Partage du savoir en Méditerranée

1-3 Mars 2010

Mer Morte, Jordanie

New energies for the future of Mankind

Carlo Rubbia

CERN,Geneva, Switzerland

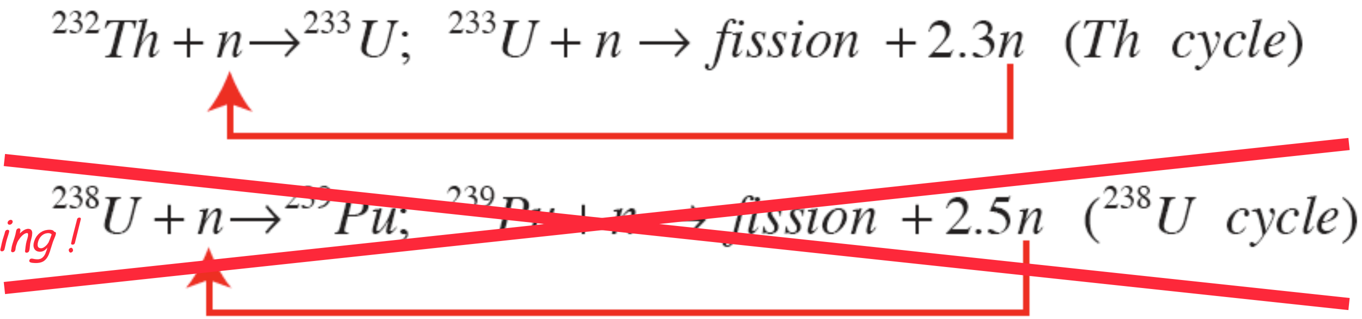
CIEMAT, Madrid,Spain

Future of the present day's nuclear energy

- Global climate change is one of the most acute environmental problems. It is believed that in order to keep global warming within 2 degrees, CO2 emissions should decrease by 30% to 60% with respect to 1990 and amount to 10 to 15 billion t/year CO2, against the prediction of 40 to 50 billion t/year by 2050, with a reduction of 25 to 40 billion ton/year.
- For instance,tripling the ordinary nuclear energy would reduce CO2 emission by 5 billion t/year, *which would not be completely 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  - An additional capacity of 25 GWe/year (one new 1 GWe reactor every two weeks), including replacement of outdated reactors;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 apparent lack of any innovative alternative, Europe and North America may be close to taking similar decisions*.

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.



$$^{232}Th + n \rightarrow {}^{233}U;\quad {}^{233}U + n \rightarrow fission\ + 2.3n\quad (Th\ \ cycle)$$

Energy Amplifier

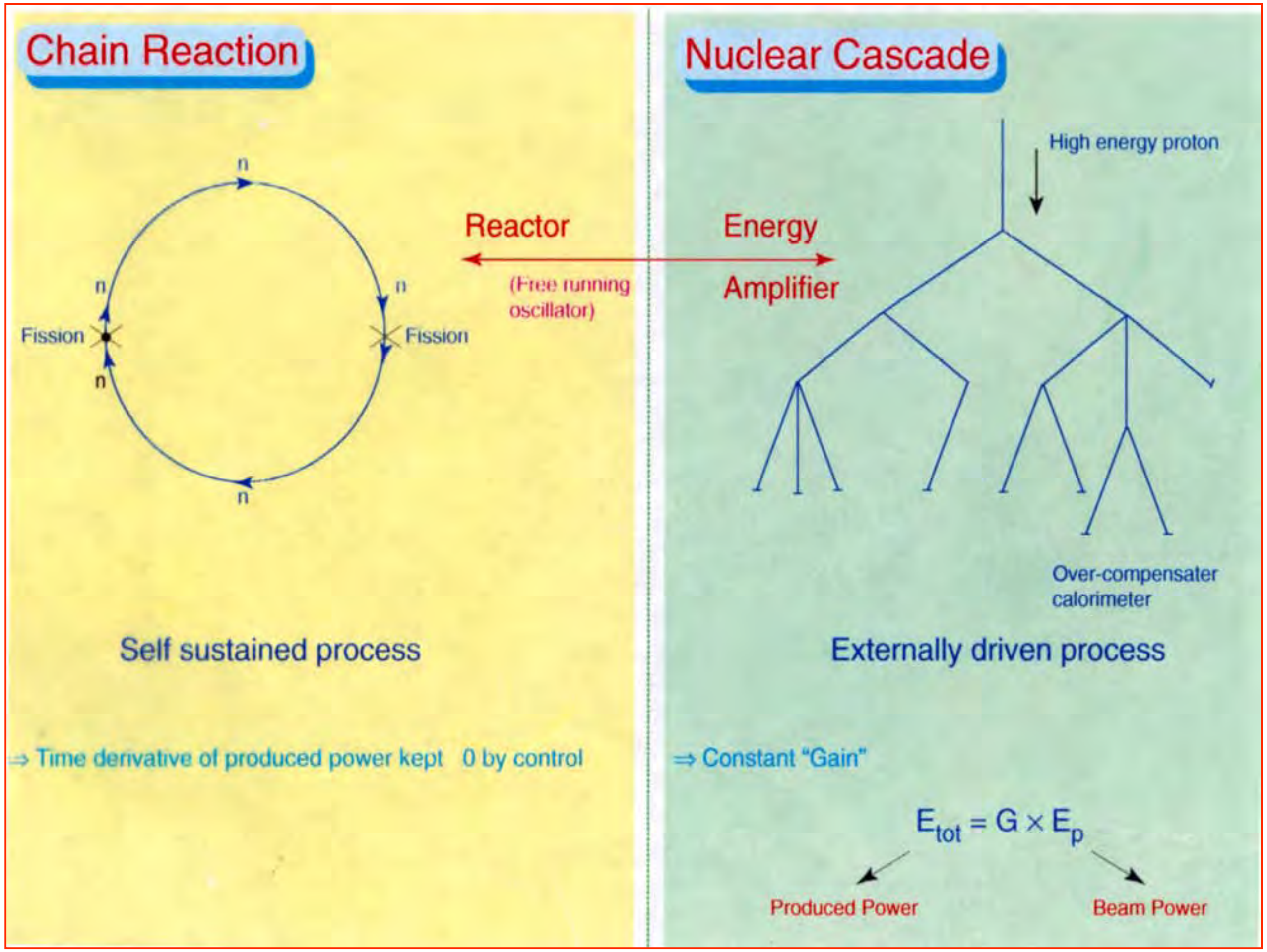
Proliferating !

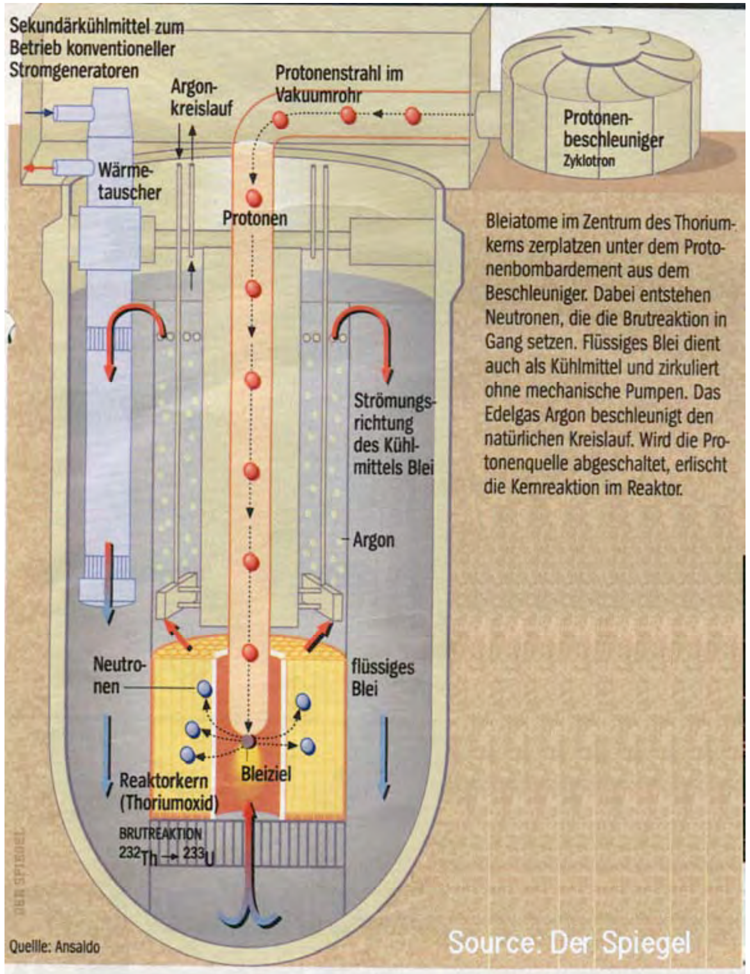
~~$^{238}U + n \rightarrow {}^{239}Pu;\quad {}^{239}Pu + n \rightarrow fission\ + 2.5n\quad ({}^{238}U\ \ cycle)$~~

Gen-IV

- 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
  - 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





Bleiatome im Zentrum des Thoriumkerns zerplatzen unter dem Protonenbombardement aus dem Beschleuniger. Dabei entstehen Neutronen, die die Brutreaktion in Gang setzen. Flüssiges Blei dient auch als Kühlmittel und zirkuliert ohne mechanische Pumpen. Das Edelgas Argon beschleunigt den natürlichen Kreislauf. Wird die Protonenquelle abgeschaltet, erlischt die Kernreaktion im Reaktor.

Quelle: Ansaldo

Source: Der Spiegel

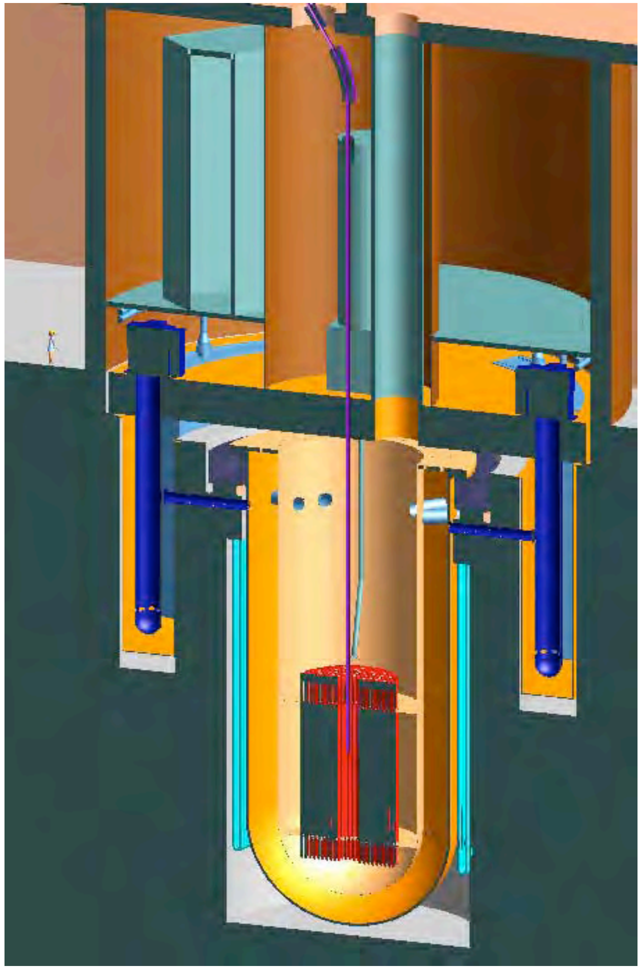
Critical reactor: prompt criticality divergent

