina and Colombia, countries with a greater degree of industrialization, are also those which have the largest labor forces in Latin America, constituting 70% of the regional total of 112 million people.

Insofar as the participation rates for the work force, Latin America is structurally different from the other regions of the world. Its activity rate is the lowest of all of the regions and it is substantially lower than the others with respect to female participation.

In the course of the last twenty years, the sectorial distribution of the work force has undergone important changes; whereas from 1950 to 1960 the majority of workers were dedicated to agriculture, from 1970 to 1980 most were employed in industry and services. This movement is perceived most outstandingly in the experiences of Brazil and Mexico, in just 20 years, the agricultural work force in both countries has been reduced from approximately 55% to 40%. Nevertheless, only one fifth of the Latin American workers are dedicated to industry, while this percentage is doubled in developed countries.

The high growth rate experienced by the Latin American work force has not had, however, the corresponding increase in employment opportunities. As a result of this situation, the unemployment rates reach almost 28%, without considering the underutilization levels.

Within this scope, we cannot be surprised at the conjunction of inflationary processes, of precarious social conditions and tensions that make it necessary for the countries to recur to emergency actions and immediate measures.

Nonetheless, evidently there are special factors and circumstances which work against the development process and economic complementation of Latin America, and which have their origins in the historical process of the configuration of the economic structure.

As has already been indicated, the economic systems of the Latin American countries have been peripheral, since the colonial era. This, as much for the economic centers that traditionally have been supplied by the region, as for the Latin American countries themselves since their economic life took place in function of exportation, commerce, rooted, in general, in the coastal regions and without cohesion in the interior zones.

Thus, the international division of labor that was created and consolidated in England, as a first phase of the Industrial Revolution, has been manifested in Latin America with a painful meaning: the region continues existing as a source of reserves of raw materials and surviving, although being "bled for all it's worth", as expressed in the beautiful metaphor of the Uruguayan writer Eduardo Galeano.

Within the process of the formation of the world economic system, the current international relations of Latin America are found within the following context:

— Existence of a nucleus of countries, those industrialized nations with a market economy, considerably advanced in the capitalization process, and concentrating a great part of their world industrial activity and almost all of the equipment production. This nucleus is also the center that finances the world exportation of capital goods, at the same time controlling the infrastructure of the means of transportation and heing the principal market for imported primary products.

— Formation of a system of international division of lahor under the hegemony of the industrialized countries.

— Creation of a network for the transmission of technological progress, as a suhsidiary of the system, which facilitates the exportation of capital and, parallelly, implants that importation in the afore-mentioned division of labor scheme thus becoming consolidated.

— Indentified with the exploitation and production of cacao, sugar, rubber, cotton, bananas, coffee, saltpeter, copper, precious metals, and oil . . ., the Latin American countries have built their industrial bases on pillars constructed for the erosion of their natural wealth.

In the last decades, these countries have understood the necessity of becoming industrialized, hut many times they have exhausted their industrialization efforts within very narrow frameworks, with the impossibility of projecting themselves towards their own national markets, be that due to geographical difficulties or difficulties of infrastructure.

Another challenge along this line, that is presented in Latin America, is that of multiplying investment rates, which according to the Leontieff Report published by the United Nations, must be increased from 17% registered in 1970 to 33% for the year 2000. This goal proves especially difficult due to the absence of financial resources and due to the deficit nature of the countries' balance of payment and of large demographic investments which are required just to compensate the population growth, and which would be of the order of 4% of capital for every 1% of population growth.

As has already been noted, the Latin American economies hasically rely on the exportation of raw materials to the industrialized nations, from which they import the greater part of their manufactured goods and even food.

The principal products of these export economies are the following: copper, oil, sugar, coffee, bananas, aluminum and bauxite, meat, tin, cotton, and fish meal.

With a brief analysis of recent economic, commercial, and financial tendencies in Latin America, we can appreciate that the annual rates of the Latin American GNP has suffered various ups and downs in the last fifteen years, although they have not gone below figures on the order of 3.5%. The overall growth rate was able to expand significantly from 1968, with annual rates superior to 6.5% at the end of the sixties and around 6.8% as an average for the last decade.

Latin America has demonstrated a tendency towards a growing deficit in the current account. In contrast, the balance for foreign trade has registered a notable improvement since the 1974-75 world recession. This evolution of exportations reflects the diversification which has not been achieved in the production system, above all, in the industrial sector.

Despite this fact, the countries have had to recur to external debts. The commercial deficit of the region, including the oil-producing countries, is estimated at 54 billion dollars for 1978. This commercial deficit, which in large part was due to the rises in the price of oil importations and which, accumulated since 1973, surpassed 25 million dollars, has hasically been taken care of by means of foreign financing. This reached record levels in the last years: from an average that did not surpass 26 billion dollars in the four-year period of 1966-1970 to almost 12 billion dollars between 1974 and 1978.

The region's public debt, including that of the oil-producing countries, estimated at 36 billion dollars towards the end of 1973, surpassed 90 billion dollars at the end of 1978. The service of this foreign debt represents approximately 20% of the total value of the exports of service goods.

Without doubt, these debts have permitted the maintenance of the growth system of the region and adaptation to the higher oil prices. However, serious doubts exist with respect to the possibility of maintaining the current capacity for importing at the cost of sustained regional debt.

3. The Latin American energy situation within the World context

Introduction

Latin America, as a whole, has important energy resources, which it has not been able to utilize fully due to human, technological, and, especially, financial limitations, without considering the consumption structure adopted from the industrialized countries, which has given priority importance to the prouction of hydrocarbons as opposed to the development of indigenous energy sources.

By means of the diagnostic which follows, it is attempted to analyze, consistently, the Latin American situation within the world context, as well as the region's internal panorama, with respect to reserves, production, and consumption of the most important energy resources.

3.1. *1979 Oil Reserves*

3.1.1. Latin America in the World Context

Region	*Reserves in barrels* 10^9	%
United States	32	4.9
Soviet Union	67	10.2
Middle East	365.7	55.8
China	20	3.1
Latin America	58	8.8
Rest of the World	112.8	17.2
Total	655.5	100

Sources: "Oil and Energy Trends" - 1980 Statistical Review Energy in Developing Countries: Present and Future.
Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

Only preceded by the Middle East, possessor of 55.8% of the world's crude oil reserves, and by the Soviet Union, owner of 10.2% of these resources, Latin America has 58,000 million barrels of proven oil reserves, a figure which represents 8.8% of the world total.

3.1.2. Latin American Panorama

Countries	*Reserves in barrels* 10^9	%
Argentina	2.4	4.1
Bolivia	0.2	0.3
Brazil	1.2	2.0
Colombia	0.7	1.2
Ecuador	1.1	1.9
Mexico	32.5	56.0
Peru	0.7	1.2
Trinidad and Tobago	0.7	1.2
Venezuela	17.9	30.8
Others	0.6	1.3
TOTAL	58.0	100

Sources: "Oil and Energy Trends" - 1980 Statistical Review Energy in Developing Countries: Present and Future.

Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

Within the total of Latin America's proven reserves, the contribution of Venezuela and Mexico — the most important producers in the region — represents 86.8%, with more than half of the total resources corresponding to Mexico. Meanwhile, the volume of Argentina's and Brazil's reserves barely reach a value equivalent to 6% of the regional total. Thus, if the reserves to population density relationship is considered, an enormous existing per-inhabitant disparity can be inferred, for these two countries, because they figure among the most populated countries, and those with the greatest relative development, in the region.

3.2. *1979 Oil Production*

3.2.1. Latin America in the World Context

Region	*Barrels per day* 10^9	%
United States	10,189 (a)	15.66
Soviet Union	11,800	18.14
Middle East	21,457	32.99
China	2,122	3.26
Latin America	5,396	8.29
Rest of the World	14,093	21.66
TOTAL	65,057	100

(a) Includes Liquid Natural Gas.
Sources: "Oil and Energy Trends" - 1980 Statistical Review Energy in Developing Countries: Present and Future.
Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

Latin America's oil production represents 8.29%, in other words, almost half that of the United States, which ascends to 15.66%, and is 4 times less than that of the Middle East, estimated at 32.99%.

3.2.2. Latin American Panorama

Countries	*Barrels per day* 10^3	*Production* %
Argentina	464	8.6
Bolivia	32	0.6
Brazil	169	3.1
Colombia	125	2.3
Ecuador	214	4.0
Mexico	1,593 (a)	29.5
Peru	195	3.6
Trinidad and Tobago	223	4.1
Venezuela	2,356	43.7
Others	25	0.5
TOTAL	5,396	100

(a) Includes natural gas and condensates.
Sources: "Oil and Energy Trends" - 1980 Statistical Review Energy in Developing Countries: Present and Future.
Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

Latin America's daily oil production, which in 1973 was on the order of 5,131,000 barrels, was reduced to 4,777,000 barrels in 1974 and to 4,276,000 barrels in 1975; then, it rose to 4,395,000 in 1976 and to 4,569,000 in 1977. The reduction in production between 1973 and 1977 is fundamentally due to the decreased production of Venezuela, brought about by the implantation of a rigorous policy of conservation of its oil wealth. In 1979 this country's production was 2,356,000 barrels of oil per day.

Despite the fact that in many countries of the region the knowledge with respect to the amount of the reserves is limited, and in others the oil prospectus is found in an initial stage, a revision of plans for the expansion of production projects an annual increase of 6.7% in the region's oil production between 1978 and 1985. Thus, towards the end of 1985, the total oil production could reach the figure of 2,800 million barrels annually.

Similarly, we would do well to point out the current Venezuelan production, which reaches 43.7% of the regional total, or 5,396,000 barrels of oil per day, and that of Mexico, corresponding to 29.5% of this total. The important production of Argentina is also appreciated, which despite its condition of being an oil-importing country, is at the point of achieving self-sufficiency, with 464 thousand barrels per day. Peru, with a daily production of 195 thousand barrels per day solved its problem of internal supply and even has exportable surpluses.

3.3. *1979 Oil Consumption*

3.3.1. Latin America in the World Context

Region	*Barrels per day* 10^3	*Oil consumption* %
United States	18,300	27.97
Soviet Union	13,500 (a)	20.63
Middle East	1,890	2.89
China	—	—
Latin America	4,557	6.97
Rest of the World	27,183	41.54
TOTAL	65,430	100

(a) Includes China and all of the countries with planned economies.
Sources: "Oil and Energy Trends" - 1980 Statistical Review Energy in Developing Countries: Present and Future.
Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

As can be appreciated, the daily oil consumption of the United States in 1979 constituted almost 30% of the total world consumption, estimated at 65,430,000 barrels of oil per day, in circumstances where this country's daily production does not exceed 15.5% of world production.

In the world context, the low consumption of the Mid-East countries is also notable when compared with their high participation in the average world oil production.

With respect to Latin America, its daily consumption represents 6.96%. This consumption figure has had an approximate increase of 45% between 1972 and 1978, whereas the world average was 45%, and the average corresponding to the developed countries, 50%.

Thus, the Latin American countries, as a whole, depend on oil to a greater extent than any other region in the world.

3.3.2. Latin American Panorama

The regional oil consumption ascends to 4,557,000 barrels of oil per day, the Latin American refining capacity being 8,420,000 barrels per day.

In this chart, Brazil's high consumption is outstanding, where with 1,066,000 barrels per day, it is the principal demander, with 50% of the region's total oil importations. The case of Brazil is surpassed by Mexico, which consumes 1,128,000 barrels per day; but it has proven

Country	*Consumption* B/D 10³	*Refining capacity* B/D × 10³
Argentina	553	676
Bolivia	—	—
Brazil	1,066	1,205
Colombia	153	194
Ecuador	68.4	—
Mexico	1,128	1,394
Peru	145	170
Trinidad and Tobago	—	461
Venezuela	340	1,445
Others	1,121.6 (b)	2,875 (c)
TOTAL	4,557	8,420

(b) Includes Bolivia, Trinidad and Tobago, and the rest of the Latin American countries.
(c) Includes Bolivia, Ecuador, and the rest of the Latin American countries.
Sources: "Oil and Energy Trends" - 1980 Statistical Review Energy in Developing Countries: Present and Future.
Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

to be better equipped to deal with this situation, since the country — whose importations constituted almost 6% of its internal consumption in 1972, has become the second net exporter of the region, for crude oil as well as for its by-products.

The volume of oil consumption for the rest of the countries in the region is dramatically considerable, since this fuel accounts for more than 70% of the total energy consumption and, in thirteen countries, represents more than 90% of the total consumption.

With respect to data on sectorial distribution, these are scarce; but we can estimate, according to studies by UNDP-OLADE that the total oil consumption is distributed in the following way: 43% to the industrial sector, 25% to transportation, 24% to the domestic sector, 2% to agriculture, and the remaining 6% to other uses.

In accordance with these estimates, the industrial sector, including mining, depends on fuel oil for 19% of its energy consumption, and it absorbs 60% of the region's total fossil fuel consumption. The transportation sector almost exclusively employs naphtha, and the generation of thermal electricity is 47%, fed by fuel oil, within the total of fossil fuels consumed in this activity.

It also remains to be said that the region will increase its net exporting position, from the 24% of the total production registered in 1978 to the 50% estimated for 1985.

Finally, it remains to note that the oil-importing countries of the region paid around 7,000 million dollars for the crude oil and oil by-products imported in 1978.

3.4. *Natural Gas Reserves*

3.4.1. Latin America in the World Context

Region	*Cubic feet* 10^{12} *reserves*	%
Canada and the U.S.A.	279.5	10.84
Soviet Union	900	34.89
Middle East	740.3	28.70
Latin America	144.5	5.60
Rest of the World	515.1	19.97
TOTAL	2,579.4	100

Sources: "Oil and Energy Trends" - 1980 Statistical Review Energy in Developing Countries: Present and Future.
Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

Latin America's natural gas reserves reached 144.5 billion (¹) cubic feet, which represent a minimal gravitation of 5.6% within the world total, estimated at 2,579.4 billion.

For its part, the Soviet Union, with 35% of this total, has several difficulties to overcome in order to make use of this fabulous potential, due to the fact that its gas fields are found at enormous distances from the consumption centers.

The natural gas reserves of the Middle East (740.3 billion) are also important and they account for 29% of the world total.

3.4.2. Latin American Panorama

Countries	*Reserves in cubic feet* $\times 10^{12}$	%
Mexico	59.0	40.8
Venezuela	42.8	29.6
Argentina	15.2	10.5
Trinidad and Tobago	8.0	5.6
Bolivia	5.4	3.7
Colombia	5.0	3.5
Chile	2.5	1.7
Others	6.6	4.6
TOTAL	144.5	100

Sources: "Oil and Energy Trends" - 1980 Statistical Review Energy in Developing Countries: Present and Future.

Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

In the regional framework, Mexico possesses almost half of the natural gas reserves, with 59 billion cubic feet, which represent 40.8% of the total Latin American reserves. It is followed by Venezuela, with 42.8 billion, and Argentina, with 15.2 billion. Thus, these three countries together have almost 81% of the region's natural gas reserves. Trinidad and Tobago, Bolivia, and Colombia, with resources estimated at 5.5, 3.7 and 3.5%, respectively, complete this picture, where the remaining countries do not account for 5% of the total regional reserves.

(¹) Billion $= 10^{12}$.

3.5. *1979 Natural Gas Production*

3.5.1. Latin America in the World Context

Country	*Cubic feet 10^9/day production*	%
Canada and the U.S.A.	63.8	44.3
Soviet Union	32.6	23.0
Middle East	3.9	2.7
Latin America	4.7	3.2
Rest of the World	38.7	26.8
TOTAL	143.7	100

Sources: "Oil and Energy Trends" - 1980 Statistical Review Energy in Developing Countries: Present and Future.
Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

As can be observed, the Latin American natural gas production, which ascends to 4,700 millions cubic feet, within the world context, is slightly superior to that of the Middle East (3,900 millions) and significantly less than those registered by Canada and the United States and the Soviet Union, which together represent 67% of the world total.

3.5.2. Latin American Panorama

With a production of 4,700,000,000 cubic feet, Latin America exploits only 0.00314% of its proven natural gas reserves.

Country	*Production in cubic feet* $\times 10^9$	%
Mexico	1.7	36
Venezuela	1.2	25.5
Argentina	0.8	17.0
Trinidad and Tobago	0.2	4.2
Bolivia	0.3	6.4
Colombia	0.2	4.2
Chile	0.1	2.1
Others	0.2	4.6
TOTAL	4.7	100

Sources: "Oil and Energy Trends" - 1980 Statistical Review Energy in Developing Countries: Present and Future.
Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

In the internal framework, the largest production percentages correspond to Mexico (1,700,000,000 cubic feet) and to Venezuela (cubic feet 1,200,000,000), followed in importance by Argentina, with cubic feet 800,000,000.

3.6. *1979 Coal Reserves*

3.6.1. Latin America in the World Context

The world coal reserves in 1979 were estimated at 10,125,253 million tons, of which the Soviet Union possesses almost half (4,860,000 million tons). It is considered that the world reserves of this resource surpass those of any other fossil fuel and are sufficient to support a massive increase in consumption during the next century.

Country/Region	*Millions of tons*	%
U.S.S.R.	4,860,000	48.0
U.S.A.	2,570,398	25.4
China	1,438,045	14.2
Australia	262,134	2.5
West Germany	246,800	2.4
England	163,576	1.7
Poland	125,500	1.3
Canada	115,352	1.2
Africa	115,338	1.1
Asia	72,455	0.7
Latin America	31,692	0.3
Others	123,963	1.2
TOTAL	10,125,253	100

Sources: World Bank.
Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

The considerable deposits of the United States (2,570,398 million tons) and of China (1,438,045 million) far out-distance those of the rest of the world, despite the reserves accumulated in Germany, Poland and England, as countries with a long historical tradition with respect to coal.

The African reserves (115,338 million tons) and those of Asia (72,466 million tons) widely surpass the Latin American reserves, which barely represent 0.3% of the world total.

3.6.2. Latin American Panorama

Despite the insignificant contribution of the regional coal reserves in the world context, the prices of the fuels that are given priority use in the Latin American countries for the generation of thermo-electricity, make the introduction of the use of coal feasible in this kind of installations.

Country	*Millions of tons*	%
Brazil	10,082	32.0
Colombia	8,318	26.2
Mexico	5,448	17.2
Chile	4,585	14.5
Venezuela	1,630	5.1
Peru	1,122	3.5
Others	507	1.5
TOTAL	31,692	100

Sources: World Bank.
Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

Within the internal panorama, Brazil possesses 32% of the coal reserves, with 10,082 million tons, followed by Colombia, with 8,318 million tons and 26.2% of the total regional reserves.

This order continues with Mexico (5,448 million tons), Chile (4,585), Venezuela (1,630), and Peru (1,122). The reserves situation of the remaining countries accounts for 1.5% of the regional total of 31,692 million tons of coal.

3.7. *1979 Coal Production*

3.7.1. Latin America in the World Context

It is estimated that the world coal production reaches 3,739.1 million tons, where the Soviet Union, the United States, and China are outstanding producers, with 723.3 million tons, 703, and 670, respectively.

Country	Millions of tons	%
U.S.S.R.	723.3	19.3
U.S.A.	703	18.8
China	670	17.9
East-Germany	250.1	6.7
Poland	236	6.3
West Germany	215.6	5.8
England	122.5	3.3
South Africa	103.1	2.8
Latin America	17.6	0.4
Others	697.9	18.7
TOTAL	3,739.1	100

Source: "Oil and Energy Trends" - 1980 Statistical Review.
Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

Compared with the volume of reserves, the world coal production is small. That is a reflection on the preference of the industrial market for the liquid fuels, natural gas, and electricity.

3.7.2. Latin American Panorama

Country	Millions of tons	%
Mexico	7.3	41.5
Brazil	4.5	25.6
Colombia	4.2	23.9
Others	1.6	9.0
TOTAL	17.6	100

Source: "Oil and Energy Trends" - 1980 Statistical Review.
Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

The total Latin American coal production is 17.6 million tons. Mexico is the largest regional coal producer, with a production on the order of 41.5% of the total. It is followed by Brazil and Colombia, with 25.6% and 23.9%, respectively. The remaining countries account for barely 9% of the total regional production.

3.8. *1979 Electricity Production*

3.8.1. Latin America in the World Context and its Own Panorama

Country	*TWH* (1)	%
U.S.A.	2,260	31.3
U.S.S.R.	1,168	16.2
Japan	479	6.6
West Germany	335	4.7
Brazil	115	1.6
Mexico	52	0.7
Argentina	28	0.4
Venezuela	20	0.3
Colombia	13	0.2
Chile	10	0.1
Others	2,722	37.9
TOTAL	7,202	100

(1) T = TERA 10^{12}.
Source: OLADE. Direction of Economic Studies and Energy Planning.

The principal industrialized countries — the United States, the Soviet Union, Japan and West Germany — together generate 58.8% of the world's electricity, whose production is estimated at 7,202 TWH.

With relation to the figures for world production and consumption of electricity, the characteristics observed in the region are the following:

— low levels of per-inhabitant consumption (660 KWH/inhab.) and even more so if they are compared with those for the European countries, which surpass 3,000 KWH per inhabitant;

— on the average, only 50% of the Latin American population has electric service, whereas in the rural area its diffusion does not exceed 15%;

— according to the production equipment structure, hydroelectric generation predominates, with 58.5%. This situation is accentuated in countries such as Brazil, Argentina, Paraguay, and Costa Rica. For their part, hydrocarbons occupy second place, with 37.7%, despite the fact that in most of the countries, they continue heing the principal energy source. With respect to coal, nuclear and geothermal energy, and plant residues, these represent barely 5% of the total.

Within the regional context, Brazil is the country that registers the largest electric production, estimated in 115 TWH.

4. Economy, energy and development

Introduction

In the meeting of the Latin American Ministers of Energy, held by OLADE in Panama last December, the Mexican Secretary of Patrimony and Industrial Development emphasized, in his speech, the urgent need for the region to put into play its capacity and rational foresight, in order to anticipate future events and to try to act sensibly, not only with a reaction or as a counter-blow to the crisis.

The decade of the eighties has begun with an immediate challenge: how to confront the second economic and energy crisis, in a situation where Latin America is even more vulnerable to the scarcity of hydrocarbons than in 1973. According to our most recent statistics, in 1978 the total oil consumption for the region was 25% higher than that registered for the year of the first crisis, despite government efforts to restrict consumption.

Parting from this focus, the regional energy panorama that we attempt to outline for you fundamentally pretends to provide a general view of the options open to the Latin American countries for meeting the present crisis, within the world context and the economic, political, and social possibilities of the region itself as a geographic unit.

The energy sector, a key element in the development process, represents a vertical chain of operations connected with mining, manufacturing, and the basic service industries.

In this regard, it would seem important to point out that the world expansion of energy consumption has had heterogeneous characteristics in the last quarter of a century. Whereas the developing countries, as a whole, raised their consumption to an annual rate of 0.6%; the developed countries raised theirs to an annual 4.3%.

The highly concentrated condition possessed by energy consumption is characteristic of the world energy panorama. The developed world, as much in the area of market economy as in those of planned economies, inhabited by 30% of the world population, consumes more than 80% of the commercial energy produced; therefore, the underdeveloped areas, where more than 70% of the world population lives, only capture the remaining 20%.

In this energy-development relationship, we note that the industrialized countries also concentrate 80% of the total world production, their average per capita energy consumption being 12 times that of the underdeveloped countries.

In view of the oil crossroad of 1973, the first temptation for those Latin American countries that import oil but possess local coal, natural gas and hydro-resources, was to modify the thermal plants that consumed oil, in order to use them with coal or natural gas, and moreover, to use their hydraulic resources. Both alternatives, however, would demand time and investments, to the end of solving the energy problem just for the large urban centers and for the interconnected systems. Meanwhile, the situation of the countries which are net importers of oil and which do not have coal or natural gas available was, and is, much more disadvantageous.

All of this preamble serves to point out the seriousness of the regional situation in light of the oil-intensive model followed up to now.

The progressive rise in prices suffered by oil has provoked serious problems in the functioning of the balance of payments, in those Latin American countries that are oil importers; at the same time it has been a factor, together with inflation imported from the industrialized countries, in the inflationary process that hits the developing countries with greater impact.

According to recent ECLA data, inflation has increased in an accelerated way in the majority of countries, with a regional average price increase to the consumer from 41% in 1978 to 51% in 1979.

The report adds, as a contradictory trait, that if the value of exported goods has indeed risen at a rhythm superior to 30%, an expansion surpassed by importations, the deficit in the current account rose to 20 million dollars, due to the sharp rise in net payments for the concept of services, interests, and profit.

This structural vulnerability observed in the Latin American external sector, and strongly accentuated by the evolution of oil prices, heightens financial dependence and transforms programs undertaken by the region into unsuccessful attempts at socio-economic development.

It is estimated that the energy production in Latin America in 1977 was approximately 350 million tons of oil equivalent, from diverse sources of primary energy: coal, crude oil, natural gas, hydro-electricity, and plant

LATIN AMERICAN INFLATION INDICES

	1972	1973	1974	1975	1976	1977
1. Argentina	59.5	62.7	22.9	182.5	44.32	176.1
2. Brazil	16.4	13.6	27.6	28.9	41.9	43.7
3. Barbados	6.9	16.8	39.0	20.3	5.0	8.3
4. Bolivia	6.7	31.4	62.7	8.0	4.5	8.1
5. Colombia	14.3	22.8	24.2	25.8	17.4	30.0
6. Costa Rica	4.6	15.3	30.1	17.4	3.5	4.1
7. Chile	79.1	351.9	505.5	374.6	211.9	92.0
8. Ecuador	7.8	NI	23.3	15.3	10.7	13.0
9. Guatemala	0.6	NI	16.6	13.1	10.7	12.6
10. Guiana	5.2	12.8	17.4	8.0	9.0	8.2
11. Honduras	5.3	4.5	13.4	6.4	4.9	10.0
12. Haiti	3.2	22.7	14.9	16.8	7.0	8.2
13. Jamaica	4.6	19.8	24.4	17.4	3.5	4.1
14. Mexico	5.0	13.0	22.5	16.8	16.1	26.4
15. Nicaragua	NI	NI	NI	1.8	2.8	11.0
16. Panama	5.3	12.8	16.9	5.5	2.3	8.6
17. Paraguay	9.2	14.9	25.1	6.7	4.5	9.3
18. Peru	7.1	12.8	16.9	23.6	33.5	38.1
19. Dominican Republic	7.7	15.2	13.1	14.5	7.7	12.9
20. El Salvador	1.5	11.3	16.9	19.2	7.0	11.9
21. Uruguay	77.5	96.8	77.2	81.5	50.5	58.2
22. Trinidad and Tobago	9.3	NI	22.0	17.0	10.5	11.9
23. Venezuela	2.8	4.2	8.2	10.3	7.6	8.2

fuels, among others. Of this total, Mexico and Venezuela possess nearly 70%.

Of the total of thirty Latin American countries, nearly three fourths of them do not produce fossil fuels, a situation which makes them dependent on the producing countries of their energy supply.

Insofar as consumption, the Latin American region consumed energy equivalent to 260 million tons of oil, Brazil and Mexico being the principal consumers, proportionately, with 75 and 60 million tons of energy consumption, respectively.

In view of the per capita energy consumption in countries such as Argentina, Brazil, Mexico and Venezuela, which surpasses an oil ton equivalent of annual consumption, other, less developed, and, unfortunately, the majority, exist and they consume between 0.2 and 0.5 per capita annually.

4.1. *Economic Indicators*

In order to be able to establish the relationships between energy, economy and development in Latin America, it is necessary to take in account some important economic consumption and especially energy consumption versus population, and energy consumption in relation to development, the latter including the agricultural sector, considered to be fundamental in the Third World development process, especially in Latin America.

4.1.1. World Energy Consumption

Countries	1960	1980	1990
United States	34	32	29
Western Europe	20	20	21
Japan	2	6	8
China, USSR, and Eastern Europe	30	28	26
Rest of the World	14	14	15

Source: OLADE. Direction of Economic Studies and Energy Planning.

As can be appreciated, the developed countries absorb more than 80% of the world energy consumption, against the 14% consumed in the underdeveloped countries, including Latin America.

With prospects for 1990, the situation does not fundamentally vary, in spite of the restrictions on energy use imposed by the developed world. This savings will be scarcely 5% for the United States and 4% for the Socialist countries, surpluses which in no case will reflect on the developing countries, but rather will tend to increase the considerable rise in consumption registered by Japan in these last two decades.

4.1.2. Energy Consumption and Population - 1970

	U.S.A. and Canada	*Latin America*	*World*
Total consumption in millions of TOE (1)	1,877.00	229.00	5,405.00
Population in millions	226.00	282.00	3,609.00
Per capita consumption in TOE . . .	8.3	0.81	1.5

(1) TOE = Ton oil equivalent, supposing a calorific power for oil of 10,000 Kcal/Kg.
Source: OLADE. Direction of Economic Studies and Energy Planning.

The development of the countries is closely linked to the per capita energy consumption.

As can be deduced from the chart, the United States and Canada, which represent 6.2% of the world population, consume 35% of the energy. Meanwhile, Latin America, with 7.8% of the world population, only consumes 4.2% and only 10% of the energy used in the Western Hemisphere.

From these data, we obtain a per capita average for the United States and Canada that is 10 times greater than the per capita figure for Latin America.

4.1.3. Energy Consumption and Development

	Food	*Industry and Agriculture*	*Transportation*	*Total*
Primitive man	200	—	—	200
Man the hunter	500	—	—	500
Primitive farmer	400	800	—	1,200
Advanced farmer	600	1,900	100	2,600
Industrial man	700	5,600	1,800	8,100
Technological man	1,000	15,700	6,300	23,000

All of the values express per capita energy consumption in TOE $\times 10^{-6}$.
Source: OLADE. Direction of Economic Studies and Energy Planning.

Energy is inherent to life and, as a consequence, to the very life of the human species. Nevertheless, the availability of energy has a close relationship to the different states of civilization reached by man since his appearance on earth. As opposed to primitive man, whose consumption was reduced to 200×10^{-6} TOE daily, only destined to his food, the species that immediately followed him, i.e., man as hunter, showed a difference of 300×10^{-6} TOE daily.

Later, the advent of agricultural society, which brought with it the incorporation of some domestic animals, raised energy consumption to $1{,}200 \times 10^{-6}$ TOE per day, and to 2,600 at a more advanced stage, characterized by the introduction of transportation.

The Industrial Revolution (1850-70), with its insufficient technology, practically quadrupled the individual energy consumption of the preceding era. For its part, the current technological revolution, characterized by the introduction of electric plants, the automobile, and other forms of technical progress, has established a per capita consumption of $23{,}000 \times 10^{-6}$ TOE per day.

With an average energy consumption of $1{,}500 \times 10^{-6}$ TOE, the Latin American man is located between the primitive farmer and the advanced farmer, whereas the average North American man has reached an energy consumption level of $12{,}300 \times 10^{-6}$ TOE per day.

4.1.4. Agricultural Sector - Energy Consumption and General Production 1972

For illustration purposes and in order to consider the agricultural sector as characteristic of the Third World, and especially of Latin America, an analysis follows with respect to the relationship existing between energy consumption and production in this sector, specifically, cereal or grain production:

	Energy/ hec. TOE	*Energy/ worker* TOE	*Prod./ hec.* TOE	*Prod./ worker* TOE
Developed countries	0.59	2.57	3,100	10,508
U.S.A. and Canada	0.48	13.27	3,457	67,882
Developing countries	0.05	0.05	1,255	877
Latin America	0.10	0.20	1,440	1,856

Source: FAO. Energy and World Agriculture.
Elaboration: OLADE. Direction of Economic Studies and Energy Planning.

— The energy consumption of a farmer in a developed country is 50 times greater than that of a farmer in Latin America.

— The energy consumption of an agricultural/livestock worker in a developed country is 13 times that of an agricultural/livestock worker in Latin America.

— The energy consumption of a North American farmer, in the U.S.A. or Canada, is 253 times that of a Third World farmer and 65 times that of a Latin American farmer.

— The cereal production of a North American farmer is only 5.6 times the production of a Latin American farmer, but it must be taken into consideration that the Latin American average is being strongly affected, especially due to the high Argentine productivity.

4.1.5. Energy Prospects for the Year 2000

With the aim of visualizing Latin America's energy future, two extreme alternatives will now be analyzed, showing, in simple form, what the Latin American energy panorama could be for the year 2000.

Basically, two hypotheses have been considered in order to make the following projections:

Hypothesis A. The current rates of population and energy growth are maintained.

Hypothesis B. Population growth, in the United States and Canada and in Latin America, drops linearly and the energy growth rate is maintained.

Results

Hypothesis A:

— On maintaining the current situation, by the end of this century, Latin America will manage to have barely one fourth of the United States' and Canada's current per capita consumption.

— Comparatively, the current relationship between the United States' and Canada's per capita consumption and that of Latin America will have been reduced from 10:1 to 8:1.

Hypothesis B:

— Despite the fact that its population growth is defined as 0%,

ENERGY PROSPECTS FOR LATIN AMERICA IN THE YEAR 2000

		1980	2000 Hyp. A	2000 Hyp. B
Population Growth	USA & Canada	1.3	1.3	0
	Latin America	2.8	2.8	0
Energy Consumption Growth Rate (%)	USA & Canada	4.3	4.3	4.3
	Latin America	6.3	6.3	6.3
Population in millions	USA & Canada	268	347	268
	Latin America	350	608	350
Energy Consumption in millions of TOE	USA & Canada	2,873	6,451	6,451
	Latin America	428	1.436	1,436
Per capita Energy Consumption in TOE	USA & Canada	6.76	18.6	24
	Latin America	1.22	2.4	4.1

Source: OLADE. Direction of Economic Studies and Energy Planning.

in the year 2000 Latin America will consume 38% of the current North American per capita consumption.

— The current relationship of the United States' and Canada's per capita consumption with that of Latin America will have been reduced from 10:1 to 6:1 for the year 2000.

5. OLADE AND THE PROCESS OF LATIN AMERICAN ENERGY INTEGRATION

The Latin American Energy Organization (OLADE) arose towards the end of 1973 in view of the need to utilize the natural resources, particularly the energy ones, as a strategic factor in the process of regional integration. Stimulated by the cross-roads circumstances of the world economic crisis of that year, Latin America thus constituted the first region in the Third World to be integrated into an organization which, in addition to foreseeing the sectorial development of all its possible alternatives, also represents an effective answer to the efforts that are made, on a wider scale, for the establishment of the New International Economic Order.

Since the signing of the Lima Constitutive Agreement for OLADE, there has been a six-year period of institutional maturation. The experience in integration accumulated by the Organization during this period has had the merit of stimulating the potential efforts that can lead Latin America towards a greater energy cohesion, through the precise objectives of "cooperation, coordination, and advising" within the sector.

To date, the Member Countries of OLADE are: Barbados, Bolivia, Brazil, Colombia, Costa Rica, Cuba, Chile, Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guiana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Surinam, Trinidad and Tobago, Uruguay and Venezuela.

The New Energy Crossroads

Due to the fundamental role that energy plays in global regional development, the integration scheme that OLADE represents reflects the new tendency of the developing countries to integrate efforts at guaranteeing their sovereivn rights with respect to their natural resources and increasing the bases of their economic independence. Together with a summary of the policies for joint action that would accelerate the future supply of energy to the Latin American countries, OLADE favors the thesis that "within the framework established for the developing world's struggle for restitution, manifested in the struggle to establish a new international economic order, it is currently indispensable to advance in the energy component, given its priority nature and the urgency of confronting the problem".

On confronting, now, a new and perhaps more difficult economic crossroads determined by the rise in oil prices, the block of 25 countries which constitute OLADE, despite their economic, social and political heterogeneity, have used the mechanism of integration as a live forum for analysis and discussion of their differences and their points of agreement.

The Pronouncement of San Jose, signed at the First Extraordinary Meeting of the Ministers of Energy, held by OLADE in Costa Rica in July, 1979, constitutes the most up-to-date energy policy conceived for regional integration. Its adoption by the Latin American community with the explicit backing of the Latin American Economic System (SELA) and the Economic and Social Council of the Organization of American

States — has been a vigorous expression of the political willingness that the common position of the region registers in light of the world energy problem.

On the basis of its seven basic programs and twenty-four points of agreement, the document favors the opening of a "universal dialogue" that would permit a real "reordering" of the problem, within a context that considers its extensive financial, economic, and technological ramifications. Within the regional scope, it points out policy actions for the energy demand, transfer of financial and technological resources, and the organization of the systems of marketing, transportation, and distribution, in addition to emphasizing the need for increasing the supply of/and rationalizing the regional demand for energy.

Recognizing the importance of favoring joint actions by the Latin American region and of achieving a common posture before the concert of nations, the governments that signed the Pronouncement of San Jose thus agreed to consolidate OLADE as the "principal instrument of energy cooperation and coordination among the Member States and the subregional organizations".

Prospects

At present, OLADE's Permanent Secretariat, as its executive body, is attempting more workable mechanisms for action, by which volume can be increased and the current conditions of utilization, supply, conservation, and savings of the existing energy resources can be improved.

To this end, a series of regional projects and programs is being promoted, coordinated, elaborated, and directed; it basically contemplates the optimization of the use of the current sources of energy, and the implementation of the non-conventional energy sources within the present picture of sectorial supply. In this regard, an advanced program has been undertaken, principally in the field of geothermal energy, whose use has not been confronted, until now, within a context of integral regional planning.

Parallelly, appropriate mechanisms are being sought, to permit the member countries to define their energy policy guidelines, deriving integral planning for their resources (energy balances, supply and demand studies, and the rational use of energy, among others).

In the search for solutions to the problems derived from regional dependence on hydrocarbons, OLADE attempts to implement a global strategy, with a view to the channeling of economic surpluses from the oil-producing and industrialized countries, towards programs that stimulate regional development of all of the indigenous non-conventional sources of energy. This programming is largely oriented to the attainment of development and the establishment of agroindustry by means of the massive use of indigenous energies and their incorporation into programs of housing, education, health, hygiene, transportation, food, and the conservation and distribution of agricultural products.

Along the lines of activities based on mutual cooperation and joint action, boosted by OLADE along with other regional and international financing and cooperative organizations, schemes have been realized and proposed which will essentially permit the assurance of a greater diversification of the regional economy, better technological development, and the formation and training of more human resources. Among these agreements it becomes necessary to mention those subscribed to with ARPEL and ECLA, in addition to the recent cooperation agreement signed with SELA for the identification of joint projects. Likewise, OLADE has developed and strengthened links with the United Nations system, principally through those United Nations agencies with substantial spheres in the field of energy, such as UNIDO and UNDP.

With regard to the IDB, contacts have been initiated which permit concrete joint actions for financial cooperation on the part of this organization, for the development of specific projects for pre-investment studies: through the Institute for Latin American Integration (INTAL), the coordination of the information exchange flow is being studied for the areas of education, research, assessment, and diffusion in the areas of common interest.

Similarly, institutional action is coordinated with that of the extra-regional countries which have offered their technical and financial collaboration, and with the intensification of the studies and projects that the organization develops in the field of non-conventional energies.

Within a historical moment propitious for the realization of its objectives, OLADE seeks to reaffirm the integration process which was begun with the signing of the Lima Agreement. Through its institutional consolidation and dynamic renovations, Latin America could be in a better position for projecting its energy interests in a new economic dimension and under new production and consumption schemes, beginning with the present decade.

6. Conclusions

— Latin America continues existing as a source of raw material reserves and surviving although "being bled for all it's worth".

— Identified with the production of cacao, coffee, sugar, rubber, cotton, nitrates, copper, precious metals, oil . . ., the Latin American countries have built their industrial bases on pillars constructed for the erosion of their natural wealth.

— Latin America has 8.8% of the world's oil reserves; it produces 8.3% and consumes 7% of the world total.

— The region has 5.6% of the world's gas reserves and produces 3.2% of the total production.

— Latin America has 0.3% of the world's coal reserves and produces 0.4%.

— The level of electric consumption per regional inhabitant is 660 KW/hr, whereas in Western Europe this consumption surpasses 3,000 KW/hr.

— The developed countries absorb more than 80% of the world energy consumption, while the Third World only consumes 14%.

— The United States and Canada, which represent 6.2% of the world population, consume 35% of the energy; while Latin America, with 7.8% of the world population, consumes only 4.2%, and only 10% of the energy used in the Western Hemisphere.

— With an average energy consumption of $1{,}500 \times 10^{-6}$ TOE per day, the Latin American man is located between the primitive farmer and the advanced farmer, whereas the average North American man has reached an energy consumption level of $12{,}300 \times 10^{-6}$ TOE per day.

— Despite the fact that the energy consumption of a North American farmer is 65 times that of a Latin American farmer, the former's cereal production is only 5.6 times greater than that of the latter.

— Even if tbe population growth were reduced to zero and the energy growth were maintained at its current rhythm, in the year 2000 an average Latin American would barely consume the 38% of the present North American per capita consumption.

— Latin America is the first region of the Third World that has become integrated around a regional energy cooperation organization. OLADE, in addition to having the objective of sectorial development in all of its possible alternatives, also represents a real answer to the efforts at establishing the new International Economic Order.

DISCUSSION

CHAGAS

Coming from a country in Latin America, I want first of all to congratulate Dr. Sanchez-Sierra for his presentation of today, in which he very clearly exposed the situation in a whole country. In some ways, I would say that the picture is rather more gloomy than he has presented, in the sense that together with the differences existing between developed countries and developing countries, which he has so well marked, there are regional differences which make the situation extremely difficult. So, when we are speaking of the Gross National Product, for instance of Brazil, we are not taking into consideration that there is at least a five to tenfold difference between people in the northeast and people in the southern part, which makes the social structure of the country more shaken, more able to be shaken, than by a pure comparison between averages taken throughout the country.

Now, there are one or two points which I would like to stress. Brazil has a big resource in coal, but it is poor coal. It is a coal of rather small content in calories, and we have to import better coal for our steel production, for instance, which makes the resources of coal not so outstandingly valuable as they would think.

On the other hand, fortunately, we have all over Latin America, non-ferrous ore and iron ore which are a big asset.

PASZTOR

I would like to ask a question to Dr. Sanchez-Sierra concerning the present use of traditional sources of fuel in Latin America, particularly wood and any other traditional sources which there might be.

SANCHEZ-SIERRA

The consumption of wood is very big in Latin America. In some countries, it will reach something like 30% of the energy consumption. It is something like the same figure as the oil consumption in many countries. It is too much, and this point is a big problem.

DESPRAIRIES

Si je me limite aux questions relatives à l'énergie, qui sont la base de nos débats, l'Amérique du Sud me parait être une des régions du monde qui a, potentiellement, les plus grandes sources d'énergie, en tout cas très supérieures à ce qu'il lui faut pour assurer son développement: pétrole, charbon, hydro-électricité, forêts, terres cultivables... L'Amérique latine a le noyau d'ingénieurs nécessaire à la mise en valeur de ces ressources et il me semble que, dans 30 ans, elle ne devrait plus figurer parmi les pays en développement. Le problème énergétique de cette région me paraît un problème de transition. Comment cette transition peut elle s'opérer avec le minimum de difficultés et le plus rapidement possible? De façon plus précise, je voudrais, à ce sujet, poser trois questions au Dr. Sanchez-Sierra: à son avis, que peut faire l'OPEP pour faciliter cette transition? Que peuvent faire les pays industrialisés? Et que peut faire l'Amérique latine elle-même?

LAURENT

Je voudrais demander à Mr. Sanchez-Sierra ce qu'il pense de la situation conflictuelle, relative au pétrole, entre certains pays d'Amérique latine et ceux de ces pays faisant partie de l'OPEP (Vénézuela spécialement), telle qu'elle s'est manifestée à la 5e C.N.U.S.E.D. (Manille) et au Sommet des Non-Alignés (La Havane)? Y a-t-il pour le pétrole une possibilité d'entente entre les pays d'Amérique Latine?

SANCHEZ-SIERRA

First of all, I would like to say that I agree very much with Prof. Chagas' comment.

I agree with M. Desprairies concerning the fact that we have, more or less, a good situation in order to improve our development and that we are in a transition period. I want to say the following:

1. O.P.E.C. is already helping developing countries and their help is too much bigger than the help from the industrialized countries (I mean per capita). In particular, O.L.A.D.E. has obtained a non reimbursed loan from O.P.E.C. They are helping us. We cannot expect more.

2. From the industrialized countries, we are expecting cooperation. We do not need a lot of help, in the old meaning of this word, but we need cooperation.

We just have to work together. This is a question of political decision from the industrialized countries. But, in the period of transition we are, the time is scarce and, if these countries want to do it, they must do it now. I think that in Latin America, we are very receptive to the cooperation, particularly with European countries. We think that cooperation is a good business for you and a good business for us. We have iron, coal and probably oil (at this time, the area already explored in Latin America is less than 25% of the potential area; in Mexico, oil has been discovered only eight years ago!), we have solar energy... we can fix a policy about energy for the next 15 or 20 years, without worrying. I mean we have the choices but we do not have the money. That is the problem. My economic consulsion is: the financial problem is *the* problem.

