Nuclear Disarmament, Non-Proliferation and Development
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New Energies for the Future of Mankind

Carlo Rubbia

Present nuclear energy situation

About fifty years ago (1956), the idea of "Atoms for peace" was greeted with the greatest enthusiasm, as a way of providing a new form of cheap, abundantly available and inexhaustible energy for all people on Earth. During the subsequent half century the position on Nuclear Energy has been profoundly modified: nuclear power is today definitely no longer viewed as it was fifty years ago. Today, it has become clear that "atoms for peace" have not been able to control the growth of the proliferation process.

The IAEA was created with two purposes: the worldwide diffusion of nuclear technologies; to limit the proliferation of technologies for production of nuclear weapons and fissile materials. One of the main reasons of the lack of adequate success has been that peaceful and military applications in the present form of atomic energy are inextricably connected – by the same common nuclear physics principles, the same scientific and technological research, the same chemical industry, and largely by the same financing and the same organizations.

The NPT – The Non-Proliferation Treaty

The Nuclear Non-Proliferation Treaty (NPT) is based on three pillars: prohibition of nuclear weapons, components and technology transfer from the five Nuclear Weapons States (NWS) to the Non-Nuclear Weapons States (N-NWS); dismantlement of nuclear arsenals by these States; widespread proliferation of peaceful nuclear energy (atomic energy, medical and industrial isotope use) only for peaceful purposes.

The question of why the present non-proliferation regime is not sufficiently effective has two overlapping answers that I would like to underline: one is political and the other is technological.

The political aspect is that an uninterrupted proliferation occurs as NWS do not want to commit to the obligations of destroying their nuclear arsenals. In this situation, as we said this morning, more and more countries may decide that nuclear weapons will enhance their security.

The technological aspect is the already mentioned result of the too close link between weapons and energy. The exploitation of a nuclear energy solely for peaceful purposes is technically possible but it requires fundamental changes in the nuclear reactions and in the associated technologies.

A political process without major technological changes may not guarantee a sufficient protection for the indefinite future of mankind.

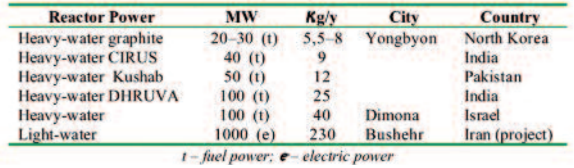
Let me touch briefly upon the question of plutonium and the question of uranium.

Plutonium-driven weapons

For many years atomic scientists carefully cultivated a myth that in order to make a nuclear bomb, special weapons-grade plutonium consisting of 239-Pu isotope over 94% was needed. In reality, a mixture of plutonium isotopes that can be obtained in any nuclear reactor is perfectly suitable for making a nuclear bomb.

One energy reactor with the power of 1,000 MW produces enough plutonium in one year to make 40–50 nuclear warheads. Even in research reactors with only a few MW power, sufficient amounts of plutonium for a bomb can quickly be produced.

Plutonium production in some military reactors has been historically described:



Reactor Power	MW	Kg/y	City	Country
Heavy-water graphite	20–30 (t)	5,5–8	Yongbyon	North Korea
Heavy-water CIRUS	40 (t)	9		India
Heavy-water Kushab	50 (t)	12		Pakistan
Heavy-water DHRUVA	100 (t)	25		India
Heavy-water	100 (t)	40	Dimona	Israel
Light-water	1000 (e)	230	Bushehr	Iran (project)

t – fuel power; e – electric power

They all have contributed with very small machines to produce only a few kilowatts per year, that was the beginning. In addition to that, a legacy of the Cold War are 250 tons of separated Pu, mostly produced by the Soviet Union and the U.S. An additional 250 tons of separated plutonium are a legacy and a premature vision of the nuclear-energy establishments for future powered by plutonium breeder reactors.