Particle beam driven EA

Thorium driven EA

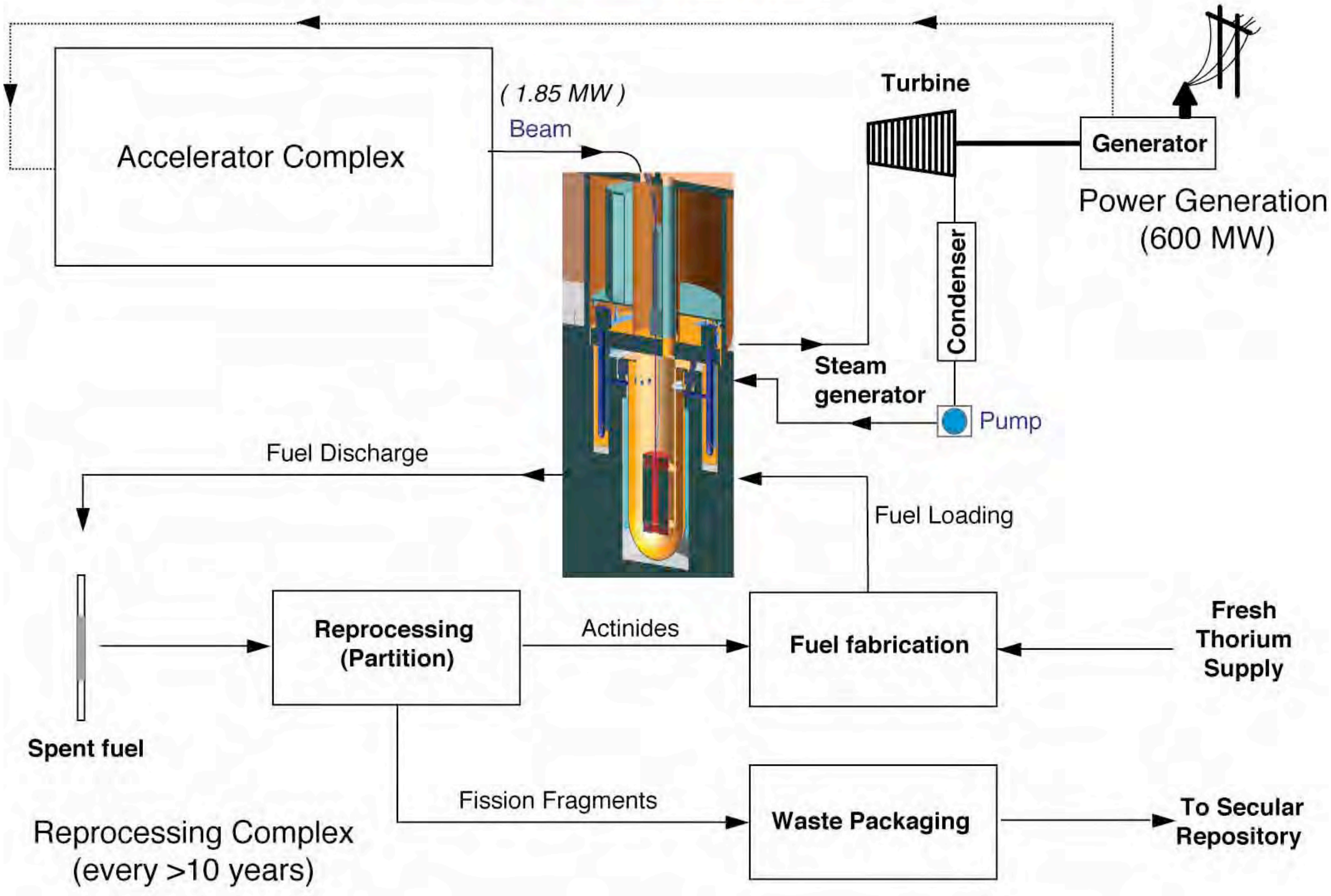
Feasibility Study: Aker ASA and Aker Solutions ASA

- 1500MWTh/600MWe
- Sub-critical core
- Thorium oxide fuel
- Accelerator driven via central beam tube
- Molten lead coolant
- Coolant temp 400-540°C
- 2 Axial flow pumps
- 4 Annular heat exchangers
- Direct lead/water heat exchange



A Thorium fuelled reactor for power generation

AkerSolutions



Accelerator Complex

(1.85 MW)

Beam

Turbine

Generator

Power Generation
(600 MW)

Condenser

Steam
generator

Pump

Fuel Discharge

Fuel Loading

Spent fuel

Reprocessing
(Partition)

Actinides

Fuel fabrication

Fresh
Thorium
Supply

Fission Fragments

Waste Packaging

To Secular
Repository

Reprocessing Complex
(every >10 years)

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

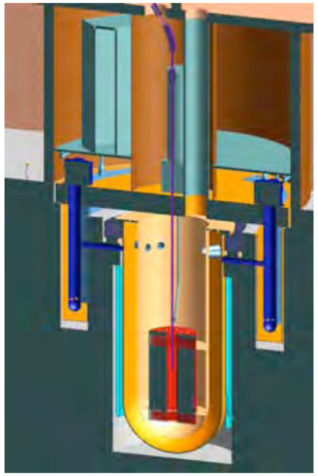
Low CO_2 impact

but challenges with reprocessing

very long-term storage of hazardous wastes

Proliferation

Enrichment



1 tonne of Thorium

Low CO_2 impact

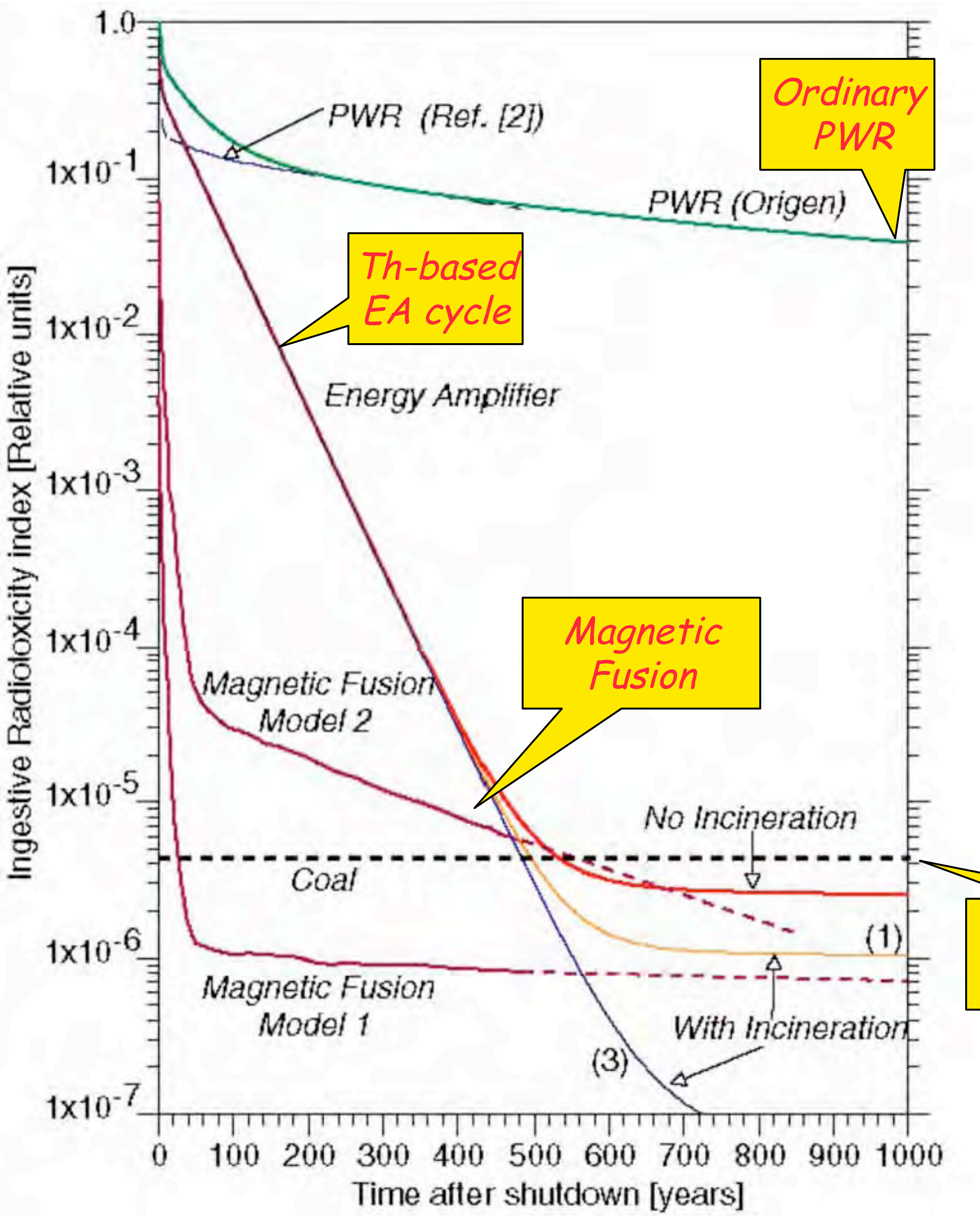
Can eliminate Plutonium and radioactive waste

Reduced quantity and much shorter duration for storage of hazardous wastes

No enrichment

No proliferation

Residual radio-toxicity of waste as function of time



Ordinary PWR

Th-based EA cycle

Magnetic Fusion

Waste may return to the environment

Comparing :

(1) ordinary reactor (PWR)

(2)Thorium based EA

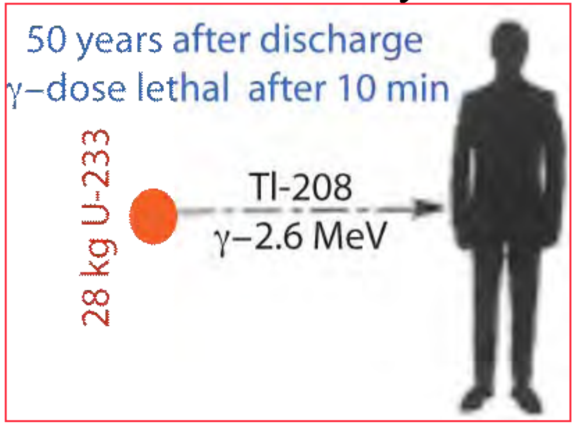
(3)two T-D fusion models

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	**380**	1.13	**4400**
Gamma Activity, Ci/CM	negligible	**1300**	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

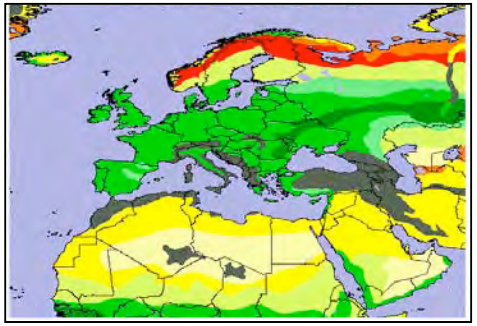
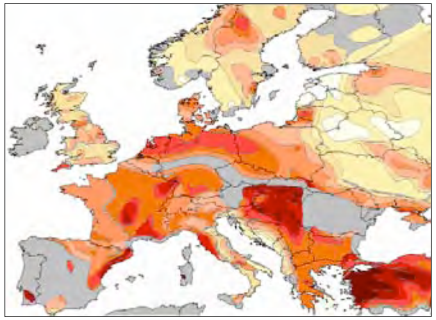
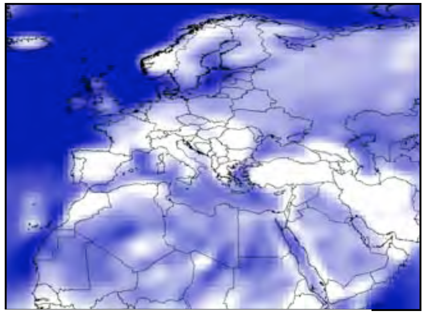
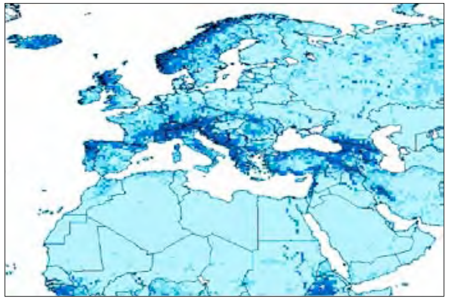
Item	**Energy Amplifier**
Safety	Not critical, no meltdown
Credibility	Proven at zero power
Fuel	Natural Thorium
Fuel Availability	Practically unlimited
Chemistry of Fuel	Regenerated every 10 years
Waste Disposal	Coal like ashes after 600 y
Operation	Extrapolated from reactors
Technology	No major barrier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

Renewable energies for the future ?

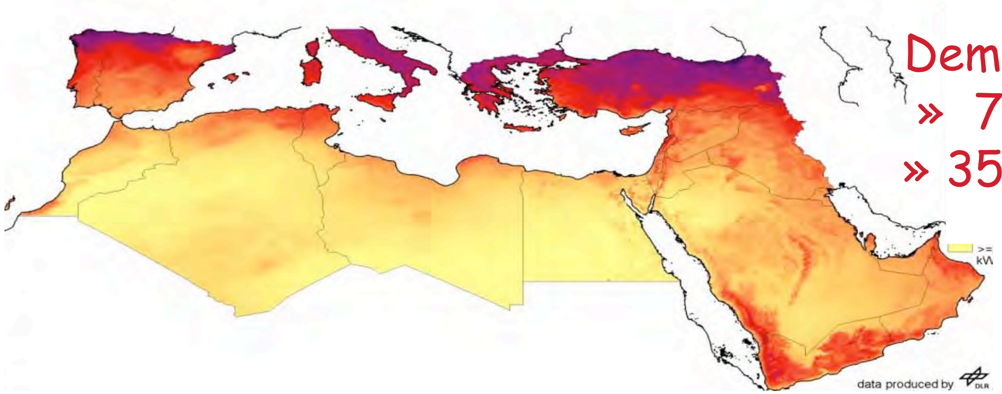
- Solar and wind energy will achieve the most success in the next tenure. For the new installations, wind costs already only 6 ¢/ kW-hour.

A new paradigm !

- In the North Sea there is the opportunity of building off-shore turbines on a 60,000 km^2 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.