3. Latin America must act to improve an energy program with the following main aspects: *a*) hydropotential, *b*) oil and gas, *c*) coal, *d*) forest and solar energy.

Father Laurent asked a question about possible tension concerning oil problems between Venezuela and Mexico from one side, especially Venezuela, and the other countries of Latin America on the other side. There are just two countries in OPEC from Latin America: Venezuela and Ecuador. Some people say usually: "Why didn't our big brothers, Venezuela and Mexico, do anything for us?". Especially for the Central American countries. But right now (and I am very happy about that) the situation is changing very much. There is an agreement between Mexico and Venezuela and they are going to sell all the oil that the Central American countries need, at the international price, but 30% of this price is going to be a good loan for them, a loan at 2% with something like a 40 years term and they have to invest this loan in development projects. With the Iranian situation and the war between Iran and Iraq, the Brazilian situation about oil could be worse, but Venezuela agreed to sell them something like 4,000 barrels more a day. I do not say that this is the perfect state of cooperation, but now we are working more closely than, say, 10 years ago.

Chagas

Returning to the discussion of wood use, I would like to point out that in Brazil a vast program of reforestation was established. They are planting about 20 or 30 million plants per year. But this is less than what is being destroyed. Secondly, during many years, the reforestation was done only with eucalyptus for industrial use, but no tree which would re-establish the ecological equilibrium was really planted.

Blanc-Lapierre

Je voudrais poser une question au Dr. Sanchez: existe-t-il actuellement dans le cadre des études ou de la planification de l'OLADE un projet intéressant plusieurs états et pour lequel vous cherchez un financement commun: par exemple, une grosse centrale hydroélectrique qui serait gérée de façon régionale par deux ou trois pays?

Sanchez-Sierra

There are many of them but these projects have to be set up between national organizations (i.e. hydroplants). OLADE is working mainly in coordination, diffusion, general planning and sometimes in specific programs (i.e. small hydroplants - geothermal...).

Hall

This is relevant to Dr. Sanchez and Dr. Chagas. If you accept that, in Latin America, probably a third, or may-be even 40% of the energy as a whole is derived from biomass (in Brazil, they run their steel industry on charcoal and 28% of Brazil's energy today comes from biomass), you must pay great attention to the importance of research and development in biological systems.

A serious *problem is the lack of plant scientists and technologists in agriculture and forestry.* It is important that this problem be recognized by energy planners and training of plant scientists to be implemented rapidly.

Silva Araujo Neto

I add two comments on Dr. Sanchez's speech which stress his opinion on the wrong way of technological cooperation between developed and developing countries.

1. Cooperation programs on nutrition assume many times that underdeveloped people do not know how to nourish themselves. The cooperation frequently hopes to change food habits. Why not increase the production

of commonly used items? Why not use money (and more energy) to increase transportation, food production, education, etc.?

2. Presently, Brazilian Ethanol Program needs some improvements concerning better strains, genetically improved strains. Some private organizations in USA have excellent strains to ferment sugar, to fertilize and ferment starch, to produce cellulolytic enzymes, etc. Cooperative Programs aim at training courses, exchange of technical people, etc. Why not get and distribute the best strains and the best procedure to use them?

MAN IN SEARCH OF ENERGY IN DEVELOPING COUNTRIES

LAMBERT KONAN

In pursuit of their destiny peoples and men from all régions of the world are today very conscious of the prime importance of the availability of the latent energy reserves which are very essential to guarantee progress, because of the boosting power which their use offers those who are able to master it.

In view of the awful awareness of the dangers of the depletion of certain basic raw materials, their inequal distribution in the world and the close analogy between cost scarcity and quantity scarcity, many are those who, reconsidering the political basis and formal orientations considered sacrosanct rally round to reconsider the end product of humanity's progress.

In the ensuing uncertainty, it is not surprising that an organised hue and cry is being raised from countries hardly at the beginning of their development, for in conditions of scarcity the section of humanity which is least prepared is also the one that is hardest hit; for this reason the ideas which would follow and to which the analysis of the situation and possible orientation might lead, would naturally be extended to a close examination of a special case, taken as an example, that of West Africa and the people who live there.

Man has always yearned to create his own destiny. As far back as one could go in history even in man's prehistoric era, there is much glaring evidence of indefatigable efforts which have led men to cover the hidden forces of the world, to enhance their knowledge. Their struggle to dominate, primarily in order to survive and later to develop, made them try various combinations of their inventive spirit, their art of organisation, and also their ability to use natural sources of energy within their environment.

Relying initially on their on physical prowess and subsequently on that of tamed animals they gradually discovered the huge amplifying factor that is available to them by potential energy that is trapped in various forms: water, fire, the force of gravity etc.

In their somewhat instinctive desire for progress men of every origin have sought to acquire the domination of the forces which surround them; as todays's most important raw material due to the fact that it permits the exploitation of all others, there is little wonder that energy has been an object of keen competition, sometimes quite cruel, and always very tough.

But then what are those requirements that man wishes to meet? It is fairly easy to classify them into three groups; those that are associated with the development of the individual, those that have to do with the regrouping of individuals into societies, and those that make man the producer of goods that he wishes to consume.

The individual as a consumer

In this first group can be mentioned: goods for the preservation of life, food requirements, shelter requirements, housing, clothing, etc.

Among the goods for the preservation of life and longevity are requirements for health and hygiene. Comfort puts man one step higher in his material liberation.

Lastly, culture enters the race for the spiritual development of the individual.

Society as a consumer

Man is gregarious and tends to regroup in family units then in social entities.

Hence a second set of requirements become evident among which could be mentioned; the group requirements for the administration of the society.

Socio-cultural requirements which are natural concomitants of the particular culture.

The requirements for social progress which is gingered by tendencies of emulation typical to human conglomerations.

The need for communication, be it the transportation of goods or of men or whether it is a transfer of ideas.

The need for domination, and for competition among the social groups.

Man and the producing society

Consumer goods are not readily available and man unfortunately does not live in the idealistic garden of the Paradise described in the Old Testament where Adam and Eve strove.

To consume these goods he must first produce them and then distribute them and he has to put his talents to work to harness the latent energies in his environment starting initially from those that are more readily prone to deployment by the group for the production of his goods.

Modern industry is the direct result of this unavoidable production which is itself associated with man's desire to gratiate his appetite; many social theories have been propounded on the subject of the mutual dependence between the producer and the consumer but the facts are there: it is a vicious circle and its boomerang effect gives rise to the criticism of societies which exaggerate and are accused of enslaving the man whom they had set out to liberate.

The impact on energy needs

Through the preceding reminiscences can be seen the alternatives which are available to individuals and to the social groups into which they fall. The choice made or imposed can engender considerable variations of energy requirements and also various degrees of achieved progress.

This problem concerns all groups of human beings in the world and from its general nature many possibilities are offered today so that human liberties can not be under-estimated and that sufficient margins of initiative are left to individuals of a community, to the communities and to the peoples of the world.

There again the enormous responsibility of the leaders becomes evident for they, unable to have every individual express a hope that is difficult to appraise, are obliged to make a guess of the guidelines selected.

The true value of the leaders derives from their vision, that of guided human communities, from the ability to choose their leaders and to let their expectations be known.

Thus we are now in a position to say that the alternatives that are selected depend as much on geograpbic, ethnic, social, as well as metaphysical factors and that other examples can hardly be put to good use by the individual.

This is what makes it more difficult in the inevitable collaboration among the people of the world whereas it is a difficult matter to bring judgement to bear on the alternatives selected elsewhere.

Choosing from the available alternatives of energy

The organisation to be set up for the exploitation of energy for the progress of any human entity must be seen as a harmonious political mosaic in which it plays a dominant role, for one thing, because of the size of its relative economic weight and for another thing the heavy impact that it has on the other sectors as progress is achieved.

What is more, if in general the list of resources available and their potential enable us to establish different strategies of action, it also appears that the classical economic comparisons are not sufficient as guides to a selection, for each one has a different effect on the behaviour of human beings in their everyday life.

In this field, which is difficult to rationalize due to the fact that the subjective decisions have a much overriding power over that which is measurable, it is useful to give certain guidelines that will lead to fundamental choices:

— The general alternatives available for the harmonious progress of the society whose development should be the essential point at stake are very closely tied to a world balance in energy: they must therefore be self-reliant because over-dependence in this field can bring about serious limits to the free exercise of fundamental choices: this need for autonomy is not incompatible with solidarity among the social groups who have similar aspirations.

— The choices made must effect an overall financial and economic balance that is compatible with the other resources listed.

— Performances made within the defined political structure should be able to be assimilated by the group involved; any setback in this aspect could start off a demolishing process and a discouragement of the men who constitute it.

— The strict adherence to these conditions inevitably leads to the result that the rate of progress becomes an end rather than a prerequisite.

Now it is true that in this connection the rate measures up to the ability of the man to assimilate progress; it sometimes happens that certain regions are so much deprived as to be unjustly denied their due development: the whole problem of brotherhood among peoples and men hence arises with the difficulties they engender.

The major economic and ethnic factors in West Africa

Grouping together in this issue the area contained to the South and to the West by the Atlantic Ocean, to the Nortb by the Sahara desert to the East by the former Inland sea whose last vestiges are indicated by lake Chad, this area is inhabited by many social groups with very diverse traditions, but which carry a similar common trait, such as the deep belief in the existence of a powerful force controlling the development of living beings and carrying the roots of a spiritualism that favours diverse religious practices, a great attachment to family life, an existence which focuses on group interest which often takes precedence over that of the individual.

These people are deeply keen on preserving their culture, and at the same time their recent contact with the world has paradoxically brought about a compelling desire to reach a stage of development and culture that is much higher.

How might the former be preserved while favouring the latter? This is the problem for this region and, in fact, it is the same problem for other regions in the world.

Reserved and perspectives of primary sources of energy

— Hydraulic resources favoured by the tropical climate provide an annual potential of the equivalent of 40 million tons of petrol concentrated mainly in the South and easily convertible into electrical power within acceptable limits of return rates: the North which is less endowed with water may however gear that which is available towards agricultural uses by building reservoirs of average size which will irrigate nearhy areas during the dry season.

— West Africa is not one of the regions with much oil deposit; in fact, for the moment it is almost-non existent. However, systematic prospecting carried on for sometime now in the Gulf of Guinea gives reasons to believe that huge deposits of oil or gas could exist: recent discoveries leave room for hope, but it would be premature to make policy development dependent on these resources.

— Nuclear resources of uranium and thorium it appears, are available in moderate quantities in the region in forms of mineral deposits economically exploitable, but the enormous unit capacities that are called in to play right from the beginning are out of all proportion with the present regional requirements, not to talk of tbe high competence in human resources that is essential for their exploitation, and which these countries do not yet possess; hence this form of energy is more of an asset for the future.

— That which is commonly referred to as new energy such as, solar, geothermal, biomass are receiving special attention in this region, for, according to some estimates, provided there is a good degree of success, these could give rise to as much energy as produced from hydraulic sources.

— The advantages are numerous especially a quick promotion, dispersed and without many problems in the poorer regions.

This is why many plead the cause of the development of this technique to favour the application of solid solutions that are operational, while the effect of repetition will overcome technical exigencies and thereby reduce the cost.

— Firewood and charcoal form a major part of present consumption, certainly as much as all the other forms of energy put together, if not more in this part of the world but we have to consider that if they cease to be used in their present form they could become raw materials for the new technique of bioconversion.

Concerning especially firewood, it must be stressed that there is the danger of its extermination and we are aware of the consequences such a situation could have on the environment and this is why the search for some new sources of energy, notably solar energy, could constitute an acceptable solution to prevent the abusive rise of firewood.

Strategy on the harnessing of energy resources

This encouraging perspective leads one to believe that approximate global balance in energy is not incompatible with the economic development of the region but we may do well to look closely at what is best preserved in the way of life of the people of this region.

The population of the present generation and the following one will very likely maintain an appreciable birth rate, a factor which affects their balance: in thirty years time the inhabitants will certainly be 50% more than the present figures, even a doubling of the population may not be excluded by that time. Annual commercial energy requirements exceed approximately more than the equivalent of 10 million tons of petrol and could go up from 60-80 million tons in the space of some thirty years according to the suggested theories on population growth and the rate of meeting per capita requirements in energy.

Hence from the preceding point a coherent plan for the harnessing of registered resources is called into play:

— The development of hydraulic generation in the South will provide energy to concentrated urban structure and industries due to its ease of transformation into electrical energy.

— The experimental development followed by the industrial application of new sources of energy in combination with the extensive uses of irrigation should easily supply the agricultural sector with light power and very diversified sources of energy especially in the Nortb where development will necessarily depend on the hydraulic and industrial investments: this will contribute to limit the alarming use of firewood.

— Prospecting for oil could be an additional solution for industrial take off and also an alternative in case the harnessing of new sources of energy should prove disappointing.

— The two major lines for complementary developments, hydraulic and new sources of energy will be naturally involved hand in hand right from the time when electric interconnection gains ground.

— Such a problem will probably be the most appropriate to permit a controlled and progressive introduction of modern methods in the poor regions while at the same time favouring industrial developments in the regions that are better adapted: it will also create the concilliatory condition whereby recognition is given to traditional practices that are most dear to the population thereby adapting to the rate of human development rather than attempting at forcing this development.

Conclusion

Countries in which technology is still in its infancy have preserved better than the others a capital which must be counted the most precious in the world today.

Being more in touch with nature, they retain certain essential values which link man to his environment and feel perhaps more keenly the attitude which must guide relations between individuals even if occasionally partisan and aggressive reactions resulting in local conflicts have a dulling effect on this perspective.

This is why it is acceptable to expect that developing countries which have the benefit of the progress imported by technologies invented by developed countries and which have the necessary perspective to appreciate the imperfections of the past should be able to show the world that the introduction of modern habits can lead to the only goal that is worth pursuing: enable humanity to believe in a better world based on powerful forces of collective solidarity and on the keenest sense of responsibility of the individual.

DISCUSSION

Blanc-Lapierre

Je remercie le Président Konan de son exposé et j'ouvre la discussion.

Konan

Permettez-moi, Monsieur le Président, d'ajouter quelques brefs compléments à mon exposé.

Je voudrais rappeler une phrase prononcée par le Père Laurent lors d'une conférence donnée à Adidjan: « Est-ce que l'intelligence appartient à celui qui la possède? ». La méditation de cette phrase me parait importante dans le problème des rapports entre le tiers monde et le monde développé. Les pays industrialisés maitrisent la science et la technologie, peuvent-ils considérer qu'elles leur appartiennent en propre?

Je voudrais insister sur le caractère très récent du début de notre développement. Il y a quelques décennies, nos trains marchaient au feu de bois, nous n'avions pratiquement pas de véhicules automobiles, notre agriculture était artisanale et la pétrochimie inexistante. Le développement de l'électricité remonte à environ 1950. A cette époque, nous n'avions aucun besoin de nous préoccuper du pétrole et l'opinion selon laquelle ce produit resterait très bon marché a retardé le démarrage de réalisations hydroélectriques. En 1973, lors de la crise du pétrole, nous avons connu une situation extrêmement grave. La consommation électrique est brutalement passée d'une croissance de 17% par an à une baisse de 7% en 1974. De 1973 à 1979 le coût moyen du pétrole a augmenté de 92% en Afrique de l'Ouest, ce qui a entrainé une croissance du prix de l'électricité de 80% à 100%. La croissance du prix du pétrole a aussi provoqué de sérieuses difficultés dans les cultures du café, du cacao (engrais,...). L'utilisation du bois a augmenté dans des proportions inquiétantes et le gouvernement de la Côte d'Ivoire a dû prendre des mesures pour la limiter. Comment remplacer le pétrole? Nous devons développer notre équipement hydroélectrique et les pays de notre région doivent s'aider grâce à l'interconnexion des réseaux. Mais l'aménagement hydroélectrique coûte cher! Nous l'étudions, ainsi que l'interconnexion, dans le cadre régional de notre union, l'U.P.D.E.A., dont je vous ai parlé avant-hier. Une complication pour les problèmes d'interconnexion réside dans la disparité des caractéristiques, notamment en tension, des réseaux à raccorder. La plus grande difficulté est celle du financement des équipements et, plus particulièrement, des équipements hydroélectriques. Un barrage coûte cher, dans les six cents millions de dollars... et la facture pétrolière est très lourde. Notre dette extérieure va en s'accroissant et ceci freine les travaux essentiels, indispensables pour nous assurer un minimum de développement. C'est le problème de tout le tiers monde. C'est le nôtre. C'est pour cela que j'ai intitulé ma communication: « L'homme en quête d'énergie dans les pays en voie de développement ». Merci, Monsieur le Président.

LESOURNE

Je voudrais poser une question et soulever un problème. Je me demande si la situation future de l'Afrique de l'Ouest n'est pas encore plus dramatique que celle que nous a décrite le Président Konan. Il nous dit que la consommation d'énergie commerciale est de l'ordre de 10 millions de Tep. La part actuelle de l'énergie non commerciale dans la région est de l'ordre de 80%. La consommation totale actuelle serait donc d'environ 50 millions de tonnes.

Si l'on tient compte de la hausse de la population, la consommation à la fin du siècle serait de l'ordre de 75-80 MTep, à consommation par tête constante. Avec une certaine hausse de cette consommation, on aboutit à 110-120 MTep.

Si l'hydroélectricité fournit 40 MTep la biomasse risque de ne pouvoir se développer que lentement (difficultés dans le Nord de la région notamment). Dans ces conditions, énergies nouvelles, pétrole et charbon peuvent avoir à couvrir 30 à 40 MTep.

En ce qui concerne le financement du développement du Tiers-Monde, je suis de ceux qui sont favorables à l'accroissement de la part du PNB des pays développés, consacrée à l'aide. Mais cette aide devrait être progressivement consacrée aux régions en situation difficile, de l'Afrique noire et de l'Asie du Sud en particulier. Au contraire, pour l'Amérique latine (ou moins pour les pays les plus développés [le cas des petits pays d'Amérique Centrale ou des Caraibes peut être différent]), n'est-il pas normal que le financement provienne de plus en plus du marché des capitaux? Le problème est alors d'assurer cette possibilité d'accès pour les pays d'Amérique latine.

KONAN

Je me limite à la première question de M. Lesourne. C'est une question très importante. A la Conférence mondiale de l'Energie, en 1976, j'avais insisté pour que soit créé un Comité ad hoc pour étudier les problèmes d'énergie dans le Tiers-Monde. Ce Comité existe maintenant. Les travaux nous permettront de mieux cerner les chiffres à retenir et leur évolution. Il faut, en particulier, tenir compte du fait que nos pays n'ont pas « décollé » autant qu'on avait pu l'espérer. En ce qui concerne les énergies nouvelles, le Marché Commun va intervenir de façon plus hardie en nous aidant au niveau régional, pour le financement de projets dans divers domaines et notamment dans ceux de l'énergie solaire, de la biomasse.

LEPRINCE-RINGUET

J'insiste, comme vieil ami de l'Afrique et des Africains, sur un aspect qui a été soulevé par M. Lambert Konan. C'est la nécessité de former des cadres moyens et d'avoir des Instituts de formation et de recherche, si possible au niveau régional (association d'un certain nombre de pays). Cela se fait déjà mais il faut développer largement ces initiatives. Ainsi, si on installe des pompes (solaires ou autres) dans divers villages, on a nécessairement besoin d'un technicien qui soit responsable de leur bon fonctionnement pour un district. Les techniciens et cadres moyens sont la base des progrès techniques auxquels aspirent les Africains dans le respect de leur authenticité.

ENERGY REQUIREMENTS FOR INDIA: A SYSTEMS APPROACH

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1. Introduction

The importance of the energy sector for the economy of India could be judged by the fact that 28.5% of the public sector investment allocations in the 6th plan (1) is expected to go to the energy sector, of which 21.3% go to the power sector alone, which is the highest allocation to any sector, followed by the agriculture sector (2) (25%), transport sector (2) (15.7%), and the industries sector (2) (15.3%), respectively.

This makes one realize that energy itself is an industry and of an enormous magnitude, particularly in India because its major energy resource is coal, investment for which has to come from within India. This contrasts with some other developing countries whose major energy resource is oil, often imported. Of course, payment for oil requires investment elsewhere in other sectors or trade of other primary goods.

Because of the importance of the energy sector for the five-year plan,

(1) The Planning Commission, Government of India, printed a "Revised Draft 6th Plan" in 1979, where the targets for the 6th, 7th and 8th plans were indicated for the periods 1977-78 to 1982-84, 1982-83 to 1987-88 and 1987-88 to 1992-93, respectively. The new Government took over after the election in 1980 and decided to revise the plan for which figures are not yet available. The new Government also decided to shift the plan periods by two years, i.e. 1980-81 to 1984-85, etc. In this paper, the reference to the 6th plan is made according to the printed version available. It is however, expected that the growth rates for the energy sector and the LEC industries will not change drastically in the new plan.

(2) However, a portion of the investment for these sectors comes also from the private sector. In the case of the energy sector, the contribution of the private sector is very small

the Planning Commission of the Government of India set up a Working group on Energy Policy (WEP). The group consisted of representatives of various energy related organizations such as Ministry of Energy, Ministry of Petroleum, Department of Coal, Ministry of Railways, Planning Commission, etc. This group prepared a report outlining the energy policy and energy required for India up to 2000 based on judgment and simple methods. The Planning Commission also set up an independent energy modeling exercise, salient features of which are described in this paper.

2. Objective and approach

The objective of the modeling system is:

— To assess future energy demand for various sectors of the economy.

— To assess the impacts of various energy policies on energy requirements.

— To identify energy supply mix for meeting the above energy requirements, i.e. optimal mix of various energy supply technologies such as coal, oil, electricity, renewable energy resources (such as wood, biogas and solar energy), etc.

The energy modeling system envisaged has three parts:

(i) A model to project macro-economic aggregates;

(ii) Dynamic, multi-sectoral models for simulation of energy demand;

(iii) Calculations of the investment and imports required for the energy sector and cross-checking the consistency with the results of the macro-economic model.

It is necessary to look at energy problems with long-term perspective because:

— The gestation periods of energy supply projects are of the order of 5 to 10 years.

— The gestation periods for changing the energy user system such as industries, transport system, etc., can be even larger than 10 years.

— Major part of the energy resources used presently are non-renewable.

Moreover, to ensure the stability of the model, it is necessary that the model give targets for successive 5 year plans up to two decades. Thus, the forecasts for the 6th, 7th and 8th Plans, along with the projections for the year 2000 are given. As the model is computerized, it has the flexibility to give projections for any year desired and analyze the effects of various policies relating to energy consumption.

Energy demand projections made have to be consistent with the socio-economic parameters assumed. In particular, energy demand in the following four sectors are considered:

— Industries;
— Transport;
— Agriculture;
— Household and Commercial.

The effects of various policies in these sectors on energy requirements are highlighted.

In this work, the description of the model is accompanied, at times, with the data base to provide the context in which the model has to be interpreted. However, as much of the data base is already given elsewhere such as Working Group on Energy Policy, NTPC, etc., major emphasis is on the model description, analysis of results and policy implications.

The modeling system begins with a macro-economic model which gives scenarios for macro-economic projections, i.e. GDP growth rates, private consumption, industrial GDP etc. In addition, there are other inputs given exogenously such as population, urban population, net area sown, villages electrified, etc.

Two macro-economic scenarios (3) — for low and high demand — are considered:

— The "High" scenario is the one used by the Working Group Policy (WEP) which assumes longterm GDP growth to be 5.87% but has high share of urban population (32% of the total in 2000).

— The "Low" scenario uses the results obtained from the simulation (SIMA) model development at I.I.A.S.A. Although this has been used to construct a number of scenarios, the lowest one of them is taken to provide two different scenarios. In the low scenario, long-term GDP growth is 4.4% and low share of urban population (26% of the total in 2000).

(3) While "high" scenario represents aspirations of WEP and the revised draft 6th Plan, the "low" is somewhat higher than the growth rate in the past.

The results of the macro-economic model are used as input parameters for the demand model which is split into four sectors. The results are summarized in Table 1. The salient features of each of these sectors are described below.

TABLE 1 — *Summary of the Energy Requirements.*

		Low Demand			*High Demand*		
	1977-1978	1984-1985	1989-1990	2000	1984-1985	1989-1990	2000
				Electricity (bkwh)			
Industries	44.17	82.9	109.2	188.2	90.6	132.4	266.0
Household	11.21	11.0	16.0	34.2	13.1	21.2	58.2
Commercial		10.2	16.3	36.2	10.2	16.3	36.2
Agriculture	10.01	17.7	24.9	45.7	17.7	24.9	45.7
Transport [a]	2.44	4.0	4.4	7.7	4.4	6.6	16.7
Miscellaneous	2.05	8.4	14.7	30.0	8.4	14.7	30.0
TOTAL	69.88	134.2	185.5	342.0	144.4	216.1	452.8
				Major Oil Products (million tons)			
LPG							
Industries		0.2	0.4	0.8	0.2	0.4	0.8
Household		0.9	1.4	3.3	0.9	1.4	3.3
	0.40	1.1	1.8	4.1	1.1	1.8	4.1
Mogas	1.50	2.0	2.6	4.4	2.0	2.6	4.4
Diesel Oil [c]							
Agriculture		1.9	2.5	4.2	1.9	2.5	4.2
Transport		9.5	11.8	20.4	10.4	13.9	26.74
	8.67	11.4	14.3	24.6	12.3	16.4	30.9
ATF	1.16	1.4	2.0	4.4	1.5	2.3	5.7

		Low Demand			*High Demand*		
	1977-1978	1984-1985	1989-1990	2000	1984-1985	1989-1990	2000
Kerosene [d]							
Household	3.95	4.6	6.9	9.4 (19.9)	4.8	6.4 (7.6)	9.4 (23.4)
Fuel Oil [e]							
Industries	3.00	3.9	4.7	4.8	4.3	6.2	7.5
Total oil products for major uses	18.68	24.4	32.3	51.7 (62.2)	26.0	35.3 (36.5)	62.0 (76.8)
				Coal (million tons) [f]			
Industries	52.8	84.6	109.9	220.2	92.6	135.4	317.8
Household (soft-coke) .	4.0	5.1	5.9	8.0	5.1	5.9	8.0
Transport	13.2	8.2	7.2	2.5	10.0	10.0	3.8
Colliery [b]	3.3	3.9	5.2	7.0	3.9	5.2	7.0
TOTAL	73.3	101.8	128.2	237.7	111.6	156.5	336.6
			Non-commercial (million tons coal rep)				
Household		217.3	224.2	229.9	217.3	224.2	229.9

[a] Include auxiliary electricity requirements for stations, workshops, etc.

[b] As of WEP.

[c] Excludes diesel for power generation.

[d] The figures in the brackets represent commercial energy requirement whereas the figure above represents the optimal level forecast. The difference is to be met either by new energy resources or kerosene itself.

[e] Fuel oil for power generation excluded.

[f] Excluding power generation.

3. Industries sector

In the macro-method, industries sector is split into two groups — large energy consuming (LEC) industries from the organized sector and the remaining industries from organized and unorganized sectors referred to as the non-LEC industries. The energy intensities, i.e., coal, oil and electricity required a rupee (4) of value added are 0.812 kg, 0.061 kg and 0.690 kwh respectively in 1976-77 which are assumed to change to 0.899, 0.019 and 0.817 respectively in 2000.

The question of an appropriate industrial mix from the point of view of energy has been examined. It is, expected that the energy intensities of the non-LEC industries would increase in future because of substitution of energy for non-commercial energy and human and animal energy. On the other hand, it is possible to expect some decline in the energy intensities of the LEC industries because of introduction of more efficient technologies. Presently, the energy intensities of the non-LEC industries are 25% to 30% of the energy intensities of the LEC industries. This gap reduces in future to some extent, but even so, it pays to pursue the policy of shifting in the industrial mix to non-LEC industries. What is also important is to watch the energy consumption of non-LEC industries, for example, 20% reduction in their electricity intensities leads to the saving of 37 and 50 billion units in 2000 for the low and high scenarios respectively. This reduction will call for R & D efforts in the non-LEC industries as well.

4. Transport sector

Only the land transport is discussed in detail here and the comments on water and air transport can be seen in J. Parikh (1980).

Analysis of the data shows the following:

— Passenger transport: Both urban and long distance transport increases with urban population and has no correlation with per capita income. The metropolitan areas generate considerable traffic where the distances of average trip by suburban railways as in Bombay, Calcutta, Madras are 19.6, 25.2 and 15 kilometers respectively. Per capita urban travel is 700 km, whereas per capita regional travel is 585 km per year.

(4) Through the paper, the rupee of 1970-71 is used.

— Ton-kilometers increase with industrial production. However, average distance by which the originating tons move is gradually saturating since 1972 at nearly 700 kilometers.

— The truck transport is the largest consumer of diesel and it is to control this phenomenon that strong energy and transport policies are required.

The objective of the transport sector sub-model is to analyze the effects of the policy measures which could *reduce oil consumption* in the transport sector. Some of the oil conservation policies considered are:

(i) Low urbanization;
(ii) Increased efficiency in transport vehicle utilization;
(iii) Increased transport by rail; and
(iv) Railway electrification.

The relative importance of each of these policies is evaluated.

5. Agriculture sector

Conventionally, while considering the energy use in agriculture, only the direct use of energy is included, i.e., direct use of diesel and electricity, for irrigation and mechanization. In the model, these requirements are calculated on the basis of cropping intensities that would be required for supporting increasing population with limited land. The energy required for irrigation is found to have good correlation also with rural areas electrified. The split of this energy for irrigation into diesel and electricity is a function of rural electrification and crude oil prices.

It is pointed out that, in addition to the direct use of energy, there are a number of points relevant to planning for energy for the agriculture sector. They are:

(i) Indirect energy inputs required in fertilizers, pesticides and food processing are three times larger than the direct inputs of energy;

(ii) Non-commercial and muscular energy provides nearly as much energy as the direct use of commercial energy in the agriculture sector;

(iii) Agriculture is one sector where *timing* for supplying energy is very crucial. This factor has to be taken into consideration for power capacity planning and supply of diesel;

(iv) Nearly 50% of the intermediate inputs used in the agriculture sector are related to energy;

(v) The regional distribution of demand for energy for agriculture is also an important factor in planning the supply.

It is found that if net area sown is not increased in future, then the long-term electricity growth required for irrigation would be 6%. This is low compared to the recent past, but the growth rate reduces due to leveling of pace of rural electrification in the nineties and reduction of population growth.

6. Household and commercial sector

The availability of non-commercial energy, which at present provides more than 80% of the use of energy required in the household sector, cannot be taken for granted in future to provide required energy unless strong measures are taken for ensuring the renewability of supply. It is envisaged that the share of demand for commercial energy would keep increasing due to:

— High urbanization;
— Increased income and its distribution; and
— Non-availability of non-commercial energy.

All the three factors have been examined and it appears that the reduction in per capita supply of non-commercial energy would contribute significantly to the rise of demand for kerosene.

Three methods have been used in order to cross-check and to get insight into substitutions, urban-rural break-up of demand, effects of income distribution, etc. These are:

— End-use method;
— Direct energy use method; and
— Income distribution method.

It is assumed that the supply of soft-coke and LPG for the household requirements would be 8 mt and 3.3 mt in 2000 respectively. Non-commercial energy is expected to be around 220 mtcr in tbat year. It is estimated that in order to keep WEP targets of kerosene demand of 7.7 mt in 1994 and 9.4 mt in 2000, the contribution that would bave to come from alternative energy sources is 5.2 mt and 14.5 mt of kerosene requirement in 1994 and 2000 respectively. These options could be bio-gas, wood plantation, solar energy, etc., and also LPG.

Few more observations are: Long-term electricity consumption growth for low and high urbanization is 7.2% and 9.7% respectively.

The share of electricity and kerosene consumption in rural areas in 2000 given by the ID method is 30% and 64% respectively. Per capita consumption in the household sector increases from 0.33 in 1973 to 0.468 ton per year in 2000. The share of commercial energy in the household sector increases from 20% to 48.1% during the years 1973 to 2000. The growth rates for electricity in the commercial sector for different time periods are taken keeping the growth rate of the service sector and expected increase in price of electricity.

7. Overview: energy demand for the economy and comparison with WEP

What do all these sector requirements add up to? As the sectoral conclusions are given above, only overall energy supply aspects are illustrated below.

Electricity requirements: The figures for 2000 are 342 and 452 bkwh for the low and high demand scenarios. These figures include conservation measures in the industries and transport sectors. Price effects for the household sector are not considered, which may give further reduction. The need for sectoral load considerations for power planning is emphasized so as to accommodate increased use of electricity in the agriculture sector where timing is very crucial.

Oil requirements: If appropriate policies to curb the demand for kerosene, diesel and fuel oil are adopted, then the saving could be 10 mt, 6 mt and 6 mt respectively per year by 2000. Thus, the requirements for major oil products could be kept at 51.4 mt ([5]) per year in 2000. The policies required for this reduction are identified. The share of middle distillates increases from 54% in 1978 to 65-70% in 2000.

Coal (and charcoal) requirements: Due to the necessity to conserve fuel oil and the need to substitute non-commercial energy, coal intensities are likely to go up. The coal demand for direct use, i.e., excluding power

([5]) Excludes minor products and non-energy uses, e.g. Naptha, Bitumen, etc.

generation in 2000 works out to be 238 mt and 334 mt for low and high scenarios.

Comparison with the WEP Scenario

It was first found that the WEP projections for the OLF (6) correspond to low urbanization. Therefore, High (L) scenario was constructed to examine the consistency of the WEP scenarios.

(a) The model results *agree* with overall magnitudes of oil and electricity consumption and small consumption items such as colliery consumption, LPG and ATF requirements, etc.

(b) The model results *differ* with sectoral allocations of these overall magnitudes and indicate higher share of electricity for agriculture:

— Magnitude of coal requirements and its share in industries;

— Projections for the transport sector such as tkm, diesel and petrol requirements.

(c) The model results *augment* the WEP efforts by extending the analysis and working out certain policy implications. It shows, for example:

— Effects of rural electrification policy;

— Effects of urbanization on various sectors;

— Implications of going on to OLF levels from the RLF levels on energy consumption norms;

— Identification of contributions expected of the alternative energy sources.

8. Investment requirements in energy sector

Can the economy provide the investment required to fulfill the energy demand? Power sector requires 21.8% of the public investment at present. This could increase up to 30% and 38% in 2000 for the low and high demand scenarios, if the present trends of the efficiencies continue. These figures could be only 18% and 25% respectively *if*:

(6) Refers to Optimal Level Forecast.

— Capacity utilization of power plants is increased.

— No cost-escalation in real terms takes place in new power projects.

— The share of investment in the GDP increases from 23.5% to 28% in 2000.

9. Regional distribution of energy demand

What are the issues relating to distribution of energy in a vast country as India? The quantification is made of certain issues such as:

— Trends of regional shares: The shares of total energy for the Northern Region has considerably increased and for the Eastern Region has declined, while the other two have remained stable.

— The mix of energy: The share of electricity has increased in each region and the share of oil has decreased in each region except in the Eastern Region.

Regional distribution of energy requirements per capita energy consumption in the Eastern Region is the lowest where the resource is maximum.

— The efficiency of energy-use: The electricity intensity declines when the region gets industrialized. The Western Region, which is the most industrialized region, has the lowest electricity intensity.

— The agriculture is power intensive in the Northern and Southern Regions and this trend is to be expected in the Western and Eastern Regions, where agriculture would be more developed in future.

Implications for energy distribution:

— In future, coal, resources for which are located in the Eastern Region, has to be transported to the states in Northern and Western Regions, the oil to Southern and Northern Regions, etc., in much larger quantities.

— To strike a supply-demand balance, the Eastern Region would have to be more developed.

— Forest areas and hydro-potential of the Northern and Southern Regions would also have to be developed.

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DISCUSSION

LESOURNE

1. Are the figures given for oil in tons of oil equivalent or in tons of coal equivalent?

2. Are the figures given for biogas in 2000 (80 MTCE) included or not in the 220 MTCE given for non-commercial energy?

PARIKH

For the first question, that is million tons of oil. For bio-gas, as I mentioned, it is 80 million tons of primary energy. When I say primary energy you realize that non-commercial energy fuels are very inefficient (5 to 10% efficiency) whereas that is not the case with kerosene for example, and so, you could require only 10 million tons of kerosene to replace 80 million tons of non-commercial energy.

HALL

The energy plan ignores non-commercial energy which now contributes about half of India's energy. It ignores household energy use which uses 44% of the total energy — both in urban and rural (80% of total) populations. An increase by the year 2000 of a factor of 4 for electricity production, a factor of 2½ for oil requirements and 3 for coal production seems very ambitious. Can it really be attained?

PARIKH

Wood prices are now getting to be so high that in fact even private entrepreneurs now instead of growing cotton, start growing wood. In the last ten years they have really stepped up their efforts. So I hope that within the next 2 or 3 years major changes may take place. But these things take time. The second question you had was about...

HALL

I was just saying that each of the commercial energies would have to increase between 2½ and 4 fold within 20 years.

PARIKH

Well, we have done much more than that in the last 25 years. We have increased tenfold from 1950, so fourfold increase is only 7 to 8% growth. And the plans are made out. Of course we might fall behind the plan. But in the initial stages of development this is not very difficult; then there are factories where we have 100-fold improvement because from zero this does not mean anything.

SILVA ARAUJO NETO

I have two small and specific questions for Dr. Parikh. The first one is about the percent participation of a small biogas plant in the overall Indian energy consumption.

PARIKH

Very small. Less than 0,1 per cent.

SILVA ARAUJO NETO

My second question is about the fuel used in the cement industries in India: oil, coal, charcoal?

PARIKH

For fuel oil we have given very strong incentives to get off. So we are at the level of about 0,23 ton of coal per ton of cement if the process is a dry process; if it is produced by a wet process, then it is 0,3 ton per ton of cement.

SCHMITT

What is the share of coal production in open cast mines and deep mines?

PARIKH

It is about 40% shallow mines and 60% deep. But now they have found many other possibilities of doing shallow mines, and I think that in the next five to ten years it will be more shallow mines than deep. Again after 1990 we will have more deep than shallow.

SCHMITT

But I am asking that because I wonder if training of several hundred, of thousand miners to produce till 2000 the amount of coal that you mentioned will not be one of the most important restraints.

SANCHEZ-SIERRA

I would like to comment on an aspect that Dr. Hall and Dr. Parikh were talking about and this is on noncommercial energy. When I gave my paper, Dr. Hall asked whether a serious problem is the lack of scientific and technical people in the agriculture and the forestry sectors. I think that this is not correct. Eventually in developing countries there are many of these people and of good quality, but I think the mental blockade that we have is more important because I understand that developing countries are going more or less in the same way that the industrial countries from the energy point of view. Unconsciously they think in the same way that industrial countries do, such as in oil, in coal, in gas, in nuclear, in electricity, etc. And we understand perfectly, you in India and I in Latin America, that in India 45% of the energy is the wood consumption. Why do we not pay attention to that problem? There is a mental blockade we have to fight. We need people in the energy planning departments thinking about these things.

PARIKH

I agree with you that agricultural people are not the only people who can solve these problems. When the planning commission was organized, this whole question of wood plantations, where wood is growing in an organized manner just for burning, was not part of their work. But recently one realized that this thing, that we had left in people's hands, was not doing as well as was thought and now we have to bring that under government consideration. It is not possible for the government to grow wood for 600 million people and this should be left to private people, but they should be encouraged with subsidies, etc.

ROLE OF ENERGY IN THE LIFE OF MANKIND: LIFESTYLES AND DISTRIBUTIVE JUSTICE (*)

M. PEREZ-GUERRERO

1. *The Emergence of the Critical Situation in the Field of Energy*

There is no doubt that energy conditions economic and social development, and that the more extensive and intensive the development effort, the greater the consumption of energy and consequently the need for expanding and diversifying the sources of energy. On the other hand, a relatively plentiful and cheap source of energy leads to overconsumption and overconcentration on this energy source and inevitably to wasteful uses. This in turn results inexorably in the rapid and premature exhaustion of this source, more particularly the easiest and cheapest *exploitable* deposits. It is exploitation at its worst.

This is what has happened in the course of the last decades of Western style development, the engine of which has been oil more than any other single factor. Such development was brought about indeed by a combination of important factors, but none as predominant as oil.

In fact, the misuses and abuses of oil have contributed in great measure to limit and spoil the basic elements which were counted on as limitless, such as fresh water and pure air and, to a lesser extent, arable land. The weather and the atmosphere itself are being degraded, fortunately not yet beyond recovery.

The twentieth century will probably be known as "the oil civiliza-

(*) The author published under a similar title in 1975 a condensed article in the first issue of the review "Energy and Development" of the institute of the same name of the University of Colorado.

In the last moment Mr. PEREZ-GUERRERO could not attend the Study Week due to professional engagements. Consequently, his paper could not be presented orally.

tion", and, depending on how we fare during the rest of this century, oil will be identified as a curse or as a blessing. If its impact were such as to be somewhere half way between blessing and curse, the negative aspects would prevail in the minds of the people.

Oil is today equated to energy. Yet one should not indulge in an obsessive attitude towards energy but situate it in its proper perspective: energy is of critical importance and so are many other issues, above all the human being and his spirit with potentialities more often than not unfulfilled. At the present juncture, energy is more than ever before related to the destiny of man. Yet man should be the master of his own destiny. In this context, the accelerated exhaustion of oil would be considered, when and if we approach that state by the turn of the century, as a calamity brought about by sheer irresponsibility of those that could have avoided it, and did not have the vision and courage to do so. There is still a hope that reason will prevail and that it will not be a calamity; that during the present critical period, through deliberate and concerted efforts, we will be able to place oil and its by-products — within the context of world-wide economic and social developments — on the track of justice and rationality, and spare us great, unpredictable hardships. Anything could happen including total chaos and destruction. We have the means for it that could be triggered by a spark in an atmosphere of tension due to miscalculation or sheer neglect. Energy conditions economic and social development but irrational and unjust energy policies or lack of policies produce distorted — irrational and unjust — development. This was not our set aim. It could not bave been. Yet it was brought about all the same. As surely as if we had been pursuing deliberately that course, albeit too unsystematic to be the case. We pretended to be unaware of it. We did not want to know. We mistook an artificial prosperity, based in large part on enforced subsidies — cheap raw materials and particularly energy — and subsequent waste, for the coming into being of a permanently growing grand society that would ultimately encompass the whole world. In fact, little attention was paid to the poorer parts of the planet, except for ensuring tbeir role as providers of key raw materials and foodstuffs and as markets for the export surpluses of developed countries. Buying cheap, selling expensive was the order of the day. The normal approach of a good merchant. Energy — oil, in reality — was at the core of it.

This situation, which was not supposed to have any end and to be able to overcome any obstacle on the way, gave clear signs that it would not go on. Something went wrong. A change of course was required:

The trade and payment system was falling apart. Rampant inflation had set in since the late sixties, as a result of monetary incontinence leading to the cutting of the U.S. dollar from its linkage to gold in 1971. The "prosperity" had to be artificially maintained to avoid the crunch called for by past mistakes, letting the world, particularly the poorer countries, share in the growing cost of such mistaken policies. Raw materials and foodstuff prices were rising, as a result of increased demand in an inflationary climate and paid for in a currency the purchasing power of which was deteriorating and had to be devalued until all major currencies were let float without any point of attachment. Oil was no exception. Its demand had reached a growth rate of around 7% annually, and its price had started to rise slowly from depressed levels against great resistance on the part of the major consumer countries — represented by the transnational oil companies.

What had to happen in these circumstances, happened and surprised even those who should have known better. The long overdue increase of oil prices during the second half of 1973 shook the international economic community into reality. It sounded as an unmistakable warning. Not a welcomed one but one that had to be faced, and the sooner and more level-headed the better. The world economy was in a clash or crash course which had to be corrected. Oil — and other raw materials — could not continue to be wantonly wasted with the prospect of exhaustion in the next decades and with the threat of an unprepared world economy struggling in the throes of crippling scarcities. The consumer society was gulping down its throats more than the planet could afford, and still the majority of its inhabitants were hungry and in a debasing state of poverty, seemingly ignored by most of the rich. The rich indeed had been living beyond their means, while the poor lacked literally the very means to live. The prosperity which had been attempted had no base to sustain itself. Prosperity that was not shared, could not endure.

This picture is brought back here stressing its grim features. There were less grim — even rejoicing ones — but only for a certain part of mankind. The sole purpose of turning to the immediate past is to recall, without rancor, what we are leaving behind, hopefully for good, while we strive to open new roads for the benefit of all. What is at stake is more than just the carrying capacity of the planet. To achieve it we will still have many difficulties to surmount, yet it is worth the effort since it is in the pursuit of a good cause: the cause of mankind, genuinely so, involving present generations — old and young — as well as future generations.