Highly Enriched Uranium (HEU)

To make a weapon, HEU does not necessarily need to be 95% enriched; research proves that even 25% enriched 235-U may suffice, but in this case it would take higher quantities of uranium. For instance, the bomb dropped on Hiroshima contained uranium, enriched up to 80%, and weighed 60 kg.

HEU is available not only to the military and government, but also to a number of civilian organizations. There are around 2 million kg of HEU in the world and it takes only 50 kg to produce one gun-type nuclear weapon, so there is the potential for tens of thousands of bombs. The main problem is that these materials may end up in the hands of terrorist organizations. Nuclear terrorism can have many forms: attacks made with stolen nuclear weapons, creation of a terrorist-made nuclear device, etc. Of course, making a nuclear device is not easy, but the hardest part is illegal access to HEU.

A gun-type HEU nuclear charge is the easiest nuclear weapon design which may not need to be fully tested first by terrorists. Although even if this weapon is a complicated device, a terrorist organization that includes engineers, metal-makers, and technicians could easily produce one.

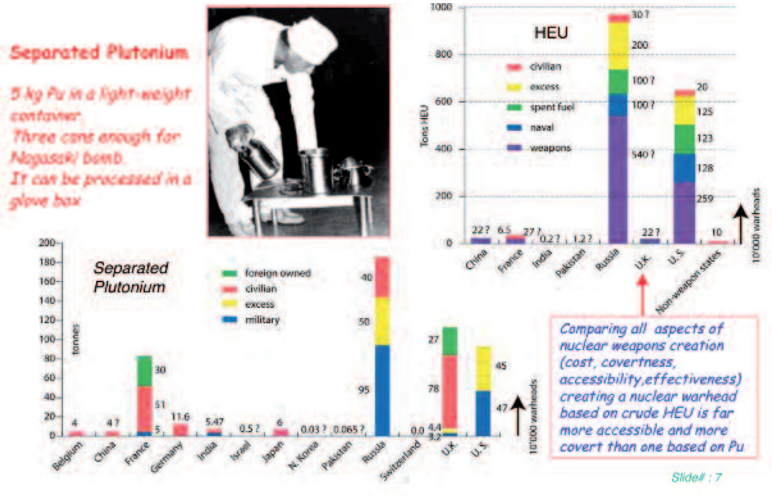
Reducing the risks of a threat with HEU

If HEU material is transported abroad, even minimal radiation encasing makes it hard to detect it. This factor also makes it one of the most dangerous substances in terms of a terrorism threat. The first attempt to launch such an initiative was made in 2005 to make sure that HEU is not used in civilian production. Civilian HEU is not as well protected as military production and more people have access to it.

This initiative was launched by a group of countries including Norway, Iceland, Lithuania and Sweden. Unfortunately, this initiative has not been ratified yet. The imposing international obligations are still unresolved. It seems to me that removing HEU from civilian use is certainly something that should be done as quickly as possible as an important condition.

The replacement of HEU with low-enriched uranium for civil applications means considerable expenditures on new fuel and reactor development. Moreover, nuclear industries are reluctant to stop the development of these HEU technologies that might become useful for other future subjects. However, the political aspect is still the more important one. We still do not pay appropriate attention to the possibility of terrorist organizations creating an even rudimentary nuclear weapon, whereas the prospect of a dirty bomb creation seems more feasible, although it is much easier to detect.

A Summary



Separated Plutonium

5 kg Pu in a light-weight container
Three cans enough for Nagasaki bomb
It can be processed in a glove box

Comparing all aspects of nuclear weapons creation (cost, covertness, accessibility,effectiveness) creating a nuclear warhead based on crude HEU is far more accessible and more covert than one based on Pu

Future of present day nuclear power

Global climate change is one of the most acute environmental problems. It is believed that in order to keep global warming within 2 degrees, CO_2 emissions should decrease by 30% to 60% with respect to 1990 and amount to 10 to 15 billion t/year CO_2, against the prediction of 40 to 50 billion t/year by 2050, with a reduction of 25 to 40 billion ton/year.