	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 $GWh_{el}/km^2/y$
				
Economic potentials	890 TWh_{el}/y	750 TWh_{el}/y	1700 TWh_{el}/y	1090 TWh_{el}/y

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



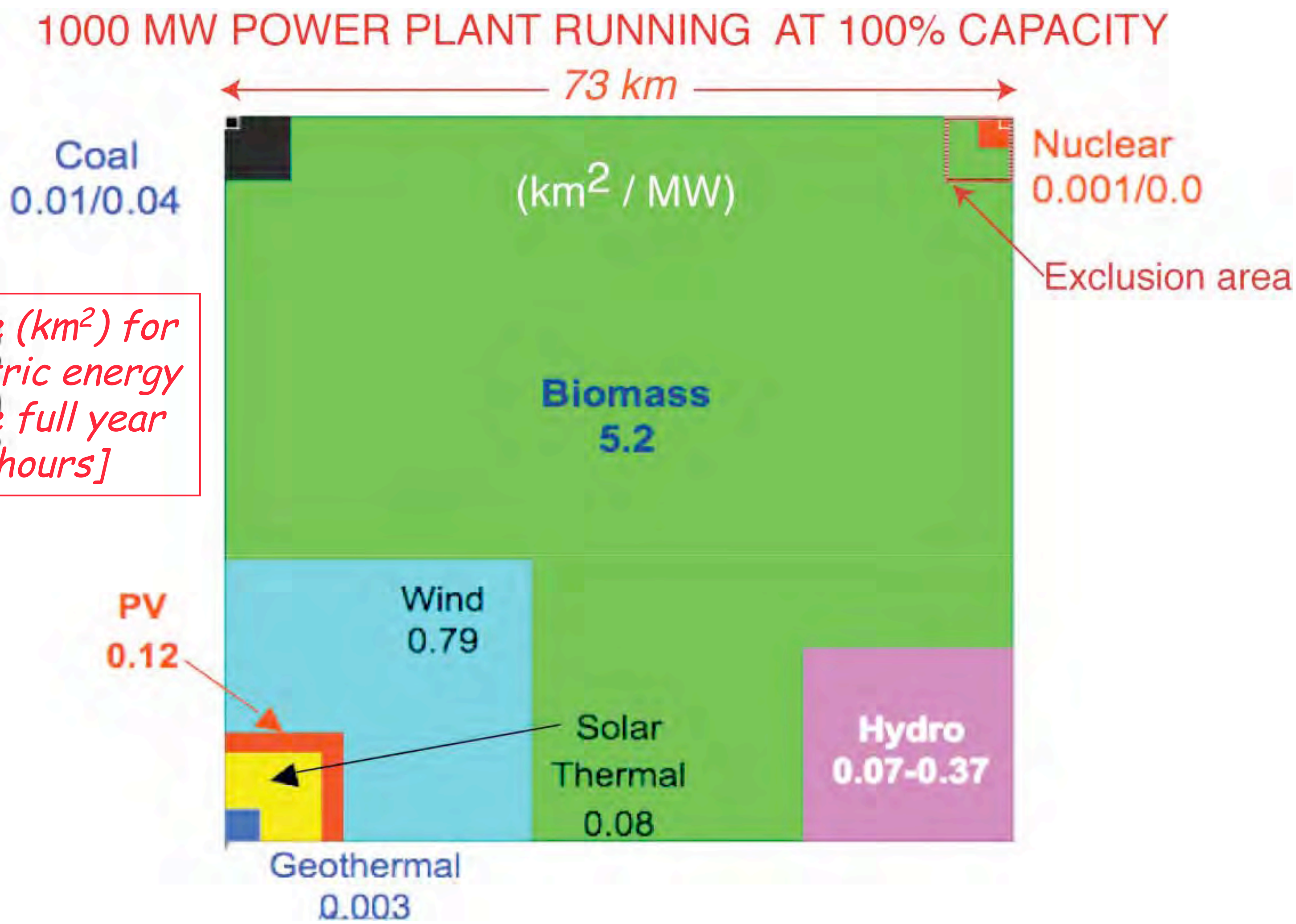
Demand of electric power:

- » 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

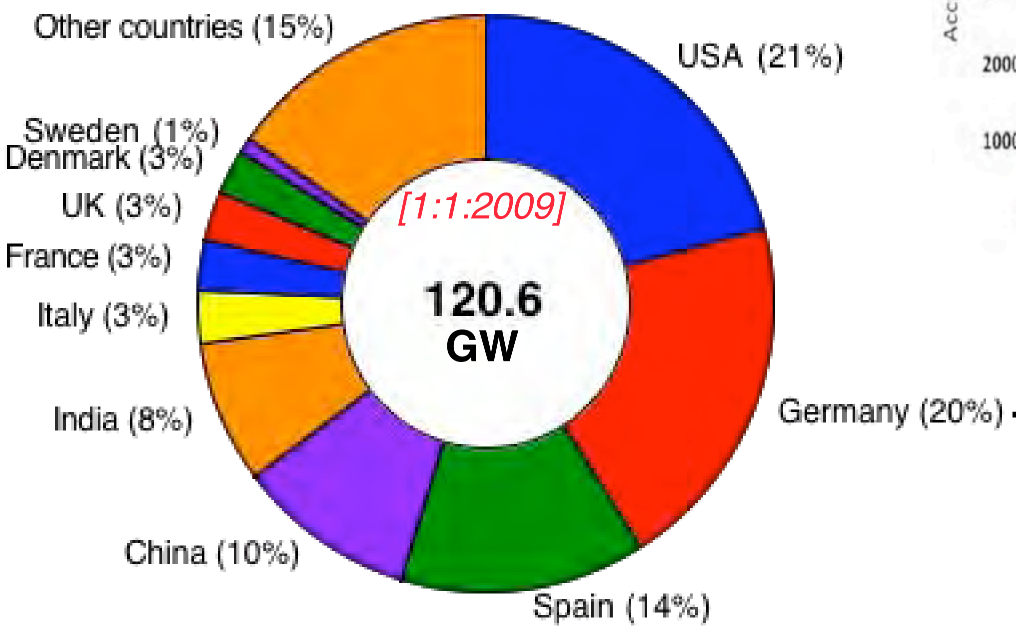


Average land surface (km^2) for 1 MW x year of electric energy [integrated over the full year 24 x 365= 8760 hours]

Source: J. Davidson 2006

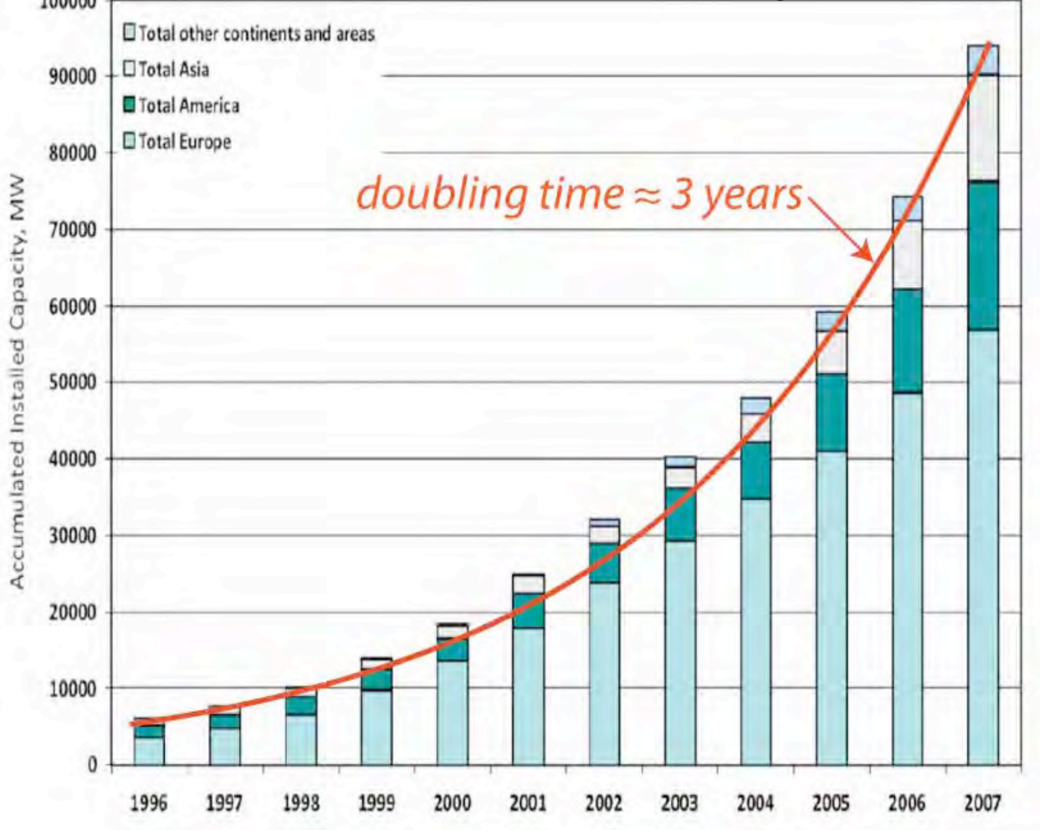
Today’s Wind

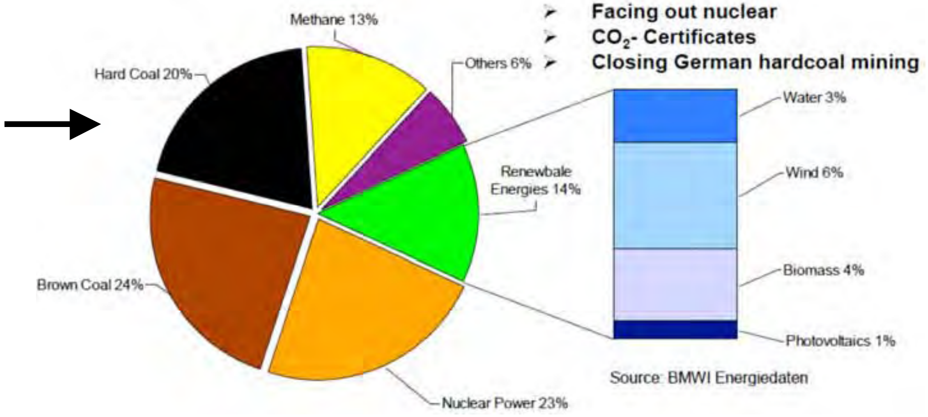
- no cost for primary energy
- Wide world potentials
- fast growing power demand (doubling every 3 y)
- cost reductions will continue
- no cooling water needed
- short construction periods



DeadSeaMarch2010

Source: DEWI-Magazin, Nr. 33, 2008

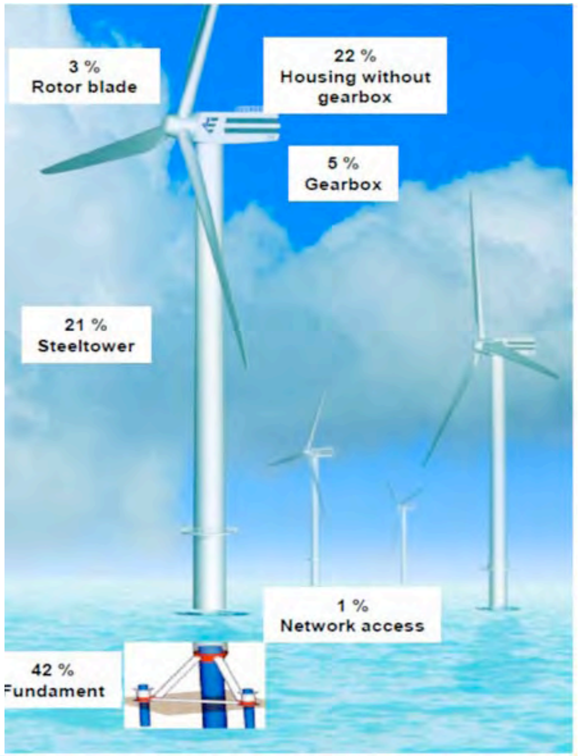




- Facing out nuclear
- CO_2- Certificates
- Closing German hardcoal mining

Source: BMWI Energiedaten

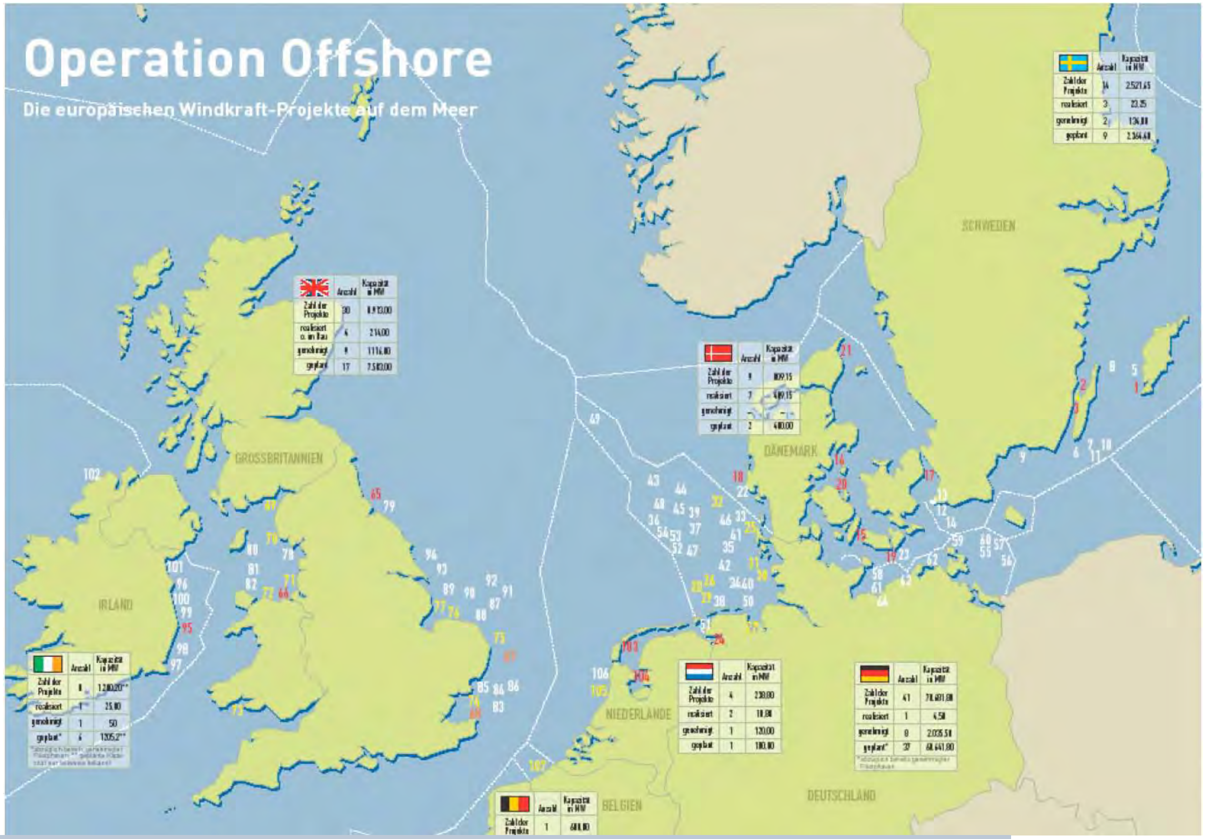
Wind off-shore: average power 6 MW/unit



Up to 700 m deep

Foto: Große Boeckmann, August 2008

Offshore wind in Germany (Status 2007)