2. *The Imperative Transition*

During the Conference for International Economic Cooperation (CIEC) in Paris (1976-1977), it became clearer that, as a result of the so called energy crisis, the world community had entered a transition period from an economy based on an energy mix where oil was prominent to one where oil will yield its place to renewable and non-polluting sources of energy, such as solar, geothermal, eolic, tidal and other ocean related energies. Before we reach that goal, non-conventional oil based energies like tar sands and shale oil, in addition to distillates from coal will be increasingly resorted to during a passing stage, the limits of which will not be the size of the reserves but the pollution inherent in its production and use, indeed the high cost in energy input reduce the net energy produced to a point which is not any longer attractive, especially if one adds the social cost involved. Oil would be reserved to its noble and/or non substitutable uses, as a raw material (petrochemicals) and a fuel, specially collective transport. This transition should be as speedy as possible in that one should not delay the availability of new and economic sources of energy, so that these would replace oil progressively yet expeditiously as oil becomes scarcer (and more expensive). On the other hand, the transition should be as long as necessary. One has to make oil last as long as possible through appropriate reduction of its superfluous consumption and so enable mankind to find alternate sources of energy and, in any case, prolong the existence of oil for future generations, as a valuable raw material (excluding non biodegradable or otherwise polluting items). The transition may well take many decades, but it stands to reason that the critical stage of it will be — or should be — relatively short. It depends largely on our adaptation to non-wasteful uses of energy and particularly of oil. That is why one should insist that the question is not only how quickly one finds new sources of energy, but also at what speed one can reduce the non essential consumption of energy. Otherwise, one would be tempted to resort extensively to new polluting forms of energy involving still many serious risks, such as nuclear energy as we use it today.

Energy is so tightly knit into the social fabric and its evolution that the transition period does concern not only energy but also all the other matters of which energy — however important — is but one. So the approach to the transition course or itinerary to be charted, adopted and followed has to be, in essence, properly integrated, in the knowledge that all elements involved interact on one another to varying significant extents. This interplay cannot be left to blind or selfishly maneuvered market forces. It has to be guided in good measure by concerted actions designed to achieve certain agreed results. This is more easily said than done. Yet it would be unreasonable or altogether irrational to intervene only when distorsions and intolerable imbalances would have developed to the obvious detriment of some groups, generally the weak and poor. Difficult and complex as these issues are, it would appear more practical to assure the success of agreed policies by an active disposition towards and timely use of certain deliberate measures, than by limiting oneself to observe passively the situation and be prepared to intervene only when it has taken an unquestionable turn for the worse. By then the situation might well have become irretrievable. More often than not, timely action would have proved less costly and painful than the lack of action. In the face of a complex situation we cannot remain perplexed.

The action required should aim at rendering the process of restructuring less rather than more complicated — whenever possible simplicity is better —, less wasteful rather than more, more in keeping with what we can expect of Mother Nature, which will be much more satisfying the more in harmony we live with her. In addition, the more complex the technical processes, the greater the power of elites and, conversely, the lesser the opportunities for the many.

While this general approach has already permeated in the minds of many people, yet it has hardly influenced our all too often destructive behaviour and habits. Obviously, greater and sustained efforts are needed. It is not Utopia we are aiming at, rather an attainable reality indispensable for all members of the world community to be given a fair chance of full realization, personal as well as collective, within the normal constraints beyond which tension and disorder increase.

There should be sufficient margin for the communities to express themselves in a variety of forms which is a characteristic of the human species, although their basic needs may call for a more uniform way of meeting them.

3. *The Global Negotiations*

The integrated approach has been conceived and tried during the negotiations between developed and developing countries which were initiated in the wake of the so-called energy crisis, one of the ostensible warnings of a more profound world-wide situation: in fact, a crisis of the whole system of international economic relations, not sparing any country or groups of countries but affecting all, depending on the defenses with which they are equipped.

At that time — propitious for reflexion and propensive to questioning — even more than the interdependence of the various issues, the interdependence of countries, rich and poor, was perceived as being at the very root of the challenge facing mankind. The countries of the Third World had — first as colonies, then as free countries — always been dependent on the industrialized countries, whose supplies of raw materials these assured by control at the source in developing countries through the payment of royalties and later taxes far below the value of the resources so yielded.

Now, with the principle of sovereignty over natural resources adopted by the United Nations, — a principle in which the developing countries have instilled growing vitality — the industrialized countries have come to realize how much they depend, in turn, on the developing countries. Oil that had been performing, through OPEC, as an indisputable pioneer, was recognized as a force one had to reckon with. Such recognition led to the already mentioned CIEC held in Paris. The Group of 77 — the developing countries — prevailed upon the industrialized countries not to isolate energy from other matters (raw materials, technology, trade, development and monetary and financial questions). Yet it did not live up to its expectations. The holding of oil prices practically to the levels of 1973-1974 resulting in a systematic loss of its purchasing power in the face of rampant inflation in the industrialized countries, took the rug from under the feet of developing countries, a situation that the great consumer countries expected to be able to prolong if not to perpetuate. The international community as a whole lost precious time in further wrangling about what to do. The political will of the industrialized countries to support a policy of change declined from a low level to a negative level and turned into stubborn resistance to the necessary structural reform. In the end, what was bound to happen with the oil price freeze, happened: the oil prices more than doubled in current terms in 1979. True, in real terms they did not significantly increase over and above the 1973-1974 level. Be that as it may, oil prices will and should continue to rise as this depleting resource becomes scarcer so as to reach gradually the price levels of alternate sources of energy and enabling these to replace oil without upsetting critically the price structure of energy. This will be the main guideline upon which to base the projection of price rises for the coming years. In recent times, it has been a guesswork.

It could become more realistic if the results of the forthcoming global negotiations between developed and developing countries were well balanced on the side of justice and based on a rational combination of factors in the various fields, namely raw-materials, trade, energy, development and monetary and financial questions. Energy prices, demand and supplies should become more predictable as should be other important matters. Yet, conservation will have to play a prominent and continuing role, mainly through a reduced demand on the part of industrialized countries.

More than what has been done will be necessary to assure that excess production of oil will gradually disappear and thereby the losses experienced by the oil producing countries through depreciation of assets in which often their surpluses are invested. In the meantime some form of value guarantee should be devised to meet the claims of these countries with respect to partly unlooked for surpluses, resulting from an excessive demand of a depleting asset.

On the other hand, the importing developing countries require assurances for their oil supplies which should be earmarked for essential, non-substitutable needs.

This situation is being attended to by OPEC, and other non OPEC countries like Mexico have already joined in this effort. In addition, particularly in the case of the poorer countries (big and small) the greater burden they have to bear, as a result of higher import prices, is being alleviated by concessional loans or grants given on a bilateral or multilateral basis by OPEC countries. In this respect, the role of the OPEC Fund for International Development is bound to expand further as it operates as a permanent agency and as its functions are extended to cover a greater range of activities. It should be borne in mind, that contrary to what has been argued by interested parties — governments and agencies — the financial burden on the oil importing developing countries is the result of the oil prices for about one quarter, and for about three quarters the result of price increases on the rest of their imports, largely from developed countries from which they thus import the inflation, as do the oil exporting countries (*).

The OPEC countries have since the Paris Conference signified their determination to help the oil importing developing countries explore and develop their indigenous sources of energy. This task calls for contri-

(*) According to calculations, based on IMF statistics, for 1979 and 1980 compared to 1978.

butions from the industrialized countries which have already announced their readiness to participate in an activity from which they will benefit as a result of an increasing availability of oil in relation to their requirements. What is clear is that the developing countries will be compelled to pursue their development on the basis of expensive energy, while the developed rich countries had their development subsidized by cheap energy imported in staggering amounts from developing countries. That is an added reason for the undesirability on the part of developing countries, including the oil exporting countries, to imitate the extravagant lifestyle prevailing in industrialized countries.

4. *Energy and Lifestyles*

To make it possible for a lifestyle to be adopted and pursued by the members of a society is the ultimate aim of economic and social policies. This includes the political framework within which private and social life takes place. Such course may be a matter of choice and conviction. It may be the result of an evolution brought about by a variety of factors favouring a given mode of life. There are variations to the resulting lifestyle of groups of people — depending on their means —, while the merchant class promotes unwittingly such lifestyle through stimulating consumption of their greatly varied production (articles or services), irrespective of the real need for it. In the capitalist system the state prides itself on not intervening — as a rule — except when the health and the morals of the people may be at stake. It is a matter of law and judgement as to when and how the state should come in. In state-socialism, the main promoter of the prevailing lifestyle and its evolution is the state itself. Nevertheless, the degree of state influence varies from case to case. In all cases, there is a demonstration effect within countries and from one country to another, to be reckoned with as an important factor in the imitation and thereby in the propagation of a lifestyle. Given the means, this is more likely to take place within a capitalist than within a state-socialist framework. Both systems claim to pursue maximum efficiency. Nevertheless, the capitalist system has a broad measure of built-in waste, while the state-socialist system has not been capable either of avoiding a considerable margin of inefficiency and waste which it ostensibly combats and condemns. This is particularly obvious and frustrating in respect of the military establishments, particularly arms production in the case of both systems, which is as onerous as it is dangerous. There is here a clear misallocation of resources that results in impoverishment when not in outright destruction. In this unproductive activity more oil is consumed than what the oil importing developing countries consume all together: over 10% of world oil production. Throughout the industrial and service sectors, the technology that prevails is energy-intensive and generally wasteful. Only since the last few years an effort is being made to raise the efficiency and increase the yield of the energy input. There is still a long way to go in the saving of oil and energy in general. This is particularly so in North America, United States and Canada, where the per capita consumption of oil is twice as much as in Western Europe where over-consumption is also notorious. In terms of quality of life the difference between the former and the latter is not one to two. In fact, in both, it is a matter more of quantity than of quality.

Energy consumption has up to a point a positive effect on lifestyles as it alleviates and speeds up tasks that would otherwise require a great deal of painstaking muscular human or animal strength. But it has been proven beyond question that excessive use of energy can become a nuisance and a danger for the individual and the community. The automotive explosion, namely the staggering rise in the use of private cars, provides us with the most eloquent example. The private car, which in the first phase of its development was held to be a symbol that enhanced freedom and pleasure, has in recent times been creating growing social troubles where cars have been accumulating at an intolerable rate. These stem from air and noise pollution presenting serious health hazards, and car accidents ranking high among causes of death and physical inabilities. The automotive explosion implies, in addition, a misallocation of financial resources in the expansion of road construction and maintenance to keep pace with increasing traffic, the fluidity of which is often impossible to assure below nerve-racking levels, along with excessive water consumption.

Caracas — the capital of my country, Venezuela — is a case in point, as it is estimated that in recent years about nineteen kilometers of cars have been added to the traffic every month. It is said that Caracas has become a gigantic garage. Such situation has made it necessary to enforce emergency regulations, like keeping off the streets each car one day a week. To compound the problem, prices of gasoline are still at very low levels and public transportation will continue to be ineffective at least until the subway now under construction is put into operation and other essential measures are taken.

Lifestyles under these conditions — which are not specific to Caracas — have deteriorated sensibly — in physical as well as in mental terms. Paradoxically, it has not slowed down the exodus towards the cities. These seem to attract more people the more congested they become. Gregarious instinct appears to provide men with almost limitless resilience to "support" inhuman conditions in the search of opportunities for improvement. Thus the increase in cars and in gas consumption runs side by side with the rise in marginal population to which poor, if any, municipal services are provided. There is no easy solution to these problems but somehow they will have to be faced with determination as they are fraught with disaster.

Oil, as a raw material, had also been considered as a source of rapid progress. Even at high and increasing prices it still should be. But greater discrimination will have to be applied to the choice of the items to be produced from among the myriads that the industriousness of the petrochemical engineers has offered; yet these, along with the managers concerned, have not shown the foresight than should have been present in such a new and revolutionary development. For example many non-biodegradable products have been allowed to cause staggering problems of disposal of residues or refuse. In a consumer society this problem assumes rapidly enormous, unmanageable dimensions. Public officials are now trying to cope with such problems. Again, lifestyles are being put in jeopardy in contradiction with the over-optimism of the pioneers. Still a good part of this fascinating industry will pass the test. Therefore, petroleum and natural gas should be reserved for the future, largely as a raw material during the final stage of the transition and beyond. It could well be energy devoted to its most noble uses and one which should be able to contribute substantially to the enhancement of the lifestyles of large and poor segments of the populations of the Third World. This process has already begun. It requires concomitant progress in other activities, most particularly in those resulting in increase of the purchasing power of the potential beneficiaries.

If their lifestyles do not improve markedly, the lifestyles of those above them are bound to be threatened. To begin with, the degradation of the environment, — air, land, rivers and oceans — by direct or indirect pollution coming largely from oil, coal, nuclear energy and their by-products, hampers the quality of life of all members of a society, rich and poor, that increasingly share tbe same conditions. Poverty itself has been recognized as one of the greatest pollutants and as pervasive as water, dirty or clean, though the latter is getting scarcer. Yet, by raising and rationalizing standards of living so as to narrow down their disparities, it is possible to have a reasonable climate for all to live together in a variety of ways of life, yet comparable in the essential features, with a greater sense of responsibility, both individual and collective in all vital matters such as population which, as other elements, interacts with all components of the economic and social body.

5. *Energy and Distributive Justice*

As energy with all its ramifications largely shapes and pervades the lifestyles of a population, it pre-determines also the availability of opportunities and leads to a distribution of resources in an unequal and inequitable manner.

Such outcome results from a given pattern of energy use, favouring the well-to-do segments of the population and leaving out of its reach a considerable part of it. Besides, in international terms, the rich countries tend to use, without due restraint — and therefore a great deal of waste — a disproportionate part of the energy available, the poor countries getting a relatively small part of it. It is also likely that when these would require a substantially increased amount of oil, this would not be any longer available.

Such situation can be explained by the overall dynamics of the prevailing economic system in market economy countries. These tend to concentrate in the managerial class and in its direct employees the energy-intensive productive machinery and the personal energy-intensive transport and electro-domestic tools. All this characterizes the market economy system under which most of the developed countries and the majority of developing countries live, although many of the latter practice a mixed economic system which offers advantages to them. Energy, especially oil, plays a decisive role in the great and growing disparities that still prevail in these countries which constitute most of the world.

The private car is the most active element in this dynamic ever changing picture. Its role varies from country to country and is less predominant in countries where state-socialism is practiced. During the beginning of the automobile age, the car was a sign of distinction and wealth over and above the average, like the horse or horse carriage in the olden times. With the tremendous development of the car industry in the United States, Western Europe and Japan, the private car has ceased to be, in a relatively short time, the exclusive possession of the upper class. Yet it became evident that such development increased the gap between these countries, — the affluent countries — and the developing countries. Within the latter the private car was still the privilege of the upper-class in the case of the majority of countries, and of the upper-class and the growing middle class in a significant number of them. In recent times the rampant inflation and the high price of motorgas have curtailed sensibly the ability of the middle class to own and use private cars. In fact, these vehicles of all forms, shapes and colors had already constituted to many of their owners an extravagant possession — sometimes a toy — and a habit beyond their means, causing them financial hardships (indebtedness, with debt service disproportionate to their incomes). It is always the poorer classes — as the poorer countries — on which falls the greatest burden of the adjustment processes that we are witnessing in a generally off-balanced economy, a source of uncertainty and malaise, within an economy in disarray.

Therefore, such situations of basic disequilibria to which conjunctural maladjustment are grafted in industrialized countries — should not be left to the so-called market forces to correct — which they would not in a positive sense — but should be oriented through deliberate and concerted measures towards an equitable solution that protects and improves the purchasing power endangered by the effects of low productivity, unemployment and inflation. This is the most forward looking way of stimulating demand and employment for the benefit of all, as is the protection and improvement of the purchasing power of the poor countries, and — within them — particularly of the non privileged segments of their populations.

In this manner, the gradual crunch that would ensue as a result of high-priced and scarcer motorfuel should be used to redistribute resources in favour of the less advantaged, as had been proposed in the United States and, thus, not let the dynamics and fluidity of the situation pass without pressing for a rectification of the misallocation of resources to the private car sector, and reducing the disparities of lifestyles due to the past accelerated development of that sector. It has become blatantly clear that the Third World countries could never "enjoy" lifestyles as wasteful as those of the industrialized countries which are already realizing that they themselves could not sustain such consumer society for long and that less wasteful and simpler lifestyles could be more congenial to the human dimension and to the promotion of genuine human values.

In these circumstances, it would appear wise not to overstress the need for rapid replacement of oil by other forms of energy to ensure the continued increase of supply. This ought to be made predictable and steady but not necessarily ensured on a high growth rate basis. Too much energy availability would again stimulate waste as it would lead to misallocation of resources in favour of the better off. Costs and prices should normally act as a brake to a possible rekindling of past and pernicious tendencies. But one has to be on the alert. Disparities in life-styles and subsequent tensions would again be aggravated. It would constitute a further setback for distributive justice with unpredictable consequences, not discarding the worst.

Indeed, the ratio of the unit of production to the unit of energy input should be increased if we want to improve the chances of attaining an effective distributive justice. In any case, an increasing proportion of the total energy used will have to be renewable — and non-polluting. In order to improve the yield of the energy input it is urgent to bring on steam production technologies less energy-intensive than the current ones. These new technologies will help, in the case of developed countries, to achieve a more rational and less wasteful energy consumption pattern and, for developing countries, they would in addition enhance the creation of many personalizing jobs through the use of appropriate more labour-intensive technologies. In the first case it would call for a considerable effort of reconversion involving an equally considerable allocation of funds, to be so carefully planned as not to subtract resources directed to the meeting of Official Development Assistance targets, which remain unattained for over a decade by most developed countries.

On the other hand, energy should be used on a more decentralized basis to counteract the phenomenon of excessive urban concentration, one of the greatest problems of this consumer society and where the phenomenon of entropy is the most felt. The new forms of energy, like solar energy, and the already well known hydraulic and hydroelectric energy appear to be particularly well suited for this decentralization, notwithstanding the well recognized fact of the existence of privileged sites.

Decentralization would be an important factor in enhancing the quality of life through the better use of clean energy wherever it can be produced economically and in harmony with the physical and social environment, thus avoiding already intolerable waste and human hardship.

A more rational use of energy will have to be supplemented by the development of adequate production structures, mainly through smaller production units, and by a more systematic energy and material waste reduction, particularly through recycling of used material, disincentive of production of disposable goods and stimulation of maintenance — declining in developed countries and deficient in developing countries — and repair of goods to prolong their lifespan. These services could be best rendered by individual craftsmen or small entreprises, which are by nature a considerable source of employment and of training and retraining of labour. Small and medium-size enterprises are also important instruments of production on the human scale, more satisfying than the huge ones and more likely to induce individual partners to engage in creative work. These enterprises are the necessary building blocks of small communities in townships or in neighbourhoods of cities as their area of coverage is by definition restricted. All this means savings of energy and, in any case, a better use of it.

This approach fits in with the fundamental concepts of a more rational and equitable international division of labour and, within countries, a better use of national spaces and a more balanced regional development (*aménagement du territoire*).

The only course of action to prevent the emerging gloomy situation from becoming an irreversible reality is for all countries to concert resolute efforts to bring about without further delay the new international economic order required to make our common objective the pursuit of real happiness for all. A world order that gives rise to and stimulates genuine human values of solidarity — namely sharing with others —, spiritual and ethical yearnings; in sum, justice, love and peace. An environment propensive to the full development of fundamental human rights and freedoms.

The transition towards a new international economic order will certainly be long — it may last many decades, perhaps a whole century — and, at times, difficult and strenuous but rewarding from the moment one feels fully involved in its realization: it would point to a common goal worth struggling for.

* * *

As is by now clear to many people, energy, together with other key elements with which it is closely interrelated, will determine in their interplay, which cannot be left to hazard, the future that can be so shaped by the concerted efforts of all as to be worthy of human dignity everywhere. Very soon we will know whether energy will become a curse or will be a real blessing.

PROSPECTS AND GENERAL DISCUSSION

Chaired by Professor A. BLANC-LAPIERRE

STABILITY CONSIDERATIONS ON WORLD ENERGY MODELING

WOLFGANG SASSIN

Symptoms of basic change

Sam Schurr's article on energy, which appeared in Scientific American 17 years ago, was summarized by the statement:

Modern man has made himself largely by burning fuel. The supply of fuel appears to be almost inexhaustible, and a high level of fuel consumption is not a prerequisite of development but a result of it.

This historic truth lost its programmatic component already 10 years later, when in 1973 OPEC confronted the world with the finiteness of its oil resources. Neither the industrialized countries nor the developing countries have since recovered from this shock. The world is still puzzled by what we have learned to circumscribe as the energy problem.

At that time, the developed countries of the post-World War II era flourished on the basis of a technical infrastructure that had been extended continuously since the first industrial revolution. This infrastructure generally depends on the production of mechanical power. At the present time, it is being extended further by addition of still another layer made up of automated information handling devices.

In order to illustrate both the ties connecting the developed countries with the civilizations from which they have emerged and the differences separating them, one is tempted to rephrase the above quotation as follows:

Modern man has substituted technical slaves for human labor and animal power. Their food is energy. In order to increase the number of technical slaves per master, modern man adds computing machines as supervisors.

Of course, there are many other facets of the existence of modern man. Moreover, the evolution of his principles of civilization still seems to be in an active phase. Yet, in a most dramatic way, energy is emerging to play a main part in the future of this planet.

In order to grasp energy's role one may want to go back to the times of James Watt. Already then great efforts were made to effectively introduce energy into the developing infrastructure. Figure 1 illustrates that energy conservation has, from the very beginning, been an integral part of the strategy of development. The various groups of technological processes exhibit a steady line of improvement in performance. Success of the engineering principle "to do more with less" permitted a rapid increase in the number of technical devices. From this development grew the specific energy consumption of the present-day industrialized world. The growth has been extraordinarily fast, leading to a highly heterogeneous distribution of the world's national energy consumption levels.

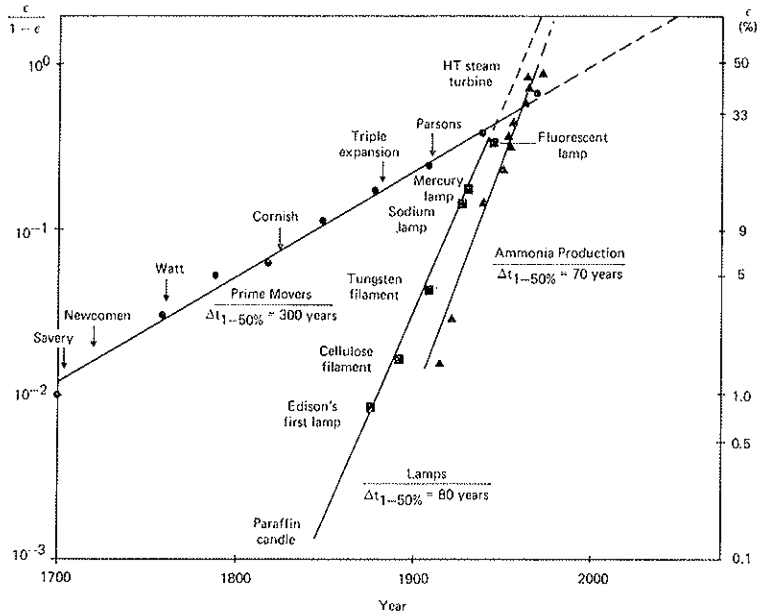

FIG. 1. Historical trends in energy efficiencies of some families of technical processes. ∈, the "second law efficiency" is defined as the ratio of thermodynamic free energy between output and input to a conversion process. ∈ is plotted in a logistic plot which represents S-shaped logistic functions in the form of straight lines. *Source*: C. Marchetti (1979).

Figure 2 shows that the annual energy consumption of 29% of the world's population until 1975 was higher than the world average of 2 kWyr/yr. Most of the third world countries group in the interval of 0.2-1.0 kW per capita. This is a factor of 50-10 below the consumption level of the average U.S. citizen using 11 kW to operate his home, means of transportation and commercial and industrial outfit. The countries of Western and Eastern Europe come in at about 5 kW per capita. There is a close and well established relationship between commercial energy input to national economies and their economic output, measured in monetary units, e.g., dollars. Given this relationship, Figure 2 may be understood to represent, in the format of a proxi-variable, the distribution of modern economic activities on world scale ([1]).

A spread of the civilization systems so far established in the relatively fewer developed countries to the developing regions will no doubt increase the hunger for energy. Its seeds are being exported together with the cultural concepts that led to the dominating position of the industrialized nations in the first place.

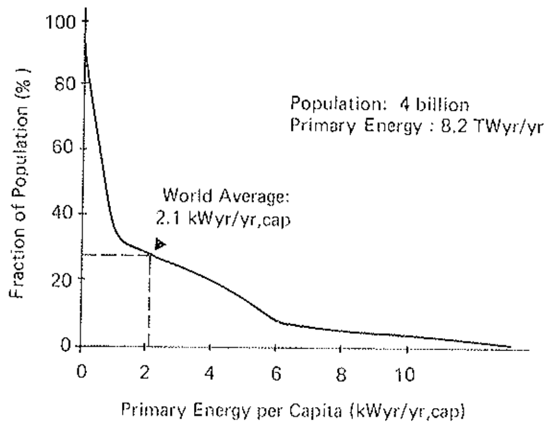

FIG. 2. Distribution of consumption levels of commercial forms of primary energy in the world in 1975. The consumption level is measured in kW per capita. The combustion of 1 ton of hard coal per person in one year corresponds to an average power dissipation of 1 kW. *Source*: J.-P. Charpentier (1976).

([1]) As an aside: The actual living conditions at the lower end of the scale are not monitored appropriately by commercial energy consumption nor are they properly reflected by monetary income. At the level of survival, other non-commercial yardsticks apply.

By way of the quantifications behind Figure 1, one cannot fully appreciate the achievements in technological performance of productive capital stock, as technical slaves are generally called by economists. Normally one adds the theoretical heating values of the various forms of energy entering an economy, comparing input and designed output. However, alternative primary energy forms differ widely in practical use. Some can be easily transported, stored and converted, others cannot. Such shortcomings entail significant losse, since part of the original energy content must be reinvested to step up the quality of the final energy form. Success of the energy industries is ultimately due to their ability to produce final energy forms attractive in terms of cost and, normally, also in terms of primary energy losses, both of which are lower than those arising in a system of distributed technical devices. Living up to that challenge the energy industries have, over the long run, tapped even more versatile forms of primary energy requiring increasingly less upgrading. Thus the industrialized world has passed through a logical sequence from wood through coal to oil and natural gas. This powerful trend towards a greater overall efficiency is exemplified by the relative shares of major primary energy forms in the global balance (Figure 3). Switching from abundant coal resources to oil and gas has led to gains

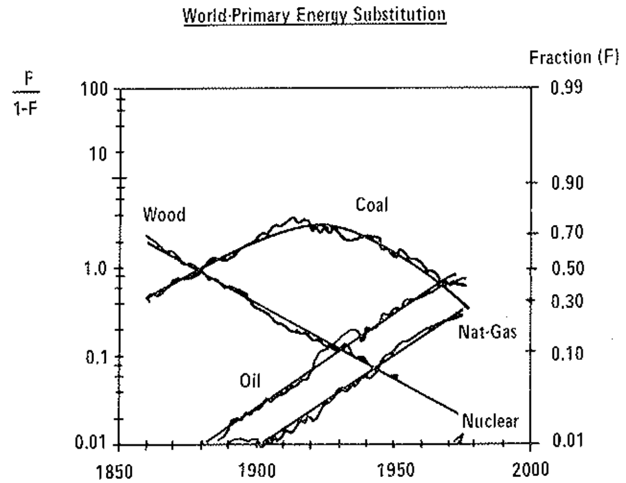

FIG. 3. Historical contribution of various energy sources to the global energy balance. *Source*: C. Marchetti (1979 a).

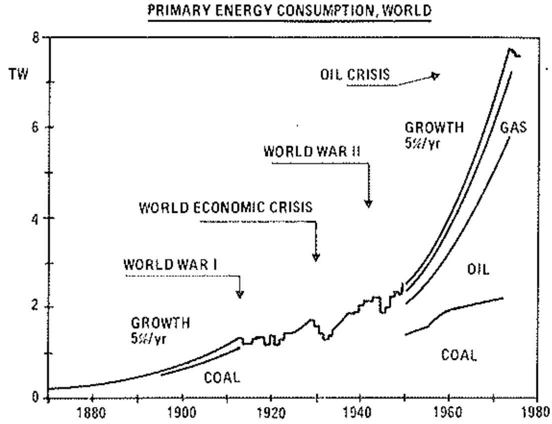

FIG. 4. Evolution of total commercial global energy consumption 1 TW = 10^{12} W. 1 TW is equivalent to the consumption of 14 million barrels of oil equivalent per day. *Source*: R. Hildebrandt *et al.* (1977).

in excess of the costs involved in setting up continental gas and worldwide oil transportation systems.

The spread of industrialization within and outside the developed world, enhanced by the breakup of agricultural societies during World War II, has led to an explosion of the global energy demand. This impressive growth, illustrated by Figure 4, has basically been sustained by crude oil.

In the early seventies, the world became aware that its further development — if it were to follow the established routes of success — would crucially depend on a few basic resources. Crude oil was in the focus, which had after all become the main material link between industrialized and developing nations. This valuable resource was advancing to become a *national wealth*.

Summing up the retrospective part of this survey, one might come to interpret the 73/74 oil crisis as an expression of deep concern, realizing that continuation of the world's development would involve fundamental obstacles that are greater than was anticipated more than a decade ago. Take, for example, the strong environmental movement that emerged in the early 1970s, and the faltering hopes to quickly bring nuclear energy on stream as a main source of energy.

Since then the world has had to live with an energy problem — the symptom of a deeper-seated development problem — which has aggravated despite all the efforts to resolve it. In order to understand it better, it is useful also to survey potential future developments in a somewhat quantitative fashion. For only then can one hope to put the present difficulties around energy into perspective.

Prospects for a long-term global energy balance

The Energy Systems Program of the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, has over the past six years carried out an investigation of the potential evolution of the global energy system. These studies focused on the medium- and long-term aspects of energy and its interaction with other systems: economy, environment, land use or settlement patterns, water and materials flows, etc. The foremost task was to critically analyze the possibilities of extending the future supply of energy to provide more oil, more of the other classical energy forms, and new ones. Any such exercise would be empty, however, without a critical evaluation of the future energy demand, the force driving any extension of supply.

Not in spite but because of the ongoing political difficulties around energy, IIASA's approach started with the presumption of a cooperating world, free of major wars or social disruptions. This was a prerequisite for the operational assumption of free access both to the world's energy resources and to effective energy production and conversion as well as to energy efficient consumer technologies. This will not necessarily be the path of evolution. Quantifications on such a basis, however, offer a kind of neutral or objective yardstick: they clarify which minimum techno-economic efforts are required to balance energy demand and supply.

The potential future development was analyzed in scenario format. Scenarios are not mere extrapolations of past trends. They contain an element of judgment, insofar as inconsistencies arising from conflicting trends have to be resolved. Carefully elaborated scenarios can be seen as ways of describing potential futures. They are not predictions. Instead they confront and combine aspirations and anticipated possibilities. The graphs and data presented henceforth refer to a picture of the energy future that emerges from the IIASA scenarios (2).

(2) The final report of the IIASA Energy Systems Program covers a 50 year time horizon. This report "Energy in a Finite World, A Global Energy Systems Analysis",

The transition from a stable world population level of about 1 billion, sustained by subsistence agriculture, towards a level of eventually 10 billion people or more is well underway (Figure 5). By a conservative projection, the world's population is to double from 4 to 8 billion within the next 50 years. Whereas *energy demand* in the post-World War II era mainly resulted from industrial development in the Northern countries, which were nearly stabilized in terms of population, future energy demand will be driven by the demographic explosion of the South. In view of the large differences between countries in their levels of economic development (as was implied by Figure 2), in population dynamics, and in their wealth of energy resources, a rather detailed consideration is indicated. IIASA has come to distinguish between seven comprehensive world regions, given in Figure 6. A complex set of computer models was used to project the economic and technical development in each region. It was found rather soon that extrapolation of past relative achievements, observed during 1950-1975 would lead to an ever greater discrepancy in the balance of global energy demand and supply. Considerable reduction in expected economic growth in all world regions and a parallel

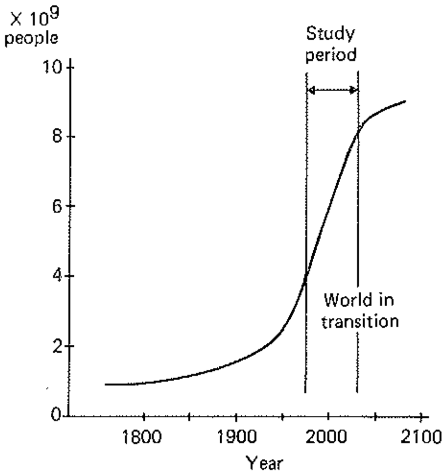

FIG. 5. Historical and projected evolution of world population. *Source*: N. Keyfitz (1979).

Ballinger Publishing Company, Cambridge, Massachusetts, January 1981, elaborates in great detail on demand and supply patterns, as well as on constraints influencing their mutual balance.

TABLE 1 — *Economic projections influenced by the energy problem: the IIASA High and Low scenarios.*

Region	*GDP per Capita (dollars)* 1975	*Projected Average Growth Rate of per Capita GDP (%/yr)* *High Scenario* 1975-2000	2000-2030	*Low Scenario* 1975-2000	2000-2030
I (NA)	7.046	2.9	1.8	1.7	0.7
II (SU/EE)	2,562	3.6	3.2	3.1	1.9
III (WE/JANZ)	4,259	3.0	1.8	1.7	0.9
IV (LA)	1,066	3.0	2.4	1.6	1.9
V (Af/SEA)	239	2.8	2.4	1.7	1.4
VI (ME/NAf)	1,429	3.8	2.8	2.4	1.2
VII (C/CPA)	352	2.8	2.4	1.6	1.4

increase in estimated energy supply — in terms of both disposable reserves and production capacities — were necessary to ensure this calculatory balance. In view of the vagaries of such a "solution" of the future energy problem, two scenarios were developed. Table 1 gives the projected rates of economic growth for these two scenarios, called High and Low, which are disaggregated for each of the seven world regions of Figure 6.

At least the Low scenario implies a break in past economic trends, leading to dramatically low economic growth rates. Though generally larger in the developing regions than in the developed world, they would not suffice for an adequate basic infrastructure to be built up in the developing countries in the decades to come. Over and above modest economic projections, both scenarios presume the realization of optimistically high conservation potentials. They combine structural trends towards larger shares of the services sector in gross national products, improvements in technical energy efficiencies in all economic sector and early saturation effects in energy-intensive services, such as transportation. Figure 7 summarizes the results of rather detailed projections of lifestyles and technological parameters.

It displays the specific demand for final energy, required to produce a given unit of economic output, in relation to the level of economic activity achieved. "Decoupling" energy and economic growth clearly have

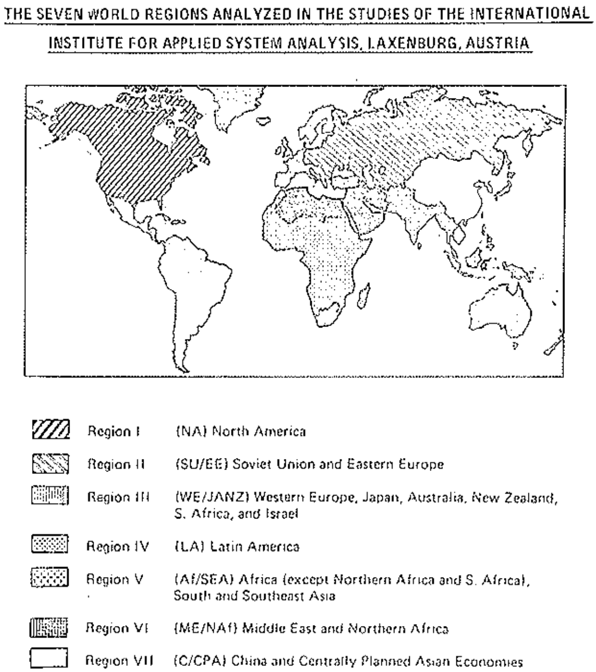

FIG. 6. The seven world regions analyzed in the studies of IIASA.

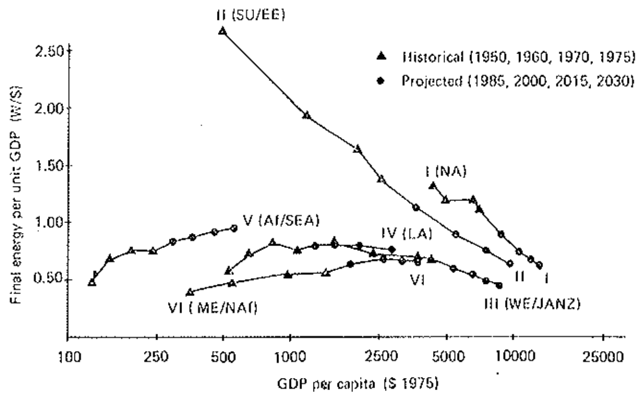

FIG. 7. Macroeconomic energy efficiency as a function of economic activity level. Roman figures denote the regions identified in Figure 6. Projections refer to the IIASA Low demand scenario.

different meaning in advanced economies and in subsistence economies. In the light of early industrialization so far experienced by the developing countries, it seems that, in the decades ahead, it will be more difficult for the less developed countries (LDCs) to limit their growth of energy intensiveness than for the developed countries (DCs) to reduce it.

Complementary to reducing energy demand figures in the IIASA scenarios was the effect to increase estimates of potential future *energy supply.*

The escalating price of crude oil — the form of primary energy now at the top of the world scale — brings in energy resources that previously, in the long period of falling energy prices and prior to their adjustment in the 1970s, were not yet considered economical. Table 2 gives potentially available recoverahle resources of coal, oil, natural gas, as well as uranium, according to increasing production costs. These figures are by far larger than the present identified economic reserves. The confortable figures in Table 2 quantify still reasonable hopes: i.e., with the help of exploration and production technologies, existing or to be developed, the world could roughly triple its present reserves within

TABLE 2 — *Summary of estimated ultimately recoverable resources according to production cost categories.*

Resource	*Coal* (TWyr)	*Oil* (TWyr)		*Natural Gas* (TWyr)		*Uranium* (10^3 t U)
Cost Categories 1975 US $	$/ton <50	$/boe <20	20-25	$/boe <20	20-25	$/kg U <130
Developed Regions (I, II and III)	1234	151	215	215	74	10,440 [a]
Developing Regions (IV, V, VI and VII)	346	313	158 [b]	193	56	12,760 [a]
World	1580	464	373	408	130	23,200

[a] Only partial entries for Regions II and III.

[b] No entries for Region VI in this category.

Compiled by M. Grenon, IIASA, on the basis of the following sources: Ashley *et al.* (1976); Eckstein (1978); Grenon (1977); Grossling (1976); Institute of Geological Sciences (1978); Lambertini (1976); Meyer (1977); Oil and Gas Journal (1978); O'Shaughnessy (1976); Penner and Icerman (1975); Perrine (1978); Uhl (1977).

the coming 50 years. Fossil fuels in Table 2 amount to an energy equivalent of 3000 TWyr within production cost ranges at or even below present market prices. Divided by a global energy demand of about 30 TWyr/yr, assumed 50 years hence, this translates into an exhaustion time of roughly one century. It is vital that such optimistic resource or reserve figures be interpreted within the correct framework, however.

First, the economic evaluation of resources — measured, for example, by the price-cost relation — in an evolutionary process leading to ever cheaper energy supplies does not apply during the uphill fight in costs ahead of us. Second, 3000 TWyr of oil, gas, and coal in Table 2 are *qualitatively* different from what can be associated with these types of energy at the present time. The rise in production cost categories hides important changes which will further limit the usefulness of such energy resources. Tar sands and oil shales are accessible only by mining and retorting and no longer by drilling. Downstream transportation and conversion of a "barrel" produced in this way are less effective and more expensive than for a barrel of Saudi Arabian light marker crude. Environmental limitations pile up if resources are to be mined and retorted not in desert regions but close to major consuming areas insisting on strict environmental protection.

Consequently, tapping a major fraction of the resources given in Table 2 implies a difficult transition, not only from cheap towards expensive resources, but also from relatively clean and easy-to-handle fossil resources to dirty energy forms still to be upgraded. Such a transition requires further adjustments also outside the narrowly defined energy sector of an economy, and takes time.

What was said above for fossil resources applies even more so to fission and fusion nuclear breeders and to solar energy. Their "resources" are unlimited, and therefore do not influence achievable levels of deployment. These "unlimited" energy sources can be conceived to substitute capital for the finite natural resources that are being depleted. Hence, the rate at which an economy can afford to step up its fixed energy capital stock will determine the "price" of these quasi-permanent energy sources and, consequently, their potential for evolution. An adequate theoretical determination of this "price" is missing. It would have to weigh the capital investments to be diverted from increasing general productivity versus the benefits for national economies to add another, quasi-permanent power increment. There is a striking similarity between the ambiguities in determining a "fair" price of scarce fossil resources and in determining the "price" of permanent endowments, such as in the form of nuclear breeders and solar power plants.

In the absence of long-term price estimates, a *balance between supply and demand* must rely on cost considerations and constraints. In the IIASA analysis, such constraints were made up by a specific spectrum of final energy requirements that is to be met by the energy supply sector; other examples are maximum buildup rates of new energy technologies, or limitations introduced by the exhaustion of certain resource categories.

Within such constraints primary energy scenarios were identified that correspond to the High and Low economic growth scenarios of Table 1. Figure 8 gives the relative shares of primary energy sources for the High scenario as a function of time. It aggregates separate calculations for each of the seven world regions of Figure 6. Although the scenario patterns of primary energy deployment appeared to be somewhat modified at the regional level for the Low economic growth case, the world aggregate supply structure came out to be practically the same as in the case of the High scenario in Figure 8.

In the figure, natural gas maintains its share of approximately 20%, but oil gradually falls back from 40% in 1980 to 20% in 2030. In order to make up for this decline and meet the demand for liquid secondary energy forms, an increasing amount of coal has to be converted to syn-

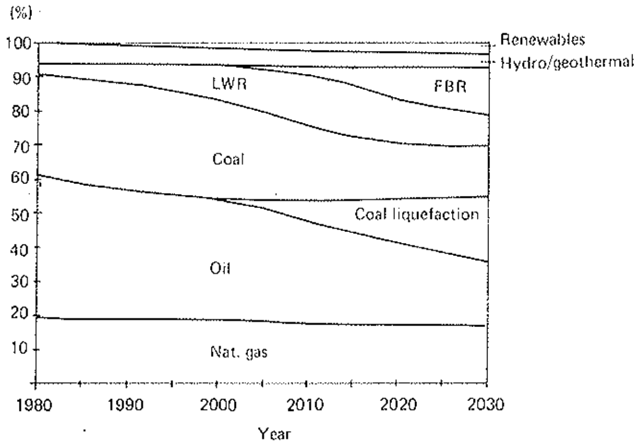

FIG. 8. Shares of primary energy sources in the global energy balance, IIASA High Supply scenario.

fuels. Substitution for this coal is partly achieved by the penetration of nuclear energy in electricity production. Because of the limited natural uranium resources, breeder reactors assume an ever increasing role from the year 2000 onward. Renewable energy sources, hydropower, and geothermal energy add up to a rather constant share of slightly less than 10% of the total demand — which implies a substantial increase in absolute production levels. From the base year 1975 to 2030, the total primary energy consumption rises from 8.2 TWyr/yr to 36 TWyr/yr for the High scenario and 22 TWyr/yr for the Low scenario.

One can assess the size of the energy operations postulated as achievable in the two supply scenarios by comparing present and future rates of deployment of the various primary energy sources. This is done in Table 3: in the High case, the oil output would have to nearly double until 2030, and coal production rates would have to increase enormously, i.e., by a factor of 5. Such challenges facing the energy supply industries also appear formidable in the Low case.

This tension in the two IIASA scenarios between frightening supply figures and modest economic development prospects is typical of the long-term global energy problem. To put the present trends and future challenges in the energy market in perspective, we have to recall at this point the principles underlying technoeconomic solutions to the long-

TABLE 3 — *Primary energy deployment levels in the two IIASA supply scenarios.*

Primary Source	1975	*High Scenario* 2000	*High Scenario* 2030	*Low Scenario* 2000	*Low Scenario* 2030
Oil	3.62	5.89	6.83	4.75	5.02
Gas	1.51	3.11	5.97	2.53	3.47
Coal	2.25	4.95	11.90	3.93	6.45
Nuclear 1	0.12	1.70	3.21	1.27	1.89
Nuclear 2	0	0.04	4.88	0.02	3.28
Hydro	0.50	0.83	1.46	0.83	1.46
Solar	0	0.10	0.49	0.09	0.30
Other	0.21	0.22	0.81	0.17	0.52
TOTAL	8.21	16.84	35.55	13.59	22.39

term global energy supply problem — which is what the IIASA scenarios represent. These principles are:

— Energy resources to be consumed within each region are made available at production cost levels. With the exception of oil, this is also true for exports to other regions.

— Oil production in Region VI (Middle East and North African oil exporting countries) has a ceiling of 33 million barrels a day.