Tripling the ordinary nuclear energy will reduce CO_2 emissions by 5 billion t/year, which would not be determinant. But it would imply:

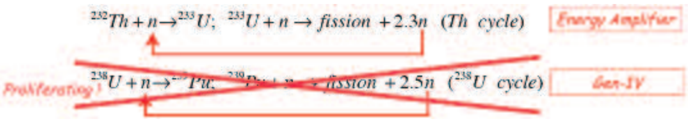
- An additional capacity of 25 GWe/year (one new 1 GWe reactor every two weeks), including replacement of outdated reactors;
- Reprocessing, MOX and breeders, construction of 50 new plants
- Creation of geologic storages, equivalent to 14 Yucca Mountains.

Notwithstanding, Russia is planning to build 40 new nuclear power units and Italy between 4 and 10 plants. Both India and China have announced a wide reliance on nuclear energy, as have countries of Latin America and South-East Asia. Due to the lack of any substantial alternative, Europe and North America are close to taking similar decisions.

Iran's case indicates the chain reaction of nuclear proliferation in the world. A number of Latin American countries (Brazil, Argentina) have announced the start up of uranium enrichment on their territories, as was already mentioned this morning.

Alternative, virtually unlimited forms of nuclear energy?

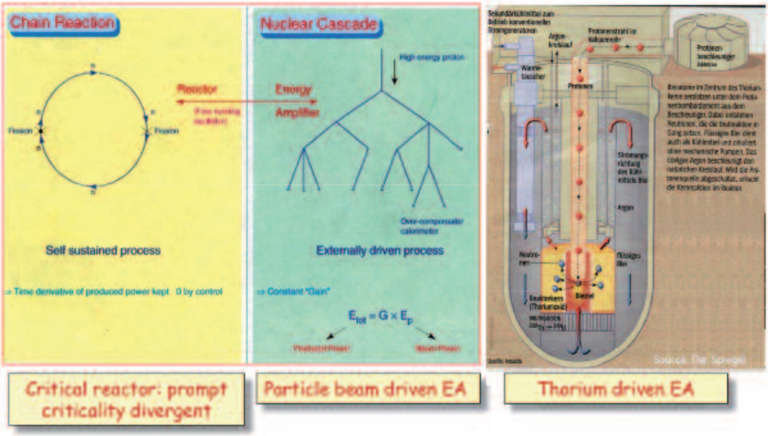
Particularly interesting are fission reactions in which a natural element is firstly bred into a readily fissionable element.



The main advantage of these reactions *without U-235* is that they may offer an essentially unlimited energy supply, during millennia at the present primary energy level, quite comparable to the one of Lithium driven D-T Nuclear Fusion.

However, they require substantial developments since: two neutrons (rather than one) are necessary to close the main cycle and the daughter elements do not exist in nature but they can be generated after initiation.

The need for a new concept: an accelerator driven system

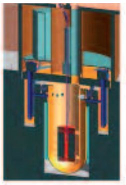


Comparing alternatives

To continuously generate a power output of $1GW_{electric}$ for a year requires:

3,500,000 tonnes of coal
Significant impact upon the
Environment especially
CO_2 emissions

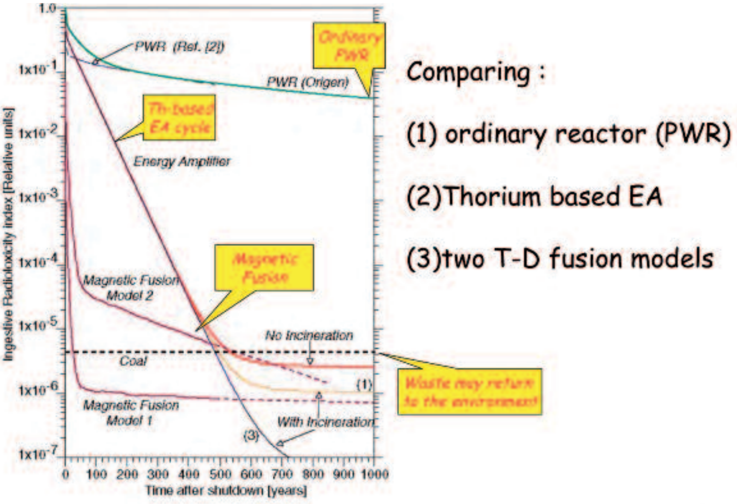
200 tonnes of Uranium
Low CO_2 impact but challenges with reprocessing
very long-term storage of
hazardous wastes
Proliferation
Enrichment