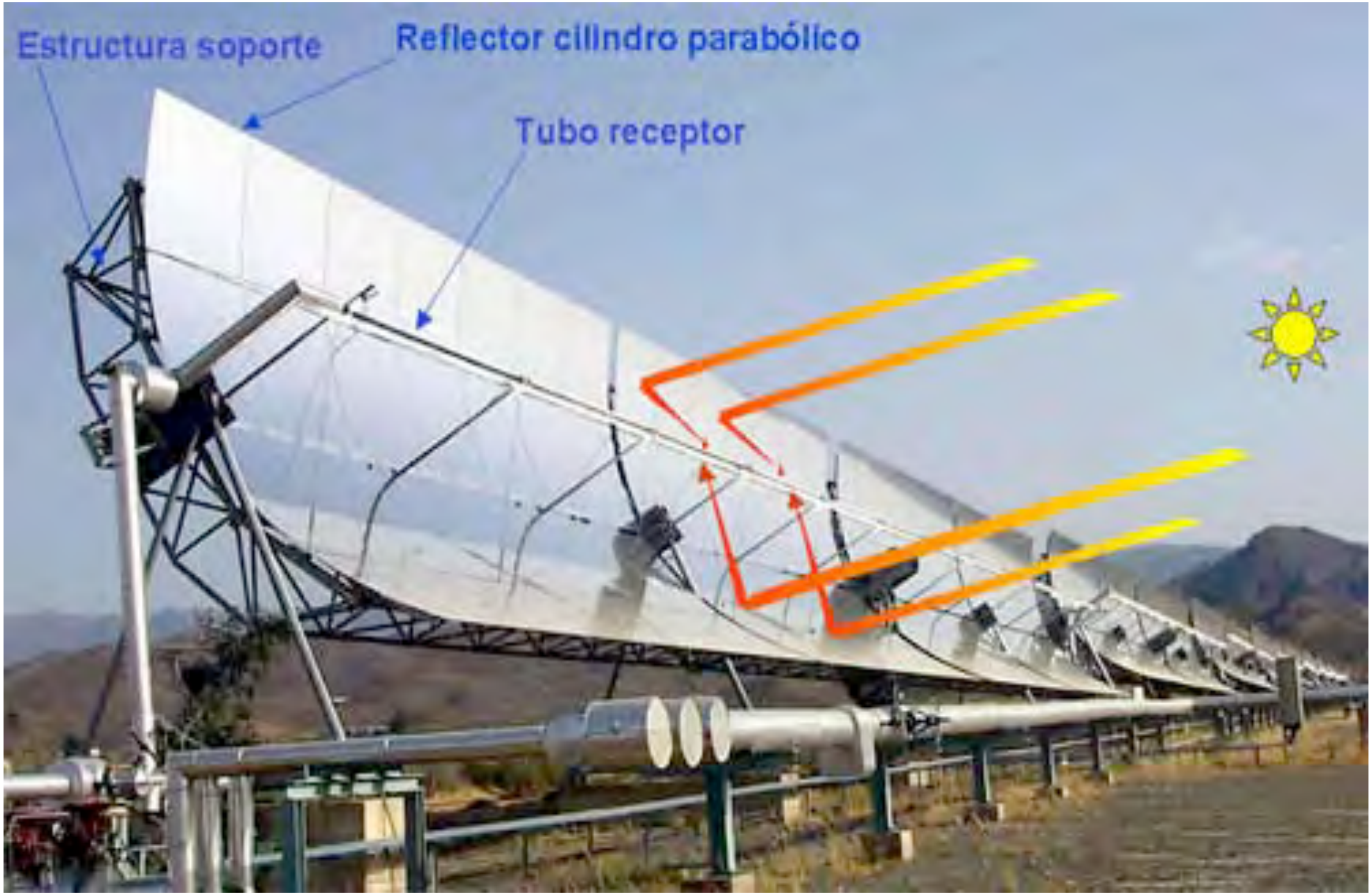
Operation offshore in Western Europe (operating, construction, planned)

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.

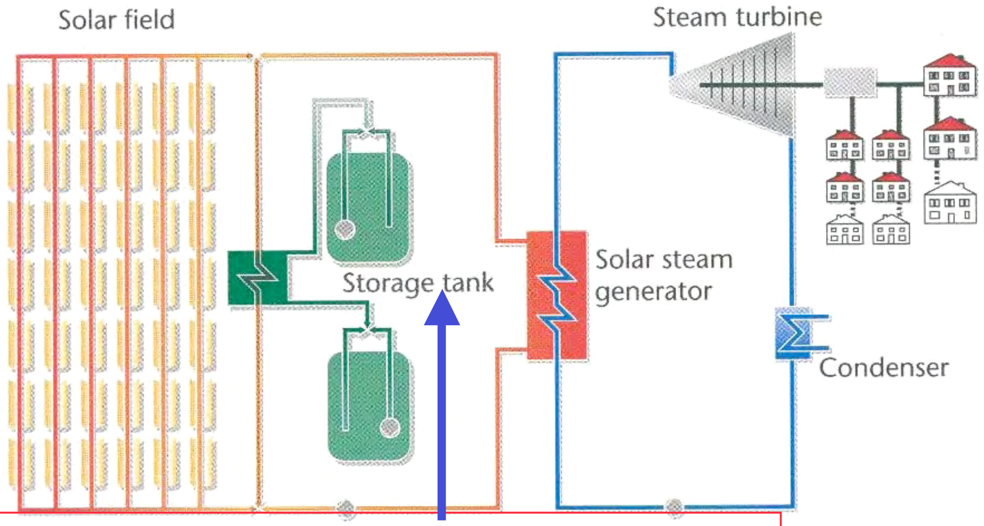
Principle of modern CSP



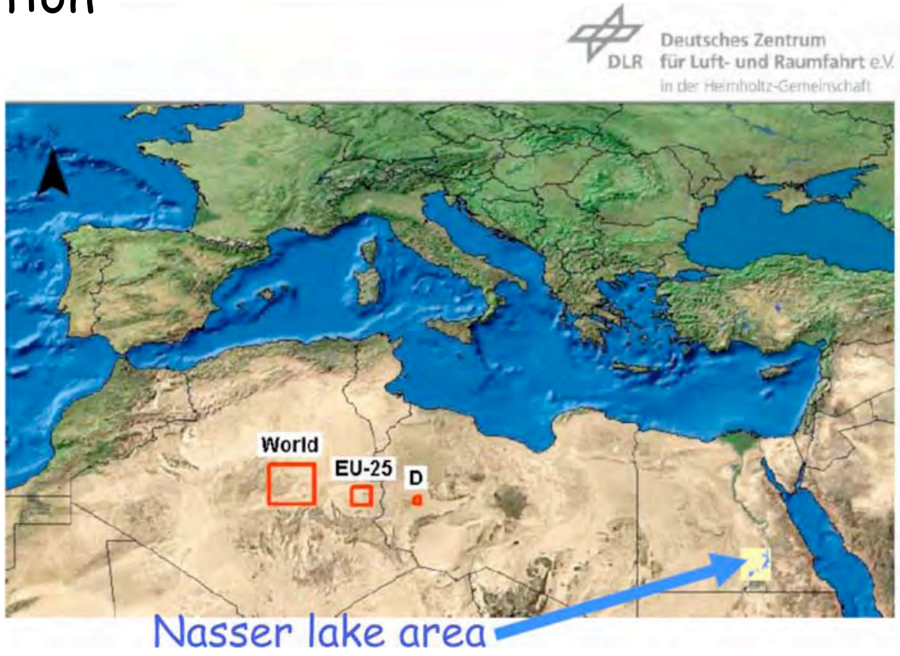
CSP modern power plant

- 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 km^2 of land may generate 50 MW of electricity
    - 1 km^2 of land may produce 200 - 300 GWh$_{el}$ / year
    - 1 km^2 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

Parabolic trough power plant with heat storage system



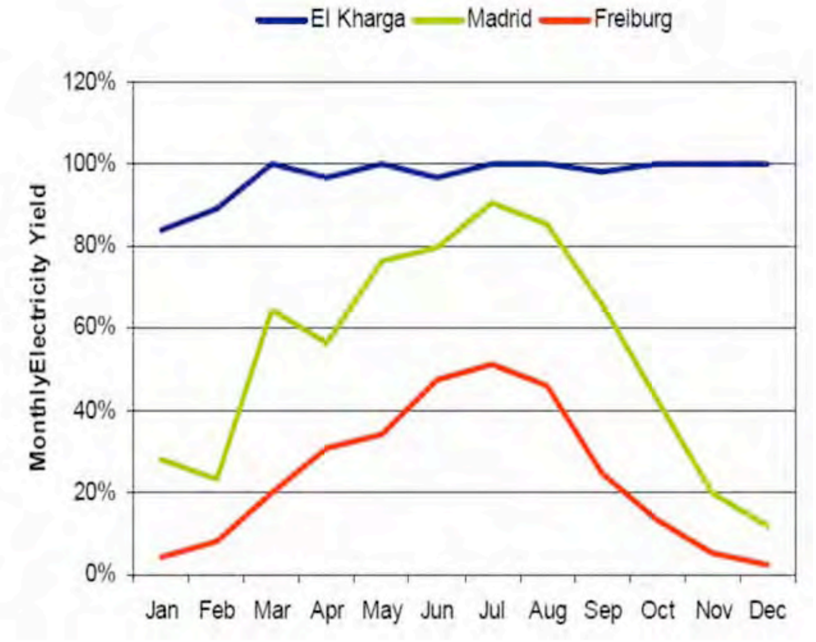
Thermal heat storage when sun is absent



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

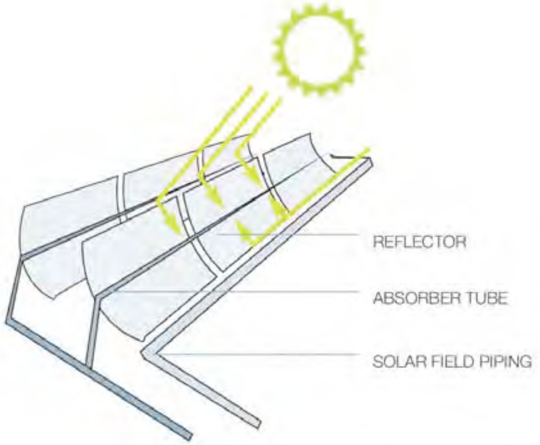
- Simulation of the relative monthly electricity yield of a CSP plant *with 24 hour storage* at sites with different annual solar irradiance and latitude. Equivalent annual full load hours
  - El Kharga (Egypt) 8500 h/y
  - Madrid (Spain) 5150 h/y
  - Freiburg (Germany) 2260 h/y



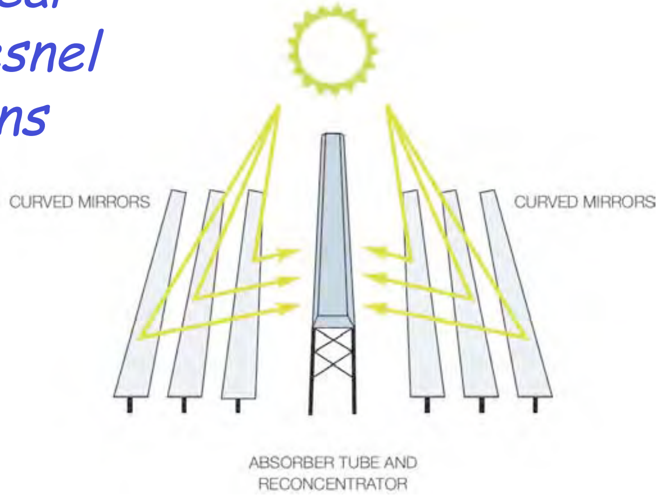
Various types of CSP

One dimensional collection (50-150 Suns)