Region II (the Soviet Union plus Eastern Europe) and Region VII (centrally-planned Asia) do not participate in interregional oil trade.

— Each of the seven world regions builds up a cost-optimal energy supply system to meet regional demands for final energy.

— Each region assumes for itself the burden of switching to a more expensive energy infrastructure.

Together with other methodological provisions, these principles would basically ensure a rational solution to the energy problem as seen in the global perspective. The cheapest resources would be used up gradually, and no region would be forced into exceptional energy cost ranges long before the others would have to follow. Other than in the case of the oil trade originating in Region VI, such a world would abstain from using energy as a leverage of redistribution of general economic productivity.

Medium-term stability

Both the Low and High scenarios presented above are conceived of as possible long-term evolutions. As such they imply a great number of determined actions and technical as well as institutional achievements to be performed in the course of the next 50 years. Some of the achievements that appear crucial for lending stability to these global evolutions are addressed below.

A highly difficult problem within the general energy problem is the adequate supply of liquid fuels in the short to medium term. Figure 9 contains the normative production achievements in liquid fuels that are necessary to balance the High scenario. Regions II and VII, i.e., the centrally-planned economies, are not included. In the logic of the scenarios, they are not driven into the tightening international oil trade, since they have enough indigenous oil resources of their own.

According to Figure 9, the world excluding centrally-planned economies will continue to depend on oil exports from Region VI (Middle East/North Africa). Outside this region new reserves will have to come on stream quickly, that is, reserves from indicated and presently unknown fields, partly in deep offshore and polar areas. The high shares they could contribute already by 1990 point to the enormous effort that would have to go into exploration and development. It is questionable if such a pace will actually be adopted; it seems all the more vital to prepare in time for the large-scale production of unconventional oil around 1990 and thereafter. Substantial shortfalls in conventional and unconventional oil production below the volumes in Figure 9 would press in coal liquefaction on a globally significant scale already before the year 2000. Except for a potential delay of 10 years in synthetic liquid fuels production from coal, the Low scenario leads to an oil dilemma that is nearly identical with that of the High scenario in Figure 9.

The short- and medium-term liquid fuels problem is a tremendous challenge to technology, but there is yet another, even more dramatic consequence. It relates to the quick shift in the energy trade relations among and between developed and developing regions. In Figure 10, energy exports of Regions VI and IV are broken down into fractions flowing into either Region I, Region III, or Region V. These exports are essentially conventional oil from present oil exporting countries, with

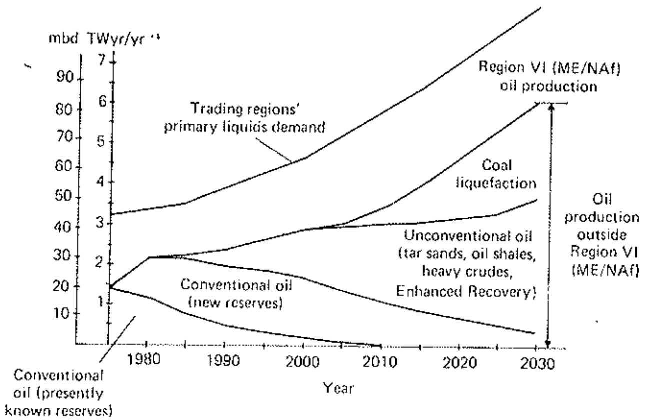

FIG. 9. Liquid fuel supply in the world excluding centrally planned economies. The calculations refer to the IIASA High demand scenario and imply an oil production ceiling of the Middle East/North African countries of 33 million barrels of oil per day.

the share of heavy crudes from Latin America increasing after 2000. This marked shift in relative oil dependence applies to all the possible global developments bracketed by the High and Low scenarios.

The year 2000 appears to be a turning point at least in two respects: first, the developing regions will separate into oil exporters and major oil importers; second, the buying competition between North America and Western Europe plus Japan will turn into a competition for oil between countries in Southeast Asia and Africa. Should Region I not be able to reduce its oil imports similarly, as is indicated in Figure 10, the competition for oil between industrialized and developing countries beyond the year 2000 would aggravate. In any case, a conceptual problem remains: which institutional arrangements could and should control the two likely transitions in trade relations between major world regions around the year 2000?

The full thrust of these questions of energy-related medium-term stability will be felt in Region III (Western Europe and Japan). Figure 11 specifies other necessary energy imports of this region resulting from the High and Low scenarios. In the High scenario, the dependence on oil

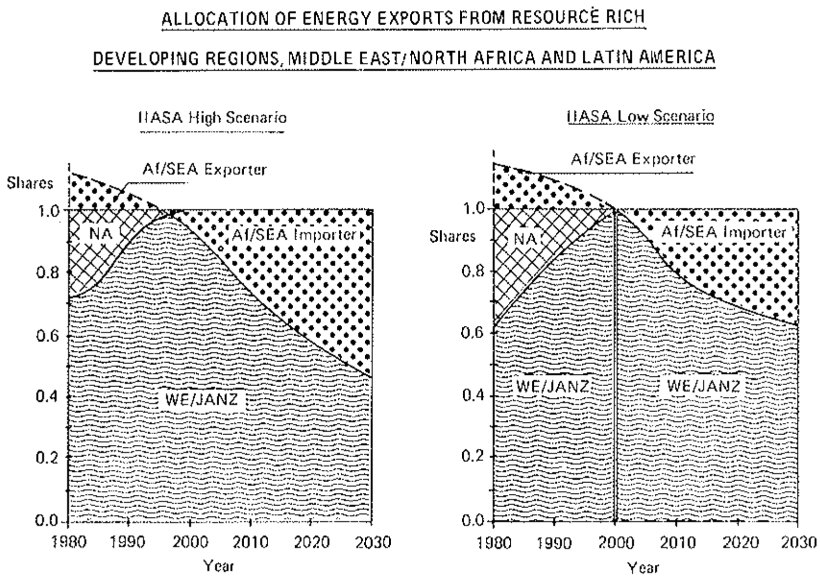

FIG. 10. Allocation of energy exports from resource rich developing regions, Middle East/ North Africa and Latin America.

of Region III can be reduced by ever increasing imports of coal (or coal products) and natural gas. The Low scenario avoids such additional gas and coal imports, but pushes Region III into an extended competition for oil at a time when it counts most: beyond 2000, highly expensive oil will have to be shared with the poor developing regions.

Constraining side effects of an extended fossil future

Both the High and the Low supply scenarios involve compromises between lesser evils. In fact, some consequences outside the balancing procedure could not even be identified clearly enough and others might have been simply underestimated. Such "side effects" might, over time, evolve into active constraints, however.

The early need to switch to large-scale substitutes for conventional oil immediately raises some crucial environmental questions. Figure 9 suggests that it will be necessary to exploit already deep offshore oil, but mainly heavy crudes, tar sands, and oil shales, in very large amounts around the year 2000. Apart from the oil located deep offshore and in polar areas, the "mineable" hydrocarbons are located in a few big basins. Already by 2000, they would have to play a role analogous to that of the giant oil fields in the Middle East. An annual production of nearly 1 TWyr/yr out of the "mineable" hydrocarbon group is envisaged for the High scenario, in about 20 years' time, most of which would have to

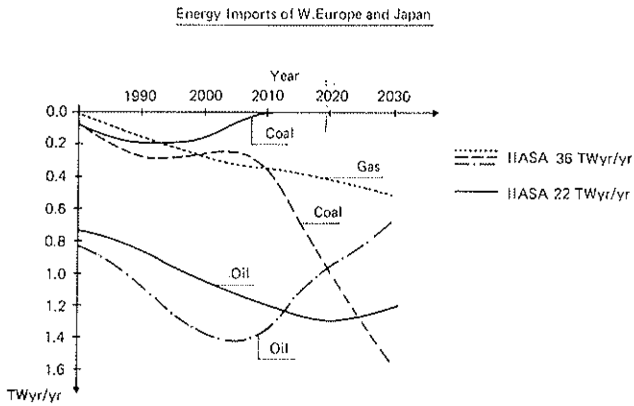

FIG. 11. Energy imports of Western Europe and Japan in the two IIASA scenarios.

come from three places: Venezuela, Colorado, USA, and the North West Territories, Canada. The regional environmental consequences of such large operations can in no way be assessed on the basis of present experience with local power plant considerations.

Table 4 compares energy ratios R — defined as the net useful production over the energy invested in this production — for alternative schemes of unconventional liquid fuel production. An output of oil from tar sands and oil shales on the order of 300-400 GWyr/yr would mean combustion of some 100-120 GWyr/yr of low grade fossil energy per basin. Over and above the huge emissions of waste heat and chemical pollutants, the water supply problems that would result appear quite tough. Depending on the process, synthetic liquid fuel production on the order of several hundred gigawatts would consume several 10 m^3 of water per second. But significant problems are encountered already now with much lower requirements of wet cooling towers in river systems, such as the Rhine and its tributaries. Tremendous land requirements, soil erosion, and water pollution add up to a picture that is not at all clear as to the constraints that are likely to put an ultimate limit on the access to these non-conventional oil resources.

The situation is quite similar for the production of synthetic liquid fuels from cheap open-pit mined coal. Prominent candidates are the coal basins in the North Western Rocky Mountains and in the Kansk Achinsk area in Siberia.

Aside from the regional problems involved in developing residual fossil resources, both the High and the Low scenarios imply a risk that cannot be quantified at the present time. This relates to the CO_2 question,

TABLE 4 — *Ratio of net useful output to energy invested for production of liquid fuels.*

Tar Sand GCOS 45,000 *bbl/d* [a]	*Tar Sand Imperial* 141,000 *bbl/d* [b]	*Oil Shale Projects* [c]	*Coal liquefaction Actual* [d]	*Coal liquefaction Advanced* [e]	*Enhanced In-situ Combustion* [f]	*Oil North Sea* [g]
3.5 - 4	1.9 - 2.2	2.2 - 10	0.8 - 1.6	2.2 - 3	2 - 8	> 100

Compiled by M. Grenon, IIASA, on the basis of the following. *Sources:* [a] Heming (1976); [b] Resources Management Consultans Ltd. (1978); [c] Marland (1977); [d] Muir (1977); [e] Bechtel Corporation (1976), Oil and Gas Journal (1974); [f] Burger (1979); and [g] Klitz (1979).

i.e., the release, due to combustion, of the carbon contained in all fossil fuels, in the form of carbon dioxide. The increases in atmospheric CO_2 concentrations that have been monitored for the past 20 years are significant. Possible consequences of the two IIASA supply scenarios were calculated on the basis of models that describe the carbon cycle in the environment as well as the radiation exchange between the earth's surface and space, which is modified by CO_2. The reliability and applicability of these models is not yet known well enough, but more research and monitoring programs are underway to improve the scientific basis for judging the CO_2 issue. Figure 12, showing the calculated CO_2 increases in the world's atmosphere and the related temperature changes, should be seen against this background, i.e., as qualifying a possible level of risk rather than as being a likely outcome of an increased fossil energy consumption.

Finally, mention must be made of a potential economic constraint resulting from the rather heterogeneous geographical distribution of all fossil resources. Figure 13 specifies the fraction of GNP to be invested in order to build up the energy infrastructure for the two scenarios. It is conceivable that such investment rates can be accommodated, but there is some doubt whether the developing countries will be able to avoid the negative impact of costly energy supplies on their overall economic performance. Figure 13, averaging energy investments over regions, hides

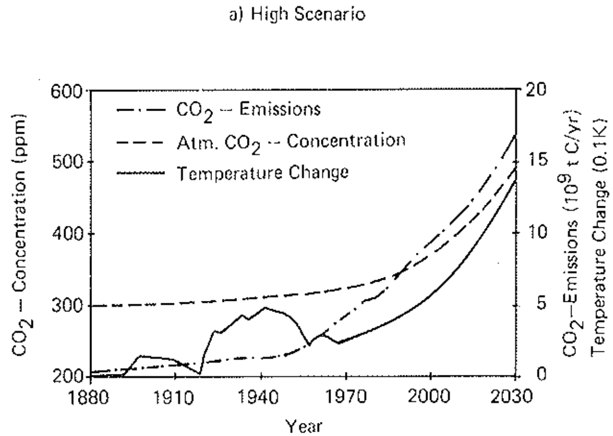

FIG. 12. Calculated CO_2 emissions, atmospheric CO_2 concentrations and temperature changes for the IIASA High supply scenario. *Source*: F. Niehaus (1979).

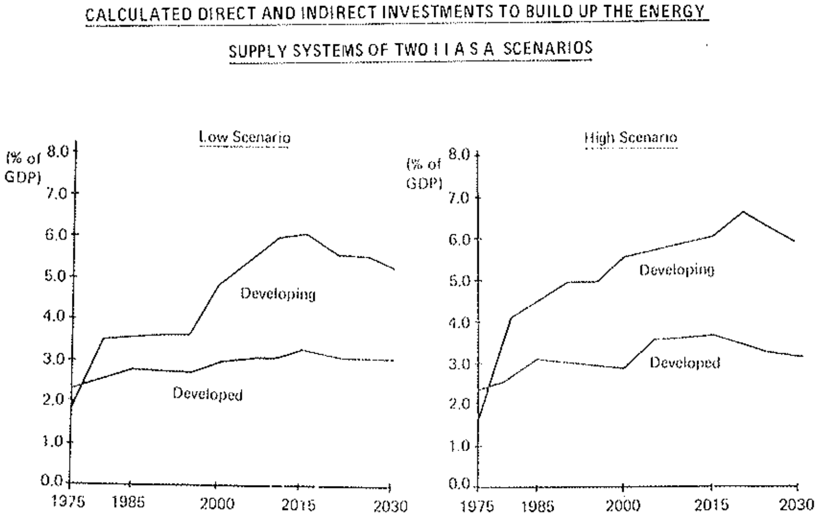

FIG. 13. Calculated direct and indirect investments to build up the energy supply systems of the two IIASA scenarios.

the increasing, overwhelming amounts of capital that have to be transferred across national borders to the resource basins for purposes of fossil power production. Development within the next 20 years of any one of the major resource basins mentioned above requires hundreds of billions of U.S. dollars. The related problems of accumulation and control of fixed capital lead into monetary dimensions that are largely unknown to even the biggest of the world's economies.

POSSIBLE RESTRICTIONS ON A RESOURCE TO RENEWABLE ENERGY SOURCES

Developing countries, in view of their tough situation, are likely to extend the use of local renewable energy sources as far as is practical. Table 5 differentiates the world's technical and realizable potentials in terms of renewables, excluding large-scale direct use of sunlight, e.g., in the deserts. The technical potential of large-scale solar to produce electricity or hydrogen for all of man's needs is infinitely large, but such systems are very costly, and, both technically and economically, still out of reach for the decades to come.

The largest practical renewable source is wood and other solid bio-

TABLE 5 — *Estimates of technical and realizable potential of renewable energy supply.*

Source	*Technical Potential TWyr/yr*	*Realizable Potential TWyr/yr*	*Constraint*
Forest and fuel farms . . .	7.5	2.5	Ecological, climatological
Organic wastes	0.4	0.1	Need for fertilizers
Hydropower	2.9	1.5	Ecological, social
Wind	3.0	1.0	Economic
Geothermal	≪0.4	0.2	Economic
Tidal	0.04	0	Computational
Solar panels, heat pumps . .	2.5	1.0	Economic technological
Otec, wave power and glacier power	1	0-1 *	Ecological, climatological (technological)
TOTAL . . .	17.5	6.3-7.3	

* Assuming favorable economics.

Compiled by W. Sassin, IIASA on the basis of the following sources: Armstead (1978); ASA (1975); Bolin (1979); Corby (1969); FAO (1975); Parikh (1977); Partl (1977); Revelle (1979); Vonder Haar and Oort (1979); Wick and Schmitt (1977); Woodwell *et al.* (1978).

matter. It is widely used at present, and meets a significant fraction of the present energy needs of the developing countries. The technical potentials in Table 5 are optimistic estimates of such power flows that can reasonably be diverted from nature — which, in most cases, is a rather small fraction of nature's total turnover. The maximum sustainable yields in managed forests make up not more than 25% of the related carbon fixation rates. Ocean currents are particularly sensitive, for even very minor extractions of mechanical power would interfere with the poleward heat flows in the ocean surface layers.

The limitations on renewable energy sources can most easily be demonstrated by comparing natural supply densities with the existing or anticipated density of human energy demand, i.e., man's energy turnover per year and geographic area. The harvesting of certain fractions of natural power flows passing through the environment results in specific yield densities. Optimistic estimates for favorable cases are introduced in Figure 14. Only some of these cases exceed the demand densities identified for the IIASA regions in the two scenarios. They fall short of even the present demand densities of urban settlements. Several determined efforts have served to quantify the possible results if all local renewable (distributed) energy sources are exploited. Table 6 summarizes three such limiting cases.

A detailed analysis of the maximum practical yields from biosystems, local solar, wind power, and hydropower, resulted in an average energy supply density of 0.3 W/m^2 for California. The land use implications are seen to be quite serious. By summarizing the maximum potentials of the world's rural developing areas for harvesting energy from renewables, the average energy yield densities turned out to be only 0.09 W/m^2. This smaller value puts the exceptionally favorable case of California in perspective. Compare the global estimates of Table 2 also with those introduced in Table 6.

The IIASA scenarios allocate altogether almost 10% of the global energy supply to renewable energy sources. By 2030, this would amount to about 2-4 TWyr/yr, a range close to the maximum yield estimates in most of the world's developing areas. Consequently, one has to expect a rigorous exploitation of all the biomass in all of Asia and Africa and,

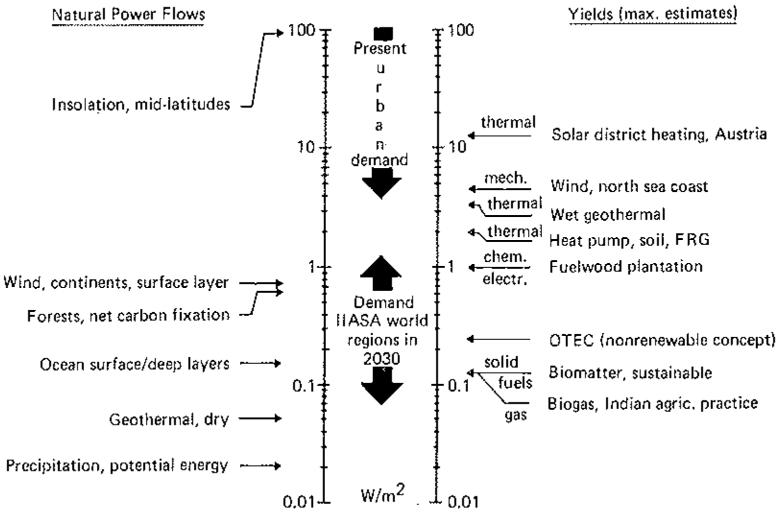

FIG. 14. Natural power flows and supply densities from renewable energy sources compared to energy demand densities. *Source*: W. Sassin (1980).

TABLE 6 — *Renewable energy supply: a comparison of limiting cases.*

Case	*California*	*Rural developing world*	*World*
Population in territory year 2025 or 2030	$33.6 \cdot 10^6$	$3250 \cdot 10^6$ *	$8000 \cdot 10^6$
Inhabitable area, of territory in 10^6 km^2	0.4	43	80
Yield from renewables in TWyr/yr	0.13	4	6.3 **
Land use implications	100% of commercial forests and agricultural land + 50% of non-commercial woods, brush and grass land; wind, solar	All forests plus wastes from doubled agricultural yields + Hydro, wind, solar heat	An all-out effort on the inhabitable land of the globe
Population density inh/km^2	97	76 *	100
Energy yield density W/m^2	0.3	0.09	0.08

* Excluding urban population in cities of > 100,000 inhabitans in same territory.

** Excluding ocean based sources.

Basic data from U.S. Department of Energy (1978) and A. M. Khan (1980).

to a lesser degree, in Latin America. This immediately raises questions of ecological stability, of soil erosion, of water requirement, and, last but not least, of potential global climatic impact. The joint impact of stretching agriculture, bioenergy, and hydropower to their natural limits is bound to transform nature into an energy garden in the decades to come. The responsible limitations to such an ecological transition are not known.

Development, a race against time?

The prospective view into how the world could balance energy demand and supply in the coming decades highlights a number of crucial issues. They are at the interface between science and politics. As they, at least partly, seem to fall outside the range of a well established experience they can only be addressed in the form of a tentative evaluation, and not at all in the sense of a rigid scientific conclusion. These issues emerge from discrepancies between "what could be", "what should be", and "what will be".

There is little doubt that the world will soon be populated by a number of people larger than the traditional renewable energy sources can sustain. This is true even if the majority were to discard the achievements of a material well-being present-day developed countries enjoy.

On their way to industrialization, as the energy demand came to exceed local supply densities, the developed countries were indeed forced to give up renewable energy sources for fossil energy sources. The early transition from wood to coal was largely driven by this experience (Figure 3). Their present dependence on oil, natural gas, and coal resources is nation-wide, and for most of them also worldwide. Since the world's recoverable resources of fossil fuels appear to be quite large (compare the notes on Table 2) the industrialized societies could in principle be supplied with enough energy for more than a century, even if the developing nations were to gradually build up a modern technical infrastructure and participate in these supplies.

Before the first oil shock there was firm hope that there would be enough fossil energy to allow for a gradual and timely build-up of non-resource limited energy sources, i.e., nuclear and direct use of sunlight. During the past decade the public has gradually begun to distrust big solutions. To some extent they are perceived as being potentially unreliable and dangerous. Public perceptions — the Zeitgeist — do not ask for rationalization, even if they merge the unmergeable: a striving for national or local independence based on an extensive exploitation of the globe's resources.

The conflict arising out of such a misconception of common human property will emerge rather slowly. Assuming global cooperation, the IIASA scenarios cannot embrace the consequences of a proliferation of national resource conservation and of a non-proliferation of alternative energy technologies. The narrow choices to strike a balance between demand and supply over the next 50 years, given a cooperative world, indicate the seriousness of this point.

There is a more imminent dilemma for decision-making, however, that can be deduced from the IIASA scenarios. What really seems to have turned the energy situation upside down in the early 1970s is a small change in trends that is not even now fully appreciated: the transition from fossil energy to sustainable sources will most probably be an uphill fight in cost and effort. This trend is in sharp contrast to the earlier experience of permanently sinking energy *costs* accompanying the previous transition from renewable to fossil resources.

The eventual consequences of this change are difficult to foresee, as they depend on the resolution of a conflict between hitherto sound economic principles: cost minimization and the concept of seizing markets through innovation.

The recent evolution of the oil market, as well as of the gas and coal markets, gives us an early example of that dilemma. The drastic increase in all energy *prices* is going to bring in gradually more expensive energy supplies as well as conservation technologies that can then be justified economically. Yet the actual production *cost* level still remains rather low. The economic differential between energy prices and costs, harvested by those controlling the prices, is definitely not used to build up new supply capacities at or close to the new energy price levels. OPEC countries use their oil surplus to develop their economies; governments of industrialized countries finance general public investments from royalties or from energy taxes, trying to stimulate consumption and thus further economic growth through social transfer payments. In this phase, high energy prices can mainly be seen as a means for redistributing the benefits of a high industrial productivity. And as long as the actual energy production *costs* remain low, there is no reason why the extension of an energy intensive infrastructure should — on a global balance — be seriously impeded.

In the years ahead, energy investments will certainly be directed towards the deployment of the second best resources. The principle of cost minimization will thus first of all lead to an exhaustion of fossil resources that are easy to produce, convert and utilize.

Despite the fact that production *costs* for residual fossil fuels will over time reach a break-even point with the substitutes derived from nuclear and solar energy, this will not facilitate a quick build-up of the fixed capital stock representing these sustainable sources: the less rewarding the basis on which an old infrastructure has to operate, the slower is the pace at which one can afford to install an even less rewarding new infrastructure. Or, in other words, the transition to sustainable energy sources might well become more difficult with time.

Should this be the case, the global process of development must be seen as a race against time. It could only be won once those disposing of high industrial productivity and those disposing of limited cheap resources ally their wealths in order to pay the price for building up a basis of sustainable energy sources. This will never be a minimum cost operation. The transition from renewable to sustainable energy sources, as conceptualized in Figure 15, seems to parallel a step mankind took in the wake of the Neolithic food system, i.e., the transition from hunting-gathering to the domestication of animals and to farming. This time we have an intermediary — exhaustible fossils — easing this transition. But

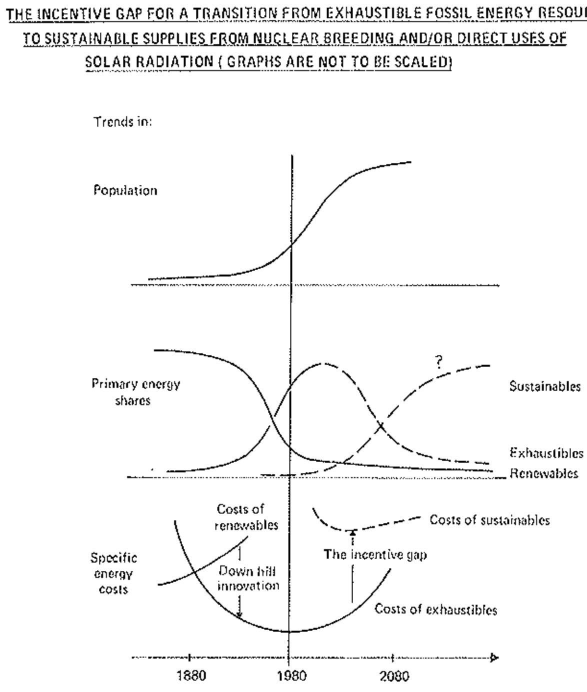

FIG. 15. The incentive gap for a transition from exhaustible fossil energy resources to sustainable supplies from nuclear breeding and/or direct uses of solar radiation (graphs are not to be scaled).

we have less time than our ancestors. We have permitted the population explosion to happen, and the mortgage is not to be pushed on to an era when the globe will have nearly exhausted this one-time endowment. Where are the correct yardsticks and principles to master this transition?

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A LOW ENERGY GROWTH SCENARIO FOR THE YEAR 2030

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Hard and soft ideologies: a dichotomy in energy system control

The decade of the '70s has borne witness to one of the greatest upheavals in technological and economic rationale of the last two centuries. Prior to 1970 there had been practically no debate on the question of technological choices in the energy field.

It came as a natural consequence of economic and technical objectives that optimality increased with the size of energy systems. The economies of scale associated with an increase of one or two orders of magnitude in the size of energy plants and distribution systems had been everywhere so evident that the question of sufficiency of standard technical and economic criteria was never even discussed. But during the '70s it became quite clear that the point at which diseconomics of scale begin to gain the upper hand might have heen reached even in the case of energy systems. This was true not only in regard to technical and economic questions related to the discrete physical system that produces, transports and distributes energy, but much more important, to the financial, managerial and sociopolitical aspects of the deployment of large energy systems.

That there was in all this a deep-rooted question of ethics and values is evident from the spontaneous birth of two irreducible philosophies; the hard and the soft which seem to disagree on practically everything related to energy technology. While hard philosophy holds absolute

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faith in the scope for technology to match up the problems of any size, and the bigger the more welcome, soft philosophy is concerned about the importance of energy systems being within the grasp of the ordinary citizen, and therefore small. So it is not only a dichotomy between big and small with all the accompanying technical and economic, financial and managerial implications, but also, and fundamentally, a dichotomy in social control. It embodies in the energy field what is more generally a "crisis of society, a crisis of political authority and a crisis of moral responsibility", that pervades our societies today (Marsh, 1980).

Notwithstanding the very broad questions of this problematique, the opposition between the two schools has centered on questions that are basically only technological and economic, leaving aside many important aspects relating to the social objectives of mankind. Haefele *et al.* in their IIASA projections to 2030 do not even question the usefulness of gross national product as a measure of societal goals (Haefele and Sassin, 1978). Energy demand growth well into the future is justified by the need to allow for increasing economic growth taken as a measure of the well-being of nations. Lovins' (1977) manifest aversion for "economic people who want as little as possible to do with their own life support systems and are content to pay their utility bills without a murmur, gobble precooked plastic food as the television exhorts, and eagerly turn every aspect of life into a prepackaged component of grip" is well known. But even Lovins enters the energy picture not at the logical beginning of the chain that leads from demand to supply, but really only half way along, when, having taken for granted society's conventional demands on end-use energy, it becomes necessary to establish the technology for supplying them most efficiently. The question at stake behind the dispute between these two schools is quite clearly not one of lifestyles, though lifestyles are in some way involved, but one of control of energy systems.

In the hard, high energy futures exposed by Haefele *et al.*, extreme centralisation of energy systems leads to ever higher energy conversion, transport and distribution losses which 50 years from now may be of the same size as all the energy used in the world today.

In Lovins' scenario most of the energy saving is achieved by decentralising the energy system to provide an optimum match between supply and demand (with minimum conversion), through "small, benign and convivial" technologies close to citizen control. The surprising feature of the classical hard and soft approaches is that there is no substantial difference between most aspects of the economic and demographic structures. Settlement, transport and industry patterns, have presumably very similar structures, since the clash appears not to be on lifestyles as much as on the size and control of energy systems. In this sense, the struggle, as we know it up to now, is basically ideological.

Energy systems beyond ideology

Aside from these two alternatives, there is a third approach which is less ideological, more pragmatic and reformist. It is concerned with the deeper lying reasons behind the demand for energy, relating it to the forces set in motion by the way people live in their different surroundings. It has been said that economic progress is nothing more nor less than the substitution of material for social and spiritual values. However, this may be, there is need for a clear distinction between human well-being as an economic goal, and GNP as a material measure of the throughput necessary to achieve this goal. It is possible, in principle, to achieve the same human well-being at a lower rate of economic throughput as measured by GNP. Rather than simply maximising output or the amount of annual consumption, assuming all the time that a man who consumes more is better off than a man who consumes less, such a social economics would seek to maximise the ratio of satisfaction obtained to input required.

The maximisation of GNP as an ultimate proxy for well-being is of course an exceedingly poor objective of policy since it ignores many social costs accompanying growth, or what is worse, counts them as if they were benefits. For example, if the average time, effort and money required to commute to work doubles over twenty years of urban growth, then the services contribution to GNP also increases because of congestion on the roads.

In the general GNP maximising approach this is counted as an increase in well-being. Similarly, an increase in the police force due to increasing crime rate accompanying urbanisation, leads to an increase in GNP. An increase in GNP can be effected by such activities as tearing down a house and building it up again, or breaking an arm in an automobile accident and having it set. An even easier way to increase GNP is to multiply the number of separate steps between production and final consumption. Economic growth leads to a rise in per capita sugar consumption which in turn leads to a rapid deterioration in the quality of our teeth. The increase in services rendered by the health sector of the economy, as a consequence of increased dental care, is reflected as an increase in GNP. On the production side it really does seem to correspond to a benefit since employment and wages are rising, but if the service rendered by economic growth on the consumption side were given its proper sign, surely the policy maker, in reaching the root of the problem, would be aiming at saving the teeth, even if this meant reducing GNP and employment in the health sector. Advanced economies may have passed their zenith of well-being some years ago without even knowing it, because their economists and policy makers were adding up indiscriminately the costs to the benefits of growth as if they had the same sign.

Recent attempts (Nordhaus and Tobin, 1973) to take into account the disamenities of economic growth are doubtless laudable, but they have barely scratched the surface of a problem which seems to be well beyond the capabilities of classical economic analysis.

Clearly, however, the problem finds its roots in human nature. At an intellectual level, current obsession with national accounts indicators of well-being based on sheer production and consumption potential, militates against all this type of common sense.

Moreover, at the practical level, the entrepreneurial drive largely in the developed countries, and the desire for power and prestige of the nation state in some of the developing countries, hamper a wide acceptance of this different type of economic thinking.

The third alternative, to which we adhere, refutes the classical demand-led approach to energy system forecasting, as inapplicable in a world of potential shortages. In the last few decades, certainly, no major problems were met in matching supply with demand both on a world and on regional scales. This has led to the conviction that supply of energy can be treated as essentially demand-led, and that, in principle, any level of demand could be satisfied no matter how high. The general methodology for projecting energy systems into the distant future is a carryover from methods that have been applied with considerable success to forecasting energy demand over short periods of time in the past. Economic activity levels are generally assumed as exogenous, then some reasonable hypotheses about price and technical coefficients are made to obtain energy demand. Once the demand for energy has been determined, there is only a question of identifying the optimum energy technologies and their contributions.

This approach to energy forecasting, which has been so successful in the easy oil and gas era, may no longer be applicable as oil and gas, and all energy in general, become not only more costly to produce and deliver, but as their price on world markets increases. In the more distant future, supply of energy in a finite world seems to be a constraining feature and it may prove necessary to reverse this approach to energy systems by looking instead at how the economy, technology and society can adapt to the natural resource limitations of the earth, including the environment and climate itself.

Unlike the hard and soft approaches, this alternative is in no way normative. It holds no preconceptions on the economy and society nor the energy technologies necessary to support them. Indeed it leaves the whole system, and not just the technological sphere, free to respond to outside circumstances in the best way possible.

The most important question regards the rate of urbanisation. Noticing that urbanisation is closely correlated with GNP, and taking GNP as a valid indicator for well-being and happiness, many observers have been prompted to seek in urbanisation some special, grandiose objective of mankind, a third and last stage in the development of the human race, from nomadic, to agricultural, to urban.

In the conventional view urbanisation is one among many beneficial fall-outs of economic growth, numbered together with tons of steel, pairs of shoes and vehicles as just another index of well-being.

In first instance this view is not difficult to justify. In a well-established and widely accepted rationalisation, the city has traditionally played the role of fostering the growth of civilisations. So close have been the concepts of city and civilisation, that the history of civilisations is conveniently told in terms of the flowering and decline of cities. The relative concentration of peoples and economic activity, the frequency of human contacts, the multiplicative effect of closely located and varied economic activities, have all favoured the creation of a social conscience and an accumulation of wealth which went well beyond the possibilities of small multi-family nuclei or village life. It was the cities and not the open country which gave rise to universities, schools of higher learning, guilds, works of art, architecture, the developments of crafts and the sciences, and the many other elements of modern Western civilisation. The city in due course became a universe in itself, with its privileges and social classes (Braudel, 1979). "The city wall separates the citizen from the peasant" goes an old German saying, and French language has given to the citizen or "bourgeois" a social and class meaning which amply transcends the simple division between city and rural dwellers.

Throughout most of history, migration to the cities has been slow or insignificant, if not even negative, implying the existence of other more powerful phenomena resisting the strong cultural and economic attraction to the city. In the conventional positivistic view migration to the cities in the Middle Ages became possible only with the existence of surpluses in agricultural production (Slicher van Bath, 1966) allowed by progress in farming techniques beginning with the millenium: improvements in the plough, the fallow and open field systems etc.

The primary evidence, however, is that the major thrust to urbanisation has come from population growth. In Europe, during the last thousand years, there have been only two long term bursts in population growth, the first in the 2 or 3 centuries prior to the outbreak of the Black Death, the second beginning with the Industrial Revolution of the 18th century and both have been accompanied by major developments in urbanisation: the birth of thousands of new towns in the earlier, their rapid growth during the latter (Bernardini, 1980).

In between, when population growth essentially stagnated, urbanisation remained at a threshold level or even declined.

The historic record is therefore not unequivocal. In contrast to the time honoured concept of urbanisation as the satisfaction of the aspirations of ambitious people from the countryside seeking higher learning and economic opportunities (resources permitting), there exists the alternative hypothesis (resources constraining) of the city as a dumping ground for surplus population in the countryside (Meier, 1976). In recent decades, rising crime rates in large urban concentrations, congestion, high living costs and other urban disamenities have challenged to the roots the positivistic traditional position. It is no longer a matter of the creation and growth of large numbers of small towns, as it used to be since the Middle Ages, but one of the uncontrolled growth of few very large metropolises. The urban disamenities of large metropolises are so outstandingly evident, yet the mechanism of attraction is so enduring, that analysts have been forced to look beyond the classical conceptual rationalisation of urban migration based on human aspirations of economic and intellectual betterment.

According to us, therefore, there exists no fundamental "law of urbanisation". If there has been massive urbanisation since the Industrial Revolution, this must be attributed, by and large, to the pressures of population growth and the availability of centralised energy systems which have been far cheaper — in urban surroundings — than the decentralised energy systems they displaced. The close relation between energy and urbanisation cannot be denied. The demand for energy set in motion by an individual varies almost exponentially with the population density of his habitat. This is fundamentally because the time and space opportunities decrease with increase in population density. There is in effect, a form of indirect substitution of energy and materials for time and living space.

Urbanisation not only increased the number of steps, between the field and the table, from production to processing, transporting, packaging and selling the food, with a corresponding increase in the amount of direct and indirect energy use, but the extreme decrease of the agricultural population which accompanied it, also called for new methods of growing and collecting the food, which were quite naturally energy intensive.

Beyond these factors, there is also the question of energy availability. Of the many theses that have been advanced to explain the attraction of population into cities and more generally the phenomenon of industrialisation in the early Industrial Revolution, it seems that the declining availability of firewood for industry in rural districts may have played no small a part. The overall picture reveals that, other things being equal, migration tended to occur more strongly towards the coal regions. So close, in fact, is the connection between coal, industrialisation and urbanisation, that the effects of the match between supply and demand for energy in the earliest phases of the Industrial Revolution are still felt two centuries later, when coal is no longer the dominant fuel. With the exception of the city of London, in fact, most urban agglomerations in the United Kingdom are localised in the immediate area of coalfields.

The fortunes of different fuels are, historically, closely interwoven with the decentralised/centralised structure of consumption. We could go as far as to suggest that if there had been no firewood crises, or if other fuels and related technologies had been available for consumption in a dispersed mode, then the phenomenon of urbanisation and industrialisation would not have occurred to the extent tbat it did. One of the reasons sometimes advanced to explain why France lagged behind Great Britain in early industrialisation, was that its forests were in ample supply and it never suffered a wood famine (Young, 1976).

Once the population began to be concentrated in central points, its thirst for energy developed very rapidly through all the infrastructures that had to be created and used to process all human requirements, direct and indirect, in useful space and time. Thus, the most rapid economic growth and urban/industrial development occurred in those areas nearest the coal fields. It is, however, unlikely that the type of economic development experienced over the last half century would have been possible in absence of oil. The relatively very low transportation cost of oil, which is a result of its liquid nature and high energy density, has in fact allowed a substantial decoupling of human settlement and energy consumption patterns from the location of energy sources. The large urban agglomerations that have developed during the course of the twentieth century, have little or nothing to do with nearby availability of energy.

Of greater importance than the nature of primary fuel to the further development of urban structures, is the form of the secondary fuels that are eventually produced from it. In making his energy decisions, the final consumer gives high consideration to quality and ease of use of the energy forms with which he comes into direct contact, sometimes frequently beyond what price considerations alone might counsel. Solids which have to be moved around in trucks, carried in buckets and fed with shovëls are clearly inferior to liquids which still have to be delivered by trucks within city boundaries but can be piped to their final use. Gases, on the other hand, present a real quality jump since their delivery throughout the urban fabric can be based entirely on a pipe network. Once the structures are laid down they can last for many decades with only minor repairs or changes in layout and clearly represent a fundamental asset to urban societies. It may be expected therefore, that when natural gas becomes scarce in certain parts of the world beyond the last decade of this century, every effort will be made to find substitutes for it at the consumer end, with equivalent physical characteristics. And the only near term alternative to natural gas is synthetic high Btu-gas made from coal, which is cost-effective only in very large conversion plants ($\sim 3 \times 10^9\ m^3/yr$), enough to feed a metropolitan area of 3-5 million inhabitants.

We find an ineluctably close connection between ease and convenience in end uses of energy forms produced from conventional primary sources, and urban centralisation. If gaseous distrihution systems are favoured over and above liquid and solid systems, electric systems represent the supreme in distribution, at least from the consumer point of view. Not only does the distribution and use of electricity involve the minimum of physical effort (plugging in and turning off switches), but this energy vector is also more ecologically acceptable (cleaner, less noisy) to the end user. Electricity, however, as a secondary form derived from conventional primary fuels such as coal, oil and gas, inherits the inherently centralising characteristics of these fuels. As for synthetic natural gas, moreover, these characteristics are enhanced by the fact that electricity from central stations requires not only a fixed conversion system where economies of scale dictate optimum sizes in the GW range, but also a fixed capital-intensive distribution system. Here, again, the underlying argument is that it costs more to distribute electricity into rural areas through a grid, than it costs to reorganise the population into urban agglomerations. Hence, the trend to centralisation is again enhanced through fuel substitution.

Nuclear energy, by many estimates the next in line in the progression of primary fuel substitution, allows a continuation of this rationale. Nuclear generating plants come today in sizes suitable only for large systems, simply because this source would not be competitive with coal, oil and gas in small sizes. The optimum size in nuclear systems is clearly the multigigawatt range, since this provides better solution to the siting problem, and a reasonable match with the upstream and downstream fuel cycle capabilities.

It might be expected that as a result of the deployment of these systems they would indeed lead to increasing urbanisation. To assert simplistically that urban growth is independent of strategic energy choices, or instead, that the choices are made with the purpose of coping with the "inevitable" process of urban growth, is clearly not sufficient in the light of effects these complex systems.

To sum up, therefore, the view advanced is that there exists an important positive feedback in the question of big breeding big. Population growth and the availability of cheap centralised energy prompts urban growth. This in turn leads to decreased time and space opportunities, in turn leading to new technologies and new systems, new products and new product sectors, requiring continuous increases in productivity, more workers drawn from traditional sectors in rural areas, reduction of agricultural population, increased productivity in agriculture, increased urbanisation and so on in a frenzied spiral moving faster and faster at every turn. In subsequent periods of development, urban growth therefore calls for the deployment of more and newer centralised energy systems, which in turn spur centralised urban development and so on in a vicious spiral with big begetting bigger and bigger yet.

The question of energy technology is therefore not indifferent to urbanisation and the pattern of human settlements. In this relation, it is rarely recognised that Haefele's high energy future based on hard, super-centralised technology, calls for extreme degrees of urbanisation in all areas of the world, while Lovins' low energy future, based on soft, decentralised technology is inconceivable without considerable de-urbanisation in industrial countries and a very substantial slowdown of urbanisation in developing countries. In other words, if we assume that urbanisation is a fundamental objective of mankind, then hard technology is the only solution. If on the contrary, as we see it, urbanisation is largely the result of two-hundred years of rapid population growth and the domination of increasingly more centralised energy systems (because they were more available and cheaper), then there is hope for a more pluralistic mix of energy technologies, a mix that is not geared to ideological preconceptions but to a very natural search for optimality under existing energy supply constraints.

With the advent of modern dispersed solar energy technologies and particularly photovoltaic energy, one of the main forces behind urbanisation — availability of cheap energy only in compact central locations — need no longer apply. In the long run, as conventional and centralised forms of energy become scarce and/or more costly, other system forces may well become dominant, tending to decentralise industry and human settlement patterns in a way consistent with the cheaper solar energy of the time. As at the beginning of the Industrial Revolution, then, there is not only a question of fuel substitution, but also one of system transformation.

A feasible scenario with low energy growth

We have recently carried out an exercise to explore such ideas (Colombo and Bernardini, 1979). Our intention was to examine how the various regions of the world might respond to a world-wide constraint in energy supply such as appears possible over the next half century. In particular, primary energy supply in 2030 was assumed to be 16 TW, on a global scale, about twice the present level of consumption. Population was also assumed to double, again on a world level, so that average per-capita consumption remained the same as today — at about 2 kW (*) — but, as will be seen, with a very different distribution between world regions.

At the same time it was necessary to make some assumptions about energy resource availability and technological development. The picture of the future is based on three basic assumptions:

1) there exists no fundamental "law of urbanisation" independent

(*) 2 kW is short for 2 kyr/yr which is the energy equivalent of 2 kW of power applied 24 hours a day, 365 days a year. A TW is 10^9 kW.

of energy availability, according to which humanity is destined to aggregate in ever larger and denser agglomerations;

2) rapidly increasing costs can be expected for all forms of centralised, conventional and non-conventional, energy systems beyond the year 2000;

3) developments in solar energy technology will lead to a sufficient reduction in costs to make this energy source competitive in dispersed applications, with energy technology — both conventional and otherwise — in centralised applications.

None of these assumptions can be proved true or false over a horizon of fifty years (although we believe they are closer to being true than false) and we therefore feel justified in offering this low energy future as an alternative to reflect upon.

We have already discussed the first of these assumptions. As regards the second, we can be quite certain that in the case of oil there is a basic resource problem since while it is true that oil resources are still abundant, additions to the resource base will become very costly indeed as the resource base is progressively exhausted. The situation for natural gas is similar to the case of oil but possibly aggravated by the added problem of transportation from supply to demand areas. A basic problem with coal is again transportation, which presently accounts for over 40% of the cost on a world average, though only 9% enters world trade. But the most serious aspect of high levels of coal deployment is related to the end use and environmental (including global CO_2) problems which greatly increase the cost of using coal. Nuclear energy, which up to recent years held great promises of a cheap energy source for the future, now appears to be not much cheaper than coal when all the system costs — short, long and very long term — are taken into consideration, rather than just the cost associated with the production of electricity.