1 tonne of Thorium
(Thorium is about five
times more abundant
than uranium)
Low CO_2 impact
Can eliminate Plutonium
and radioactive waste
Reduced quantity
and much shorter
duration for storage of
hazardous wastes
No enrichment
No proliferation

So anybody in their right mind would say, why don't we develop Thorium? The answer is, Thorium does not seem to have enough interest to be a replacement for uranium for the reasons that I mentioned before.

Residual radio-toxicity of waste as function of time



Comparing :

(1) ordinary reactor (PWR)

(2)Thorium based EA

(3)two T-D fusion models

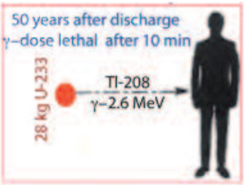
Proliferation issues

The breeding reaction on natural Uranium is badly proliferating, since it implies the vast production of Plutonium; Instead the breeding reaction on Thorium is largely immune from proliferation risks.

The three main elements of the discharge, if chemically separated, namely U, Np and Pu (Pu-238) exclude the feasibility of an explosive device (CM= critical mass)

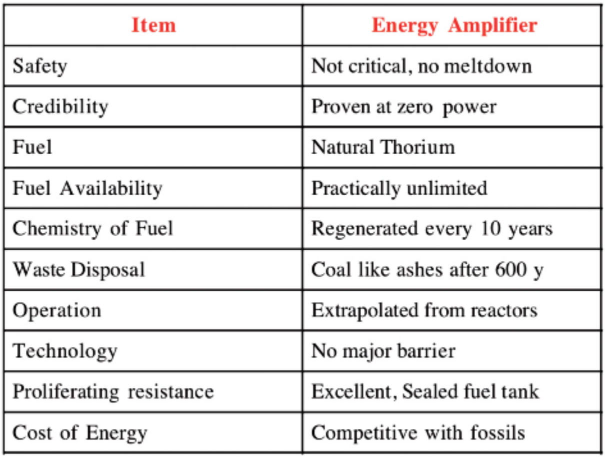
Element	Bomb grade Pu-239	Uranium (U-233)	Neptunium[3] (Np-237)	Plutonium[3] (Pu-238)
Critical mass (CM), kg	3	28.0	56.5	10.4
Decay heat[1] for CM, Watt	8	388	1.33	4400
Gamma Activity, Ci/CM	neglegible	1390	small	small
Neutron Yield[2], n g^{-1} s^{-1}	66	3000	2.1 10^5	2600

(1) Equilibrium temperature ≃ 190 °C for 100 W, due to presence of HP explosive shield
(2) Neutron yield must be ≤ 1000 n g^{-1} s^{-1}
(3) Very small amounts produced at discharge



The long duration of the fuel cycle (10 y) permits to keep it sealed under international control, avoiding an illegal insertion of any other possible bomb-like materials

Conclusions for a better Th based nuclear



Item	Energy Amplifier
Safety	Not critical, no meltdown
Credibility	Proven at zero power
Fuel	Natural Thorium
Fuel Availability	Practically unlimited
Chemistry of Fuel	Regenerated every 10 years
Waste Disposal	Coal like ashes after 600 y
Operation	Extrapolated from reactors
Technology	No major barrier
Proliferating resistance	Excellent, Sealed fuel tank
Cost of Energy	Competitive with fossils

Renewable energies for the future?