Parabolic Through

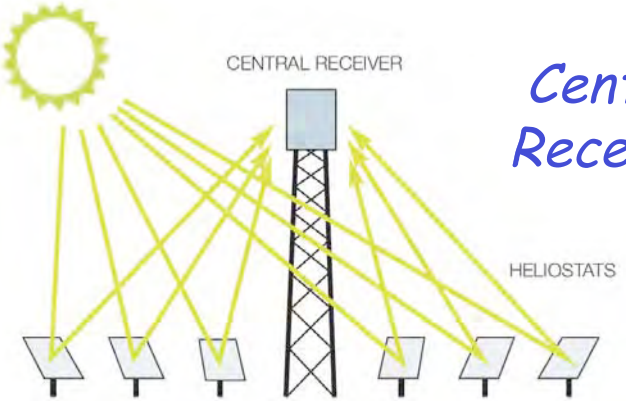


Linear Fresnel lens

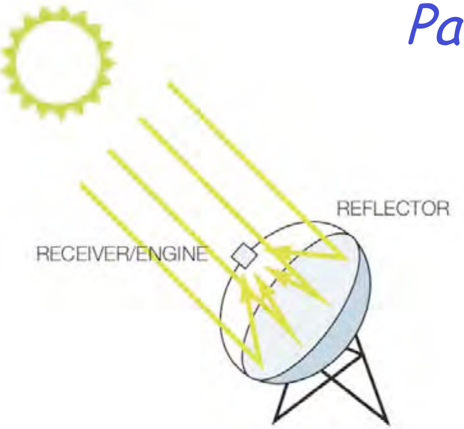


Two dimensional collection (up to 5000 Suns)

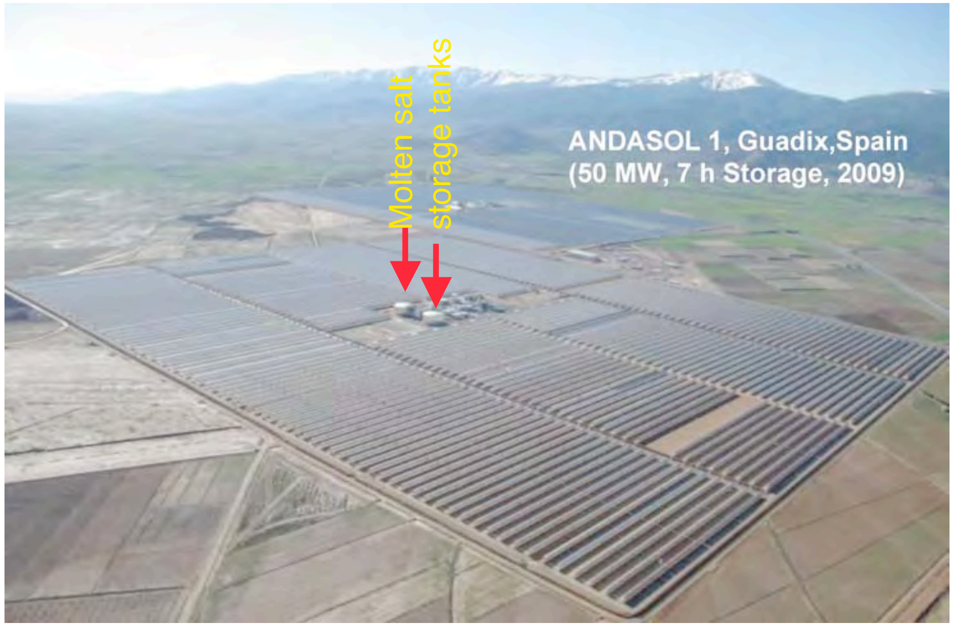
Central Receiver



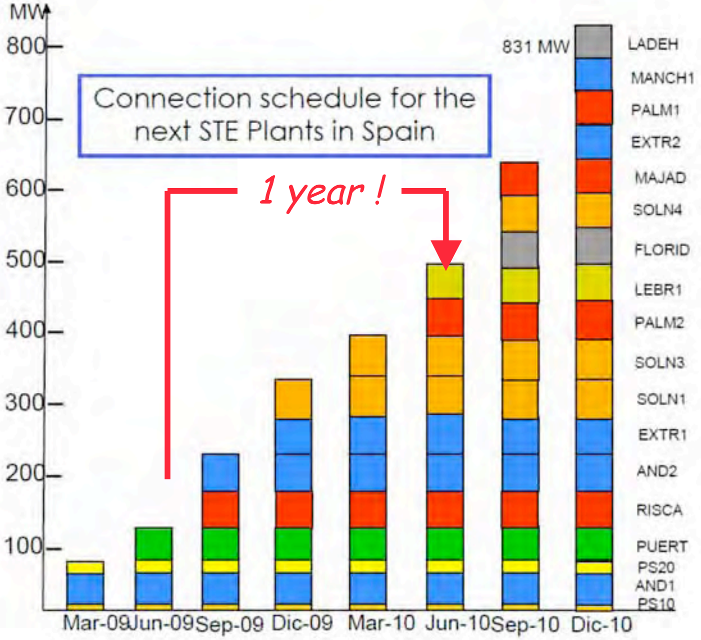
Parabolic Dish



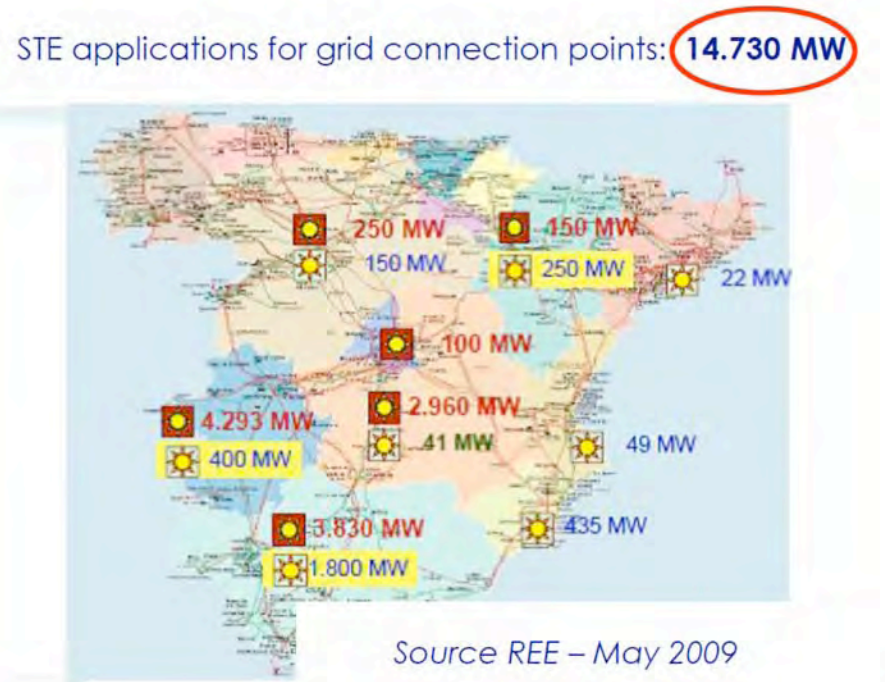
CSP plants in Spain



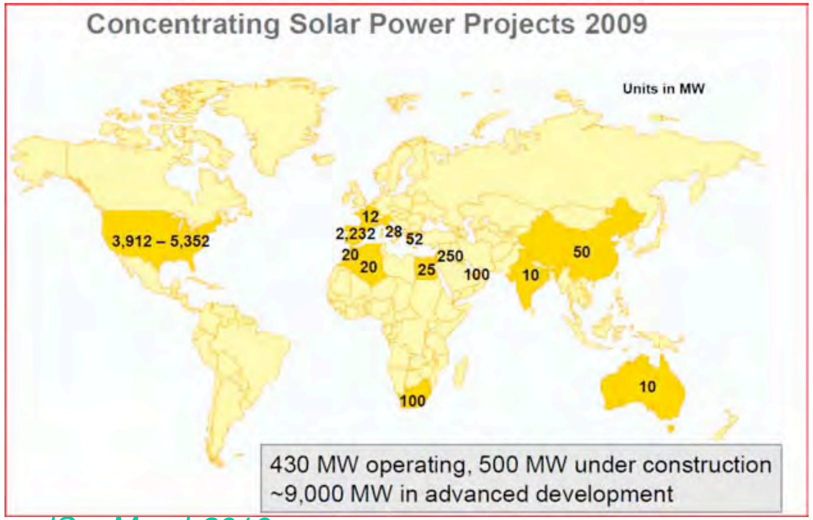
Growth of CSP


Connection schedule for the next STE Plants in Spain

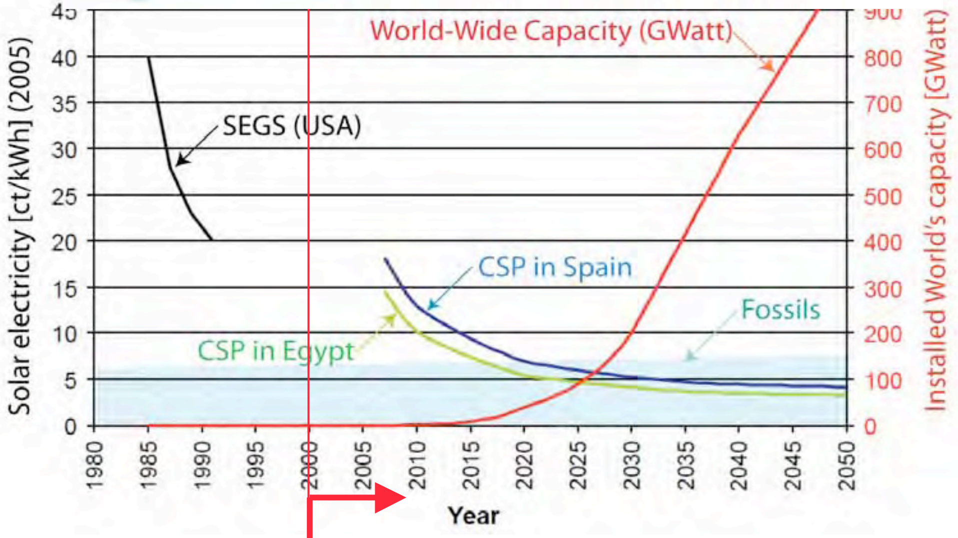
1 year !


STE applications for grid connection points: **14.730 MW**

Source REE – May 2009


Concentrating Solar Power Projects 2009

430 MW operating, 500 MW under construction
~9,000 MW in advanced development



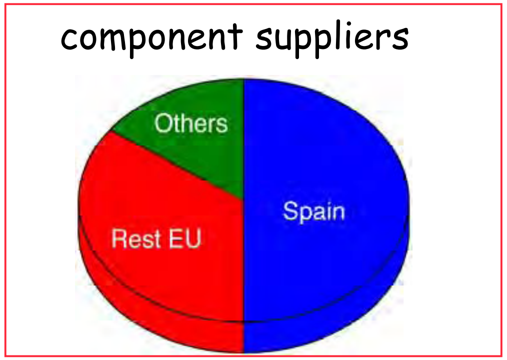
Renovated CSP in EU (Spain, Italy, +)


Ciudad Real
Badajoz
◆ In operation (9)
◆ In construction (25)
Alicante
Granada
Seville
Almeria
Malaga
Gibraltar strait

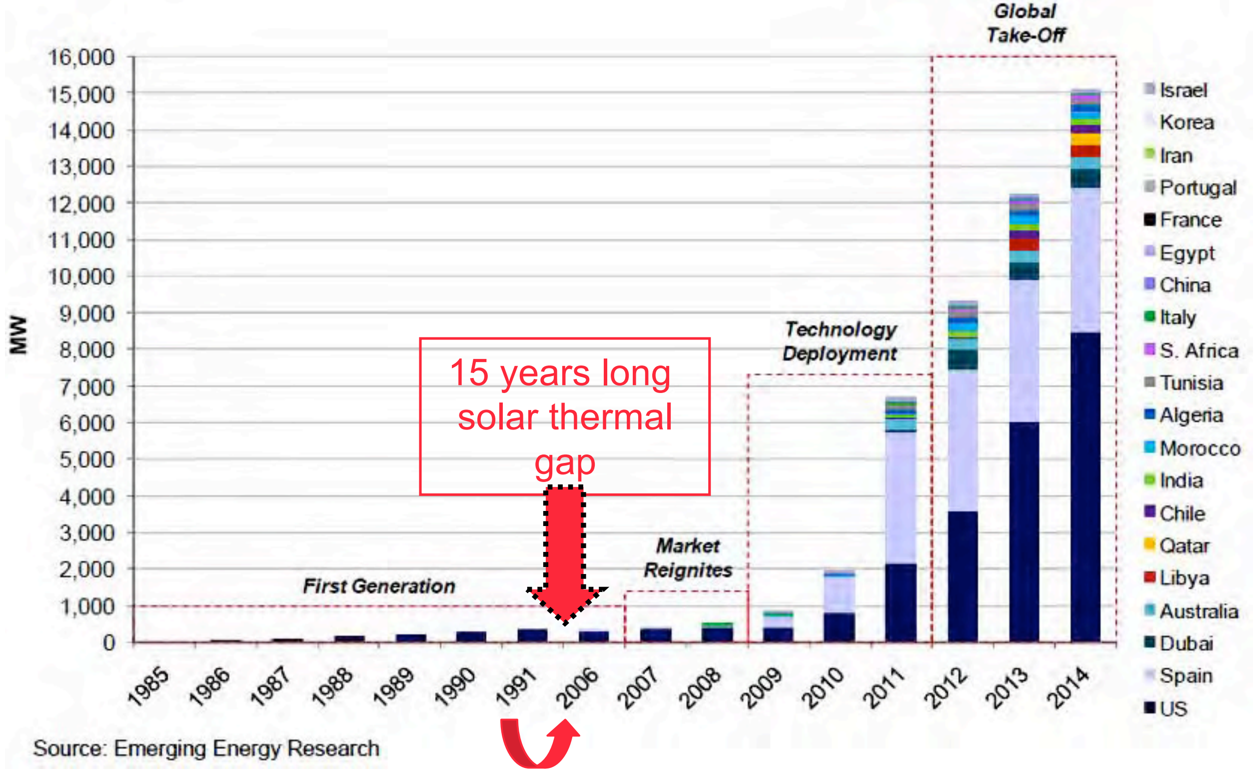
The reasons behind the European (Spanish) leadership on CSP