As regards the third assumption, there appears to be no doubt that cost reduction will be obtained across the range of solar technologies, through fairly standard developments usually not requiring real breakthroughs. Although we are talking mostly about research and development, we also wish to emphasise the demonstration and commercialisation aspects, since learning curve effects and production plant scale-up can be expected to lead to substantial cost reductions as solar systems expand on the market. If these very probable developments are set on a background of increasing costs of conventional energy forms, the likelihood that solar energy technology will become competitive in the medium to long term is clearly improved.

The declining availability of oil and gas, the well publicised environmental and social limits on coal and nuclear development, open up heretofore unforeseen spaces for solar energy and other renewables. But these can be acceptable alternatives only if their cost comes down sufficiently rapidly. Our estimates of solar energy development is in line with other middle of the road assessments that are neither too conservative nor too optimistic. In particular one of the key assumptions of this scenario is a dramatic decline in the present cost of photovoltaic arrays, and developments of the last 3 years indicate that improvements of this technology are quite on schedule. Expected cost reductions in solar energy technologies and substantial increases in the cost of conventional energy technologies is one of the driving assumptions of our scenario.

Overall, however, competition might be expected to he more favourable in the case of decentralised solar technology offering the possibility of integration with the human habitat and requiring one order of magnitude less structural material per installed power unit than centralised technology. Indeed, cement and steel which are basic material components of centralised solar energy systems, may be expected to inflate with increasing energy costs more rapidly than the basic solar components, which are also more labour intensive. Thus a substantial cost differential in favour of decentralised solar technologies should develop in due course. Our estimates indicate that the ratio of the cost of decentralised versus centralised energy technologies, which was about 16 to 1 in 1975 could well be around 1 to 1 in 2000, and 0.8 to 1 in 2030. The numbers are round averages for the world as a whole and clearly wide variations may be expected between regions.

Such developments are consistent with a long-term rate of GNP- growth between 1975 and 2030 which averages 2.5% for the world, breaking down to 2.0% in the developed regions and 3.8% in the developing regions. This is considerably lower than the corresponding figures for the preceding 50 year period (respectively 3.6%, 3.5% and 4.4%) but a direct comparison is not even very meaningful. Economic growth, in many ways, is a measure of the rate of urbanisation.

While the urban population in this scenario does not pass through discontinuous changes, nevertheless, the drastic change in the convenience of decentralised versus centralised energy forms relative to previous periods, does introduce substantial variations in comparison to past trends. Population pressure is such that the urban population continues to grow in absolute terms, particularly in the developing regions where it increases from 660 to 1671 millions between 1975 and 2030, but even in the developed regions, where it grows from 579 to 706 millions. However, in relative terms, there is a substantial decline or inversion in trend, with the urban population dropping from 50% in 1975 to 45% in 2030 in the developed regions, and increasing only very slightly, from 24% to 26%, in the developing regions.

The distribution of energy demand between world regions arising from such developments as have been described, departs substantially both from previous trends as well as from other more conventional demand-led forecasts. In the developed group of countries, total primary energy consumption increases from 6.4 TW in 1975 to 8.0 TW in 2030, while the analogous figures for the developing group are 1.3 TW and 8.1 TW.

Thus, the total primary energy supply in this scenario distributes almost equally among developed and developing countries. Nonetheless the much higher population growth in the developing group ensures a continuing difference in per-capita terms: 5.1 to 1.3 kw per capita respectively in the developed and developing groups in 2030, as compared to 5.5 and 0.5 kw per capita in 1975. Thus, while developing regions have drawn nearer, they are still far away.

Many will hold it inconceivable that per capita energy consumption in the developed regions could actually decline (from 5.5 to 5.1 kw) while per-capita GNP continues to increase. Indeed such a decline may be taken by some as an indication that this scenario implies a decrease in standard of living. As discussed previously, however, it is a distortion, arising from our historic frame of reference, to rely on such indicators as per-capita GNP and energy consumption as measures of well-being and happiness. The reduction in per-capita energy consumption in the developed regions can be consistent with an improvement in the standard of living if account is taken of two fundamental factors which accompany this scenario.

Foremost is technological development in end-use technologies, which either directly or indirectly can reduce the energy content of GNP, over the next half century, by as much as 40%. The energy savings potential of end-use technologies can be very high, given sufficient time for capital stock turnover. Fifty years is a long enough time to allow, on average, at least one asset turnover in all sectors from transport to housing, to industrial plant. Further energy savings can arise from the development of completely new technologies in replacement for old. Information technologies and bio-technologies are two such developments which hold great promises for bringing down the level of energy consumption. Information systems are all too frequently seen as an aid to increasing economic activity, and it is sometimes held that their diffusion will increase material transfer and thus energy consumption. But this is not the case in the type of scenario we describe, based on the decentralisation of human settlements and industrial activities, in which the primary role of information technologies can be sought in the direct substitution of information for material transfer. Biotechnologies, which are highly adapted to decentralised uses, can also lead to very great energy savings. Within 50 years, for example, there is some hope that developments in the field of biosciences and related technologies, could lead to nitrogen fixation on a large scale, thus eliminating the need for huge amounts of nitrogen fertiliser production, which is a major energy consumer within the chemical industry.

Over and above technological development, is the adaptation of human settlement patterns to the new decentralised energy technologies now beginning to sprout all over the world.

Decentralised energy systems are dependent on land use and local circumstances. It may be expected, therefore, that their development over the coming decades will imply significant changes in human settlement patterns privileging small to medium sized towns rather than large megalopolises. This development is consistent with the new decentralised technologies of the future, and will lead to further substantial decreases in the energy content of GNP without sacrificing well-being, probably even increasing it.

Our scenario projections are consistent with a 58% decrease in the energy content of GNP as an average for developed regions: from 1.14 koe/US \$ (*) in 1975 to 0.48 koe/US \$ in 2030. The decrease is much weaker, however, in the case of developing regions: from 0.60 koe/US \$ in 1975 to 0.52 koe/US \$ in 2030, a 13% decrease.

These regions are mostly at a stage of development where economic growth implies strong increases in the energy content of GNP, due mostly to the strong currents of urbanisation and industrialisation, while technological developments and decentralisation, such as discussed above, need to be superimposed on these prior dynamics.

(*) In this calculation, U.S. dollars are considered fixed at their 1973 value.

TABLE 1 — *Primary energy breakdown by groups of countries (developed and developing) in 2030 (TW).*

	Developed	*Developing*	*Total*
Oil and gas	1.06	1.65	2.71
Coal	2.83	2.12	4.95
Nuclear	1.15	0.60	1.75
Renewables	2.86	3.71	6.57
TOTAL	7.90	8.08	15.98

Primary energy breakdown into the various primary energy forms in 2030 is given in table 1.

This table shows the importance of solar energy in meeting the demands of the developing group, but it is not much less important in the case of the developed countries. The differences between the two groups largely reflect the different degree of urbanisation and the different resource availability. In particular, solar energy availability is much greater in the developing countries and it is only the relatively high front-end cost that prevents it from growing even more rapidly.

The results shown in table 1 indicate that, under the assumptions of this scenario, over 40% of the world's energy supply in 2030 is solar. Notice that most of this energy is harnessed and consumed in distributed form. Nevertbeless, we would like to point out that at least 60% of all energy consumption would still depend for its production and distribution on thoroughly centralised energy technologies. The process of change is inevitably slow, even under fairly extreme circumstances such as the ones assumed in this scenario, and ideology does not help in speeding things up.

The capital costs of the energy transition we have just depicted look at first sight enormous. Global energy investments between 1950 and 1970 can be estimated at about 940 billion — US $ (1973). Energy investments will need to totalise over 5 times this amount in the two decades between 1980 and 2000, and a further 3 times in the subsequent 30 years to 2030. Solar energy is highly capital intensive and this explains the sustained increase, at 2 to 3 times the rate of growth GNP.

These figures however, need to be read with two different measures. Overall energy investments are not a good measure of comparison, since they include both energy sector investments and individual household and other small private investments in solar devices which have entirely different logistic management and financial properties. It is one thing to mobilise the capital for ten thousand 100 kW projects, quite another for one large 1000 MW project. Household investments in photovoltaic apparatus, and thermal solar energy devices, multi-family biogas plants etc. can be compared to private sector investment such as in housing, or even to private consumption such as in the acquisition of consumer durables, of which the automobile is the most striking. As table 2 shows, the vast majority of energy investments once the energy transition is in full swing are not large projects in the classical energy sector, but small to medium-size decentralised projects in the private household and industrial sector.

TABLE 2 — *The capital costs of the energy transition* (10^9 US $ 1973).

	1950-70	1980-2000	2010-30
Decentralized	*30*	*1730*	*10800*
Centralized	*911*	*3030*	*4300*
Oil and gas	709	700	600
Coal	105	1480	1200
Nuclear	20	550	1800
Solar	80	300	700
TOTAL	*941*	*4760*	*15100*

Because they are small projects and because they are largely in the household and industrial sector, we should not be worried about the magnitude of the investments involved. We may note, for example, that the 10.8×10^{12} US $ outlay over the twenty year period from 2010 to 2030 corresponds to an average contribution of 1.7% to gross world product, which is still considerably lower than the 2.5% of gross world product that was devolved to the private acquisition of automobiles in the period after 1920.

A scheme for survival

During the past two centuries the world system has become increasingly more interdependent with each new successive wave of urbanisation creating, and itself created by, economic growth. Each of these Kondratieff waves (there have been 5 in number since the beginning of the industrial revolution) carried with it at first increasing agricultural dependence as countries experiencing economic growth over-favoured their leading industrial sectors, in turn induced by previous waves on urbanisation, lost agricultural workers to the cities and exported capital and labour to frontier regions and later carried with it increasing energy dependence as only logical conclusion to the positive causal spiral: urbanisation → productivity increases in agriculture and industry → economic growth.

But today there are no more fertile expanses of frontier lands to push wheat production as the developing peoples of the world leave agricultural activities and increase their reliance for food on imports. Nor does the world hold other energy-rich and easy regions of the magnitude required. Yet, to a large extent, the space for economic growth in the industrialized countries of the world depends on the potential for industrialisation (and thus urbanisation) of the developing world. This sequence of relations provides a very strong negative feedback which may ultimately interrupt the familiar sequence of Kondratieff cycles that have emerged as a consequence of unbalanced, but free, growth during the course of the last two and a half centuries.

Certainly, the situation in the energy field is not likely to improve substantially in the coming decades. It is true that new energy technologies are expected to become commercial by that time, but these new technologies also pose major problems. To take coal as an example, extensive reliance on this fuel throughout the industrialised world would require the construction of huge infrastructures to cope with world-wide transport and use, it would increase environmental problems considerably both locally, regionally and globally, it could also pose a question of security of supplies not substantially different from that posed by oil today. For the longer term up to 2030 and beyond, it is clear that substantial changes in energy systems will have to occur in order that supply may match up to demand in a stable way over significantly long periods of time.

On the one side stands the approach to the future, which emphasises highly centralised systems and which attempts to solve the problem of fragility and resilience by recourse to extreme redundancy. On the other side stands the approach we have outlined, emphasising the role of decentralised energy systems, which derives its resilience through decreases in critical material and energy interlinkages. The former solution is a continuation of the old path: according to it the world system, as presently conceived, is resilient and capable of absorbing major changes in boundary conditions without undergoing significant changes in state. The latter solution advocated a fundamental change from the old path, emphasising the participating power of local, regional and national governments in reciprocal harmony. According to it, the world system in its present development, exhibits aspects of dangerous fragility which can be corrected only with a major effort in decentralisation and delegation of power.

Yet it may be questioned that the transition to a new state with greater stability poses some exceptional problems.

Each country will respond over time in a uniquely individual way within the limits set by the world system, according to its stage of industrialisation, to its energy resource base, to its urban/rural balance, and so on. Some countries with abundant energy resources will be in a better position to continue on a centralised, urban-industrial model of growth, even though other countries may not find this so easy on account of global supply limitations and will find themselves moving on a decentralised path. But can these two worlds coexist, the one centralising, the other decentralising? It is difficult to say, but one might think that those systems that could continue on a basically centralising, urban/industrial path may need to adjust, after a lapse of time, to the changing shape of technology, living patterns and international trade in goods and services which will be occurring in a progressively decentralizing world.

In the past as in the present, leading technologies, because they came from leading sectors with large economic potential in leading industrial countries, spread far beyond the apparent geographical and resource limits of their development and were embedded, through technology transfer, quite firmly even in economic, social and resource environments without any consideration for their appropriateness.

The international diffusion of leading technologies can be traced to their economic potential, real or perceived, in opening up markets at home and abroad and altering the patterns of world trade. For analogous reasons, also decentralisation and its accompanying bag of technologies might well spread to countries and regions, which do not have severe limitations in the supply of conventional energy forms for a long time to come.

We have tried to offer a framework for a different approach to energy futures that avoids being trapped within ideological convictions. A complete assessment must involve the whole system, not just the energy technologies, but also the societies that those technologies serve, not just the material welfare of these societies, but also their social and spiritual harmony.

We have tried to gain some insights into the driving objectives of societies. Our conclusion that there is now urgent need to redress the balance between centralised and decentralised energy systems is not ideological.

We would like to avoid any misinterpretation of our approach. Ours is a pragmatic view that does not ignore the fact that the world will continue in the future to be a complex coexistence of centralized and decentralized systems both in relation to human settlements and to productive activities including energy. We therefore wish to emphasize the critical rôle that centralized energy systems, based on hard technologies, will continue to play in the next fifty years and certainly beyond. Our real aim in developing this scenario has been to confirm the hypothesis that a plurality of energy sources and technologies, both soft and hard — the latter including nuclear and coal — is necessary for our complex and heterogeneous world.

We reaffirm our belief that, while we must avoid favouring an excessive urbanisation process, we should also be aware that the opposite solution represented by a world consisting of a scattered multitude of small urban settlements, is to be avoided if we want to preserve the diversification of lifestyles and values, which is the essence of the cultural richness of our society.

Perhaps it is not by chance that, while the debate between hard and soft energy sources to make the transition from oil is in course, two sources appear on the horizon, which promise to be definitive; one of them, nuclear fusion, is highly centralized and obviously hard, while the other, solar, is well-matched to meet the energy needs of decentralised societies.

Above all, we wish to underline the need, in the real world, for a continued critical reassessment of options, in order to maintain strategic flexibility in the face of uncertain and changing conditions in technology, as well as in the economy and society itself.

Political leadership and, behind it, society at large, must be profoundly aware of the real alternatives for the long-term future, as well as their implications not only for material welfare but also in regard to the ethical values of society.

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CHANGEOVER HARGINBER DATA: IS A LOW ENERGY CONSUMPTION "COMMUNICATION CIVILIZATION" IN THE OFFING?

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Humanity is confronted by two questions raised by the energy crisis. Practically speaking, these questions intermingle but, for clarity's sake, it would be advisable to set them apart as distinctly as possible by bringing out the difference in their natures.

The extrapolation of the development curves observed for the last quarter of a century supplies the perspective in which to frame the first question: how is it possible to further the growth of the GNP (Gross National Product), both in achieving calories savings and in creating alternate sources of energy, without perturbing the economic structure? Most of the recently published studies focus on this way to extricate ourselves from the problems we are beset with.

The second question is tantamount to considering human activities in their depth. Can one conceive a thoroughly different civilization in which living conditions would no longer be dominated by the dependence on energy? Can we fancy an economic activity with new contents? Can we develop new consumption proposals? Is this new model of a society plausible? Is it credible? Could it be the subject of research which would clarify its contents and turn it into a "project for humanity"? Are we, at least unwittingly, that is, progressing toward such an event?

In this paper's conclusion we will see that the basic philosophical idea underlying this series of questions is resting on the current concepts regarding evolution and, more specifically on Ilya Prigogine's Bifurcations and Fluctuations theory. However, it may be best to forgo any preconceived idea and to try to restrict the analysis to the observation of a number of concrete facts. The post-industrial society, which in this instance I would prefer to call "The Technician Civilization", shows indeed the existence of particularly significant phenomena. I will discuss some of them. In my opinion, they provide a way to appreciate the intensity and the quality of the harbinger conversion forces which may be sensed nowadays.

1. The "work contents" evolution

Marc Porat, an American researcher working at M.I.T. in the early 70s, came up with the idea of renovating the employment analysis in the United States.

Marc Porat did not wish to subscribe to the conventional agricultural, industrial and service sectors classification of the active population. He centered his classification of the professions on data collection, transmission or processing jobs.

In a somewhat arbitrary manner, although not altogether weakening his conclusions, M. Porat divided the active American population into two categories. The one in direct contact with objects or services in the course of its occupation and the one only collecting, classifying, distributing data, figures and symbols. The first category will include the farmers tilling their fields, working in industrial greenhouses or on cattle ranches, but not their accountants or their social advisers. The latter, together with the teachers, the research people, the insurance agents and the bank representatives, the marketing specialists, the design engineers, the clerics and the legal profession people as well as many other carefully tabulated categories of professional people are part of the "data employment" class. These men and women work without ever seeing or touching the objects they are dealing with. A bus driver, in direct contact with his machine and with the passengers, will belong to the first category, while the employee of a travel agency taking care of airplane and hotel reservations will, of course, be part of the second one. Following an assiduous tabulation of these two types of occupation, Marc Porat studied their relative density, in the United States, during the last 100 years. The result he obtained provided a wealth of information. In less than one human generation, our own generation, the data employment people have become the largest group. They represent nowadays 50% of the active population, 10 times more than the farmers, more than twice the number of industrial workers . . .

There is probably nothing more telling about the post-industrial civilization evolution; there is no index giving a better account of the development status than this ratio. The figures are: 50% for North America, approximately 40% for Western Europe; Eastern Europe, including the USSR is undoubtedly below 25%, the Third World still stands below the United States 1900 level: 5% at the most . . .

Additional research has been carried out, particularly in France, by going over, within the industrial manufacturing activities proper, everything regarding the work involved in the tasks preparation, description, in the drafting of safety provisions, of set up and of maintenance. When these are added to the specialized professions tabulated by M. Porat, it is discovered that, in 1979, 54% of the active population in France was engaged in data acquisition, processing or broadcasting.

2. "Software" activities development

The "télématique" neologism, launched by the Nora-Minc report [1], designates the aggregate of the activities grouped up to then under the electronics, telecommunications and data processing terms. Give or take a few details dealing with printing and photography techniques, "télématique" comprises more or less what the Americans group under the "Information Technology" term (cf. table 1).

A mere twenty years ago, the transmission of voices, pictures, graphs via telegraph, telephone, radio or television broadcasting and data processing through computers, all this new technology, was construed as being above all a matter of machinery, cables and equipment. It was clearly understood that transmitters and receivers had to be manufactured, that telephone wires had to be stretched or that Hertzian beams and coaxial cables had to be installed, that memories and logic circuits had to be developed for data processing; what was not known then, was that these techniques' focus of activity was going to steer away from the material implementation toward non-material engineering realizations. It was only in the early 60s that the phenomenon was clearly identified,

(1) Nora-Minc, *A report to the President of the French Republic.* "Informatique et Société". La Documentation Française, Paris 1977.

TABLE 1 — *Products of the telecommunication, electronics and data processing industries.*

— Telegraph, telephone, telex.
— Teleconference, telecopy, telemail, videophone.
— Data transmission devices.
— Radiobroadcasting and television transmitters and receivers, car-radio, radiotelephone.
— Hifi sound reproduction.
— Picture and sound shooting studio equipment.
— Tape recorders and video recorders.
— Records, radio-cassettes, video-cassettes, magnetic tapes.
— Radars, radio-detection devices.
— Weapons electronics.
— Instrument sailing and flying.
— Missiles and satellites radio-control devices.
— Scientific instrumentation (electron microscope...).
— Automation, control, sorting ... devices.
— X-rays, gamma rays, infrared, ultraviolet rays.
— Robots.
— Supersonic generators and detectors.
— Atomic particles analysers, accelerators, detectors ...
— Radio telescopes.
— Pocket calculators, mini-calculators.
— Computers.
— Computer networks.
— Display terminals, printers, computer operated plotting tables.
— Remote inquiry and partial local processing terminals.
— Punched cards, magnetic cards, memory cards.
— Electronic components.
— Microprocessors and memories.
— Temperature, pressure, motion pick-up devices ...
— Lasers.
— Wires and cables, Hertzian cables, optical fibers.
— Telecommunication, remote detection and weather forecasting satellites.
— Data processing systems for documentation, management, control economic forecasting, computer-assisted design.
— Electronic clocks.
— etc. ...

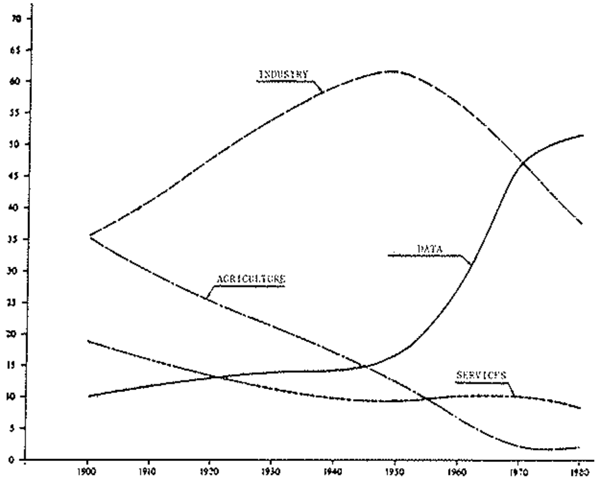


FIG. 1. Proportion of "people active in data employment" in the United States active population.

when the "hardware" and "software" terms were coined. Nowadays, as far as implementation and operating costs are concerned, the software tends to be the major element.

The recent evolution and the short term projections are shown in figure 2.

What is true for data processing tends to become true as well for electronics and for telecommunications, i.e. for all the "télématique" activities: intellectual elaboration of patterns, programs write procedures which will provide the equipment with the capacity of properly transmitting, memorizing and performing logical operations on data, are becoming a largely overwhelming share of the work required for the existence and the proper operation of the technical means. A sort of vanishing of work on matter in favor of work of the mind is taking place.

Besides, the place taken by these industries in the global equipment stocks available to man in the technician civilization, is becoming very important. If the aggregate of the construction and service activities concerning these data technologies is considered globally as of today, it is found that their share of the GNP (Gross National Product) is constantly growing; while almost non-existent around the middle of our century, it represents today more than 5% in countries such as the United States or Japan. The most conservative projections assign an

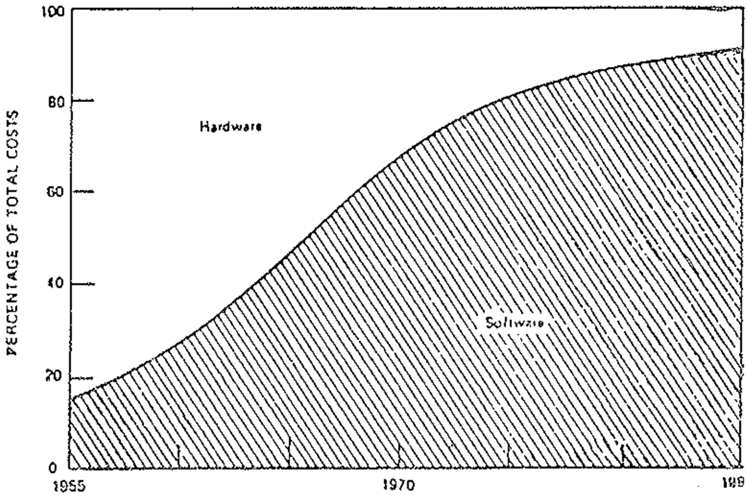


FIG. 2. Proportional evolution of "hardware" and "software" costs in data processing costs.

importance of 7 to 10% of the GNP for the end of the century in the most developed nations.

Thus, new activities whose major expenditure is of an intellectual nature are being born right before our eyes. A comparison between curves 1 and 2 is certainly in order. Is not what is happening with data processing a foreshadowing of what is in store in the human work activities as a whole? The move of the main work forces toward data processing (Fig. 1) leads us to think that the software concept is in the process of spreading to all human activities (Fig. 2).

3. ENERGY SAVINGS IN DATA-RELATED TECHNIQUES

It would be too time-consuming to retrace all the ups and downs through which, in less than 30 years, it was managed to significantly increase the services provided by the data electronic transmission and processing means, while achieving energy savings in a 10,000 to 1 ratio. I will merely show here two graphs (Figures 3 and 4) taken out of a remarkable unpublished study of G. Broussaud ([2]).

([2]) G. BROUSSAUD, *Réflexions sur l'évolution des Télécommunications à l'horizon 90.*

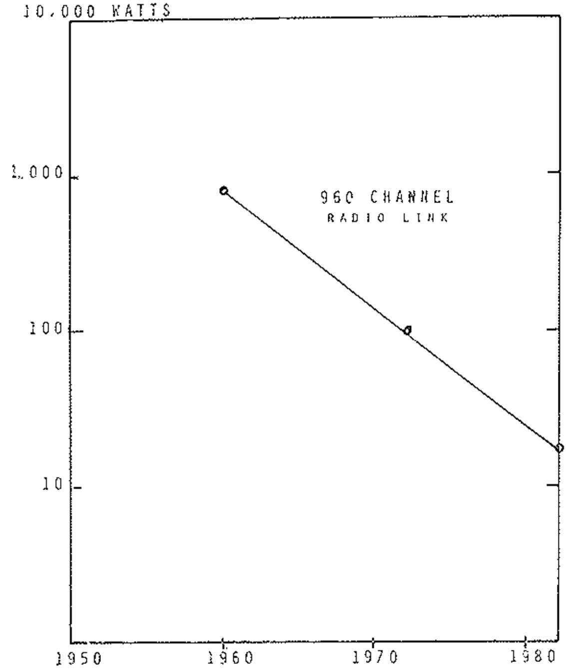


FIG. 3. Evolution of energy needs. Requirements for a set of professional equipment.

It is worth pointing out, in passing, that these energy savings were not researched for their own sake, but for other processing and reliability speed-up technical reasons. Only inasmuch as they have the capacity of processing a huge amount of operations in a very short time, do computers find acceptable applications.

Therefore, research went in the direction of the time reduction in memories read or logic circuits switching procedures. Thus, components whose status change is measured in nanoseconds have been obtained. One nanosecond represents the time light takes to travel 30 cm in vacuum, and only a few centimeters in magnetic and dielectric materials. Therefore, such speeds can be physically compatible only with an extreme reduction of sizes; currently, the units used in connection with microprocessor active components are the thousands of millimeter, or microns (μ), and even fractions of same. Hence, the energy brought into play has to be extremely low, otherwise these devices' characteristics would be destroyed and their reliability altered by the heat produced.

We find there, the example of physical phenomena reproduced in

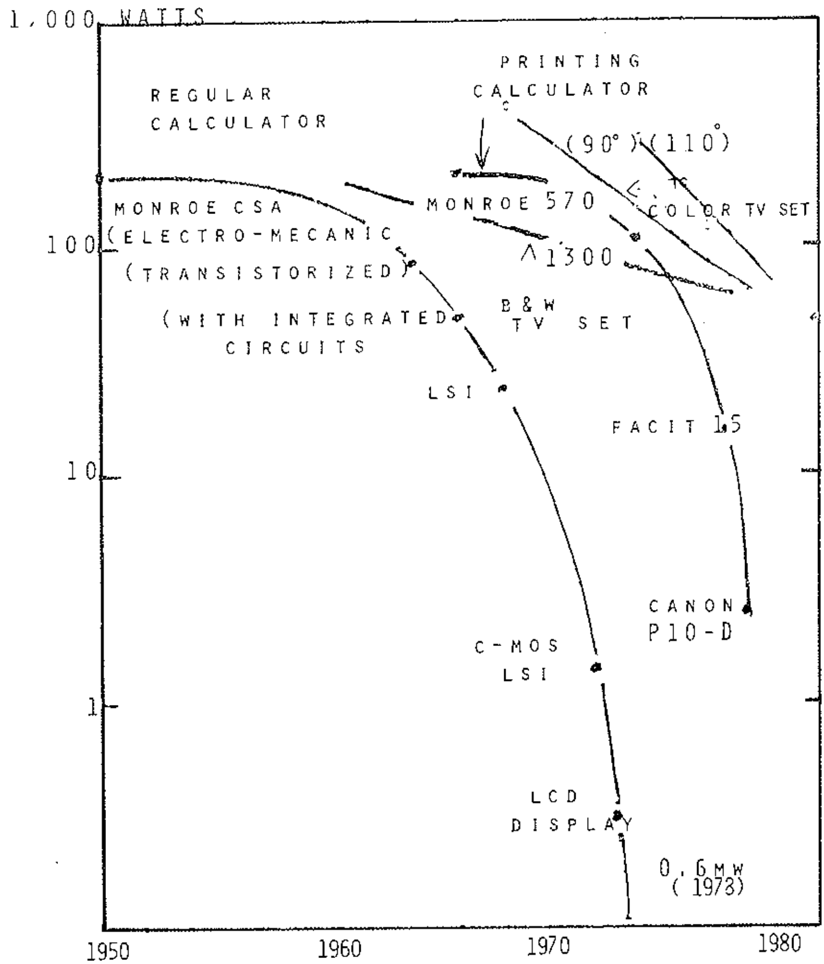


FIG. 4. Evolution of energy needs. Requirements for standard equipment.

hundreds of billions of instances in current electronic units, and whose performance — speed, sizes, safety, costs — are improved inasmuch as the energy spent is lower. This is why the numerous "télématique" specializations are designated by the "light (i.e. fuel free)" techniques, while the most frequent ones in energetics are the "heavy" techniques.

On the energy savings plane, we have another example of outstanding performances. I mean the biology field in which data processing systems (genetic data or growth programs and vital metabolism control data) can be found. The biological solutions are 10^4 to 10^7 more economical in energy than the most performant current laboratory electronic solutions. As a matter of fact, scientific research will be guiding us toward new achievements of these "super-light" techniques in the near future.

4. The reflection concerning time scheduling

It has become customary to express human achievement in respect to the balance sheet of the material wealth obtained, and more precisely to the wealth accountable in the GNP while considering as of no value the non-invoiced work, performed in the doer's own behalf or as volunteer work for the benefit of the collectivity.

In respect to the quality of life, this expression of the economic wealth is a very ineffective indicator in relation to the time schedule analysis. On what type of balance sheet can we account for the lifetime span we are granted? How do we record on this time span the portions we allocate for our education, our further training, our thinking? What share of our schedule do we devote to our vital physiological rest, to our salaried or directly productive work activity, to transportation, to recreation, sports, play, television, to self-oriented production, to volunteer activity? By studying the time-balance sheet, it becomes possible to better appreciate the structure of consumption in tangible and intangible goods, and, consequently to approach more closely the energy requirements.

Among the variations it has been possible to measure experimentally since the beginning of the century, there are three specifically significant growths. These are: the average transportation time in large urban centers, the leisure time and the time allotted to education.

For salaried people living in the Paris area, around Lyons or Marseilles, the increase in transportation time comes, on the average, to a 2 and one half-hour daily loss of time, while it was only 1 hour at the turn of the century. In the course of one lifetime, the average city dweller with an approximate 73-year life exceptation will spend the equivalent of 6 full years in waiting lines, in mass transportation or in automobile traffic jams (Figure 5). This represents an enormous waste of the most precious wealth available to us, whatever leisure time we have, and, of course, a huge waste of energy. Such are the facts yielded by experience permitting today's observation. So far, the transportation technique's only effect has been to balance the increase in traffic complexity, so much so

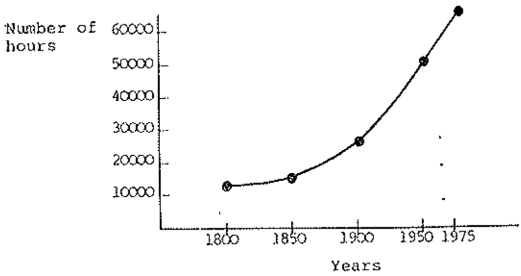


FIG. 5. Total amount of hours spent for the transportation of people in the course of one lifetime, in large urban centers.

Note: This total is the combination of 2 phenomena:

a) The average increase per day lived.

b) This increase in the number of days lived as a consequence of the increase in average life expectation (which went approximately from 36 to 72 years between 1800 and 1980).

that, at peak hours, the cars' average speed in an urban center is hardly above that of horse drawn vehicles one century ago. In addition, urban centers have spread out and have become segregated in residential sectors and production areas, as a rule very far apart from each other, as if transportation times had been increased on purpose.

The Increase in "Leisure Time"

Leisure time is whatever time remains available, after all the priority activities have been deducted: childhood, schooling period, and during adulthood, the physiological time required for sleep, for vital rest and meal time, work time, time spent in transit. This "residual amount" may be used by men and women as they see fit; it is above all the time of freedom, of the gratifying activity, of individual expression, of generosity and of participation in altruistic collective actions. Undoubtedly, society is changing in contents, especially as far as the essence of consumption is concerned, when this "residual amount" becomes large enough to raise a major activity problem.

Figure 6 gives an illustration for France, of the observations carried out for 150 years. It represents a kind of "phase shift", to use an expression with which physico-chemists are familiar.

This increase in leisure time results mostly from the technical phe-

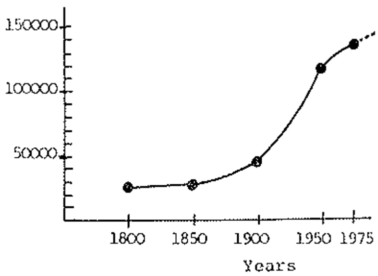


FIG. 6. Total of leisure time available during one lifetime for an average person born in France, on the basis of observations carried out from year to year.

nomenon of the growth of productivity in agriculture (3), and then in industry (4) and, in the near future, it will come from the tertiary sector occupations through the improvements brought in by the "télématique" tools (5).

The leisure time problem is currently being reinforced by the increase in unemployment in the industrialized countries and by demography in the developing countries. In the OECD countries, 6 to 7% of the active labor force is unemployed. Either the unemployment problems will be solved by sharing the work, but then leisure time will significantly increase for everyone, or it will not be possible to avoid having large masses of unemployed people and for them the whole time is turning into leisure time . . . As to the poor countries, the problem is to secure the necessary financing to create jobs. As of now, China is faced with an annual demand of 10 million new jobs; according to its birth rate, in a relatively near future, Algeria will be confronted with an even more serious problem at its scale with 500,000 jobs to provide every year. And what shall we say about countries such as Egypt, India or Mexico?

It becomes evident, according to the analysis rendered necessary by the energy crisis, that said leisure time cannot be simply that of idleness; the economic impoverishment would intensify but, to a higher degree

(3) Agriculture benefited at the same time from developments in fertilizers, in pesticides and in mechanization. It is entering the biological development phase.

(4) The drive on industrial productivity was at first organizational (taylorism) and mechanical; it becomes electronic and data processing in nature especially through microprocessors. The "robotique" is only in its early development.

(5) Office work is becoming automated through "burotique" (automatic text processing, magnetic filing, teleprocessing networks, distributed data banks, etc.).

yet, political stability would be affected by it: no society rooted in idleness could be conceived.

Therefore, there is a two-way energy/leisure time interaction. The type of activity accepted for the leisure time will determine the consumptions and, hence the energy costs. Reciprocally, the energy amount available for the creation of jobs will determine the amount of leisure time available and probably its social and geographical distribution. Only one element may be considered as highly probable: no stop or even no slowdown will occur in automation developments, i.e. in organized work productivity (6). The distribution of the industrial and commercial opportunities between the industrialized countries and the expectations of the new electronic, data processing and telecommunication techniques are too promising to be overlooked. On the other hand, why would man give up this golden age dream in which he could watch machines work for him?

The Growth of Time Devoted to Education

Since the XIXth Century, in the more developed countries, school attendance has become compulsory for everyone. The practical consequences of this decision have been a constant lengthening of the studies duration and a progressive loading of the program contents. An increasingly larger number of students enrolled in higher education, to the point that there no longer is any adequate ratio between the number of diplomas issued and the number of high level positions offered.

In spite of this drive, a triple failure is being registered. It is becoming impossible to transmit the amount of knowledge accumulated by the development of science and of techniques; the courses are as frequently as not anachronistic in content because teachers are teaching what they learned themselves 10 or 20 years before while preparing men and women to assume responsibilities 10 to 20 years later in a very different scientific, technical and geopolitical context. Children and teenagers receive their training from two sources: the schools and the media, especially radio and

(6) This assertion runs into the objection of the global drop in productivity observed in recent years in the United States. Actually, there is no stop in the agriculture and industry productivity gains any more than in the tertiary sector work, but there is a rise in the society complexity, hence an increase in the "social software" activities which conceals the other activity gains.

television. However, schools and media are broadcasting messages most often with no relationship with one another.

The energy crisis supplies an additional factor of change. Normally, provided the governments accept to exercise their responsibilities, the research and development effort should be encouraged and new economic and social adaptations should help accelerate the changes to which our civilization is subjected. The problems of program contents and of their anachronistic nature will remain impossible to solve, as long as the basic concept according to which the essential share of the knowledge must be imparted in the early phase of life will persist. It should be acknowledged that the transmission of knowledge, i.e. training, is becoming one of the top priorities in the time-balance sheet of one lifetime, that knowledge acquired during youth should be above all helpful to "learn how to learn", because the knowledge actualization and the improvement and changeover efforts will go on during the whole lifetime; a type of continuum needs to be established between school attendance, continuing education and information. On the other hand, it should be acknowledged that the preparation for the proper utilization of leisure time is becoming just as important as the preparation for professional activities; not only will children become workers, but citizens as well, and it should be expected that one of rhe fundamental duties of adults will be to assume responsibility for themselves in the full respect of the infinite value of the human being.

There is nothing new in what was just said concerning the time-balance sheet, about the wastes in transit, about the usefulness of leisure time as an economic asset and as a human furtherance value and an education. As early as the 60s, many sociologists and philosophers attempted to call our attention to these reflections of a major import ([7]), but it took the energy crisis for the media to subscribe to these topics and for the political opinion to start considering them as valid, without, however, showing so far, either enough creativity or enough fortitude to carry them to their practical conclusions.

The new data technologies and the "ligbt" biological technologies supply their active contribution in these areas as well. In this, we link up, through another way, with the thinking of Umberto Colombo regarding urban development and decentralization. Through the telecommunications, the teleprocessing and the data banks, it becomes once more possible to offer an intellectual potential to men residing throughout the countryside and to bring back the rural areas from their isolation. The "burotique" tools will permit carrying out the secretarial, administrative or accounting functions at home, the way some of the so-called liberal profession activities have been carried out for a long time. And if women and men wish to work away from their residence, in order to multiply the opportunities of interpersonal relationships and to avail themselves of a sophisticated equipment, the same new transmission and processing tools would make it possible to regroup the jobs far from the production system and close to the involved people's residences; such experiments are in progress in most of the industrialized countries, and particularly in France, in Marnes-la-Vallée. The whole housing and job geographical distribution problem could be re-examined.

It may be hoped as well that, little by little, we will learn to use properly, for schools and for continuing education, the high capacity data and experience exchange means offered by the audiovisual devices, in spite of all the disappointments encountered so far.

5. The birth of an interconnected world

The phenomenon of the across-the-state-border intercommunication of economic and cultural systems is nothing new. History abounds in examples: the "road of the tin" was the supply way for the bronze age, the "road of the silk" provided the distribution of the wealth of the Orient to the West. But never, as this has been the case in the recent years, did the across-the-border exchanges attain such an intensity, to the point it can probably be stated that their nature was changed.

The air transportation up-to-date techniques, but above all the new data technologies throughly modified the commercial, financial, scientific, technical and cultural exchange conditions. The volume of scientific periodicals is rising by approximately 14% every year, so much so that, in the course of one single year between 1985 and 1990 the publishing of periodicals will surpass in quantity, if not necessarily in quality, all that scholars have produced since the origin of science up to mid-XXth century.

This wealth of data is intended to be distributed throughout the world for the benefit of the scientific community. Thanks to the telecommunication satellites, distance no longer is a cost-wise, quality-wise and transmission speed-wise sensitive variable. Thanks to the data banks

(7) Cf. chiefly, Bertrand de Jouvenel, *ARCADIE, Essai sur le mieux-vivre*. Futuribles, S.E.D.E.I.S., Paris, 1969.

and to the computer networks, data may be rendered accessible, marketable, easily consulted and supplied in an almost complete fashion. The same amazing development of the data exchanges, most frequently aimed at organizing product transfers or human transportation, i.e. now with the object of entering commercial circuits, can be observed between financial and commercial centers, travel agencies and police forces for the the control of fraud or terrorism. Table 2, without claiming to be exhaustive, illustrates some of these across-the-border flows constituting nowadays a kind of nervous network covering the whole world, independently, or nearly so, from any political control.

The weight of the international solidarity thus created is worth becoming aware of. These data flows reinforce or launch material or cultural exchange flows. Europe's and Japan's very existence is based upon

TABLE 2 — *Flow of the across-the-border data.*

- — International business transactions.
- — Multinational firms management.
- — Processing of major remote computing on specialized control systems.
- — Remote search of large data banks:
  Concerning scientific data;
  Concerning technical data and patents;
  Concerning economic and social statistics.
- — Remote search of decision making assisting mathematical models (economic projection, study of offer-demand equivalences concerning energy, raw materials, demographic projections, etc.).
- — Airplane, train, hotel reservations for tourism or business travel.
- — Organization of freight traffic.
- — Remote financial transactions (stock market, foreign currencies etc.).
- — Application of observation satellites, especially in remote detection and in weather forecasting matters.
- — International delinquents surveillance (drugs, terrorism, etc.).
- — Armed force management within large military alliances.

Note: Of course, this list is not exhaustive. Each one of the listed activities rises by 10 to 20% in data flow volume annually. According to an FCC (American Federal Communication Commission) study, the annual growth of the across-the-border flows from the United States on leased lines was estimated at 21%. For France, the Ministry of Industry has projected a 15 to 30% annual rate of growth up to 1985.

the production of these exchanges upon which neither disposes of any actual political control. The Western and Third World economics developed through interrelations within the framework of an outstandingly expanded commercial freedom; thus every country has become dependent on the world around it. Only the two superpowers, the USSR and the United States could survive isolation without undue adverse effects.

Nations differing as widely as Argentina and Poland can develop their economies only on the basis of outside financial credits. In West Germany, as in France, one of two industrial jobs is involved in the manufacturing of products for export. Food supply for whole African and Asian area populations is possible only through the import of agricultural food stuffs. Even China had to renounce its isolation policy.

This observation has a very important implication in the search for solutions when confronted by the energy crisis. It would be unfortunate for decisions to be made solely upon the consideration of national self-interest. The transformation of agricultural spaces assigned nowadays to the cereal production into solar energy production spaces, by means of radiation collectors or through the indirect way of photosynthesis, may represent a suitable solution for the energy independence of some countries. Should such decisions be made on a large scale, it would be disastrous to remain unaware of the possible consequences on the world food problems. Similarly, should autarchical trends prevail, the damages inflicted upon some economic areas by restrictions of international trade freedom could be significant, especially for such development centers as Western Europe, Japan and Southeast Asia.

But the expansion of the international nervous system through the development of across-the-border data flows is far from having only adverse characteristics. Owing to them, international trade could keep on developing, even in the event of limitations in people's rapid transit. Certain geographical specializations, corresponding to a better international work distribution in regard to energy sources, could be organized. On the other hand, the wealth conjunction created by the intensity of exchanges leads to non-war status. As pointed out by Samuel Pisar, a war between France and Germany is nowadays unthinkable, not only for humanitarian reasons or because it would not be advisable in function of the price to pay, but basically because both German and French economies have become complementary: no ill feelings can be harbored toward a neighbor who is both one's major supplier and one's own most faithful and wealthy customer. The political structure based on the international informational, cultural and economic exchanges systems is a vertical structure; no longer is it the geographical space but the technological superiority and the commercial action capacity which characterize the competition stake. The contest did not vanish, but it passes from the military field to the economic field and, for causality reasons, to the scientific and technical field. While not being fully satisfactory, this situation constitutes an advance over the solutions contemplated in history to solve crises by resorting to armed domination. Such an advance should be preserved and even be amplified in consideration of the evolution of the challenge leveled at us by the energy crisis.

In consideration of the solidarity requirement, the simultaneous existence of glutted industrial economies, of huge capital surpluses coming from oil sales searching for a utilization on one hand and of urgent basic needs in poor countries on the other hand, is more than a moral scandal, it is an absurdity.

The West's Responsibility

Last summer, I was in the China People's Republic and I had the opportunity of meeting there some persons responsihle for the future of this vast country. "The economic development", they told me, "seems to be based on energy consumption; each American consumes annually 11 tons of fuel oil equivalent. In the year 2,000, in spite of the very strict measures taken for birth control, there will be 1-2 billions Chinese. How is it possible to find the energy required for their development? How is it possible to find the capital required for a decisive advance in the per capita availability in energy for a country blessed with such an enormous population, even if it could be assumed that fossil reserves and renewable resources may physically allow this progression?".