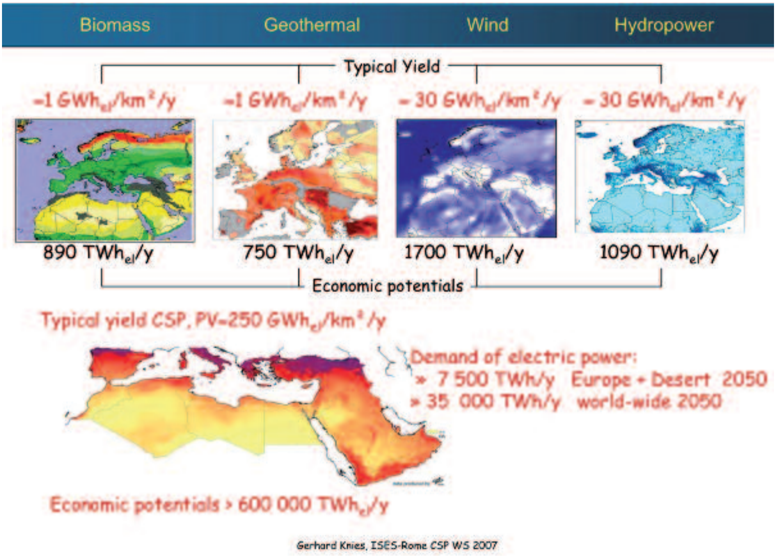
Solar and wind energy will achieve the most success in the next tenure. For the new installations, wind costs already only 6 ¢/kW-hour.

In the North Sea there is the opportunity of building off-shore turbines on a 60,000 km2 area, which can provide electric energy for the entire EU. In the sun belt, the electric energy produced by a CSP of the size of Lake Nasser equals the total Middle East oil production.

Without any doubt capacities of such new energy sources will only grow very quickly. By 2017, wind will grow larger than nuclear energy.

Today technologies develop fast. In 1990, we had 100 kW, in 2010 a wind turbine will have the capacity of 10 MW. Therefore, wind and solar may substitute coal, oil and gas, as a result of a number of advantages.

Let me show you here something that is relative to the European Union.



Biomass | Geothermal | Wind | Hydropower

Typical Yield

~1 $GWh_{el}/km^2/y$ | ~1 $GWh_{el}/km^2/y$ | ~30 $GWh_{el}/km^2/y$ | ~30 $GWh_{el}/km^2/y$

890 TWh_{el}/y | 750 TWh_{el}/y | 1700 TWh_{el}/y | 1090 TWh_{el}/y

Economic potentials

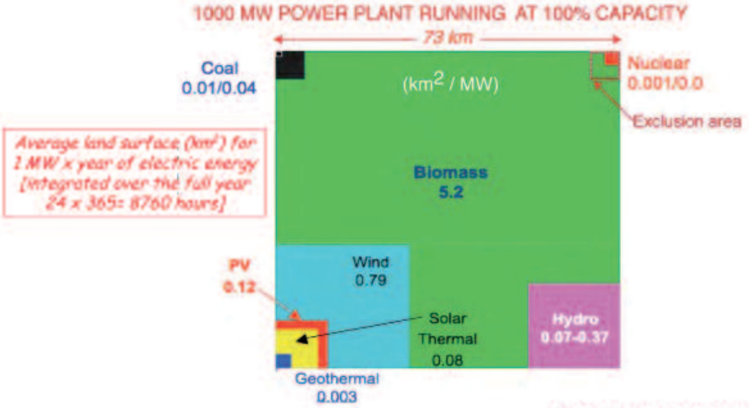
Typical yield CSP, PV~250 $GWh_{el}/km^2/y$

Demand of electric power:
» 7 500 TWh/y Europe + Desert 2050
» 35 000 TWh/y world-wide 2050