- Continuous support to R&D since late 70’s
- Specialized and highly qualified education in several Spanish Universities
- Active role of Research Centres and International collaborations
- The encouraging feed-in tariffs established by the Spanish Government
- Dynamism of the companies : The Industry is investing more than 10 billion Euro in the 2007-2013 period

First Spanish heliostat (1978)

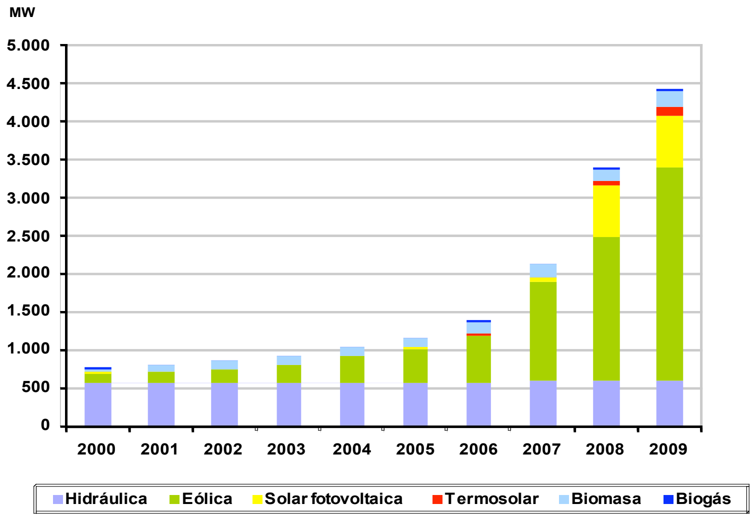


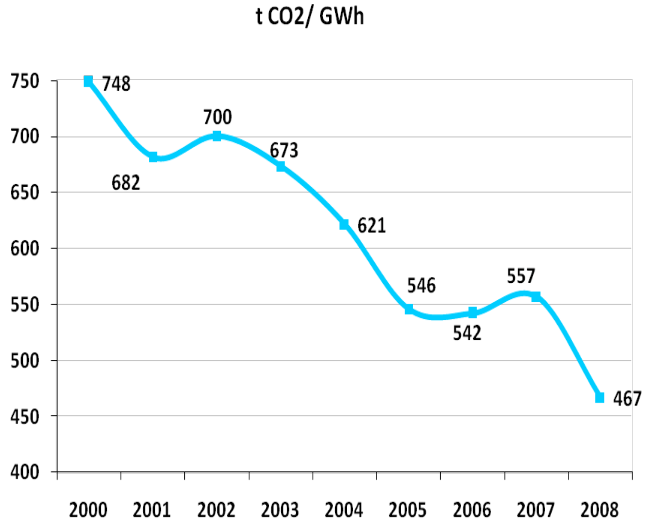
component suppliers



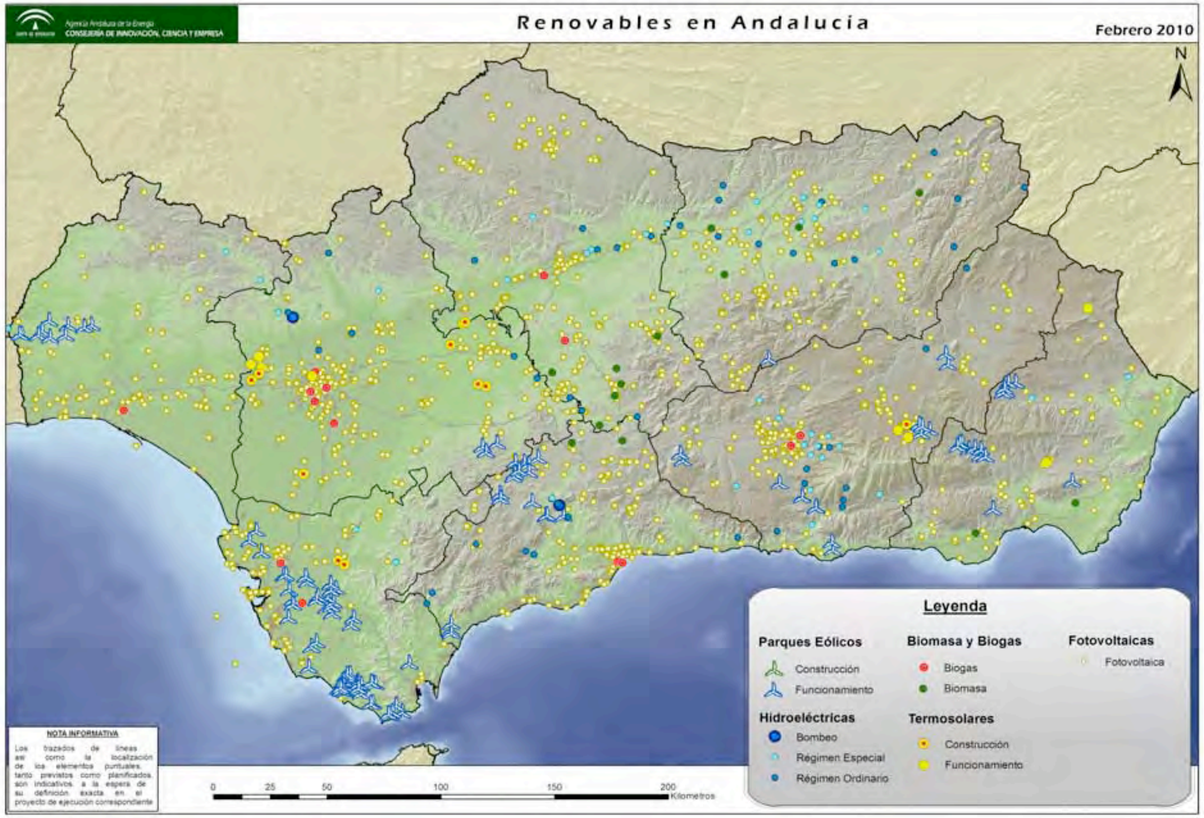
Source: Emerging Energy Research

Example of penetration of renewables: Andalusia





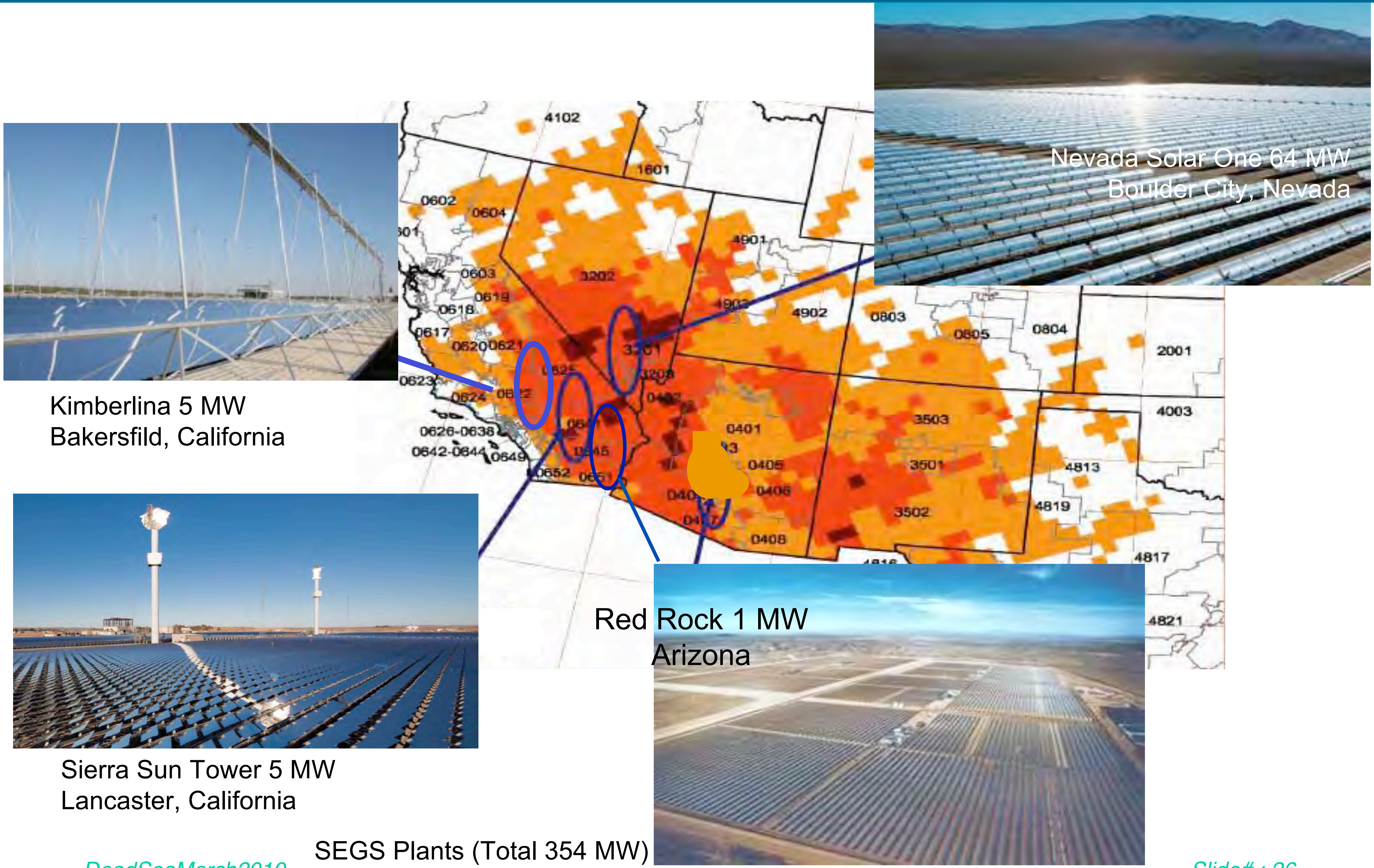
CO2 emissions from electricity



NOTA INFORMATIVA

Los trazados de líneas así como la localización de los elementos puntuales, tanto previstos como planificados, son indicativos, a la espera de su definición exacta en el proyecto de ejecución correspondiente