The people I was speaking to must have been disappointed with my answer: "It is up to you", I tried to explain, "to create a new society in which economic activity is not tied to the available energy resources, as this is the case today in the West". I was fully sincere, but there was nothing which could prove that I was not simply trying to circumvent an issue by refusing, besides, to share the knowledge and the power which are at the basis of our technician civilization.

Indeed, the changeover harbinger data can find their development conditions only in the technically most advanced civilizations, characterized besides by a certain measure of freedom left to individual initiatives. It is in the West, and there only — Japan of course being included — that the factors propitious to the "light" technologies' ("télématique" and biology) strides may be initiated and amplified. This is where the data harbinger of a change in the work and consumption contents do appear, where the issue of time scheduling begins to be raised, not out of mere intellectual curiosity but under the pressure of the full employment requirements and of a follow-up of the social objectives to suggest to the citizens. For circumstantial reasons — because they are leaders in the technical evolution — but also because they still command the financial wealth needed for such changeover, these nations having reached the technician civilization phase may act as pioneers to help humanity accede to the "knowledge civilization", in which intellectual activities will prevail over purely materialistic ambitions, in which information, knowledge, culture will become the priority raw materials. Of course, it cannot be denied that man is "incarnate", i.e. that his full development requires the expenditure of large amounts of material goods and facilities, especially for work automation, which assumes a minimum, relatively high energy consumption level. But man is first of all spirit-bound and all the advances achieved in the technical fields concerning data seem to both invite him to become once more aware of his destiny priority condition and to offer him the tools of a better achievement. The energy crisis is providing a caveat: should we fail to curb our excesses, we will create unsolvable problems, i.e. catastrophic accidents.

This responsibility of the West, which is tied to its very power, is also the consequence of the fascination its apparent success exercises on other populations. It would be advisable for the various areas of the developing world to find in their own culture the path for their advance without relying excessively for their inspiration on the technician civilization model.

Because we are aware that this civilization cannot physically expand to the whole world and that it entails a surplus of errors connected with the wasting of resources and with the insufficient consideration of man's superior needs, the spiritual and moral callings. But it should be acknowledged as impossible for the people in charge of the development, struggling with poverty, not to be strongly attracted by the only economic solutions bearing all the semblance of success and power, those established by the industrialized countries.

Therefore, as a last resort, the energy crisis materializes as a call for our own changeover and, from this viewpoint, it includes aspects to be considered as beneficial.

Reassessment of Evolution Consideration

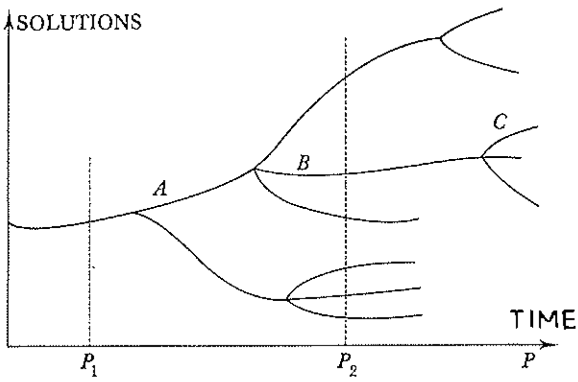
The knowledge we possess today about the evolution phenomena may help to better grasp humanity's present status. Jean Couture's paper elicits the steps our ancestors went through in the control of energy: fire, coal, electricity, the atom. Human progress could also be considered in connection with the conquest of materials: stone, ceramics, bronze, iron, steel, aluminum, titanium, uranium, organic compounds, biological products; or yet with the conquest of shapes: the wheel, the amphora, the chariot, the wheelbarrow, the train, the airplane, the spatial vehicle. Of course, such advances generate one another and there can be no achievement in one given field unless the attainments reached in the other fields are first well established. Up to now, although it has been determined that civilizations are mortal, there has been no sign of actual retrogression in this domination of nature by man, except for sharply limited in time and rapidly overcome accidents. Available knowledge, its exchange and memorization possibilities may also be taken as a reference; attention is then called to "data" and to the tools for its communication. The evolution steps are the following ones: the invention of articulated speech, of writing, of printing, of electronics, of telecommunications and of data processing. Matter, energy and data, which we know according to physics' recent acquisitions, may be transformed into one another, constitute the indivisible expression of these advances in human power.

Depending on one's own professional specialization, each person assigns the major role in advances to materials, or to energy or to data. The energy experts who are in large numbers in this symposium, may be apt to grant it priority. Personally, I would be rather tempted to follow J. Ruffie ([8]), the biologist, who, as he observes the evolution of the mineral world and then that of the living world and of human societies, discovers a non-variant in these phenomena: "the constant thrust of complexity and psychism"; which I would unabashedly translate into other words by: "the laborious emergence of mind from matter, thanks to energy".

Two facts are particularly noteworthy: on one hand the acceleration of the evolution and, on the other hand, the importance of the random element in the process.

The acceleration of the evolution raises for man a new acculturation problem; the accessible universe is no longer a natural one, but an artificial one. The "mechanical kingdom" dominates the mineral, vegetable and animal kingdoms with which the children in some large urban centers are no longer acquainted. Men experience difficulties in incorporating such a rapid change in their culture and the cultural tools available to them seem inadequate in proportion to the events. The energy crisis should remind us of the forgotten priority of the cultural values; the more quickly the technique impact progresses, the more vigilantly should they be cared for.

The importance of the unpredictable, of the random elements, has been mentioned by Darwin who, as early as 1865, had clearly brought out the importance of the trial-selection process in the evolution mechanism. Recently, Ilya Prigogine supplied an essential contribution to this thinking on the random element in calling our attention to the evolutions through bifurcations (Figure 7).



Bifurcation diagram

FIG. 7. Bifurcations diagram (PRIGOGINE).

This dissipative system evolution theory can be expressed as follows: — when an energy flux passes through a finite system, it uses a portion of this energy to make its structure evolve. During a certain period of time, the structure evolves in a continuous process by feeding, so to speak, on the environment. For instance, the economic activity corresponding to a given industrial, commercial and social structure did, in the course of recent years, so to speak, develop by gorging on oil. This structure-environment relationship can be only of a limited duration,

(8) J. RUFFIE, *De la Biologie à la culture.*

because the gradual environment modification, in the present case the finitude of tbe fossile resources, leads to nonadaptations. Then, a bifurcation point is reached where the considered phenomenon undergoes a mutation which is akin to what is called in physico-chemistry a phase shift. As a rule, there are several new possible solutions, more or less equiprobable. The selection between these solutions will be made under the effect of a "fluctation", an initially low amplitude perturbation which may be rejected by the environment and vanish in there, or on the contrary, be accepted in there so that it may develop its effects to the point that the tipping toward one of the solutions, and one only, will become irreversible. Most frequently, such fluctuations are of a random nature at their origin; they succeed or fail through the trial-selection process provided of course, that the degrees of freedom be sufficient to allow "the trial" to take place. If the system is excessively constrained, it may pursue its course for a while in a metastable condition which is very similar to the change of state lag phenomena in physics. If this has to do with economy, it may go into supercooling, so to speak; this is our current situation in which the nonadaptation signs are numerous: — inflation, unemployment, monetary disorders, inequalities having reached unbearable levels — without any will on the part of the political systems to accept the risk of a new distribution of the structures such as a fundamental modification of the consumption structures, of the work structures, of the time scheduling structures. Indeed, such changes would come together with a new distribution of the powers and of the privileges.

However, the fluctuations are there: they are these changeover harbinger data which we discussed in the first part of this paper. Their random nature should be stressed, random in that most of them were unpredictable and do not result from a rational will on the part of man. In 1950, nobody, although the first transistors were already operating, nobody could have foreseen the coming of the microprocessors, of the lasers, of the optical fibers, of the telecommunication satellites with their assortment of performances and applications. The way through which these inventions came into being is in itself strange and irrational. It is under the effect of a research for ever more sophisticated weapons and through vying for the spatial performances prestige race, that human evolution's decisive elements have been born and not through the precise and concerted intent of improving well-being conditions.

Thus, it would seem that man is merely a companion in a creation which could go partly without his participation, above him. He cannot oppose evolution, but he may alter its course, he may try to delay its evolution by subscribing to a nonadapted conservatism; inescapably, one day, a break occurs which can be apprehensively looked at as a generator of catastrophes. He may also make himself available to accept furtbering the growth of the fluctuations which will appear beneficial to him for a propitious change. Man still has the option to change the environment's receptivity by introducing in it cultural and spiritual values, particularly by broadening his mind, not only with scientific and technical, but also with philosophical and metaphysical knowledge.

The energy crisis should incite us in becoming aware of our responsibility; it is evident it is placing us at a bifurcation point. The action on fluctuations which will make us tip toward a new development cannot find its origin solely in technical matters and we must accept the risks of a changeover in structures and in attitudes. With this provision, and the studies already carried out on the subject being taken into account, it seems legitimate to me to answer with some optimism to the questions formulated in this paper's introduction. Yes, it is sensible to contemplate a new future for civilization: the tools of its advent are there. Of course, huge efforts should be undertaken, especially in the alternate source of energy field, because it will not be possible to radically reduce the consumption level of this essential element and right now, we must think in terms of an approximately 10 billion human being population and not 5 or 6 billions. But, all things considered, if we know how to meet the crisis challenge, the period we are presently living in will be regarded by our descendants as a particularly fortunate and opportune event. What would have happened to us if we had waited to act until the complete physical exhaustion of our fossil resources?

ENERGY AND THE LONG-TERM PROSPECTS FOR THE INTERNATIONAL SYSTEM

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The true dimensions of the problems raised by evolution of the world energy system during the coming decades can only be grasped when considered within a more global analysis. The truth of this is demonstrated by noting the impossibility of finding satisfactory answers to many essential energy-related questions within the simple framework of the energy system. Two examples are:

— Why have other primary energy sources not been progressively substituted for petrol as the price of energy has regularly increased?

— Why have the developed nations, particularly the United States, reacted without great vigour to the threats clearly revealed by the first (1973) oil crisis?

The present report attempts to analyse this global interaction between the energy system and the international system. However, a few preliminary remarks are in order:

1) The difficulties facing mankind in the field of energy are ones of transition, rather than very long-term problems. This transition will include a first phase, in which the main substitutes for petrol will be other fossil fuels (coal, etc.) and thermal nuclear fission reactors, then a second phase, characterised by the large-scale use of renewable and quasi-renewable energy sources (fast breeder reactors, solar energy, nuclear fusion reactors, etc.). Although these two phases may overlap, the second will occur mainly in the 21st century, whereas the first will dominate the next three decades.

This report considers only the first phase.

2) Three types of energy "crisis" are capable of occurring at the same time during this phase: a crisis due to the progressive depletion of petrol reserves (but the term "crisis" is not at all suitable for this continuous phenomenon); a crisis due to the limitation of petrol production, resulting either from policies of restriction, deliberate or otherwise, on the part of oil producing countries, or from the worldwide distribution of investments in exploration and extraction, and having both economic and political roots; and purely political crises due to conflicts or revolutions in the Middle East (1973 Arab-Israeli war, the revolution in Iran, the war between Iran and Iraq, etc.).

3) Understanding of the second two types of crisis (the most important) can come only from an economic, social and political analysis taking account of all the following:

— transformations in the international system;
— the evolution of the developed nations;
— the difficulties of the Third World;
— world economic prospects.

These four subjects are considered successively herein, with particular reference in each case to their relationships with energy issues, ending with some reflections on non-energy policies capable of facilitating necessary changes in the energy system itself.

1. Transformations in the international system

With the exceptions of the Russian "empire" and China, the world has been dominated since the end of World War II by the regulating role of the United States. The USA is far and away the leading military power in the world; it accounts for a considerable fraction of the planet's total GNP [1]; its currency, the dollar, is central to the world monetary system; it has persuaded its allies to accept free trade and free transfers of capital and technology; and, until its engagement in Vietnam, it did not oppose granting political freedom to the Third World, at least insofar as formal independence was concerned.

[1] 32% in 1970.

The results are known to all:

— rapid economic growth in Europe;

— the rise of Japan, with previously unheard of growth rates;

— complete modification of the world political scene, with about a hundred new states becoming members of the United Nations, but with widely diverse economic performances on the part of the developing nations, due to their widely differing internal social dynamics and to the economic dominance of the center of the world economy;

— considerable increase in world trade, the developed countries not hesitating to increase their dependence in a context characterised by the stability of external relations.

With respect to energy, the two major facts during this period were:

— the progressive substitution of petrol for other sources of energy, with Europe and Japan receiving most of their petrol from the Middle East;

— the preserving by the United States of a certain stability in the Middle East, but with greater and greater difficulty.

The policy of the United States in the Middle East was based on a quadrilateral system: to the North, Turkey (a member of NATO) and, after liquidation of the Mossadegh regime, the Iran of the Shah, with an extension outside the zone to Pakistan; to the South, Israel and Saudi Arabia (and, to a lesser extent, Jordan). Political crises have been numerous in this region during the last 25 years: Nasser's revolution in Egypt; coups d'état in Syria; the revolution in Iraq; the coming to power of Ghadafi in Libya; turmoils in the Lebanon; the Arab-Israeli wars; disturbances fomented by the Palestinian diaspora; etc. Once, when Nasser called for the help of Russian troops, and the USSR drew Syria, Iraq, Aden, Somalia and others into its orbit, the United States lost control of the situation, caught between its support for Israel and its Arab friendships. Sadat and Kissinger reversed the situation, but throughout this period, the privileges of the petrol companies were steadily eroded, and frustrations and resentment progressively built up within the Arab world.

In view of this, the sharp rise in oil prices in 1974 may be seen as one sign of the transformation in the international system, rather than as simply the effect of a fortuitous political crisis. Partly because of the success of post-war policies, the international system is becoming *multi-polar* and *interdependent*, and these two evolutions are the key to understanding certain aspects of current energy issues.

A. *The international system is becoming multipolar*

It has become fashionable to talk about the decline of the United States, with the risk of going from one extreme to the other and extrapolating to the medium- and long-term the image left by recent events. Our analysis must go deeper than such a superfluous view of the future. The United States of tomorrow will probably be characterised by both unquestionable strengths and definite weaknesses. The strengths will include very large fossil fuel and mineral resources; enormous agricultural potential; an unrivaled network of international banks; major multinational industrial companies; and military might, however blunted. Amongst the weaknesses we may count the conflicting aspirations and values within American society (even if these conflicts hold promise for the future); the large number of citizens deprived of the benefits of economic growth; forms of management perhaps on the decline; administrative and political systems in need of reform; ageing industry; and insufficient innovation, evidenced by a negative flow of patents. Under these conditions, some have forecast the emergence of a new isolationalism in the United States, but this is unlikely. However, the "world presence" of the United States may well take different forms from the past: a quest for collegial management of the world economy, in partnership with the main developed nations, so as to progressively reform the functioning of the international economic system; a preference for policies determined uniquely according to the short-term interests of the American economy; etc. In this respect, the United States' choices for the future will be fundamental to the evolution of the international energy system, because they will govern world demand for imported petrol and world availability of coal for export.

Although lacking domestic energy and mineral resources, and with an unfavourable agricultural situation, Japan is a rising economic power, despite its vulnerability. If the international trade system remains as "open" as at present, Japan may well by year 2000 account for 10 to 13% of world GNP, with a per capita income in terms of real purchasing power roughly equal to that of the United States. However, although at the end of the century, it will probably he the world technological leader and the center of a string of Asian countries undergoing rapid development, Japan cannot replace the United States. It will make great efforts to maintain free trade, reduce its dependence on imported petrol, and assure secure supplies of coal from Australia, Canada, the United States and South Africa.

The third major economic pole in the North is the European Economic Community (EEC). As for the USA, its part of world GNP will decline, from 20% in 1970 to 14-16% in year 2000. Its handicaps are evident, and continuing dependence on imported oil and raw materials is one of the certitudes of Europe's future. Even if a vigorous policy of energy conservation and development of substitutes for petrol and gas is pursued during the coming decade, Europe will still in 1990 depend on the outside world for about half of its primary energy, and will have to import at least as much petrol as now. Also, the position of Europe in the new international distribution of industrial work is by no mears assured. European agriculture is technically advanced, but its production costs are often higher than world market prices. As for the machinery of the Community, it can be nothing but cumbersome and chaotic. Thus, for the EEC, it appears that freedom of action is diminishing, dependence and vulnerability are increasing, and the sources of dispute are multiplying. However, on the other side of the balance sheet, the EEC is unquestionably rich in human resources, augmented by the diversity of European cultures, and possesses a major scientific and technical potential, a market which although heterogeneous will still be the second largest in the world at the end of the century, an industry covering the entire spectrum of human activities and products, and highly-developed economic and political relationships with virtually the entire planet. In the future, the EEC will become the world's leading coal importer, but will continue to depend for its petrol largely on North Africa and the Middle East. As a consequence, one of the main unanswered geopolitical questions concerning the future is the nature of the relationships that will exist between Europe and the Arah world, in all areas (energy, industry, food and agriculture, finance, tourism, human, etc.).

Facing the OECD zone, the situation of which is outlined above, the USSR and the European members of Comecon will experience during the next two decades internal conditions less favourable to economic growth than during their recent past. For this reason, their growth will be slower, their capacity to pay for imports reduced, and the cohesion of the Comecon countries threatened. Despite this, the hypothesis of a continuity in the strategy of the USSR and of the present status quo in Western Europe is the most likely, although not the only envisageable. The energy supply situation of the Eastern Block countries will deteriorate. Although the USSR has immense reserves of coal and petrol, their extraction will be more and more expensive, and many experts do not exclude the possibility of oil and gas supply difficulties in the East

European countries after 1985, the USSR being unable to simultaneously satisfy the needs of its Eastern Europe allies, and maintain exports towards the West.

As for the vast Third World, a feeling of community is certainly growing, as witnessed by the Group of 77, but it is at the same time profoundly marked by differences in economic growth. According to one of the scenarios in the OECD Interfutures study, the world population at the end of the century will he distributed as follows: 22% in the developed countries of the West and East; 12% in the new industrial nations (per capita revenue greater than 2500 US dollars, 1976 prices), mainly in Latin America and East and South-East Asia; 28% in the two great poor regions of South Asia and Black Africa (per capita revenue less than about 300 US dollars, 1976 prices); 38% in China and in countries with intermediary per capita GNPs, scattered throughout the world. With an industrial growth rate of around 10% per annum, China may become at the beginning of the 21st century — but probably not before — a significant industrial power, accounting for perhaps 8% of world industrial added value. In all, the proportion of world GNP associated with the Third World will rise between 1970 and 2000 from 18% to 32%, while its corresponding total GNP may be multiplied by 4.

Geo-economic multipolarity and, to a large extent, geopolitical multipolarity both directly influence the capability of the international system to manage energy crises, because they make it more difficult to preserve stable and united coalitions capable of regulating the factors governing world economic growth. A multipolar world is vastly different from the two extreme cases for which economists consider themselves capable of making predictions, namely the monopoly (or, at a pinch, certain forms of duopoly) where a single player controls the situation, and perfect competition, in which the players are dominated by an environment which they cannot influence and which draws its stability from the sheer multitude of its constituent parts. A multipolar world is like a complex oligopoly, in which players of various sizes and forces modify their mutual environments and are sources of mutual instability, which is the greater the higher the degree of interdependence between the constituent elements of the system, and which excludes neither revolutions nor wars.

B. *The international system is increasingly interdependent*

This interdependence is not only economic. It is also cultural, religious and social, covering almost all human activities. In the economic area, it affects:

1) mechanisms and their associated institutions: the International Monetary System, international markets and exchange regulations, etc.; and

2) flows of resources: energy, raw materials, agricultural products, industrial goods, technology transfers, financial transfers, etc.

As for energy interdependence, its future dimensions are well known, and it is not necessary to analyse them in detail here, with the proviso that due allowance must be made for the financial and technological transfers necessary for development of resources, particularly in the Third World, as well as flows of energy resources proper (petrol, liquified natural gas, coal, nuclear fuel). Instead, and in view of the subject of this report, discussion is concentrated on the influences of energy interdependence on the other aspects of interdependence.

Firstly, on *financial interdependence*. After the first sharp rise in oil prices, the total current account surplus of the thirteen OPEC countries was multiplied by at least 11 in just one year, increasing from 6 billion dollars in 1973 to 67 billion dollars in 1974. Many experts then predicted a catastrophe which, as we are all aware, did not occur. Due to the explosive rise in imports of goods and services to the petrol exporting countries, the following years saw a progressive decline in the annual surplus. Indeed, the global current account surplus of the OPEC countries even went 1 billion dollars into the red in 1978. What happened to the previous years' surpluses? They were invested as short-term bank deposits, in securities, and for a small part as long-term loans and in real estate. At the same time, the network of international banks greatly increased its loans to developing nations, accounting in 1977 for 27.2% of their external financial revenues compared to 3.4% in 1970. In 1979-1980, with the second sharp oil price rise, history seems to be repeating itself, but on a larger scale.

In two years, the OECD countries have accumulated a supplementary balance of payments deficit of 61.5 billion dollars and the Third World (excluding the OPEC countries) an additional deficit of 107 billion dollars! However, the similarity between the two crises is fallacious, because the banking system is saturated with short-term deposits, like blotting paper saturated with water, and is reluctant to increase its risks; because the petrol exporting countries want to master their growth, and thus prefer to limit or reduce their production, investing their surpluses through the only channels that remain open, namely US and British treasury bonds, direct loans to the governments of developing nations and, perhaps tomorrow, loans to the IMF. What must be preserved at all costs is the availability of loan capital for the entire Third World. One certainty is that recent energy crises have increased the fragility of the international monetary and financial system, to the extent that a major crisis in this system cannot be excluded in the event of insolvency of a major debtor, of massive movements of short-term deposits, and of the incapacity of governments to rapidly create a "safety net" for the banking system. However, the probability of such a crisis is lower than at first sight.

Although less direct, the influence of the energy system on *agricultural interdependence* is just as certain. In 1977-78, the Third World countries (including OPEC members) imported from OECD countries about 40 million tons of cereals, representing about 10% of their consumption. If current trends in supply and demand continue until the end of the century, this figure may reach 80 to 100 million tons in 1980, and 140 million tons in 2000, or 18% of Third World consumption! Of course, we must be prudent, as such forecasts are highly sensitive to the assumptions made. Anyhow, the origins of this demand are threefold:

— firstly, the OPEC countries, for which the degree of food self-sufficiency is rapidly dropping, and which will probably use an increasing part of their export earnings to import agricultural products;

— secondly, the new industrial nations, which can acquire agricultural products in exchange for manufactured goods, but in which competition will be severe between the demands for imported energy and imported food;

— lastly, the very poor nations of South Asia and Subsaharan Africa, which suffer from infrastructural, institutional and climatic constraints that cannot be rapidly overcome, and for which export earnings are too low for large-scale importing of food products. However, for this group of countries, the forecast food deficit is only 5% of total planned food production (except in a few cases, where the figure is as high as 15%), and a massive effort to reduce losses in storage and distribution (more than 10% at present) would greatly reduce the deficit. Even so, for these nations, the rising price of energy will make it even more difficult to balance external payments and will increase agricultural production costs. For this reason, increased financial and food aid by the OECD and OPEC countries is essential.

A third aspect of interdependence is that of *industrial interdependence*. Even though the part of the Third World (excluding China) in world industrial added value may rise from 7.7% in 1970 to 17-18% in 2000, this is a worldwide process, much more than a rebalancing of North-South differences. This worldwide process involves increasingly intense competition between developed nations, the emergence of new industrial nations, and growing exports by the Eastern Block countries to reimburse their debts. The world energy system has a triple influence on this industrial process. The first is obvious: The rise in the price of petrol increases imports of capital goods by the OPEC countries. The second is easy to understand: each industrial nation is attempting, using subsidies when necessary, to increase its exports so as to reduce its balance of payments deficit, and this is aggravating international competition. The third influence is more subtle: Thanks to a tacit collusion between OECD governments, multinational companies and Third World governments, the energy crisis encourages worldwide wastage of capital and labour, reinforcing the trend towards poorly directed industrialisation advantaging equipment and disadvantaging employment. The OECD countries must at any cost balance their external payments, and for this they must export, with their governments not hesitating to subsidise exports of capital goods to the extent that interest rates on loans to purchasers are often negative in real terms. The multinational companies, for their part, often promote equipment designed for the developed world and the result is a long technical evolution designed to minimise the scarce production factor in such nations, namely labour. Finally, the Third World governments tend to work in the same direction because, for understandable reasons, the most modern technologies have the favour of their functionaries, of local businessmen and sometimes of the trade unions. The abundance of liquid assets created by the International Monetary System, partly because of the petrol revenue surpluses, inevitably facilitates this waste of capital, as well as the consequent creation in the Third World of less industrial jobs than would be possible otherwise, and totally inequitable distributions of wealth and income, which curb development of markets for mass consumer goods.

Thus, while multipolarity influences the transformations of the energy system, the latter in turn are the cause of increasing energy interdependence between groups of nations and of profound modifications in other forms of interdependence. In a multipolar context, interdependence can be equated with vulnerability and, for this reason, some experts strongly recommend dividing the world economy into a number of "uncoupled" blocks. However, the adequate response to a relationship of interdependence is not always the same. Thus, when a country limits its energy consumption to reduce its risks, this also diminishes tension within the entire international system, reducing the probability of breakdowns and increasing stability. Inversely, refusing imports of industrial goods from the Third World so as to avoid local difficulties in the developed nations slows growth in the new industrial nations and can accentuate the cleavage between the developed and developing countries. In other words, mastering a multipolar, interdependent international system involves policies more complex than is sometimes admitted.

However, we cannot truly understand energy issues if we limit ourselves to analysis of the relationships between nations, because the internal evolution of national societies is at least as important, principally that of the developed countries.

2. The evolution of the developed nations

During the first 20 years after World War II, the evolution of industrial societies at the national level could be explained by economists largely in terms of macroeconomic growth. Whatever the extent of political differences between social groups, a consensus seemed to exist in favour of an objective of economic growth accompanied by low inflation and almost full employment. Structural transformations during this period were deep-seated, but the rate of growth was high enough to accommodate the changes it engendered, while also allowing the pursuit of other objectives, particularly those of equality and security.

From now on, however, the complex relationships between values, growth and structures preclude a linear view of future development, and we should ask ourselves whether the advanced industrial societies are not about to start long internal transformations of a nature going far beyond the economic sphere.

A first type of transformation will concern values or, less deeply, people's aspirations. This transformation is already exerting multiple influences on governmental policies, including energy policies.

A second transformation will involve forms of social oligopoly (various social groups organised to negotiate with each other and with the government) which curb social adaptability.

More generally, the industrial societies seem to have secreted rigidities which modify the conditions in which function the three major economic institutions on which their post-war development was based; the market, the Welfare State, the macroeconomic policy.

As a result, while the energy system multiplies the problems that must be resolved by governments, the implementation of adequate government policies is coming up against considerable difficulties in the developed countries.

A. *Value changes in industrial societies*

If the system of human values, the secret motor of human action, is really changing in the industrial societies, this will have immense future consequences. However, announcing such a change is one thing, understanding and proving it is another. Changes in social demands may simply result from increased income and from greater choice. Conversely, their roots may go much deeper. Discussion of this lies beyond the scope of the present report, and we shall therefore limit ourselves to noting the progressive emergence in most developed nations during the last decade of new aspirations, which seem to be organised around two main desires: to be liberated and to establish roots. Although initially expressed by minority groups — who lived them out to a widely varying extent — these aspirations have been progressively adopted by large parts of the population.

The desire to be liberated manifests itself in all the social roles played by the individual, including the sexual, family and professional roles. The desire to establish roots does not translate into identification with the vast social groups of the past, but instead into a quest for integration into concrete groups dominated by inter-personal relationships: friendly groups in the factory or at the office, small geographical communities with specific purposes, religious sects, small political groups, linguistic and ethnical communities, and so on. Dialogue is based on an atmosphere of mutual understanding, in which each avoids judgements, self-assertion and condemning others. The counterpart is a disinterest for the functioning of society as a whole, indifference to the responsibilities of the individual towards the Nation, the Churches or a Party, and reduced understanding of the mechanisms which allow standards of living to be preserved.

The above tendencies also modify attitudes towards nature and the environment. For the responsible individual, the physical environment is a source of multiple exchanges, which are not limited to the conventional or the functional, while for the individual who is establishing roots, the environment is part of his or her "human space". It is thus hardly surprising if all that is artificial, including nuclear power, is seen as an aggression against what is considered an extension to the individual being.

Similarly, new scientific and technical developments give rise — at an unconscious psychoanalytic level — to the fear of a change in the relationships of the individual with himself (neuropharmacology), with his intelligence (computers), with the human species (mutations and genetic engineering), with the living world (destruction of ecosystems), with the cosmos (colonisation of Space and of the Oceans), and so on.

The extreme forms and attenuated versions of these new aspirations nonetheless have a common consequence: emergence in the advanced industrial societies of multiple groups with heterogeneous and divergent demands. This diversity and incoherence risk occurring also at the international level, due to wide variations in the equilibrium between social groups from one country to another. We may see a United States transformed into a coalition of minorities, a Japan in which awareness of dependence on the outside world will be a brake to change, and a dismembered Western Europe.

B. *Reinforcement of the social oligopoly*

For developed societies, the crisis in values is the seed of the future, but the organisation of social groups is inherited from the past, a heritage that will weigh heavier and heavier on their future. Although this organisation evolved throughout the 19th century and the first half of the 20th century, the Second World War was, above all in Western Europe and Japan, at the origin of a social regeneration founded on the institutional ruins left by the war. The social groups created new superstructures, new political parties were born, and new trade unions came into existence. However, with time, this creative fever died away, leaving the solidly entrenched elements of a social oligopoly, armed to negotiate between themselves and with the government. Why is this phenomenon so important, even essential? For two reasons:

— firstly, social oligopolisation tends to curb growth and slow adaptation within developed societies;

— secondly, social oligopolisation tends to transfer many demands from the economic system to the political system, and the functioning of these two systems is completely different. In the political arena, the only profits and losses that count are those sufficiently important to be grasped by the persons concerned and, for this reason, the political authorities satisfy one after the other the demands of the various social groups, ignoring each time the resulting adverse effects of these measures for the majority.

It is not exaggerated to say that the future of advanced industrial societies depends to a large extent on the evolution of their social oligopolies. In response to the aspirations of multiple social groups, these oligopolies prospered in the favourable context of fast growth, increasing the security of all, but at the price of sclerosis. A less stable external environment, more severe international competition, slower growth, and new values and demands will now put them through a severe test.

C. *The evolution of economic institutions in the industrial societies*

This progressive sclerosis is also evident in the evolution of the institutions that were the pillars of the developed economies during the last 30 years: the market, the Welfare State, and the macroeconomic policy.

Like a phoenix, the market constantly rises again from its ashes but, in the developed nations, the way in which it functions is being transformed.

1) On the one hand, the States are rejecting in the name of national independence the arbitration of private enterprise between the present and the distant future, between risk and security (even the United States, the home of free enterprise, recently taxed the windfall profits of petrol companies, to finance a public corporation set up to promote the development of energy projects).

2) At the opposite extreme, we are seeing the timid emergence of new economic forms which are independent, at least partially, of the monetary relationships governing the market and the Welfare State: transformation by households of goods into services, creation of not-for-profit associations for the production of goods and services, extension of illegal economic activities such as moonlighting, and so on.

At the same time, there are signs of a crisis in the Welfare State, encumbered by the absence of links between the behaviour of citizens and expenditures, handicapped by the complexity of its organisation, poorly regulated by the budget constraint, and threatened by the multi-faceted wave of claims from social groups seeking financial benefits from fiscal or parafiscal resources.

The third traditional pillar was the macroeconomic policy, which could be summed up as follows: stimulate the economy by increasing the budget deficit when unemployment rises in a depressed economy, and cool down the economy when growth is hindered by full employment, the balance of payments becomes overly negative, or the rate of inflation starts rising dangerously, the ideal being unemployment limited to that due to insufficient demand, and inflation limited to that due to excess demand with respect to the factors of production. At the beginning of the 1970s, this magic remedy stopped working: new forms of unemployment appeared, that could not be explained by cyclic factors, along with new forms of inflation not due to full utilisation of production capacities. In both cases, the cause was probably social rigidities that had slowly built up during the preceding period of fast growth.

This may help explain why many governments in the developed nations have hesitated in their reactions to the oil crisis. The sharp rise in energy prices has reduced the possibilities of economic growth, because of the need to limit imports; caused a recession and created new unemployment, over and above the other, pre-existing forms of unemployment; reinforced inflationistic tendencies; and created new pressures for a restructuration of the productive system, in addition to those arising from other causes. At the same time, the necessary adjustments can take place only slowly, because of the rigidities, and governments do not dare oppose a public which is disoriented and profoundly divided as to its aspirations. The most striking example is that of nuclear policies, the countries that have renounced its use being bardly more active than others in the areas of energy conservation and medium-term development of other sources of primary energy.

This lack of vigour in the energy policies of the developed nations risks having serious consequences, not only for those countries, but also for most of the developing nations, as explained below.

3. The difficulties of the Third World

The countries of the Third World face problems arising both from the ambiguity (favourable and unfavourable) of the influences on them of the international economic system, and from the internal dynamics of their societies: population growth, explosive urbanisation, insufficient growth in agricultural production, the difficulties of mastering industrialisation and exploiting natural resources, internal distribution of wealth, political stability, etc. It is thus hardly surprising if two closely related questions are central to discussions amongst the elites of the Third World:

— whether to "couple" or "uncouple" their nations' economies with those of the developed nations. Uncoupling would eliminate the effects of domination and allow them to choose new paths to development, but would also deprive them of the support of the international economy (hence the subsidiary question: at what level should autonomous development occur? at the level of the nation? of the region? or of the entire Third World?);

— the choice of development strategies. There are many possibilities: classical strategies based on growth of the national per capita GNP, industrialisation and integration in the world market; reformist strategies characterised by the different relative priorities given to the objective of wealth redistribution and that of economic growth; radical strategies centered on satisfying essential needs in the areas of food, housing, health and education, or on giving priority to autonomy, to reduce dependence on the outside world and enable a policy directed more towards the satisfaction of fundamental needs.

The paths to development are multiple, but none is easy, and all have social and political risks. Thus, it is not surprising that the transformations of the energy system profoundly disturb the evolution of Third World economies, but of course in a very different manner according to the group of countries considered:

— petrol exporting countries, particularly those in North Africa and the Middle East;

— new industrial nations;

— intermediate countries;

— the poorest nations.

A. *Petrol exporting countries (particularly the Arab members of OPEC)*

Western public opinion seriously misjudges the situation of the oil producing countries, seeing only the abundance of their petrol revenues. By quickly making some people very rich and distorting the national distribution of wealth, the increase in petrol revenues is at the origin of vast social changes in these countries, while at the same time undermining traditional values. Hence the risks of social explosions, the Iranian revolution being just the first example. Also, these countries are now playing their joker, and in the medium- or long-term they must not only change their sources of energy (like the developed nations), but also find new sources of national income.

This is very well illustrated by the situation of the Arab League countries, including those that are not petrol exporters:

1) There are immense differences in per capita GNP between these countries. Whereas for certain oil exporting countries, the per capita GNP exceeds that of the United States, the countries without petrol resources are in many cases amongst the world's poorest nations.

2) If we exclude petrol income from the GNP, it being the counterpart of a diminishing capital, the per capita GNP is less than 1000 dollars in all the oil exporting countries considered, and for some of them this figure includes financial revenues from accumulated financial investments. For the zone as a whole (North Africa and the Middle East), the figure in 1976 was less than 600 dollars.

3) The population of this Arab zone will increase from around 145 million in 1976 to about 268 million in year 2000, when the five most populated of the countries (Egypt, Morocco, Algeria, Sudan and Iraq) will by themselves total 187 million inhabitants.

4) The distribution of petrol reserves is extremely uneven between the countries, the ratio of reserves to annual production varying in 1979 between 14.9 years for Algeria to 80 years for Kuwait. Also, it is by no means certain that all the countries have during the recent years carried out suitable policies for reconstitution of their reserves.

5) The agricultural situation is tending to deteriorate throughout the zone. Between 1967 and 1978, per capita agricultural production declined in Iraq, Jordan, Saudi Arabia and Lebanon. From 1970 to 1977, the value of the region's agricultural imports increased in real terms by about 14% per annum, the percentage for individual countries ranging from 3 to 27%. For example, the Arab countries of Asia produce only 40% of their consumption of wheat, 50% of their consumption of red meat, and 37% of their consumption of vegetable oils. Considering the growth in population, the greatest problem for the Arab world during the next 20 years and, above all, during the next century will thus unquestionably be that of securing sufficient food supplies.

6) Arab industry is urgently in need of restructuring on an intra-regional or inter-regional basis, especially in the countries with local raw materials, abundant labour and sufficient capital.

Considering only the Arab petrol exporting countries, there would thus appear to be four vital problems for their long-term future:

(i) How can their petrol be used to create, in the long run, self-sustaining growth?

(ii) When financial constraints are not dominant, how can the main constraints on growth be overcome?

(iii) How can the social-political structure be changed so that it does not curb development, but without violent revolution?

(iv) How can development be managed in relation to the pressures of the industrial societies, which have a critical need for petrol?

The types of energy crisis outlined in the introduction to this report may, in view of what is said above, be considered a direct consequence of the internal dynamics of the major petrol exporting countries.

B. *The new industrial nations*

These countries constitute a new "middle class" in the world economy — although their situation is still very fragile — and are mainly located in East Asia and Latin America, without forgetting the group of such nations in South Europe, namely Portugal, Spain, Yugoslavia and Greece.

Their situation in 1976 was as follows:

— per capita GNPs ranging from 3000 dollars for Spain to 700 dollars for South Korea (but with an under-valued currency), with intermediary values for the other countries, including 1060 dollars for Mexico, 1300 dollars for Brazil, 1750 dollars for Portugal, and 2580 dollars for Singapore and Greece;

— per capita energy consumption ranging from 0.9 TOE (South Korea and Portugal) to 1.9 TOE (Spain);

— an already minor role for non-commercial energy sources, except in Brazil, where they still accounted for 40% of total consumed energy, thanks to widespread use of wood for heating.

Despite these wide differences, the economic evolution of all these new industrial countries (N.I.C.s) during the coming decades should have two common features:

— GNP growth rates much higher than in developed nations and in the poorest countries (between 1960 and 1976, the rate of annual growth of GNP in the N.I.C.s ranged from 6.5% to 9.6%);

— primary energy consumption growth rates even higher than for the GNP (the elasticities of primary energy consumption with respect to GNP will be much greater than 1).

Putting it another way, these countries will be particularly sensitive to the energy crisis, which will strike them right in the middle of their industrial take-off.

C. *The intermediate countries*

Although these countries will represent about 18% of world population by the end of the century, they show a mixture of the characteristics of the new industrial nations and those of the poorest countries, in varying proportions, and we shall not therefore discuss them in length herein, just noting three points:

— Many intermediate countries are exporters of the major commodities, minerals and agricultural products, from which they derive most of their foreign currency earnings. Hence the importance of all the discussions during recent years on how to stabilise the prices of these products and the corresponding export earnings, because the effects of the energy price rises on their economies will be in direct proportion to the stability of their export earnings.

— The intermediate countries are probably the best places for developing modern technologies which make more use of labour and less of capital equipment. As these technologies should consume less energy, the struggle to avoid wasting human resources and equipment will be the same as the struggle to avoid wasting energy.

— The energy resources of the intermediate countries have been insufficiently exploited in the past. Helping them by making available the necessary technologies and funds is evidently a priority.

D. *The poorest countries*

Herein, we shall limit analysis to two regions: Black Africa and South Asia. Ignoring all the pecularities and special aspects of each country, which are nonetheless very important, the situation in these two vast regions can be summed up as follows:

— particularly fast population growth;

— development linked above all to agriculture, which employs most of the active population;

— only modest prospects for industrialisation (in most of the scenarios studied in the OECD Interfutures report, the part of Black Africa in world industrial added value remained less than 1% at the end of the century, and that of South Asia about 1.5%);

— PNB growth rates similar to those of the past (4 to 5% per annum, on average).

As far as energy is concerned, it should be noted that consumption of non-commercial energy still accounts for a considerable fraction of total primary energy consumption in these regions: almost 80% in Black Africa and 45% in South Asia! However, during the next 20 years, the commercial primary energy demand of the poorest nations will expand greatly, because of population growth, and because of the constraints preventing further development of non-commercial energy sources.

Finally, as pointed out by the International Institute for Applied Systems Analysis (IIASA), very many Third World countries have to accommodate two different types of demand for energy: in urban agglomerations (most of the major cities will be in the Third World by the end of the century), energy consumptions per square kilometer are often comparable to those in the West, but of course with much higher population densities; conversely, in rural areas, consumption per square kilometer is much less than in developed nations. This is important, because it largely determines the types of secondary energy suitable for consumption.

The preceding brief review of the problems of the Third World is intended only to underline how easy it is to make erroneous judgements when allowance is not made for the internal dynamics of each group of developing countries and for its interaction with the world energy system.

4. World economic prospects

How can the preceding analyses be integrated into a description of possible futures for the world economy? The first step is to make a distinction between continuous evolutions and evolutions with breakdowns, the breakdowns leading to cumulative divergences after an initial shock.

A. *Possible breakdowns* (²)

The first area in which a breakdown may occur is evidently that of *energy*. The recent example of Iran shows that complete modification of the complex and fragile geopolitical equilibrium in the Middle East can occur at any time, followed by conflicts with the Western nations and partial interruption of petrol supplies. After such a breakdown, several evolutions would be possible:

— local military interventions by certain Western countries, entailing increasing terrorism, an extension of revolutionary activity in the region, and heightened tension with the Soviet Union;

— use by the United States of its agricultural resources as a "food weapon" to force some foreign political leaders to change attitudes. However, a certain time would necessarily elapse between application of such measures and their effects on petrol supplies;

— an explosive rise in petrol prices or, if consumer nation governments managed to co-operate, petrol rationing. In both cases, the sharp drop in national incomes in the industrialised countries would be followed either by even higher unemployment, or by a significant decline in productivity obtained through central economic planning of the type applied in wartime. If this recession were not controlled by the governments, it could be the source of social turmoil and political upheavals, sounding the death toll of existing forms of democracy.

A second set of breakdowns involve *breaking-up of the world economic system.* Although, as demonstrated by the Interfutures report, an escalation of protective measures between the North and the South is just as unlikely as a closing of their frontiers by the three main economic centers of the developed world (the USA, Japan and the EEC), we cannot exclude the possibility of a crisis in the monetary and financial system due to bankruptcy of a major operator in the Eurodollar market following, for example, insolvency of a developing country. In any case,

(²) See "Demain la France dans le Monde", a report by the Commissariat Général du Plan, published by La Documentation Française, Paris 1980: pages 133 to 135.

considering the present high level of interdependence, fragmentation of trade would precipitate the world economy into a recession with incalculable consequences.

A third possibility for breakdown is *an accumulation of local crises* which, because of their number and their interactions, the governments of the developed nations are unable to control: revolutions in the rapidly changing Third World countries are likely, and may engender civil wars, conflicts between neighbouring countries and clashes with developed nations, leading to famine, massive flows of refugees, limited military operations, and temporary interruptions in supplies of raw materials or petrol. Incapable of effectively co-ordinating their policies, the developed countries would then attend to the urgent things first, each using its particular advantages, without an overall strategy. Their growth rates would fluctuate as a function of short-term political developments, but average growth would be low (3).

Finally, though all countries attach great importance to peace, co-operation and internationalism, it is impossible to exclude local conflicts, particularly in the Third World and especially the Middle East, degenerating into *major conflicts*, with direct confrontation between superpowers. However, analysis of this possibility lies beyond the scope of the present report.

The above catalogue of possible breakdowns is not exhaustive. Without depriving the scenarios of continuity outlined below of their significance, it puts them into perspective, reminding us of the threats latent to the current trends of the world economy.

B. *Scenarios of continuity*

Analysis of these scenarios can be based on a small number of relevant dimensions:

— The first is *the nature of economic and political relations between the major OECD centers of power* and, more particularly, whether the future will see collegial management of the developed world's interests by the largest nations, assuring a relatively high degree of "openness" and some measure of economic stability, or a partial abandoning of free trade and free financial exchange, with Japan, the EEC and the United States then behaving primarily as competing poles.

(3) See "Demain la France dans le Monde", *op. cit.*

— The second dimension concerns *the internal dynamics peculiar to the developed societies*, distinguishing:

on the one hand, "the cultural phenomenon of the possible appearance of new values, shared to a greater or lesser extent by the community as a whole, with all the consequences this may have . . . more especially for the level and content of national income";

on the other hand, "the social phenomenon of the collective ability to effectively organise the growth of social production hy innovating, redistributing production factors, accumulating capital and adapting institutions" (4).