Economic potentials > 600 000 TWh_{el}/y

Gerhard Knies, ISES-Rome CSP WS 2007

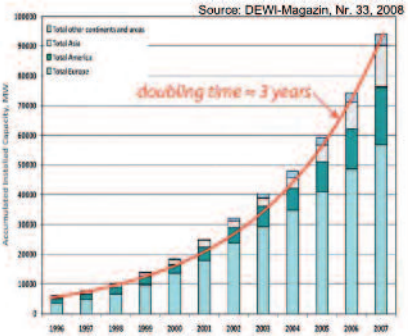
Environmental impacts: Area requirements

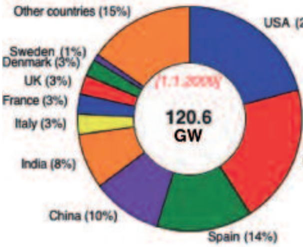


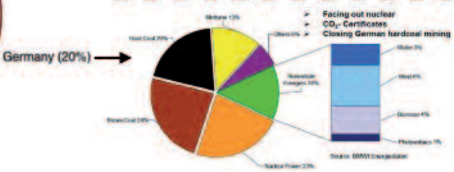
Source: J. Davidson 2006

Today's Wind

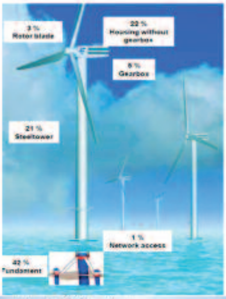
- no cost for primary energy
- Wide world potentials
- fast growing power demand (doubling every 3 y)
- cost reductions will continue
- no cooling water needed
- short construction periods

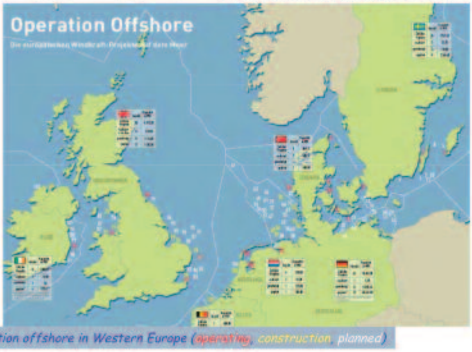






Wind off-shore: average power 6 MW/unit

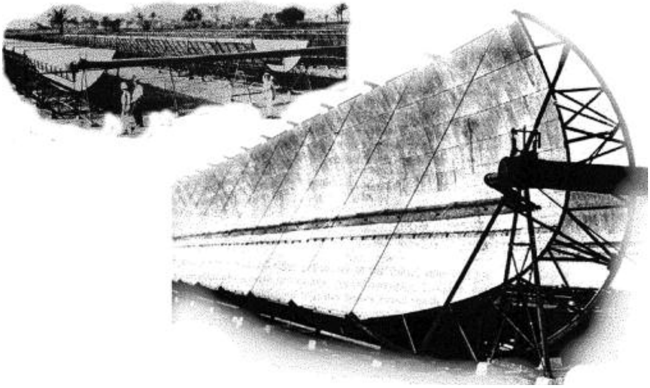




Operation offshore in Western Europe (operating, construction, planned)

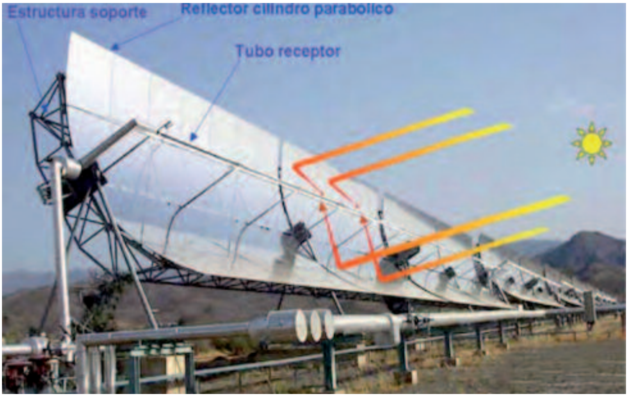
Concentrating solar power

Swiss scientist Horace de Saussure built the world's first solar collector in 1767.