Operational plants in USA



Nevada Solar One 64 MW
Boulder City, Nevada

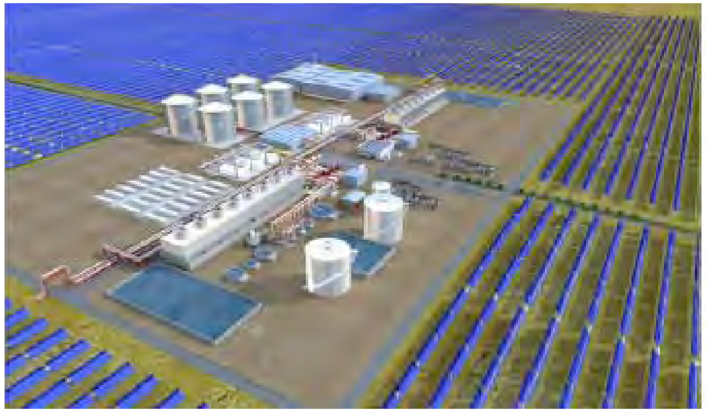
Kimberlina 5 MW
Bakersfild, California

Sierra Sun Tower 5 MW
Lancaster, California

Red Rock 1 MW
Arizona

SEGS Plants (Total 354 MW)
Kramer Junction / Harper Lake, California

Examples of large projects in promotion in USA



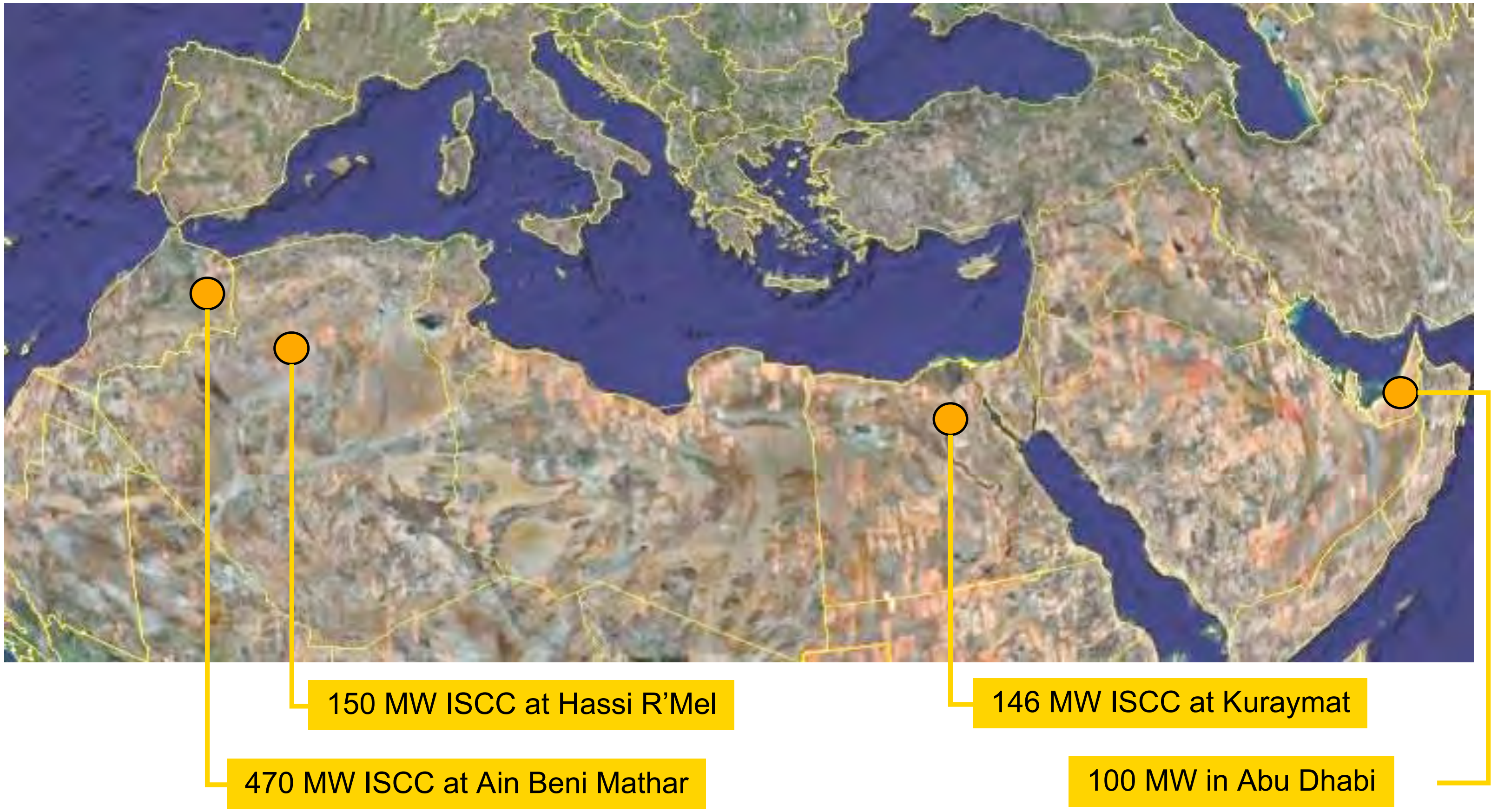
Solana project in Arizona/ Abengoa

- 280 MW gross output with conventional steam turbines
- "Solar Field" will cover 775 hectares (3 square miles) and contain ~ 2,900 trough collectors

Fort Irwin project in California / Acciona

- 500 MW gross output with conventional steam turbines
- "Solar Field" will cover 5.600 hectares using trough collectors

First projects in the MENA region



150 MW ISCC at Hassi R’Mel

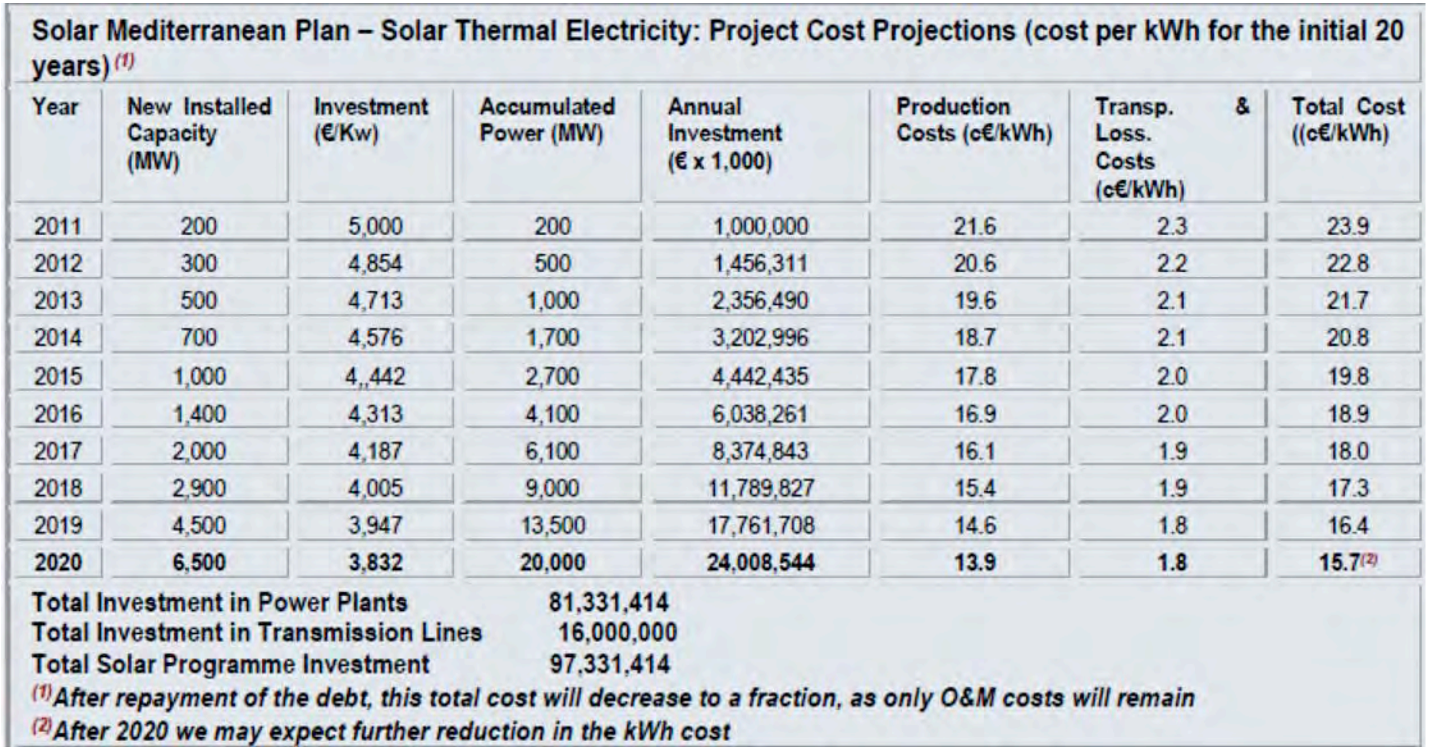
470 MW ISCC at Ain Beni Mathar

146 MW ISCC at Kuraymat

100 MW in Abu Dhabi

Several countries have announced ambitious plans that could be financed under the PSM schemes + concessional WB loans ($750M)

The Desertec and the Mediterranean solar plan



Solar Mediterranean Plan – Solar Thermal Electricity: Project Cost Projections (cost per kWh for the initial 20 years) (1)

Year	New Installed Capacity (MW)	Investment (€/Kw)	Accumulated Power (MW)	Annual Investment (€ x 1,000)	Production Costs (c€/kWh)	Transp. & Loss. Costs (c€/kWh)	Total Cost ((c€/kWh)
2011	200	5,000	200	1,000,000	21.6	2.3	23.9
2012	300	4,854	500	1,456,311	20.6	2.2	22.8
2013	500	4,713	1,000	2,356,490	19.6	2.1	21.7
2014	700	4,576	1,700	3,202,996	18.7	2.1	20.8
2015	1,000	4,,442	2,700	4,442,435	17.8	2.0	19.8
2016	1,400	4,313	4,100	6,038,261	16.9	2.0	18.9
2017	2,000	4,187	6,100	8,374,843	16.1	1.9	18.0
2018	2,900	4,005	9,000	11,789,827	15.4	1.9	17.3
2019	4,500	3,947	13,500	17,761,708	14.6	1.8	16.4
2020	**6,500**	**3,832**	**20,000**	**24,008,544**	**13.9**	**1.8**	**15.7** (2)

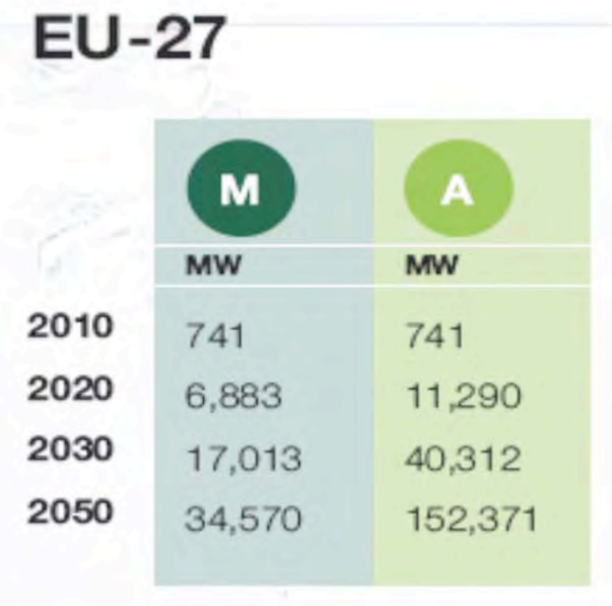
Total Investment in Power Plants	**81,331,414**
Total Investment in Transmission Lines	**16,000,000**
Total Solar Programme Investment	**97,331,414**

(1) ***After repayment of the debt, this total cost will decrease to a fraction, as only O&M costs will remain***

(2) ***After 2020 we may expect further reduction in the kWh cost***

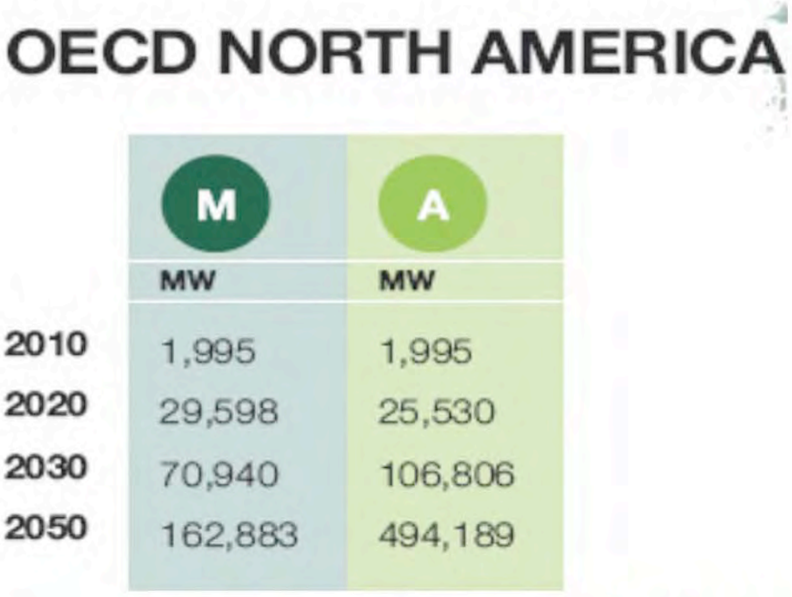
Source: ESTELA

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

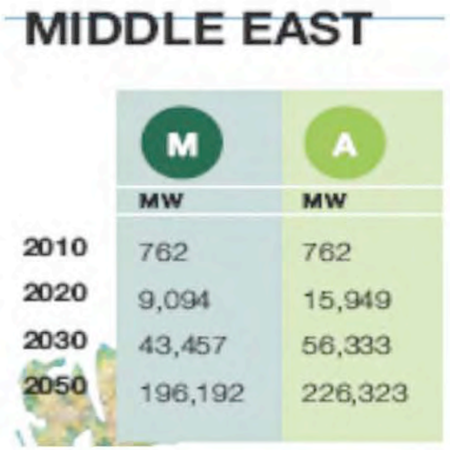
	M MW	A MW
2010	1,995	1,995
2020	29,598	25,530
2030	70,940	106,806
2050	162,883	494,189

LATIN AMERICA

	M MW	A MW
2010	0	100
2020	2,198	2,298
2030	8,034	12,452
2050	33,864	50,006

🟩 120,144 KM² (TODAY)

🟪 30,483 KM² (2050)