Several hypotheses are then plausible: the developed societies give priority to economic growth in the traditional sense of the term and accept the adjustments that it entails; the developed societies do not experience unanimously approved changes in values, and conflicts between social groups hold up adjustments; rapid value changes in the developed societies enable a consensus to be re-established on the basis of slow growth and a different content of national income; etc.

— Another dimension encompasses the *relations between advanced industrial societies and the various groups of developing nations, and between the developing nations themselves.* The OECD countries will play a central role here, but we must also take into account possible evolutions of North-South relations as a whole, including: increased economic exchanges and increased aid to the least advanced countries; more pronounced dissensions between North and South; a break-up of the South, with the formation of large North-South areas inside which trade of all sorts is given priority.

— Finally, a fourth dimension relates to *the internal dynamics specific to the various groups of developing societies*: in other words to the problem of choosing development strategies.

Based on these dimensions, the Interfutures study investigated several scenarios for evolution of the world economy. Without describing these scenarios in detail, it is worth recalling some of the main conclusions:

(i) Resumption of high growth supposes a vigorous energy policy in the developed nations; close co-ordination of their economic policies; agreement with the OPEC countries to assist the latter's development in exchange for a regular but moderate growth in the price of petrol (and increased exploration and extraction); increased trade with the new

(4) Interfutures final report, OECD, Paris 1979, page 79.

industrial nations; and a massive growth in aid to the poorest countries. It goes without saying that the likelihood of this is presently rather low.

(ii) A scenario of "new growth" accompanied by rapid value changes in the developed countries leads to the following paradox: "While (this scenario) is more stable and less conflictual than others if it extends to all world societies, it has to contend in its emerging state with a variety of obstacles if the various groups within national societies, the various advanced industrial societies, and the various groups of world societies are evolving at different rates" ([5]).

(iii) Rapid extension of protectionism within OECD countries would have serious consequences for the per capita national income in Western Europe and Japan, but would probably run up against obstacles preventing it becoming general.

(iv) Whatever the scenario, the number of people that are undernourished or in a state of absolute poverty (as defined by the World Bank) will not decrease, even if they are a dropping percentage of total world population. Also, the gap between the richest and the poorest countries will close only very slowly, because the highest growth rates are in countries which lie between these two extremes. Even so, world GNP will increase considerably. With a moderate growth scenario, it is multiplied by 3.4 between 1974 and year 2000, the per capita income being multiplied by 2.3. In particular, for the Third World as a whole, per capita GNP rises from 290 US dollars (1970 prices) in 1975 to 790 dollars (1970 prices) at the end of the century. At the same date, and again in 1970 dollar terms, there is a difference of 10 to 1 between the poorest and richest Third World continents: 184 for South Asia, 266 for Subsaharan Africa, and 2040 for Latin America!

(v) "A possible trend, but one to be emphatically avoided, could arise if there is no major shift in government policies in the North and South and no cumulative breakdown occurs. It is the following: the present slow or moderate growth of the developing economies continues for some 15 years with a continuation of structural unemployment. Co-ordination of short-term economic policies continues to be inadequate, and structural adjustment goes on in a haphazard fashion under cover of direct protectionist measures directed against imports from other industrialised regions and from the Third World. Some countries show greater flexibility in adjustment, notably Japan, and their productivity

([5]) Interfutures report, *op. cit.*, page 312.

increases without the productivity of any other country constituting a kind of ceiling. Governments have difficultly in arbitrating between the traditional demands, which continue to be pressed, and new demands from active minorities. Only a few countries opt more definitely for the new growth, and control some of their external trade to make it possible to develop in that direction".

"Differentiation continues in the Third World countries. In the poor continents, some countries attempt reformist or radical development strategies to improve basic needs satisfaction in all social groups, but these attempts are not certain of success. The Third World also tries to organise co-operation within itself, but succeeds only in a very partial fashion, the more so as close links continue to exist between Latin America, North America and Europe; between Africa and Europe; between the Middle East, the United States and Europe; and between South-East Asia and Japan, for cultural, political, military and economic reasons".

"Despite the semi-protectionism which exists within the North, between the North and the South, and in the South, the redeployment of economic activity throughout the world continues intensively, and the newly industrialising countries increase their trade with the developed countries. Without becoming really integrated in the world market, they depend increasingly on it" ([6]).

Such an image, although possible, is extremely disquieting:

— peoples show unsatisfied aspirations;

— harassed by the multiplicity of problems to be solved, governments are unable to establish co-operation on a regular basis.

As long as the world economy's dependence on petrol is not greatly reduced, there is a real danger of continuity giving way to a breakdown.

Although summary, the above analysis of relations between the energy system and the international system has the merit of high-lighting a series of areas in which strategies adopted by the Western countries outside the energy sphere will have considerable impact on the control of energy crises:

(a) Democracy is a splendid system of short-term political control, because citizens can vent their dissatisfaction by their votes, without even the slightest justification, and without resorting to Molotov cocktails and the like. On the other hand, the system often reacts too late to internal

([6]) Interfutures report, *op. cit.*, page 396.

and external threats. In the world that is taking shape around us, it will be necessary to give more consideration to long-term aspects when making political decisions in democratic countries, this involving administrative and, in some cases, constitutional reforms.

(b) In a democracy, political leaders' will to act and support by the citizens are mutually reinforcing. For this reason, in the Western countries, greater information must be given to citizens on the transformations taking place in the world. This should concern not only adults, but also the transformation of education, presently overly concentrated on the internal aspects of just the developed countries.

(c) Even if their relative position in the world progressively declines, the developed nations of the West will continue during the coming decades to have considerable influence on the evolution of the international system. In the economic area, they should invent a new form of co-operation allowing them to reinforce their energy policies, develop their own resources, maintain a certain degree of openness in international trade, reform the international monetary system and, as far as possible, regulate growth.

(d) However, world stability also depends on the types of relation that will be established between the groups of developed countries and the groups of developing countries. Even though the scope of this report excludes in-depth discussion of the advisability of various long-term strategies for the developed nations with respect to the Third World, the analysis herein has brought out three essential points:

— the importance of the industrial countries' contribution for development in North Africa and the Middle East, including Turkey and Pakistan;

— the need to protect, insofar as possible, the new industrial countries (N.I.C.s) from the effects of energy crises. The best way of doing this is probably to adopt vigorous energy policies in the developed countries, to provide the N.I.C.s with large access to the international financial market, and to facilitate growth of reciprocal industrial trade;

— the attention that must be paid to agricultural development in the poorest countries and, more generally, to the struggle against hunger in certain regions of the Third World.

To conclude, energy policies are indispensable for mastering the future, but will only be fully effective within a more general framework of strategies designed to adapt the international system as a whole.

DISCUSSION

DÖBEREINER

From the paper Dr. Sanchez-Sierra presented yesterday and several others we could conclude that the elimination of poverty and unhuman living conditions in developing countries is strongly dependent on the increase of the availability and consumption of energy in these regions.

On the other hand, today, from Prof. Colombo's paper and also from Dr. Danzin, there is suggested a low energy scenario and we could conclude that perhaps in the farther future, after 2000, the decentralization of living areas will be the solution of many problems. There are different ways of looking at things. Increasing energy supply means industrialization and, with this, migration to large cities and therefore this can be considered in fact the cause of increased poverty, crime and violence because they are the origin of the favelas mentioned by Dr. Sanchez-Sierra. Venezuela and Nigeria are rich due to their large oil wealth and it is just in these two countries where the problem mentioned are most prominent.

STARR

The papers presented this morning were all very brilliant and worth a great deal of discussion. I am concerned, however, with one impression that these papers give. All the models for the future tend to be oversimplified and subject to very arbitrary assumption, such as, for example, that decentralized sources such as solar photovoltaic will be competitive with centralized sources in 20 years. This leads to the danger that full exploration and use of all energy alternatives will arbitrarily be restricted by premature choice, with dangerous consequences.

A model exercise is important because it opens up the opportunity to think about what one would do if the circumstances occur. And science and technology are not predictable. But as a basis for decision-making it is extremely dangerous. The danger is, that if you believe the models then you use them to make decisions which cut off options. Mr. Colombo makes the point in his paper that he wants to see a plurality of approaches and a plurality of developments, and I agree with that conclusion. But the difficulty with believing the model is that it says to you that there are things that you should not do today because something may be different in the future, and so you cut off an option. Now Mr. Colombo kept referring to Mr. Levins' philosophy. Mr. Levins' philosophy is very complex and I will not discuss it here, but the conclusion of this philosophy is that we should not today be investing in large central power stations because it in effect reinforces a society which Mr. Levins does not feel is an optimal one. He may be right, but he may be wrong, and I think that my concern with the presentations is that as exercises they are good and stimulating and deserve a lot of consideration. As bases for decision-making they can be very dangerous. And I therefore suggest that if there is any one conclusion that one draws from these studies, that is: we need to have an opportunity to let that variety of things which technology and science develop be tried out and let us see what happens, and let the peoples of the world make their choices of these options which they wish to take. We need a plurality of approaches and free choice among these for a variety of reasons.

I have only one other comment: there is another assumption which is inherent in many of the papers, that we live in a world of scarcity. I do not believe this is new or revolutionary. In fact, I do not know of any resource situation in the world which has not been scarce from the very start. The oil situation was a scarce situation until about 30 years ago when the cheap Arab oil was discovered. If you look at the basic prices of oil around the world, they were going up steadily and then they dropped very suddenly when the Arab oil came in. We have run out of that, so we have a perturbation which we have to adjust to. But the whole concept that something new has happened and the future of the world has given us a new problem of living in a world of scarcity I believe is false. We have always had to adjust to resource availability versus cost — there is nothing new about this problem — and we have done it, incidentally, by using science and technology to use the resources more effectively. So I think that the element of a new doom that is threatening the world is not justified.

DESPRAIRIES

Je voulais dire à peu près la même chose que M. Starr.

1. Il ne faudrait pas se méprendre. Le modèle du Prof. U. Colombo est certainement très intéressant pour l'horizon 2030. Mais il n'apporte pas de réponse au problème urgent de la pénurie d'énergie entre 1980 et 2000 qui peut amener des guerres, des famines, un chômage insupportable. Il ne faudrait pas que le public s'y trompe.

2. Il y a un paradoxe à envisager en 2030 que 46% de l'énergie renouvelable devrait être produite dans les pays pauvres et 36% dans les pays riches, alors que l'énergie solaire est la plus diffuse et réclame le plus d'investissements par TEP.

3. L'urbanisation n'est pas liée principalement à l'énergie.

Je suis très frappé par la remarque de Mme Döbereiner, que les bidonvilles sont particulièrement grands et affreux au Vénézuela et au Nigéria, où l'énergie décentralisée du pétrole, transportable par bidons au fond des campagnes, est extrêmement abondante. L'urbanisation est liée à beaucoup d'autres causes que l'énergie. Il faudrait l'étudier plus en détail.

CHAGAS

J'amerais présenter deux commentaires. Le premier est d'ailleurs renforcé par l'intervention du Dr. Starr. Je crois que l'homme a toujours su s'adapter aux conditions ambiantes dans lesquelles il vit. La culture est pour moi la capacité qu'a l'homme de s'adapter à l'équilibre métastable qui constitue son interaction avec le milieu physique et le milieu psychobiologique dans lesquels il vit.

Il est probable que nous sommes actuellement dans une des crises d'adaptation culturelle les plus difficiles que l'humanité, dans sa longue existence, a vécue. Mais je pense qu'elle peut la surmonter.

D'autre part, j'amerais dire, mais sans attribuer à ce terme la nuance péjorative que lui confèrent généralement les mass media, que nous vivons ici une « aventure » *élitiste*. Mais le problème important, c'est de transmettre au grand public cette connaissance que nous avons accumulée, pour que le grand public soit conscient de la situation actuelle réelle et il nous faut faire cet effort d'adaptation culturelle dont j'ai parlé.

Au sujet de l'exposé du Prof. Colombo, j'amerais dire ceci: d'abord c'est toujours très agréable de trouver bien présentées les idées que vous avez confusément dans la tête, et que vous avez cultivées pendant longtemps. J'ai seulement une remarque. Je ne crois pas que l'énergie soit la cause principale de l'urbanisation. Je pense qu'il y a des facteurs différents, des facteurs sociaux surtout — évidemment qui sont indirectement liés à l'énergie, mais pas directement de la façon dont Colombo l'a présentée — et qui sont d'une extrême importance. Je pense, par exemple, aux possibilités d'éducation, à la santé et à cette fausse image, pourtant très incitative, qui est donnée par la télévision de la vie dans la cité, dans la grande ville.

J'insiste donc beaucoup pour dire que, dans un pays comme le mien, la décentralisation des sources d'énergie est un facteur d'une extrême importance pour le développement social et économique du pays.

Sanchez-Sierra

Dr. Colombo's paper is not an exercise. It's a very different point of view about the actual relations between industrial and developing countries. The big difference is to analyse the future with two approaches:

one is just with numbers and technical point of view;

the other (Dr. Colombo's point of view), with numbers and with *social* and *political aspects*. And this is the reason why I think that we can expect to see a different world, and I hope to see that.

Colombo

I will try to give a very short reply to each one of the comments. Madame Döbereiner, I agree fully with you: I think there is a correlation between the fact that Venezuela and Nigeria and other countries have had a rapid development thanks to their wealth — which is largely due to energy — and urban development. Therefore I believe really that these favelas and these bidonvilles which are in many cities around the world and particularly in the developing world, are caused by the disorderly process of urbanization. We like an orderly urbanization, not a disorderly one.

Dr. Starr, you criticized the assumption that we made that decentralized energy sources, and particularly solar, will be competitive. However, you said two days ago that the high cost of solar was largely due to structural expenditures, and we believe that, by integrating solar plants with habitat and already existing structures, we could save most of this cost. This is our base of work. We believe also that the need for storage will be minimized in a decentralized approach, because only the part of energy which is needed for lighting and for the lower consumption at night-time, should be stored and not all. Our assumptions are not just guesses, they are the fruit of some studies, which unfortunately I was unable to present. You said it is dangerous to use these exercises for policy decision makers.

I have two remarks on this. First of all, I had not the time to pronounce the last sentences in my speech, which were: above all we wish to underline need in the real world for a continued critical re-assessment of options in order to maintain strategic flexibility in the face of uncertain and changing conditions of technology as well as in the economy. Political leaders, and behind them, society at large must be profoundly aware of the real alternatives for the long-term future as well as their implications not only for material welfare but also in regard to the ethical and spiritual levels of society.

I think political decisions are always made with some ideas of the future, so if you prohibit policy makers to think in a different way in the future, this would mean that policy decisions must reflect a conservative attitude of the present into the future. That is what some may call conservative and some others reactionary. Finally I do not share Mr. Levins' views. If I had given the impression of sharing them I was misunderstood. I do not share his views. He may be determined from an ethical viewpoint, but our own approach is totally different.

Well, Monsieur Desprairies, why renewable energies in the less developed countries? Because simply we have different assumptions about the future costs of oil and renewable energies. I believe that oil will be much more costly in the developing countries in the future and that, as I explained before, renewable will be less costly. I may be wrong, I admit, but if my assumption is correct, I just reverse the case. I do not believe oil will cost less just because we, in the developed countries, will have coal and nuclear. I believe oil is going to cost more than coal and nuclear, full stop. No matter what the supply is, I do not think a market economy concept is valuable, and, by the way, I think that there is an error in many positions of some of us. We believe in market economy. but what is market economy in energy planning? When we invest in a nuclear power plant, we must make a reasoning on what the market condition will be eight or ten years from now. And market economy concepts typically react to immediate stimuli. We must make assumptions on the future, we cannot apply market concepts to long-range planning and because of the lead time, which is long, we are all embedded in non-market hypotheses.

Prof. Chagas, I believe you are right, when you criticize the fact that energy has been perhaps a little bit overemphasized in our paper as one of the main causes of urbanisation. We of course in the paper refer to the indiret effects as well as to the direct, and we think urbanization, if we look at it from a scientific viewpoint, has typically been related to population explosion and to the availability of better jobs, which in turn are related to the whole productive system, which in turn is related to the energy system. And it is through this spiral that we believe that there is a relationship; at least we will seek more studies to analyze this. But I fully agree with Professor Chagas also on his comment about the image that the mass media provide of the city and this attraction that goes to the city. I think, again, the mass media are part of the system, and the system must be regarded as a whole. I agree also with Mr. Sanchez of course and I think he has understood fully the implications of our work. I think it is very difficult to summarize in 36 pages something which needs to be explained in much more detail, and I apologize if we may have seemed to be a little dreamers or perhaps superficial.

Sassin

The assessment of a scenario depends on the standpoint from which we perceive a problem. Being a citizen of the Western Developed World I am tempted to focus on the part of Prof. Colombo's scenario, comprising the needs and possibilities of supply of energy in the Third World Countries. The concept of a non-urban decentralized evolution in the high population growth part of the world is certainly appealing for a western man. Should it be realized, it would certainly reduce the burden, the development of the developing countries would put on him.

I am surprised that the representatives of developing countries have positively responded to Prof. Colombo's scenario. Maybe they have focussed on the low prospects of energy consumption allocated to the developed world in this scenario.

I would have expected that they had raised the open question how to interpret a population density of e.g. the main-land of China. If we had somebody here from China, he could have said, "Well, look, in about 20 years time, our population density in China, if we exclude the highlands of Tibet and the desert areas in the northwestern part of our country, will be about the same as the population density in the larger metropolitan area of New York". Is the concept of decentralized development style applicable with these prospects in mind?

Teillac

Nous avons discuté de sources possibles d'énergie et de certains aspects techniques. Nous avons essayé aussi de percevoir les liens entre forme d'énergie et société et les mécanismes nouveaux qui peuvent s'établir entre nations. Je voudrais revenir à un point plus proche des réalités: celui des responsabilités que prennent les hommes s'ils ne décident pas des mesures qui doivent être prises dans l'immédiat. Les pays industrialisés en particulier ont une double tâche urgente:

— développer des formes de production d'énergie permettant une grande variété d'utilisations notamment dans les pays en voie de développement;

— se munir pour leurs économies des sources d'énergie indispensables pour suppléer le pétrole et permettre leur développement.

Je voudrais insister sur cette responsabilité immédiate; ne pas y répondre serait lourd de conséquences.

LESOURNE

My comment is related to the comment of Mr. Teillac.

When, in a scenario, you strongly depart from present or recent trends, it is essential to look closely at the path and not only at the final image.

For instance, urbanization rates will not immediately decline in the Third World. They only will change as a consequence of different development strategies. So, they will pass through a maximum before declining to the level named by Prof. Colombo.

To the same extent, nuclear and coal may be necessary for the next twenty years, though their role may decline thereafter.

Then, there may be some misunderstanding of the scenario by political decision-makers if the paths are not considered.

COLOMBO

I will say just a few words. Thank you, Dr. Sassin, for your comments. I think you were a little bit paradoxical in comparing the people of Republic of China to New York. I believe the definition of urban and rural area is not only a matter of density, even though if we calculate the density of population in China and their present plans for limiting population development, it is certainly less than in a big metropolitan metropolis. For us a rural area is an area of agricultural activity integrated with small industrial units, and that is largely as I see China. Anyway I think you are right in your comments and I do not think there is opposition of opinions between us.

I am not against nuclear, otherwise I would not have accepted to be the chairman of the Italian Atomic Energy Commission. I believe in nuclear strongly; but I will fight against a hegemony of nuclear and coal as the sole sources of energy on which we may count. I think you are right, for the next 20 years, 30 years, they may be the best solutions, but let us keep in mind that more distant future. And Mr. Lesourne is right; the more we consider the long trend, the more we have to look into the past. But looking into the past, I do not find only good things; I find bad things, and I must learn from the errors of the past not only to design an extrapolating future but to design a future where human beings may live more harmoniously together.

HALL

The gist of this meeting is that nuclear is inevitable and there is no alternative. Personally, I am very unhappy about this over-all conclusion. I am afraid that I have not been party to the first two days, therefore I should not interject this, but if the meeting is going to say nuclear and coal are the only alternatives, I would express my disquietness, Mr. Chairman. I am inclined to say that some nuclear is inevitable, but I agree with Prof. Colombo that we must encourage other ways of doing things and not starve them at the early stage.

TABOR

This is in response to the morning's discussion on solar energy. In the remarks of Dr. Starr against the renewable sources — in particular solar energy — he seems to have been responding to the overselling of solar energy as a source of *central* power supply in the US. I agree with him that in the visible future these solar systems will not be competitive with oil, coal or nuclear. Solar will — and in certain circumstances can already — compete with the conventional sources for non-centralized regions. I quote the case of a farmer who installed a windmill (plus batteries) at a capital cost less than that to bring an electricity line to his farm; and this was in the US! In many regions — India is an example — the electricity set will not cover the whole area within the next several generations. Thus the viability of a solar device is decided by comparison with the *local* alternative possibilities.

In some additional notes, I have indicated that the industrialized areas can only provide *part* of their energy needs from the sun — because of limitations of space and the high energy consumption density. This constraint does *not* apply to most of the developing world. I therefore particularly appreciate the approach of Prof. Colombo who, although himself concerned with large central energy supplies, expresses the need for a *mix* of energy sources, such as the sun for non-centralized energy supplies.

BLANC-LAPIERRE

M. Danzin: comment va-t-on faire face à tous les problèmes d'éducation liés à la nécessité d'une bonne utilisation du temps libre?

DANZIN

My question is whether and how universities which are conservative, high-inertia systems will educate the next generation of students with an understanding of the new environment of energy and information largely arising since 1970. The professors were educated in an earlier era. They are not acquainted with the subjects discussed here this week. Innovation is needed but how? The university graduates of the 1980's should go into the world prepared for the parameters of 1990-2030. Will they? If not, what should be done to change their education? and how?

CHAGAS

J'amerais faire deux commentaires au sujet des propos de M. Danzin.

1. D'abord j'aimerais dire que le loisir est un des programmes de l'époque post-industrielle. Le loisir doit servir au développement plus humain de l'homme, au moins pour la grande majorité des hommes. Il doit être assuré par le privé et naturellement par les gouvernements. Cette dernière forme présente le danger de faire du loisir un instrument de développement des principes idéologiques comme nous l'enseigne l'histoire.

2. Quant à l'éducation, elle s'applique à tout ce dont nous avons parlé. Je crois qu'il faut montrer que cette éducation ne doit pas être purement académique. Comme en informatique elle se pose à trois niveaux: celui de la création, celui de l'action créatrice et d'actions de haut niveau et celui d'opérateurs.

DANZIN

L'importance de l'éducation ne peut pas être sous-estimée. Il est urgent de reprendre toute la pensée sur l'éducation de manière à vaincre les défauts d'inadaptation et d'anachronisme qui caractérisent la plupart des enseignements donnés aujourd'hui dans les différents pays.

Le temps d'enfance et d'adolescence devrait être essentiellement consacré à « apprendre à apprendre » de manière à préparer le « continuum » qui devient nécessaire: s'éduquer devient l'affaire de toute la vie et personne ne pourra plus espérer acquérir son bagage de connaissance pendant la seule période scolaire.

Par ailleurs, l'Education ne doit pas avoir pour principal objet la formation à l'exercice d'une profession mais tout autant la préparation de l'homme à sa dimension culturelle, affective, esthétique, spirituelle. Le fait que le « temps libre » va s'accroître oblige les éducateurs à prendre en compte la préparation à une bonne utilisation du temps libre (auto production, éducation complémentaire, activités culturelles, esthétiques, sociales, services rendus bénévolement...) de manière que ce temps libre ne soit pas celui de la passivité ou de l'oisiveté qui conduiraient l'homme à une forme de dégradation qui rendrait probablement la société ingouvernable.

ENERGY FOR THE FUTURE

JANOZ PASZTOR
World Council of Churches

(See Paper in "Nuclear Energy" Session)
(Cf. page 279)

ENERGY AND HAPPINESS

LOUIS LEPRINCE-RINGUET

What is the relationship between energy and happiness? Are men and women the happier the more energy they have at their disposal? Or is the contrary true? Or, again, are the two concepts unrelated?

I started thinking many years ago about the connection between science and happiness, especially between happiness and the applications of science, whose multiplication inevitably increases energy consumption. Since the end of World War II, all the world's industrial nations have chosen the path of unconstrained scientific development. Basic science at first, followed by the astonishing applications of recent years. To take an example, enormous progress has been made in medicine. Most of the diseases that existed when I was a child have almost disappeared, like the major epidemics that decimated entire towns and regions, but are now forgotten. People live much longer, children survive to adulthood, and mothers do not die in childbirth. Food intakes are balanced, and we no longer fear famine or malnutrition.

Women's lives have completely changed, for the better. Are today's young women, in their kitchen-laboratories, equipped with a refrigerator, washing machine, dishwater, running hot water, and a gas or electric cooker, really aware of how their grandmothers lived, of the exacting, exhausting labour that used to be involved in heating the home, preparing meals, and doing the washing? Can they even imagine themselves reduced to the slavery of the 19th century, they who only have to turn a knob or push a button on a programmed machine?

And yet, the chores I have just mentioned do not belong to the distant past. People in their thirties who were born into large, poor families can recall the crushing obligations of their mothers, getting up at 5 o'clock in the morning to finish the family washing before starting the daily housework. But the past is quickly forgotten, and there is no going back. There is less physical fatigue, less hard work in the lives of modern Western women, but also new concerns and worries, often trying for the nerves, and inherent to modern life. Of course, this liberation from household drudgery, based on increased energy consumption, is far from general on our planet. What differences between the conditions of life of women in different parts of the world! But, which are happiest? Western women are incredibly free. They have time to study, to hold down a job, to participate in the intellectual, artistic and political life of society. This revolution has taken place thanks to scientists, physicists, chemists and technicians, rather than the Women's Lib movement. Thanks to electricity, motors, heat engines for refrigerators and freezers, low temperature technology for preserving and transporting perishable goods, chemistry, conversion of coke to gas, giant dams, and drilling techniques for obtaining petrol to produce electricity. What progress would have been possible to free women from household slavery if science had not blossomed the way it has? I often wonder.

A revolution has also occurred in communications, largely due to extraordinary developments in the field of solid-state physics. The transistor has completely transformed our previously limited possibilities of communicating, and has made available to everyone, on records, radio and television, and mini-cassettes, the works of the great composers of the past and present, performed by the best orchestras of the five continents, and reproduced with incredible fidelity.

Everything one could wish to have for one's personal, intellectual and artistic culture, or just for information, is readily available. Fast means of transport have multiplied, offering unlimited possibilities of travel. Progress in chemistry, electronics and data processing have limited the need for effort and hard work. We have guaranteed, multi-faceted comfort that our grandparents could not have even dreamed of. We are satiated.

Indeed, the industrial world produces so many goods that all the media must be put to use in inciting us to buy them, to choose such and such a supercar, anti-wrinkle cream or slimming product, for which omnipresent publicity extolls the supposedly outstanding merits. All day long, in the newpapers, by radio and television, by neon signs, and on bills and posters, we are satured with publicity, pushed along the path of ever greater comfort. Our civilization drives us to acquire masses of useless, artificially differentiated objects, that must absolutely be sold, the alternative being bankruptcy and ruin. Hence the excesses of publicity, whose purpose is to stimulate our appetites. If it were possible, by a biological process, to create an insatiable human appetite — like that of the geese we stuff to produce liver pâté — then our society would have advanced one step further along its strange and disquieting path, in which we often spend more to sell goods than to manufacture them, choking in our opulence, while just 3 hours away by plane, children and adults are literally dying of hunger, incapable of surviving in the face of malnutrition, disease, famine and death.

Even worse, this thirst for ever more comfort does not make people happy. The rich are satiated, have lost their appetite for living, and just go round in circles, lost for noble causes, trying to forget their ennui, and negating their best human qualities, such as consideration for others, ardour and wonder. Bogged down in their comfort, they are spiritually dying. They are not only satiated, they are spoiled.

Others, without the same wealth, are haunted by the view of the most favoured. Their craving for personal, egoistic pleasures does not make them any happier, but instead puts blinkers on them, stunting their potential for generosity and devotion, and extinguishing all inner life.

Finally, there are those who fight, who battle, living in difficult conditions, and unhappy with their lot when they see others, better off. It is true that there are more merits, spiritual qualities and potential for devotion in the poor than in the rich. But they too desire a better, more comfortable life, and this desire can bring with it the poisonous ferment of envy and hate.

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Our civilization, marvelous by its discoveries and possibilities, also creates new fears, new problems, new anxieties. For example, the fear of a nuclear holocaust has appeared in Europe during the last year, after having been pushed to the back of people's minds. In the life of every day, our existential environment is hard to support.

Gigantism is everywhere, surrounding and overwhelming us. It is one of the most vigourous symbols of our civilization, and it is hard to conceive modern life and technological progress without it. One example is the need to build ever more powerful computers, which certainly have their place, and are even indispensable. Those used to reserve seats in planes and trains are so sophisticated that, from almost any travel agency, anywhere in the world, it is possible to find out instantly whether a seat is available on any plane between any two points on the planet. Few people would deny that this is a positive aspect of gigantism.

But gigantism is also the giant cities, the megalopolises such as Paris, London, New York, Chicago and Tokyo, insane agglomerations which no longer correspond to the concept of the town, whose basic purpose is that of allowing its inhabitants to meet easily and rapidly, and to form a community. We are far from this ideal. In modern big cities, the access roads are blocked in the rush hours, there are incessant queues on ring roads and inner avenues, cars are more and more difficult to park, distances are too great to be walked, and the never-ending, anarchical proliferation of new housing areas artificially brings together masses of uprooted families in groupings that have no relationship at all to true communities. Indeed, such proliferation has often been compared to the metastases of cancer.

And then, there are the sixty storey office blocks, cathedrals of concrete and glass, the only profitable way of building on land whose price has become exorbitant, but which create almost insoluble problems, including the rush in the lifts in the morning and at the end of the day, and their vulnerability to outside events, such as electricity blackouts, strikes and fires. Immense symbols of power and prestige like the Chrysler Building and the Rockefeller Center in New York are inhuman, despite their architectural beauty. "No one sings any more under the balconies", as the French singer Michel Legrand so aptly puts it.

The gigantism of cities, which is not always fairly localized like in Paris — the area between New York and Washington is an almost uninterrupted, 300 kilometers long urban strip — is also accompanied by a series of personal disturbances, frustrations and constraints. First of all, the time and petrol wasted in getting from place to place. What is there to do of any interest whatsoever in a queue of cars at a standstill, bumper to bumper? This is real slavery, except for the rich and powerful, who can telephone and dictate letters in their cars, almost as if in the office. Then, there is the monotony and boredom of modern city life, due partly to repetition of the same basic shapes in all modern buildings, leading to a drab uniformity, which is another form of slavery. Whereas the cells of our bodies carry, without exception, the stamp of our individual personalities, large towns, with their uniform housing, transport, clothing styles, food and working hours, manage to stifle and obliterate all originality, turning the individual into nothing more than part of a crowd.

I must admit having felt a malicious pleasure when reading about the blackout which hurled New York into darkness for an entire night in July 1977. It was 12 hours of panic, with all the disorders that one can imagine in the damp heat of the American summer. The fire brigade was overwhelmed, and the police even more so. Two thousand looters were caught red-handed, and the prisons were filled to overflowing. In the working class areas of the Bronx and Brooklyn, shops were ransacked and robbed, and streets were littered with the broken fragments of shop windows. Thousands of people were trapped in lifts, waiting for the fire brigade to rescue them, but unable to alert anybody, unable to communicate with the outside world. Perhaps worst of all for many, the air conditioners were stopped throughout the night, making sleep impossible in the damp, 100° F heat. Everything was paralyzed. No more traffic lights, and hence monstrous traffic jams. The underground stopped, with some trains trapped in the tunnels between stations. Kennedy Airport closed. A sort of sudden solidification of a fluid!

Another bitter fruit of gigantism is loneliness and rejection by society. People are far more alone in a big city than in a village. They cross each other in the street, by the thousand, but never meet. If one has no family, the case for many, it is possible to fall sick or even die at home, without anyone knowing. The result of all this is a terrible anonymity in life, in suffering and in death. I know two old ladies. One is a widow, who lives in her own small house in a village in Burgundy. Her children live a long way away, and only see her from time to time, during the holidays. She has difficulty in walking, and never goes out (luckily, she has the television). And yet, she does not complain, and is not unhappy, because her neighbours, who pass by her door every day, are always popping in to see her, to say hello, or to chat. Thsi friendly warmth and affection comfort her, and help make her life still worth living. The other lady lives in Paris, in a small two-room flat. She is desperately alone, and has hardly any visits. As she is beginning to lose her reason, the neighbours are afraid she may accidentally leave the gas on or start a fire. They almost wish her to die.

Society's solution to the problem of old people in towns and cities is to park them in special homes, where they spend the rest of their lives amongst themselves, without participating in the daily bustle of life. In the country, to the contrary, old people still have their place, and remain an integral part of the life of the farms and of their families.

Handicapped people also rarely have their place amongst the rest of the population in urban areas, whereas they too are accepted in country communities, rather than separated out in special centers. Village people are used to their presence. Inhuman gigantism rejects people on the fringe of society, by a form of partitioning and segregation unworthy of civilized men and women, and which we must fight at all costs. Groups exist for the social reinsertion of the old and very old, but their task is made extremely difficult by the very structure of our giant cities.

In the 60's, gigantism was seen as the hallmark of technical progress, and great pride accompanied the most spectacular constructions. Nowadays, we have come to distrust and reject such gigantism, and people are starting to feel and understand its inconveniences. Anyway, nothing can grow indefinitely on earth, and the size of constructions cannot forever continue to double every 5 or 10 years. Long-term exponential views of the future are always absurd! Many big cities are already showing alarming signs of failure. Management of New York, for example, has become virtually impossible. Companies are moving out of the city, there is not enough money, "big apple" is bankrupt. Other cities will go the same way. And yet, the buildings and infrastructures exist, and there is no question of destroying everything and starting again from scratch, while at the same time, towns and communities on a more human scale are appealing to growing numbers of people, and smaller, lighter industries are again finding the favour of the public. Giant cities and giant companies can be compared to the very large reptiles of the secondary era, whose perfection and gigantic complexity were initially the source of their power, but became the cause of their disappearance when ecological conditions changed.

Despite this, it is difficult to see how the superpowers could accept to significantly reduce their enormous arms expenditures. There too, all we can do is observing and trying to influence the course of events. In this, intellectuals certainly have a role to play, that of helping the populations to understand, but it is the working people who will have the most direct responsibilities for slowing and progressively sapping the spread of gigantism.

The future is uncertain, and always has been, but the dread of unemployment, which menaces an increasing number of our fellow-citizens, the diffuse fear of a seizure in international relations, and the risks of a planetary conflict, are at the origin of the world's present anguished mood.

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Another tendency in the overdeveloped countries is the refusal of all constraints and the renouncement of all effort. Hard work is progressively disappearing. In large, modern steelworks, for example, the workers are no longer slaves, but instead themselves command operation of huge automatic conveyors, furnaces, mills and presses.

Similarly, the vast majority of the population no longer makes the slightest physical effort, at work or in leisure.

This refusal of constraints has become a sort of dogma of our society. In everyday life, in housework for example, all effort is eliminated by the use of machines, which are ever more perfect, and now even programmed. Families spend their evenings sprawled in armchairs in front of the television, without moving, totally passive, watching the pictures change. This is the new form of bliss, in which people will watch and listen to anything, whatever the subject, provided the pictures move. All intellectual effort is rejected, all conversation and exchange are abolished. Sometimes, whether young or old we go to sleep in front of the small screen, which pitilessly continues its animation.

The high priests of this dogma are active right from our childhood. Teachers are told to give the greatest freedom to their pupils, who must not be opposed, upset or, above all, made to feel guilty. Under the influence of psychologists, competitions and examinations have been done away with. Permissiveness is accepted and has become widespread. And yet, it is not in this way that we can possibly hope to educate and prepare boys and girls for the future.

Such absence of constraints and rigour, such permissiveness, eliminates the very notions of fault and sin, and leads our society to secrete unbalanced persons and neurotics in quantity. It encourages participation in facile pleasures, consumption of all sorts of drugs, self-centredness, sluggishness of the mind and, above all, the soul. Inversely, self-equilibrium necessitates a personal effort, an ascension, the acceptance of constraints, and control of the body and its muscles, as well as of the character and one's impulses, combined with a continual active seeking after physical, psychological and spiritual self-fulfillment.

Deep down, people understand this, and admire those who manage by strength of character, self-control and tenacity to win in sports, the arts, the sciences, and business, who become champions. In our age of golden materialism, they are seen as exceptions who compel admiration.

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During the last 15 years or so, youth has begun to react against our energy-greedy civilization, with its gigantism, compulsory gregariousness, negation of personality and uniformization, against the cold perfection of concrete. May 1968 in France was an explosion of this reaction, which translates into unrational attitudes, the young tending to be against science and technology, the ferments of material progress, which they accuse of all sins, all fears and all evils.

Two main tendencies exist in the youth of today. Firstly, a general desire for human comradeship. The great modern festivals and demonstrations (like the one against the Creys-Malville breeder power plant in France) are perfect examples. This desire, which is often stronger than interest in work or money, is to live with others like human beings, particularly with those met every day, including at work. Hence the allergy towards inhuman gigantism, where true, congenial contact between men and women hardly exists. Hence the tendency to live in small, friendly communities. Hence the choice, when possible, of jobs where friendship is the rule. Hence the fact that, in general, people are less unscrupulously ambitious than in the past. This attitude also corresponds to the falling of social barriers, and is particularly striking amongst students. It is certainly one of the reasons for the cordiality encountered within ecological movements.

The other tendency is the rejection of overly far-seeing views of the future. Young people live much more on a day to day basis than their parents, taking advantage of the present, without attempting to make plans for even the near future. They know that it is always possible to live, or at least keep body and soul together, with any old job. As the future is uncertain, and the forecasts of today have a good chance of being proven false by the reality of to-morrow, they try to simply live happily, here and now, without worrying about all the imaginable and foreseeable catastrophes threatening mankind.

These two tendencies have many marvelous possibilities but, inversely, lead to certain forms of mediocrity. At the one extreme is the human wreck — the drug addict, for example — who rejects all the obligations of life in society, and folds up in a shell. At the other extreme, are the best, those who seek to change our society, but without destroying it. Knowing full well that we cannot return to the stone age, they denounce the misdeeds of modern life, without however refusing everything. Of course, there are also the revolutionaries, who want to demolish society. Yet, even they do not renounce all the delicious products of our modern civilization. In fact, it is impossible to fight against technical progress and Western civilization without using the very objects that this progress has made possible. Microphones and loudspeakers are needed to address the crowds. Cars, motorbikes and trains are needed to get the crowds together. Even so, why do the revolutionaries profit shamelessly from all the delights of modern technology, why do they so often possess powerful motorbikes, sports cars, transistor radios, magnetophones, and so on? (Of course, I am talking here about the "rich left". Manual workers and labourers, who are not so esteemed in general, and are in fact the victims of the anti-technical racism so popular at the universities, know what it takes in terms of hard work, concentration, fatigue and time to make an object, and they respect the products of their labour).

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At the other end of the world, amongst the disinherited and starving peoples, those are without resources, and do not possess the minimum of energy necessary for the essential development of the human being, and for basic self-fulfillment, life is far from easy in general. They are too busy with daily, unrewarding chores, striving to acquire the basic necessities of life, to have time to turn their minds to other, more distant, more serene visions.

But we do not have real experience of these dramatic, lifelong situations, which we perceive only through pictures and stories, and we cannot therefore honestly talk about them.

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Coming back to happiness, I do not feel capable of defining it. Some say that happiness is a quiet life, or hope, when life is difficult, agitated or disturbed. It is certain that wealth does not bring happiness. Many people wbo had a difficult childhood, in large, poor families, where they had to participate, under difficult material conditions, in the daily life and chores of the household, in the little problems of every day, nonetheless have a happy memory of this period. Inversely, are rich people happy? They who possess everything, yet can be likened to the stuffed geese who always want more, whose heart is hardened, whose desires are purely egoistical, and who live a life in which they never have to surpass themselves.

So where is happiness? Should one try to enjoy life, in the present, or is it better to be attentive to others, helping them, and trying to surpass oneself? Is the latter true happiness? Each of us has thought about these questions as a function of our own personalities, our own experience, and the circumstances of our lives.

Certainly, one should enjoy life here and now. Happiness must be built in the present, starting immediately. There are so many marvelous things around us, so many possibilities of joy, discovery and human contact, even though perhaps the most difficult is to recognize them. But, this does not exclude wider and less immediate concerns. He who is capable of self-renewal, of creating within himself a great project, of paying attention to the world and his fellows, and helping those around him, both near and far, is not destined to a quiet or routine existence. He will have difficult moments to go through, and will need a resolute soul, but he will be radiant and great amongst his travelling companions.

Does life have a meaning? And what meaning? We have all asked ourselves this fundamental question and, in our unstable and disquieting world, it is probably even more important than in the past. The answers are not easy for him who searches a personal meaning to life, something that is not purely and simply the acceptance of a credo laid down by others, and which does not lead to coopting by a system. Nothing is gained without stubborn will and determination. Live and let live has never led to anything good or lasting. To live serenely in our troubled world, one must be strong enough to make the effort towards self-improvement necessary to attain equilibrium. "The constraining equilibrium between order and enthusiasm", as Nadia Boulanger so beautifully puts it. I cannot insist enough on the importance of a lucid and persevering effort in this direction.

However, this ascension must be in the service of a principle of life and happiness. And the source of all life is love. It is not reason or logic, however well established, however convincing, that mobilizes men and women, individuals and crowds, but love — and hate, its counterpart. Only it can overcome routine, sweep away egoism, and allow us to rise above our desire for power and money. Only it brings encouragement and true comfort. Much more is obtained with a little love than with a lot of logic. It is often said that love is blind. The love I am talking about is, however, not at all blind. It is always accompanied by great lucidity. It is an attitude of the heart towards human beings and things, which one has learned to understand. Only by understanding our fellow-beings, with their habits, qualities, faults, ambiguities, and ups and downs, can we truly love them. Similarly, we must learn to understand the less favoured populations with whom we are in contact, with their customs, traditions, hopes, reactions and feelings, if we are to be capable of helping them in their long march towards a better future.

Love implies active devotion to others, and constant self-renewal. Being trusting without being credulous, generous without being blind, lucid without being unfeeling, aggressive without being unkind, balanced without being static, and open to others without dissipating our efforts. Are we capable of this, despite the constraints of all sorts inherent in our nature? It is, anyhow, the objective we should set ourselves, to avoid becoming a sort of weather-cock, turning with the prevailing winds and fashions, a lost soul capable of acting without weighing the consequences, of blindly adopting causes without interest, of crying with the pack, of becoming a fanatic for whom aggression replaces thought, an unrepentant pleasure-seeker, or simply a drowning soul drifting out of control.

Perhaps, to end, and being in a Christian land, I can admit that, for me, the Gospel is the essential guide, giving a meaning to life, teaching that all action can be positive, that we are the children of God, that all men are our brothers, and that we must do our best to understand and love them. Prayer enables even the most disinherited to influence the fortunes of the world. Personally, we should follow the parable of the talents, which asks us to develop our potentialities, and seek self-fulfillment. Certainly, a risk is involved, but it is a salutary one in our civilization of general comfort and social protection. Indeed, the Gospel's message is that taking this risk is a condition of true life. In our magnificent and inhuman world, perfect in some ways, but cold and unfeeling in others, the Gospel brings us indispensable warmth. Christ teaches us the path of self-improvement, inner life and happiness. Yes, we can be happy, here and now, whatever the amount of energy at our disposal, whatever the kilowatt-hours consumed, whatever the number of different objects offered for sale. And by our attitude, we can also make happier those who live around us.

ELEMENTS FOR AN ETHICAL APPROACH TO ENERGY ISSUES

FATHER PHILIPPE LAURENT

Scientific endeavours are necessarily accompanied by ethical reflection. Science is an activity of mankind for mankind and, like everything affecting the present and future of humanity, thus directly concerns the Churches — especially the Catholic Church —, which consider themselves responsible for revealing to men and women their true identity, over and beyond the multiple and diverse manifestations of their acts and thoughts, and for proposing the most adequate paths into the future.

In his address to UNESCO on June 2nd, 1980 — impressive by its scope and firmness — Pope John-Paul II, repeating the theme of his encyclical letter "Christ, redeemer of mankind and the world", emphasized the extent to which humanity, its true nature and its future are central to the reflection of the Church and his own preoccupations. We must not only deal with energy issues in the most scientific manner, but also carefully examine their relationships with humanity in general, as suggested by the title "Humanity and Energy". The most important and difficult aspect of this is precisely to situate the interface between energy and humanity, and to first of all learn to understand the men and women of today and tomorrow, with their needs and hopes, and to understand the true nature of mankind.