The first solar facility to produce electricity was installed in 1912 by Shuman in Maady, Egypt. The parabolic mirror trough concentrates sunrays on a line focus in which a tube was situated containing water that was brought to evaporation. It produced 55 kWatt of electric power.

Principle of modern CSP

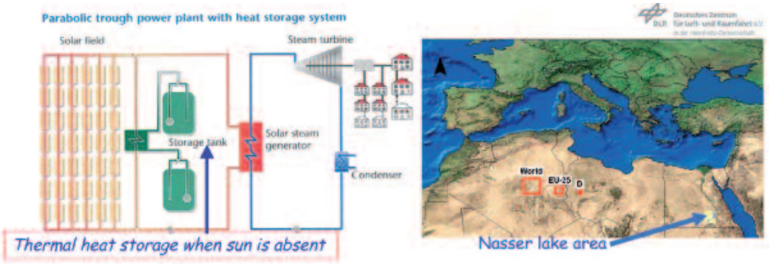


CSP modern power plant

Solar radiation is by far the most abundant source of energy. The CSP technology with heat storage is the most economical way to to harvest such vast resource in the sun-belt areas

– 1 km2 of land may generate 50 MW of electricity
– 1 km2 of land may produce 200-300 GWh_{el}/year
– 1 km2 of land avoids 200,000 tons CO2/year
– heat storage may cover electricity supply around the clock

The electrical energy produced by a CSP of the size of Lake Nasser equals the total Middle East oil production



Advantages of CSP with storage

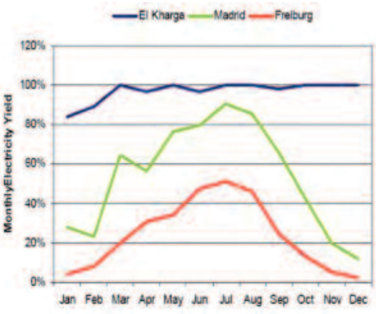
Solar thermal power plants

– can be integrated into conventional thermal power plants
– provide firm capacity (thermal storage, fossil backup)
– serve different markets (bulk power, remote power, heat, water)
– have the lowest costs for solar electricity
– have an energy payback time of only 6-12 months
– Have a lifetime of the plant of ≥30 years
– Dismantling at the end of the plant's lifetime is simple, quick and easy

Simulation of the relative monthly electricity yield of a CSP plant with 24-hour storage at sites with different annual solar irradiance and latitude.

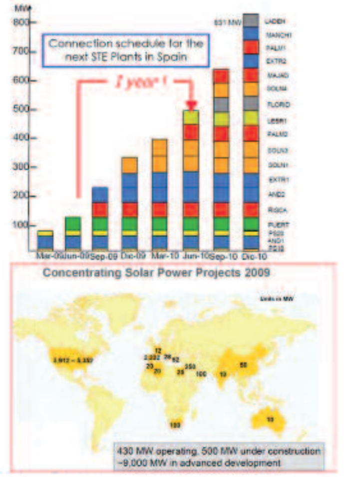
Equivalent annual full load hours

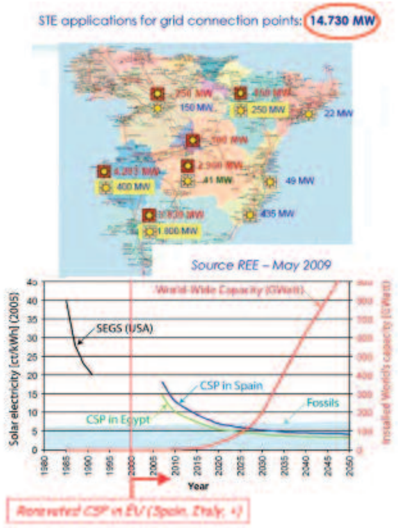
– El Kharga (Egypt)	8500 h/y
– Madrid (Spain)	5150 h/y
– Freiburg (Germany)	2260 h/y