MIDDLE EAST

	M MW	A MW
2010	762	762
2020	9,094	15,949
2030	43,457	56,333
2050	196,192	226,323

CHINA

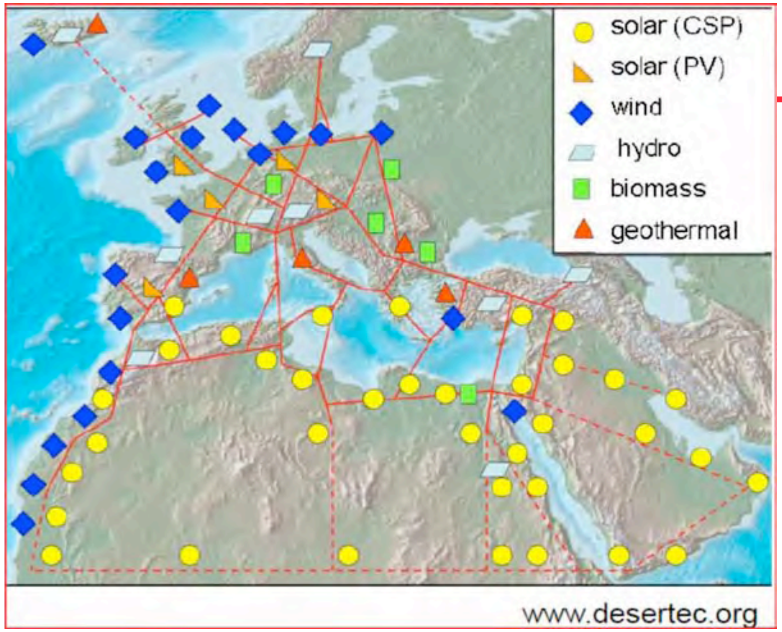
	M MW	A MW
2010	30	50
2020	8,334	8,650
2030	37,481	44,410
2050	156,360	201,732

GLOBAL

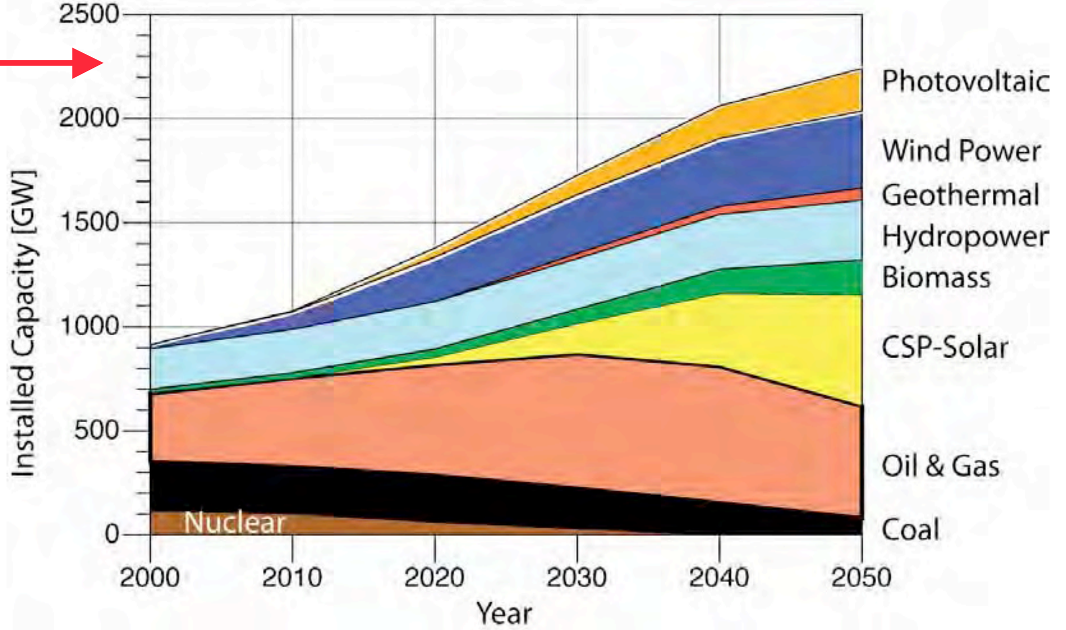
	M MW	A MW
2010	3,945	4,085
2020	68,584	84,336
2030	231,332	342,301
2050	830,707	1,524,172

By 2050 the predicted CSP capacity will be between 830 and 1'500 GW

Forecast of the installed capacity of EU



Source: EU-IP NEEDS (New Energy Externalities Developments for Sustainability)

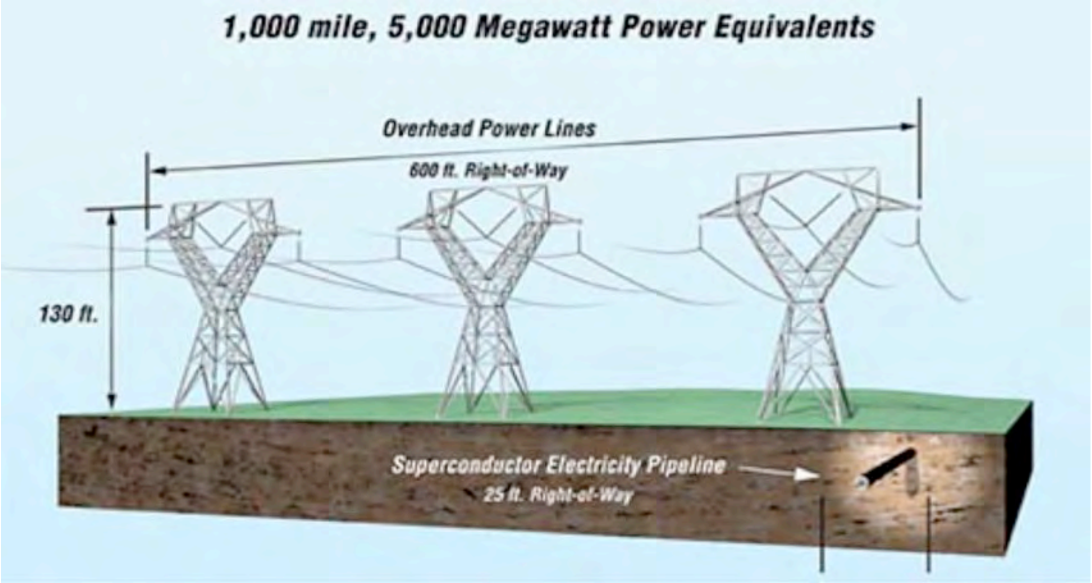


- A geographic distribution of many different novel technologies: PV, CSP, Wind, Hydro, Biomass, Geothermal over EU and surrounding territories.
- Total CO2 emissions reduced to 38% of the year 2000 values.
- EU dependency on fuel imports reduced from 80% to 32%.
- Ordinary Nuclear power may be faded out.
- Hard-coal mining is progressively closed.
- Renewables and liberalisation require bulk transmission capacity to ensure electricity transport over many thousand kms from off-shore wind and CSP.

A new development: very long distance power lines

- The development of renewable energies (wind and CSP) optimal only in remote locations requires a new breed of high power electricity carriers from the location to utilization.
- Electricity transport over ≈3000 km:
  - AC / HVAC lines: high cost and 45% / 25% energy losses
  - 800 kV HVDC lines: lowest costs and 10% energy losses
  - Superconducting (SC) power lines: new promising line for development

Example.
A 20 x 5 GW system of 800 kV HVDC proposed by EU-MENA by 2050 to supply 15 % of the EU electricity, with an average distance of 3000 km and a loss of 15% has a current of 140'000 ampere, a conductor cross section of 2400 cm^2 and it requires 1.2 million tons of Aluminium conductor. The annual power losses for an electricity cost of 6¢/kWh are 7.9 billions.



With 800 kV HVDC, the overhead surface for the EU-MENA-2050 lines is 3600 km^2, to be compared with 2500 km^2 for the CSP plant itself: SC lines are almost a necessity.

Le Monde
WEEK-END

». www.lemonde.fr

TAINE — SAMEDI 6 SEPTEMBRE 2008 FONDATEUR : HUBER

Le solaire s'impose comme l'énergie du futur

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

Thank you !

Present Nuclear Energy

- 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 50 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 world wide 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, largely the same financing and the same organizations.

The NPT- the non proliferation treaty

- The Nuclear Nonproliferation 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: political and 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, 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.*

Plutonium driven weapons

- For many years atomic scientists carefully cultivated a myth that in order to make nuclear bomb, special weapons-grade plutonium consisting of 239-Pu isotope over 94% are 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 be quickly produced .
- Plutonium production in some military reactors have been historically:

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*

- 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 U. For instance, the bomb dropped on Hiroshima contained U 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.

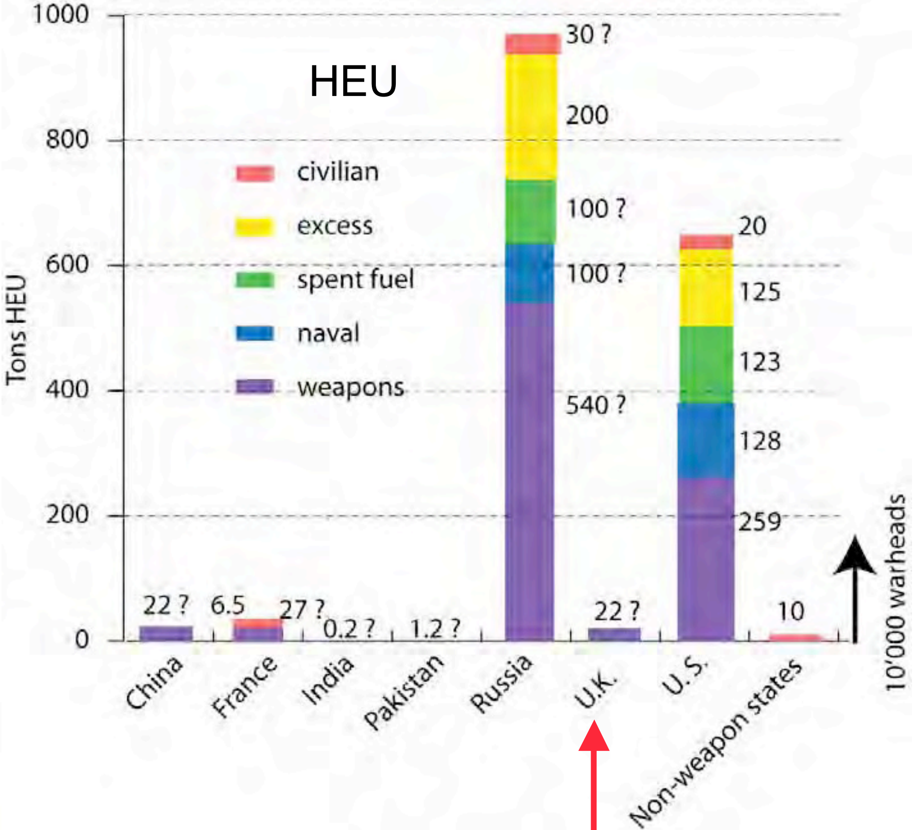
Reducing the risks of a threat with HEU.

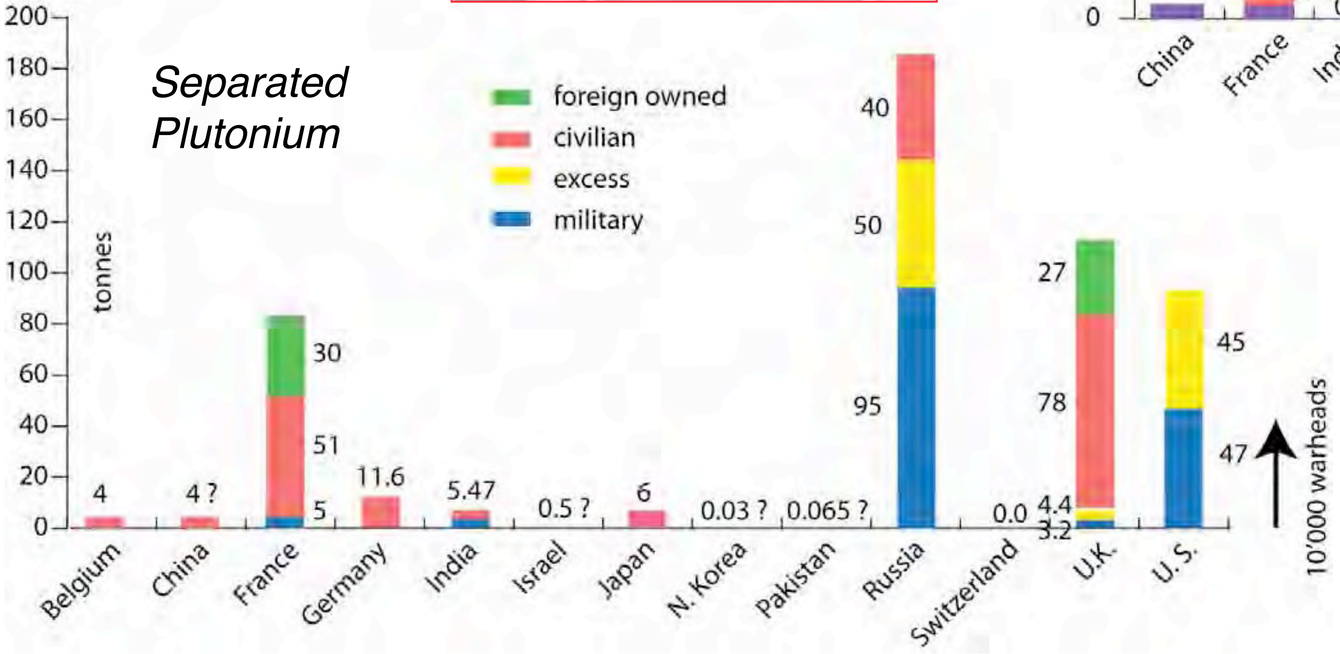
- If HEU material is transported abroad, even minimal radiation encasing makes it hard to detect it. This factor also makes it one of the most dangerous substances in terms of a terrorism threat.
- The first attempt to launch such an initiative was made in 2005 making sure that HEU is not used in civilian 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.
- 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 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