Alluding to menaces for the future, John-Paul II, in his speech to UNESCO, made a direct and moving appeal to men of science: "I address you in the name of this terrible threat to humanity, and in the name of the future and well-being of men and women throughout the world. I implore you to devote all possible efforts to *establish and respect*, in all branches of sciences, *the primacy of ethics*". On the 10th of November, 1979, John-Paul II also addressed the Pontifical Academy of Sciences, in the following terms: "Scientists will truly aid humanity by remaining conscious of the transcendency of man over the world and of God over man".

The question today is how to lay the groundwork for an ethics of energy issues, taking into account all available scientific data on energy and its various forms. These issues are new, by their scope and their social implications, and by the stakes involved. Yet, we must try to find the solutions, scientists and moral philosophers together, each with their specific concerns. In this, moralists are hardly helped — except for very general principles — by the meditations of the past, because of the novelty of the issues, and they too must show the "prospective imagination" mentioned by Paul VI in Octogesima Adveniens.

1. *Fatalism and energy*

Michel Pecqueur of the French Atomic Energy Commission opened the 11th World Energy Conference at Munich in September 1979 in the following terms: "The essence of my message is to refuse submission to fate and resignation". Indeed, there is no fatalism in the field of energy, because the issues involved are the direct responsibility of men and women, whether scientists, political and social leaders, or industrialists. The role of ethics is to help them determine and more closely define the available options with intellectual and political objectivity and honesty, and then lay down energy policies based on carefully thought out criteria, before implementing these decisions, made in the light of ethical considerations.

Public opinion is often impressed by the statements of scientists, as if their truths were so evident and objective as to be irrefutable, leading to an attitude of fatalistic resignation, which is not always accompanied, however, by profound conviction.

Although science can and must throw light on the options available, it is not for science alone to make the decisions. Its role is to make available as many options as possible, and to weigh very carefully the potential consequences of each option. However, in the energy field, like in science, there are inevitable imprecisions and margins of uncertainty. What, for example, are the exact possibilities offered by alternative energy sources? And what are the precise pollution hazards associated with a massive return to coal? In the so-called exact sciences, including those related to energy (geology, physics, chemistry, etc.), the scientist is modest in his statements, and aware of how much remains to be discovered. This is even more so in the social sciences (economics, sociology, social psychology, behavioural sciences, political science, etc.), which also have their role to play in resolving energy issues. It is evident that the type of society (low energy consumption, or high energy consumption) and civilization is influenced by the forms and levels of energy consumption. Indeed, the relationship is reciprocal. However, in the humanities, statements are less affirmative than in the exact sciences, with a greater readiness to indicate the initial assumptions and the factors influencing decisions.

Accordingly, the first ethical attitude is to refuse all fatalism and all mechanism, and to ask scientists and other experts not for solutions, but for options, and to enlarge the range of such options as much as possible, so that mankind can assume ethical responsibility for its decisions. These decisions then become a true exercise of responsibility, rather than simple adherence to a unique scientific solution to each problem.

Faced with many possible choices, the ethical attitude also consists in refraining from overly spontaneous judgements of what is good and what is bad, of what is possible and what is simply desirable, of what is better and what is worse. Ethics is the science of enlightened, critical and motivated decision making.

2. *Many ethics*

When possible solutions have been found, ethics introduces elements into the decision process which transcend the issues in question, namely the ultimate raison d'être of humanity and society. Ethics also introduces criteria for selecting appropriate ways of achieving goals, without however favouring any one of two equally legitimate means.

For this, one must necessarily refer to an anthropology, to a conception of mankind, its acts and its future, to a view of human history, both individual and collective. It is here that divergences can arise, according to the philosophical system adhered to by individuals and their groups. Indeed, is there, in the modern world, a single, incontestable view of humanity? Although the nations agreed in 1948 on a common "Universal Declaration of Human Rights", its interpretation and application are diverse. Such concepts as equality, liberty and justice do not have the same meaning for all, giving rise again to considerable differences in application.

Religion, for its part, throws precious and decisive light on this subject. Christian ethics is different from all others, because based on the person of Jesus Christ, his teaching, and his perfect example — in a word, on his Gospel. Christians cannot conceive separating moral philosophy and religion, even though each has its own methods and the link between the two is not always easy to explain. It would certainly be over-simple to expect the Gospel to directly provide the solution to current energy issues.

The plurality of ethical sources raises a real difficulty: how, in the energy field, can ethics of different origins be brought into agreement and made to concur with a common decision? In this respect, it is interesting to note the emergence in our complex and changing societies, with their doubts about the future, of a need for standards of behaviour and ethical guidance. Is this an awakening of moral conscience, or more simply the need to found a national and international consensus on solid bases? I would like to point out some signs of this, at various levels, but without however going into details.

Thus, in the remarkable OECD report by J. Lesourne, entitled "Facing the future: mastering the probable and managing the unpredictable", we may note the importance given to values and their evolution. This is new in prospective studies of the sort, and signifies the (still modest) introduction of an axiology in the sciences which develop scenarios for the future.

We may also note the slow, difficult, yet vital work of the United Nations towards the elaboration of "codes of conduct" in such fields as maritime transport, technology transfer, multinational companies, and restrictive practices, and towards the clarification of the rights and duties of human beings and states (e.g., Charter of the economic rights and duties of states), in new areas like the right to information and the law of the sea.

3. *The global aspect*

An ethical approach to energy issues cannot neglect the global environment, despite the fact that such issues are today even more urgent and have greater priority than in the past.

For almost 20 years, during the 50's and 60's, the world — or, at least, the Western world — lived with an ethics of continual growth, seen as necessary and beneficial, provided its fruits were equitably shared amongst all, and based on assured, positive scientific and technical progress. The Churches supported this point of view, speaking of growth as a "moral duty", but at the same time warning against a growth that is purely quantitative and economic, and against economic competition based simply on the comparison of GNPs. The most ancient justifications for human technical and industrial activities are to be found in the Bible, in the Book of Genesis, where God tells man to "replenish the earth and subdue it". Paul VI, in Octogesima Adveniens (1971) noted that: "Since the 19th century, Western societies, and many others in contact with them, have placed their hopes in indefinite, continuously renewed progress. Progress has become an omnipresent ideology". And yet, he continues: "Doubt exists today as to its value and its end result".

A change is taking place, accompanied by critical examination of certain forms of progress and industrial society, and of the relationships between mankind and nature. When the biblical texts are studied closely, it is found that humanity is told to respect nature and life, as much as to use it. After all, humanity is the manager of earth, not its owner. Scientists and engineers must take this new point of view into account.

Even more, we are entering a future in which the fundamental challenge is the collective survival of humanity. The Brandt Commission is establishing a "program for survival". Should we let ourselves be influenced by this and give priority to a global ethics of survival, rather than the ethics of growth? Should we concur with analyses which give priority to the global, imminent dangers threatening humanity and our planet? Should we take these threats seriously (John-Paul II has often spoken of them), registering collective fears, acknowledging their validity, and preparing programs for survival? The trouble is that, when one announces imminent danger, either of two things can happen: the fear of catastrophies can give birth to collective self-sacrifice and a true, wide spirit of community; inversely, the individualistic tendencies of citizens and nations can be reinforced, leading to conflicts in which some survive thanks to the death of others. The final result can be either a sharing of resources, or the use of force to hold on to privileges and continue the domination of some over others.

Let us now consider in greater detail the ethics of energy issues, first examining their global environment, in which the desire for survival so often goes hand in hand with fear. But, is fear a good basis for ethical choices? I doubt so. "Although the Christian faith offers no miracle solutions, its first task is to eradicate our fears for the future" (Bulletin of the Centre Protestant d'Etudes: Energy and the crisis in civilization). Our faith encourages us to analyze these fears, so as to put them into perspective, and better situate the object of our hope. Today, we need a moral philosopby founded on hope.

Facing an audience of scientists, I can hardly but mention the global ethics proposed by Professor Jean Monod in his inaugural speech to the Collège de France in 1967. His point of view was both tempting and terrifying, being based on an ethics of scientific knowledge. Let me quote from his speech: "The only purpose, the supreme value, the sovereign interest of the ethics of knowledge is not the happiness of mankind, even less so temporal power and comfort, nor even the 'know thyself' of Socrates, but objective knowledge itself. This must be said, and we must render this philosophy systematic, determining its moral, social and political consequences, then disseminating and teaching it: it is the only ethics compatible with the modern world, which it created".

We can recognize here a very modern aspect of the Promethean attitude, which is also very ancient and mentioned in the Bible as an original sin: namely the tendency of men to seek to dominate, by their own force, all things and their own nature, and to behave like God.

Constructing an ethics for energy issues requires that we clearly situate ourselves in a more global environment, with the choices this implies, some of wbich I have mentioned. Inversely, the ethical groundwork laid down for energy issues will also help to clarify and resolve other critical issues, such as those raised by genetic engineering, the marriage of telecommunications and data processing techniques, and demographic trends, for which deep thought and the construction of an ethics are also necessary.

We must relate energy issues to these other issues, and we must understand that they concern not only scientists, hut also many other political, social, cultural and religious leaders, above all from the ethical point of view, and whose voice must be heard: ethics always benefits when the approach is multi-disciplinary.

4. *The priorities*

The first ethical step consists in setting priorities and frameworks for drafting energy policies. I would like to mention three aspects which, in my opinion, sbould have priority.

a) Energy issues have assumed today — even more than in the past —

an *international, even worldwide dimension*, and this worldwide dimension (available resources, substitute energy sources, energy conservation, etc.) must be given priority. However, the economic and political world is divided into nations, each with very different energy needs and resources, and with the firm intention of promoting its own interests. An equitable solution cannot be reached by simply juxtaposing and opposing purely national points of view, with some nations trying to preserve or regain positions of force, while others attempt to emerge from positions of weakness arising from their energy dependence on other countries. In the vital field of energy, and because it is vital, *priority must be given to worldwide cooperation and solidarity.* According to some, this is an area — like food and hunger — in which a competent World Authority should be created. This is probably a utopic desire. Even so, for as long as no attempt is made to give preference to universality and the totality of mankind before considering the needs of individual nations, very little progress will be possible towards just solutions. The Catholic Church has traditionally taught that earthly possessions belong to all, and recent United Nations documents outline the concept of a common heritage of mankind. Perhaps this heritage should include the non-renewable energy sources, despite the fact that the sovereignty of each nation over the economic wealth of its soil and subsoil has been proclaimed a right. Ethics can help go beyond the legitimate rights of nations, to prevent them sliding into national egoism, and help them prepare for the future reality of the World Community of Mankind.

Of course, giving priority to such ethical considerations in behaviour and decisions would not be accepted by everybody. But is this necessary? The ethical approach would avoid struggles between rival nations for control of off-shore petrol, and would temper the race towards nationalization of marine resources. It would bring about changes in attitude by all the countries which are fortunate enough to possess major domestic reserves of fossil fuels, and which are currently preparing to reap for their exclusive benefit what they did not sow.

b) After fixing the geographical framework, it is necessary to consider the time aspect, which is probably easier. We must *build the medium and long term future* while *avoiding being dominated by the present and the short term*, which, despite the urgency of current issues (e.g., the 2nd oil price shock in 1979), are not the major priority. Governments — because of periodic elections in the democratic countries — and the public are very sensitive to short-term aspects and economic fluctuations.

The fear of restrictions and temporary shortages incites them to choose easy, short-term solutions, whereas the ethical attitude is to refuse to be influenced by current events, to address the medium-term issues, and to make true choices. This is the only language of reason and responsibility towards future generations. It is the most important moral obligation for the leaders of today.

Inversely, although very long-term studies have their use, they must not distract from the importance of medium-term policies. And yet, decisions concerning scientific and technical research policies must be made today, without delay. Choices must be made, because it is not possible to do everything at the same time, although much would be gained by active, loyal international cooperation, which although somewhat competitive, is also stimulating. The choices are difficult, because the chances of success are basically unpredictable, and yet are indispensable, and must be based on evaluations of the positive and negative consequences of each option. This need to decide acts whose future consequences are considerable and yet largely unpredictable is a very new moral situation, basically unexplored by theologians. The future, even scientific, cannot be completely mastered, and yet we cannot renounce shaping the future. Accordingly, we must determine the successive thresholds at which new decisions, based on ethical considerations, will be needed, right through the process leading from basic research to applied research to industrial, cost-effective implementation.

c) The third priority is to *first take into consideration the growing needs of the least favoured nations*, in the field of energy, and with respect to their levels and possibilities of development, inventing ways of satisfying these needs.

The two most recent World Energy Conference (at Istanbul and Munich) initiated a change of views on this subject. But, over and above facts and calculations, it is behaviours and policies that must be transformed, giving active and priority attention to the needs of the least favoured, and showing imagination and impartiality in discovering the solutions to their problems, both of which are eminently Christian attitudes. We are still far from this ideal. Nowadays, in international meetings, a special place is reserved for representatives of the least favoured nations: however, the intentions of all are not always characterized by their probity.

5. *Energy and international relations*

In the energy field, a highly central role is played by *international relations and their ethics*, and national governments have important responsibilities.

Let us examine some aspects of this.

a) During the last eight years or so, the "oil crisis" has transformed *international balances of power*, creating a new center of economic, financial and political power, the Organization of Petroleum Exporting Countries (OPEC), whose decisions have multiple influences on world economic and social situations, and whose acts are based more or less exclusively on its own economic, political and, probably, also ideological interests. Faced with this new power, the industrialized nations are attempting to act in concert (IEA, summit meetings, etc.) to re-establish a balance of power that is more to their advantage. It is striking that the most affected by mushrooming oil prices, the non-OPEC developing nations, are hardly involved at all in this international struggle.

This is just one aspect of the present international "economic warfare", in which policies based on balance of power considerations and the use and abuse of positions of domination are far from satisfying requirements for international social justice, and indeed are the cause of gross injustices. Moral philosophers and men of good will must think about a whole series of new ethical problems: Are unilaterally decided price increases permissible? Is it legitimate to limit production in order to perpetuate a position of force and conserve energy reserves when, at the same time, there are needs to be satisfied? What conditions justify an embargo? Should we morally condemn operations on spot markets which increase price disorder and encourage speculation? Is the enrichment of middle-men acceptable? How can we devise a method of recycling petrodollars that benefits the developing nations, rather than funneling the funds towards investments in the most industrialized countries?

These are some of the ethical questions we should be thinking about.

b) International relations have suddenly been invaded by energy issues. The current major concern of governments is to protect energy supplies, safeguard the balance of payments, and seek greater national energy independence. As a consequence, less importance is being attached to other vital international issues, such as:

— satisfying the essential needs of humanity, particularly feeding the world's populations;

— armed conflicts between nations, and invasion of national territories;

— promotion and respect of human rights.

The priority given to (in some cases, the obsession about) energy issues can lead governments to turn a blind eye to certain international injustices, so as to preserve "energy friendships".

c) Finally, energy issues, by their urgency, risk creating serious international tensions, and *jeopardizing "world peace"*.

Countries without domestic energy sources seek to safeguard their access to available resources in other countries and to assure the freedom of sea routes for the transport of these resources, even if this entails bringing pressure to bear on other nations, which can go as far as latent threats of military intervention (naval task forces in the Gulf, Strait of Hormuz, etc.). These are serious menaces for peace.

Furthermore, some OPEC countries are using their newly acquired wealth to purchase massive quantities of arms, and are capable of triggering regional conflicts. In some cases, they may also be envisaging becoming nuclear powers, progressing beyond civilian use of nuclear energy to its potential military use.

International political ethics is a subject that goes largely beyond the limits of action and reflection of scientists and other private citizens. However, they cannot ignore it, and it is one of the central concerns of the Churches, as witnessed by John-Paul II's speech to UNESCO.

6. *Energy and society*

A further subject of ethical reflection is the relationship between the forms and levels of energy consumption and the type of society or civilization. This is a very broad topic, often addressed by the Churches.

That there exists a link between "energy" and "society" is evident, and warrants reflection. However, this link must be examined in great depth if we are to avoid being led into spontaneous and ill-founded opinions. Analysis must be rigourous, avoiding overly rapid, symbolic interpretations, such as those often found in books on nuclear energy (see "La propthétie anti-nucléaire" by Alain Touraine, and others). Also the quantities of energy consumed and its uses play an important role in determining the type of society in which we live, by transforming working conditions and habits, multiplying human mobility and the possibilities of travel, influencing the evolution of machines (and weapons), etc. Nonetheless, energy is not the only determining element, nor perhaps the most important. Some modern criticisms of energy policies concern in fact our "technical" society in general (engineering is gradually encroaching on all aspects of life), our "scientific" society in general (with its unique rationality, that is just as pervasive). Thus, criticisms that the energy sources presently in use, such as nuclear energy, concentrate power in the hands of technocrats, and lead to a regression of participative democracy, concern just as much other fields of science and engineering. However, energy sources are seen as exemplary, and are at the center of a concentration of psychological and ethical concern.

The question is thus vast, but with a central, critical issue: energy, especially nuclear energy. For Jean Rossel (Director of the Physics Institute at the University of Neuchâtel in Switzerland): "The problem of nuclear energy and its industrial development is just one aspect of contemporary society, which is dominated by technology and its apparently unlimited material power. During the last two centuries, science and engineering have played a dominant role in the construction of modern society, and have largely taken the place of traditional Christian values... The triumphant scientific spirit of the 19th century and the first half of the 20th century took the form of a new religion. This deification of applied science was the main cause of the excesses of our civilization and the accelerated destruction of nature, but is today the subject of increasingly violent reactions and criticism which are, at least in part, justified... Whether one likes it or not, nuclear energy and its industrial organization have become a sort of extreme symbol of our arrogant and fragile technological society, along perhaps with space programs and their excesses" ("Science without conscience?", Labor et fides 1980, pages 96-97). J. Rossel goes on: "All countries are starting to be confronted with serious difficulties related to the consequences for the future of their societies of the energy policy decisions that must be made here and now, and must accept the risks inherent to these decisions". He then develops some personal ethical ideas.

The active attention being given today to the consequences of energy policies for mankind and society will probably help us to better master them, whereas in other fields where the potential dangers are just as serious, if not more so (e.g., genetic engineering), the authorities and public opinion are much less aware of the stakes and the risks, and a safe outcome is therefore less certain.

Independently of the evaluation of the risks inherent to all forms of energy and to their massive, increasing use, and independently of the centralized or decentralized solutions that accompany each energy source, it is certain that increased energy consumption over the centuries has had many positive influences on the evolution of the human condition, considerably alleviating the physical burden of men and women (although other, more psychological fatigues have grown in importance), allowing more efficient and varied control of the forces of nature, favourizing human mobility, travel and encounters, and creating new forms of communication and services. However, the negative aspects must not be forgotten, particularly our increased capability of self-destruction. As for everything, there are good and bad uses of energy.

The newest issue is that of determining the "best" level of energy consumption in a society. Is there a minimum threshold necessary to attenuate some of the most difficult aspects of human existence? Is there a maximum threshold above which men and women, surrounded by all sorts of gadgets which spare them even the slightest effort, and alienated by bodily comfort which has become a necessity, are so fragile, vulnerable and dependent on these multiple "energy-based" aids that their sudden absence (due, for example, to an electricity strike) creates a shock, a traumatism? Unused to all physical effort, except in leisure, they become incapable of reacting and adapting. Without the high energy consumption to which they are used, they are paralyzed, and incapable of rediscovering the simple gestures of personal effort and mutual assistance. Although certainly liberated by increased consumption and availability of energy, in all its forms, mankind risks falling into excesses and losing part of its autonomy of action and reaction. This is a simple possibility, but which must not be ignored.

Even if the international comparison of GNPs as a measure of development, power and well-being has, quite rightly, now been condemned, similar comparisons (often made at World Energy Conferences) based on differences in per annum and per capita energy consumption from country to country, with the assumption that it is possible to progressively absorb what is called "backwardness", must also be considered with discrimination. It is by no means certain that all societies should or want to reach a situation of high energy consumption: intermediary, "appropriate" solutions may well be more satisfactory.

The comparison with feeding the populations is interesting. Although there are, of course, malnutrition and hunger thresholds, there are also excess eating habits verging on luxury and waste, and detrimental to health. Dietetics indicates the right level of food consumption, and this can perhaps encourage a general sharing of the world's available food resources. Is the same not true, all things considered, for energy consumption? If eating should be first of all an art of living together and communicating, then energy should be an art of acting and operating together. An energy dietetics — and ethics — is still to be invented.

After this survey of some of the aspects of developing an ethical approach to energy issues, a final remark should be made. In talking of various forms of energy, we implicitly refer only to material energies, drawn from nature. Yet, as we are aware, there also exist *spiritual energies*, which circle the globe, bringing dynamic, sometimes revolutionary forces into play. These energies count and have counted in human history. Today, we must rediscover their source and their place in our society. They can give meaning to the flows of material energies that we create and multiply, helping us to make sure they do not slip out of our control. The interaction and harmonization of spiritual and material energies is certainly the best path for societies and civilizations. This was the language of John-Paul II at Paris in June of this year when, addressing international catholic organizations, he said: "Through the Church, the Gospel fecundates moral and religious energies, and makes an original contribution to the establishment of a culture, and of a civilization founded on the primacy of the spirit, justice and love".

DISCUSSION

Couture

1. My intervention will be largely political and I apologize, but we were encouraged to speak freely and I will make use of this possibility.

2. Democracy is not easy to define. Ballots are no proof of democracy if citizens are submitted to information distorsions or psychological pressures.

If citizens are supposed to be informed on energy matters to give their opinion, why wouldn't it be the same with any other subject, from food production to transportation, to international politics etc.? Even if they had time enough, very few of them are in a position to make the necessary trade-off between so many different and difficult matters.

To be precise, the parliamentary system has been invented by the English as a substitute for the Greek agora, after checking the monarchy absolutism. I do not know of a better system than that, even if it is far from perfect.

3. If you look at what has been said in this room for the last five days, it seems to me very clear that high technology is a must if you are to cope with the enormous population growth which we are facing. Only high technology developments in industrial countries (notably nuclear) will leave enough oil available for developments of less developed countries, and especially agricultural mechanization, which Mr Sanchez rightly showed is necessary.

So, even if it is a bit difficult to mention this point in this place, I believe that a low-energy long term scenario cannot be taken into consideration without a correlative limitation of the growth in world population. And even if such limitations were put into application now, it would hardly be of any consequence for the next twenty years, and my previous conclusion would hold for that time space.

4. So, in conclusion, I must state that I am in complete disagreement

a) with the assimilation of high technology with lack of democracy, and,

b) with the possibility of doing without high technology, whatever happens in the medium term future.

Teillac

Je serai bref. J'ai beaucoup apprécié les réflexions que nous ont apportées, cet après midi, M. Leprince-Ringuet et le Père Laurent. L'approche du problème du Père Laurent mériterait une longue discussion. Je voudrais simplement rappeler ce que j'ai dit ce matin: à côté de réflexions portant sur le long terme, comme celles qui viennent d'être évoquées, il y a des problèmes urgents; il existe des situations dans lesquelles le futur immédiat prend le pas sur le moyen et le long terme. Il est absolument indispensable que ce point reste bien présent à l'esprit. Ceci est d'ailleurs en accord avec ce que dit le Père Laurent lorsqu'il note que les problèmes énergétiques, par l'urgence qu'ils ont, peuvent susciter des tensions graves dans les relations internationales et compromettre la paix mondiale.

D'autre part, permettez-moi, Monsieur le Président, de protester vigoureusement à l'encontre de l'assertion de M. J. Pasztor lorsqu'il prend comme exemple les mesures prises par le gouvernement français pour montrer le caractère policier et la réduction des libertés que peut apporter une centralisation de moyens énergétiques.

Starr

I would like to make a general comment on the three formal papers that were presented. First, I find myself completely in agreement with Father Laurent on his approach to the ethical relationships between energy, science, technology and society. I would like to start off with one of the key points made in that paper, namely, that the role of science, and I presume technology, is to revise options for people to use, for society to choose from, not necessarily to dictate what should be done, but to provide options and choices. And those are the two key points: a spectrum of options available and freedom of choice of what options you use for the particular circumstances you need.

As for the paper of M. Leprince-Ringuet, I find that these comments could have been made about society one and two hundred years ago. It is not clear to me that this really relates to the technological development of our society. It may relate more to the problems of an urban living and of city life, which is characteristic of any age. And so I have a question of whether his comments really give us any guidance on the issues relevant to the role of energy.

Now the paper of Mr. Pasztor disturbs me because basically it is not a paper against energy, it is a paper against our social structure and our social values, and it is not clear to me why energy is being picked as a vehicle for trying to change that society, except that at the moment it appears that energy is a great issue of public discussion and decision.

From a fundamental point of view, the energy systems and their changes are having much less effect than the development of the semi-conductor and the information industry, which will radically change the whole structure of our society.

But there is another comment which was also made in the World Council paper, that is the supposed vulnerability of a high technology society as compared to a low technology one. Now in my group at EPRI, we have put together for the past year a qualitative study on the vulnerability of technological societies versus primitive societies, the data base being an almost ten-year study that the National Science Foundation has supported on how different societies behave against natural catastrophes: earthquakes, tornados, hurricanes, floods. It turns out that high technology societies are much less vulnerable than low technology ones. Even though the system is complicated and easily damaged, the recovery is very great and very fast. For example, if you look at earthquake areas in a high technology society, you will find that the damage to human life is much less than the earthquake damage in a low technology society. And that is true for floods. We have had floods in the United States, we have had floods also in other areas of the world; and the comparison is startling. So I find that some of the approaches that the World Council of Churches uses in its analysis are inappropriate. The essence that society has faults that require changes, I cannot argue with, but I do not think that the energy systems are really the right vehicles for doing this.

LESOURNE

As stressed by R.P. Laurent, it is important to separate the criteria from the evaluation of policies. From that point of view, no advocate of a given energy policy has a right to confiscate "a priori" the votes of the generations to be borne. Each policy has advantages and disadvantages for present and future generations and the problem is to arbitrate between the two.

PASZTOR

I want to comment on the paper of Prof. Leprince-Ringuet:

I am not a theologian, but I have a theological question. On page 12 you mentioned that "love is a source of all life".

When I look around and recall the genocide of millions of Jews, just 30 years ago; or the civil war in El Salvador; or the man who sleeps on the stairs everynight — right next to our hotel — I don't seem to see that love is a source of *all* life.

There is sin in the world, we don't always love our neighbours. I wonder if your kind of analysis is helpful at all? I think that we should start out with the fact that there is sin and that after we do not love our neighbours and others. May-be we should start from there?

LEPRINCE-RINGUET

Les problèmes que j'ai abordés rapidement se rapportent bien aux temps modernes, à l'époque actuelle et absolument pas à ce qui pouvait se passer dans les grandes villes il y a cent ans, ou cent cinquante ans. Actuellement la dépense en énergie, le temps perdu pour circuler, pour stationner ne sont absolument pas comparables avec ce qui se passait autrefois; le gigantisme des grandes villes est un phénomène actuel, tout-à-fait moderne, et ce gigantisme entraîne un grand nombre de difficultés et de « stress » pour les habitants des grandes villes.

Le gigantisme des villes actuelles a joué un rôle important dans les réactions de mai 1968 à la base desquelles on trouve le refus d'entrer dans une civilisation rationnelle, dans une civilisation technique. Tout cela est récent; ce sont des réactions sur ce qui passe précisément aujourd'hui.

Ce que vous disiez sur le fait que j'ai indiqué dans mon texte que l'amour est indispensable pour que la vie entre les hommes soit possible me paraît absolument évident. Le monde actuel est un monde qui produit, qui secrète quelque chose de froid, quelque chose de dur, qui secrète des inconditionnels, des ensembles aggressifs. Je suis un scientifique, un scientifique nucléaire, un scientifique des particules fondamentales; par conséquent, je ne suis pas suspect d'être rétrograde. Au contraire, je suis pour le développement le plus large possible de la science dans tous les domaines, car on ne sait pas quel domaine donnera naissance à des applications bénéfiques dans vingt ans ou dans cinquante ans, mais je pense que le monde technologique est un monde froid, dur, agressif. Même s'il était parfait, même s'il répartissait équitablement la richesse dans le monde entier, il resterait froid; le monde a besoin d'autre chose, il a besoin d'un souffle qui ne soit pas rationnel; il a besoin d'une certaine convivialité, d'une possibilité de contacts chaleureux entre les hommes, et ce n'est pas ce que le monde actuel fabrique.

PASZTOR

There are a number of questions, and I would like to start with Prof. Teillac. About the right to strike in France I would be very glad if he can correct me on that — I got that information from *Le Monde* and if it were incorrect I would be very happy. That is one point. About the question of nuclear having a connection between military and civilian, I would like to read what I wrote: "In *some* countries, existing civilian nuclear programs are closely related to the military nuclear programs. Either can be an offshoot of the other". I was not talking about France, but there *are* such countries. The fact is as we heard before, that there are very similar technologies involved in both cases and there can be a relationship between the two matters.

Answering to Prof. Starr, I agree that we are using energy as a sort of scapegoat, you are completely right. But comparing the vulnerability of societies, I could not agree with you except on the fact that nobody wants to go back to a primitive society here.

As I mentioned in my talk, we are opposing the further trend toward even more centralization, even more high technology. And a simpler society, I do not think it has to evolve into what you would call a primitive society. It will be a different society, but not necessarily primitive.

CONCLUSIONS

Invited by the Pontifical Academy of Sciences, the participants in the Study Week "Mankind and Energy" have studied the scientific, technical, social, political and ethical problems associated with the energy issues facing mankind.

It is not possible adequately to cover all the arguments discussed during the Study Week.

The participants are in general agreement with the following:

Current Status

Energy plays an essential role in the material, social and cultural life of mankind. At the present stage of world development it is not possible without additional energy availability to cope with the population growth, increasing demand for food, and with the problem of unemployment: furthermore, a lack of energy can indeed menace world peace.

The abundance and the low price of oil, altbough leading to some waste, has contributed to rapid economic growth after World War II. This period, which is now over, was characterized by:

a) a narrowing of the differences between the GNP per capita within the industrialized countries;

b) conversely, no reduction in the economic gap between the industrialized countries and the third world countries. In some cases a widening of this gap has even occurred;

c) an increasing role played by oil in the world economy (45% of commercial energy in 1978 against 27% in 1950). This resulted in a severe dependence on the petroleum exporting countries, many of which are located in the same region of the world, and this dependence has contributed to the instability of the world economy.

In any case, the energy needs of mankind will, in the next decades, continue to increase, as a result both of population growth and of the necessary increase in mean energy consumption per capita, primarily in the non-industrialized countries.

On the other hand, the experts agreed that the level of oil production is not likely to increase, essentially due to political and economic constraints. Without increasing contribution of energy sources alternative to oil, mankind will be unable to meet its energy needs, thus leading to a very severe crisis during the period from now to the end of the century.

The slowing down of the economic growth and, in addition, the steep rises in oil prices in the 70's have already produced major problems for both the developed and developing countries. These oil price rises have led to major disturbances in the international financial flux threatening the stability of the entire existing system, and contributing to the growth of inflation and unemployment.

This situation has placed the non-industrialized countries in an extraordinarily vulnerable position, considering the fragility of their external trade and the importance of their energy needs at such a crucial time in their development.

Urgent Actions

We have no time to waste. Energy policies are urgently needed, involving concerted action by the responsible bodies, and this requires the support of public opinion and energy users. Unfortunately, even in the industrialized countries, the public consciousness of the problem is lacking.

Moreover a joint effort by the industrialized countries and oil exporting countries is required to provide means — such as a joint fund — to help the poorest countries to develop their own energy resources.

Only coal and nuclear power — together with a strong energy conservation policy and continued gas and oil exploitation and exploration — can allow us to effectively meet the additional needs for the next two decades. It is emphasized that the industrialized countries must reduce their oil consumption and leave it essentially for specific end uses (transportation, petrochemistry, etc.), and for the basic needs of the developing countries.

No energy source should be neglected if we wish to resolve the energy crisis. A strong research effort must be made to develop renewable energy sources which, among other things, can encourage decentralization of human settlements, thus reducing the disturbances of the excessive urbanization process that has occurred and is still occurring in the world.

In particular, solar energy, under its various forms (thermal, thermodynamic and photovoltaic energy, biomass, etc.), have demontrated good potential especially for non-centralized energy supply.

Wood fuel is used by about half the world's population for cooking and heating and is supplied by about half all the trees harvested. This biomass resource, so essential for subsistence, is threatened by deforestation and soil erosion. It is recommended that increased attention be paid to tropical forest management, and to use of modern agricultural techniques for energy farming (e.g., for liquid fuel production, which is quite promising) under those conditions where it will not compete with food production.

A mix of energy resources and technologies is essential to reduce the vulnerability of the socio-economic system and to retain the necessary flexibility, thus being prepared to cope with unforeseen events like possible sudden changes in source availability. Moreover, this flexibility would allow changes in future energy policies.

It is important to analyse energy issues not only at the global level but also at national and regional levels, taking into account such specific characteristics and needs as local resources and security of supply, economic structures, balances of payments, conditions of employment, etc.

Not only are we faced with problems of energy sources, but also with those of energy management, storage, transportation, and transformation to its final form. Electricity can be expected to play an increasingly important role in the life of mankind, in view of its convenience and flexibility.

As far as environment is concerned, particular attention was paid to the possible consequences of an increase in the carbon dioxide content of the atmosphere. As carbon dioxide effects on climate are not yet completely understood, continuing extensive researches on climate, on photosynthesis and on the photochemistry of carbon dioxide fixation should be pursued so that possible detrimental effects of carbon dioxide may be detected early enough to take appropriate actions.

As regards the use of nuclear energy, some concern has been voiced as to the possible links between nuclear energy and the proliferation of nuclear weapons. In this field, however, it is recognized that, once a certain general level of knowledge and technical expertise has been acquired, a country's development of nuclear weapons is primarily determined by political considerations. Thus, with adequate precautions, there is no reason to bar the development of nuclear energy for civil uses.

Serious consideration should be given to the safety and health of those engaged in the entire chain, from primary energy production to ultimate distribution of energy. Energy development and management should always take into account the respect of environment and the protection of the health of humanity.

Prospects and Hopes

Mankind should be able to assure adequate availability of energy before or about the turn of the century, provided necessary actions are taken now with sufficient vigour. Intensive research and development action can make it possible to satisfy the long term energy needs of mankind using the vast reserves of coal, non conventional oil and gas, uranium in breeders, and renewable energies. However some participants expressed their concern regarding the fact that the rapid growth of the world population makes more difficult the long term solution to many problems, including energy.

The recent growth rate of energy consumption in the industrialized countries cannot continue indefinitely. To resolve the present energy crisis is not sufficient. It is also necessary for these countries to evolve new less energy consuming ways of life, which will promote new patterns of development.

The developing countries should also evolve courses of action, appropriate to their specific situations. In this process, the role of the industrialized countries is essential to promote cooperation with the developing countries for technology transfer, education and training.

All nations have become interdependent, not only insofar as growth rates are concerned, but also with respect to raw materials, agricultural products, technologies and the knowledge necessary for development. This interdependence and the problems that it poses emphasize the necessity of new kinds of cooperation between nations.

The magnitude of present and future energy problems and their human consequences imply the responsibility of scientists, who must precisely evaluate the data and necessary research policies, of political leaders, who must, in a new spirit of cooperation, take decisions adapted to the needs of both current and future generations, and of all those who can influence the future of our societies such as engineers, sociologists and churchmen. Cooperation between these groups is highly desirable, at the national and even international level, especially insofar as it brings out the human and hence ethical dimension of energy issues.

CONCLUSIONS

Invités par l'Académie Pontificale des Sciences, les participants à la Semaine d'Etudes « L'Humanité et l'Energie: Besoins - Ressources - Espoirs » ont étudié les problèmes scientifiques, techniques, économiques, sociaux, politiques et éthiques posés à l'humanité par les questions énergétiques.

Il n'est pas possible de résumer en quelques phrases l'ensemble des travaux de cette Semaine d'Etudes.

Un large accord des participants s'est dégagé sur les points suivants.

Situation présente

L'énergie joue un rôle essentiel dans la vie matérielle, sociale et culturelle de l'humanité. Au stade actuel de développement du monde, il n'est pas possible, sans quantités supplémentaires d'énergie, de faire face à la croissance démographique, à celle des besoins alimentaires et au chômage: une pénurie grave en énergie peut menacer la paix du monde.

L'abondance et le faible prix du pétrole ont, malgré un certain gaspillage, facilité la forte croissance économique qui a suivi la dernière guerre mondiale. Cette période, qui est maintenant révolue, a été marquée par:

a) une diminution des disparités en revenu par habitant au sein des pays industrialisés;

b) inversement, le maintien des disparités économiques entre pays industrialisés, d'une part, et pays du Tiers Monde, d'autre part (pour certains de ces derniers, l'écart s'est même accru);

c) le rôle croissant joué par le pétrole dans l'économie mondiale (45% des énergies commerciales en 1978 contre 27% en 1950). Ceci a entraîné une dépendance grave vis-à-vis des pays exportateurs de pétrole dont beaucoup sont situés dans la même région du monde, dépendance qui a contribué à l'instabilité de l'économie mondiale.

En tout cas, les besoins en énergie de l'humanité continueront à croître au cours des prochaines décennies, à cause, à la fois, de la croissance démographique et, aussi, de la nécessaire augmentation de l'énergie moyenne par habitant dans le monde, surtout dans les pays en développement.

D'autre part, les experts s'accordent à penser que la production de pétrole dans le monde ne peut guère dépasser le niveau actuel, essentiellement à cause de contraintes liées à la politique et à l'économie. Si l'humanité ne dispose pas à brève échéance de nouvelles sources d'énergie, elle ne pourra pas faire face à ses besoins, d'où une situation de crise aiguë pour la période qui nous sépare de la fin du siècle.

D'ores et déjà, le freinage de la croissance économique, aggravé par les hausses brutales du pétrole, pose un problème grave à l'ensemble de l'humanité qu'il s'agisse des nations industrialisées ou des pays en développement. Ces hausses ont entraîné des perturbations considérables dans les flux financiers mondiaux, compromettant l'équilibre des systèmes existants et contribuant à aggraver l'inflation et le chômage.

Tout ceci place les pays en développement dans une situation particulièrement dramatique, compte tenu de la fragilité de leurs échanges extérieurs et de l'importance de leurs besoins énergétiques dans une phase cruciale de leur développement.

Actions Urgentes

Il n'y a pas de temps à perdre. Il faut promouvoir d'urgence des politiques énergétiques vigoureuses, comportant des mesures concertées de la part des organismes responsables; ces mesures appellent le concours des opinions publiques et des consommateurs d'énergie. Malheureusement, dans les pays industrialisés, cette prise de conscience demeure radicalement insuffisante.

Bien plus, afin d'aider les nations les plus pauvres à développer leurs ressources en énergies, une action conjointe est nécessaire de la part des pays industrialisés et des pays producteurs de pétrole pour la mise en place de moyens communs comme, par exemple, la création d'un fonds d'aide conjoint.

Seuls le charbon et l'énergie nucléaire — combinés avec une politique ferme d'économies d'énergie et la poursuite des explorations de gaz et de pétrole et de leur exploitation — peuvent nous permettre de faire face efficacement aux besoins d'énergie supplémentaire pour les deux prochaines décennies. Il faut insister sur le fait que les pays industrialisés doivent réduire leur consommation de pétrole de façon à ce que ce dernier reste disponible pour ses usages spécifiques (transport, pétrochimie, . . .) et ne fasse pas défaut aux besoins fondamentaux des pays en développement.

Aucune source d'énergie ne doit être négligée pour concourir à stopper cette crise. Un effort de recherche important doit être fait et poursuivi pour hâter le développemnt des énergies renouvelables qui, entre autres choses, peuvent contribuer à décentraliser les activités humaines, réduisant ainsi les inconvénients de l'excessive urbanisation qui s'est développée et continue à le faire.

En particulier, l'énergie solaire, sous ses diverses formes (énergie thermique, thermodynamique, photovoltaique, biomasse, etc.) a montré toutes ses potentialités, notamment comme source d'énergie décentralisée.

Le bois est utilisé pour le chauffage et la cuisson par la moitié environ de la population mondiale. La moitié de tous les arbres abattus le sont à cette fin. Cette ressource énergétique de biomasse, essentielle pour l'humanité, est menacée d'épuisement par le déboisement et l'érosion des sols. On recommande donc de porter une attention accrue à la gestion des forêts tropicales ainsi qu'à la mise en oeuvre de techniques agricoles modernes pour la production d'énergie par des cultures appropriées (par exemple pour la production de combustible liquide qui paraît prometteuse), là où ces cultures ne compromettent pas la production alimentaire.

Le pluralisme des sources et des techniques constitue un facteur d'équilibre et réduit la sensibilité des systèmes économiques vis-à-vis des à-coups possibles dans les approvisionnements. De plus, ce pluralisme procure une flexibilité permettant, éventuellement, des changements dans les politiques énergétiques futures.

Il est important de considérer les problèmes énergétiques non seulement à l'échelle mondiale mais aussi au niveau des nations et des régions du monde en fonction de leurs caractéristiques et de leurs besoins propres, tels que: ressources locales et sécurité d'approvisionnement, structures économiques, balances des paiements, conditions de l'emploi, etc.

Il n'y a pas que les problèmes de sources d'énergie, mais aussi ceux de la gestion de l'énergie, de son stockage, de son transport et de sa transformation avant l'utilisation finale. Du fait de sa souplesse et de sa commodité, l'utilisation de l'énergie électrique est appelée à jouer un rôle croissant dans la vie des hommes.

En ce qui concerne l'environnement, une attention particulière a été portée aux conséquences possibles de l'accroissement de gaz carbonique dans l'atmosphère. Ses effets ne sont pas entièrement élucidés et il est nécessaire de poursuivre les recherches sur l'action climatologique du gaz carbonique, sur la photosynthèse et la photochimie de sa fixation de manière que des effets nuisibles éventuels du gaz carbonique puissent être décelés avec un préavis suffisant pour permettre la réaction appropriée.

En ce qui concerne l'énergie nucléaire, certains ont exprimé des inquiétudes du fait des liens possibles entre l'énergie nucléaire et la prolifération des armes atomiques. Dans ce domaine cependant, il est reconnu qu'à partir d'un certain niveau de savoir et de connaissances techniques, l'accès d'un pays à l'armement nucléaire est essentiellement conditionné par une volonté politique de le réaliser. Aussi, et sans que soient négligées les précautions à prendre pour ne pas faciliter cet accès, il n'y a aucune raison pour condamner le développement de l'énergie nucléaire à des fins civiles.

Une attention particulière doit être portée à la protection et la santé de ceux qui travaillent dans la chaîne complète allant de la production d'énergie primaire jusqu'à la distribution finale de l'énergie. La production d'énergie et sa gestion doivent se faire en respectant l'environnement et la santé des populations.

Espoirs et Perspectives d'Avenir

Si les actions nécessaires sont menées dès maintenant avec une force suffisante, l'humanité doit pouvoir retrouver une certaine aisance énergétique avant ou aux alentours de la fin du siècle. En plus, et pourvu que des programmes vigoureux de recherche et de développement soient entrepris et poursuivis, les besoins de l'humanité pourront être couverts pour une longue durée grâce aux importantes réserves de charbon, au pétrole et au gaz « non conventionnels », à l'utilisation de l'uranium dans les surgénérateurs, et, bien sûr, aux énergies renouvelables. Cependant, certains participants ont exprimé leur souci concernant le fait que la rapide croissance de la population du monde rend plus difficile la solution à long terme de nombreux problèmes dont celui de l'énergie.

La récente croissance de la consommation en énergie des sociétés industrialisées ne peut continuer longtemps. Il ne suffit pas de résoudre la crise actuelle de l'énergie; il est tout aussi nécessaire de rechercher, pour ces mêmes pays, des modes de vie différents permettant, avec une moindre consommation énergétique, de promouvoir de nouveaux types de développement.

Les pays en développement ont à définir et à promouvoir leurs propres évolutions en fonction de leurs caractéristiques respectives particulières et de leurs situations actuelles. Le rôle des pays industrialisés est essentiel pour que soit mise sur pied une efficace coopération avec les premiers dans les domaines des transferts technologiques, de l'éducation, et de l'entraînement du personnel.

Toutes les nations sont devenues interdépendantes, non seulement en ce qui concerne les taux de croissance, mais aussi les matières premières minérales et agricoles, le potentiel technologique et les connaissances nécessaires au développement. Cette interdépendance et les problèmes qu'elle suscite renforcent la nécessité que se créent entre les nations de nouveaux liens de solidarité.

L'importance des problèmes énergétiques d'aujourd'hui et de demain et les conséquences humaines qu'ils comportent, impliquent des responsabilités. Celles-ci concernent non seulement les scientifiques dans l'évaluation exacte des données et des politiques de recherche à mener, mais aussi les hommes d'Etat qui doivent, dans un esprit nouveau de concertation, prendre des décisions adaptées aux besoins des populations présentes et des générations futures. Participent aussi à ces responsabilités tous ceux qui ont une influence sur l'orientation des sociétés: techniciens, sociologues, hommes d'Eglise. Une concertation entre responsables, au niveau national et même international, est fort souhaitable, surtout dans la mesure où elle fait surgir la dimension humaine et donc éthique de tous ces problèmes.