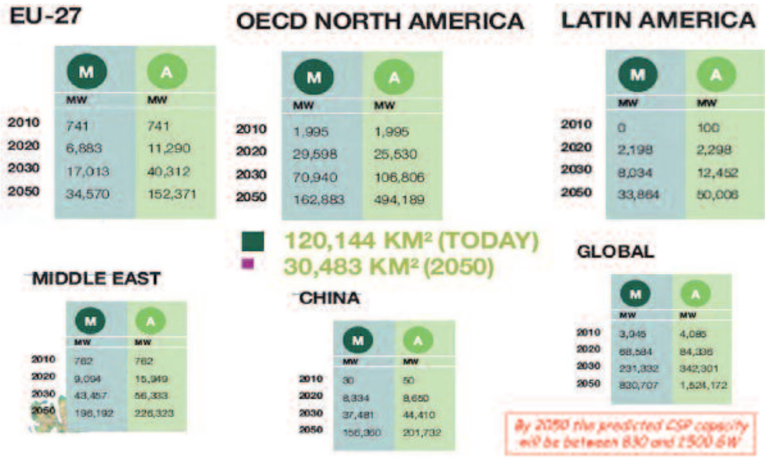
CSP plants in Spain

Growth of CSP





Evolution of CSP according to IEA



EU-27

	M MW	A MW
2010	741	741
2020	6,883	11,290
2030	17,013	40,312
2050	34,570	152,371

OECD NORTH AMERICA

	M MW	A MW
2010	1,995	1,995
2020	29,598	25,530
2030	70,940	106,806
2050	162,883	494,189

LATIN AMERICA

	M MW	A MW
2010	0	100
2020	2,198	2,298
2030	8,034	12,452
2050	33,884	50,008

🟩 120,144 KM² (TODAY)
🟪 30,483 KM² (2050)

MIDDLE EAST

	M MW	A MW
2010	762	762
2020	9,094	15,919
2030	43,457	56,333
2050	196,192	226,323

CHINA

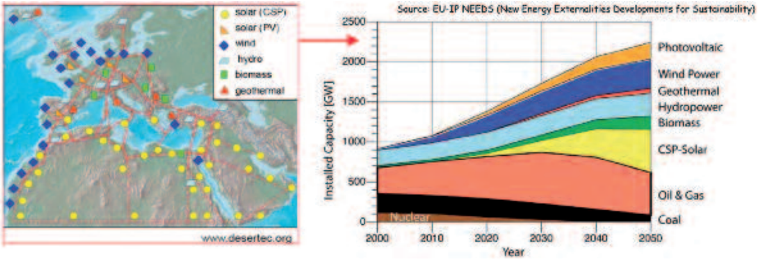
	M MW	A MW
2010	30	50
2020	8,334	8,650
2030	37,481	44,410
2050	156,360	201,732

GLOBAL

	M MW	A MW
2010	3,045	4,085
2020	68,584	84,336
2030	231,332	342,301
2050	830,707	1,524,172

By 2050 the predicted CSP capacity will be between 830 and 2500 GW

Forecast of the installed capacity of EU



- A geographic distribution of many different novel technologies: PV, CSP, Wind, Hydro, Biomass, Geothermal over EU and surrounding territories.
- Total CO_2 emissions reduced to 38% of the year 2000 values.
- EU dependency on fuel imports reduced from 80% to 32%.
- Ordinary Nuclear power may be faded out.
- Hard-coal mining is progressively closed.
- Renewables and liberalisation require bulk transmission capacity to ensure electricity transport over many thousand kms from offshore wind and CSP.

The last question we have to solve is really how are we going to carry all this energy from the Sahara or from the North Sea into the middle of the towns of Europe.

Le Monde

WEEK-END

Le solaire s'impose comme l'énergie du futur

Electricité Le secteur photovoltaïque croît au rythme de 40 % par an