Energies for the Future

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Reducing CO2 emissions

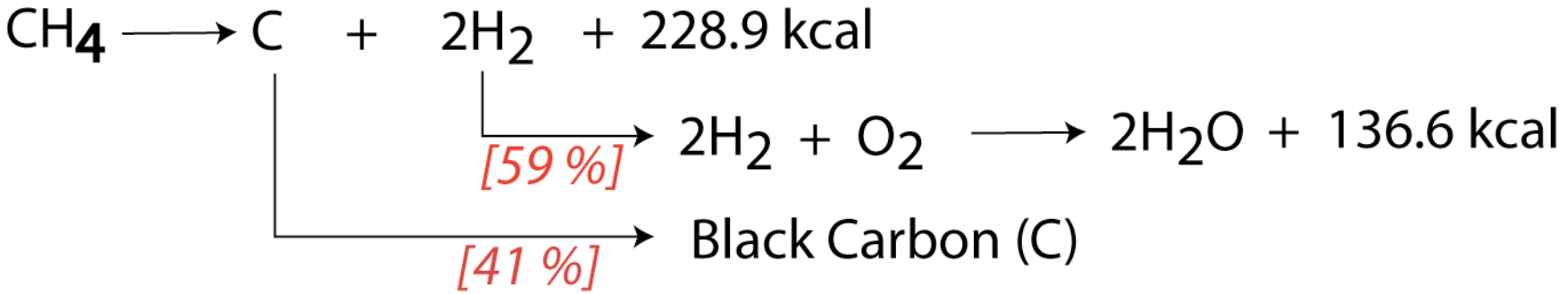
and keeping Fossil Fuels

Clean coal: a reality or an illusion ?

- Some of the world's biggest economies rely on coal. It provides almost 50% of USA's and Germany's power, 70% of India's and 80% of China's, a livelihood for billions of people, with a secure, domestic energy. But it produces twice the CO2 of NG.
- Is there a way of reconciling coal and climate ? Politicians' hopes are very high. The job is huge if one thinks that about 20 billion tons of CO2 are produced every year.
- Sequestration (CCS) is seriously considered: inject the CO2 down into the earth and at the bottom of the ocean. Some $3.4 Billion have been already spent by USA and similar incentives have been given by EECC.
- But so far CCS will be incredibly costly to build and to operate, reducing electric plant's efficiency by at least 10-40%.
- How long will it stay down there ? CO2 is a very volatile and chemically dangerous material. If it escapes at a concentration of > 10% it causes sudden death in less than 4 minutes.

Another method: burning Natural Gas without CO2 ?

- At an appropriate temperature of about 1200-1300 °C, NG simply bubbled through a bath of molten salt or metal, will crack completely into carbon and hydrogen.



- Molten liquids include Iron, Tin, Lead or salts like NaCl, NaF.
- Since the solid black carbon has a density smaller than the molten material used to effectuate the cracking, it will float on the surface and be easily separated out from the reactor.
- Essentially pure hydrogen may be produced by a simple and cheap methane decomposition reactor, without CO2 emissions from ordinary NG: the black carbon may be used to produce useful products, like for instance car tires or other C products

The hydrogen alternative ?

A "Hydrogen" economy ?

- Oil and NG are not only our main energy sources: they are also essential materials for a great variety of products (for example many petrochemical and chemical products including synthetic materials, plastics, pharmaceuticals, etc.).
- Given by nature as a gift, they are being used up rather rapidly and become significantly depleted and increasingly costly. We need to search for new sources and solutions.
- Much has been said about a future "hydrogen economy". Hydrogen is indeed clean, giving only water and energy.
- Governments and some major industries seem to be committed to develop the "hydrogen economy" (see for example the statements by President Bush's January 2003 State of the Union message and President Prodi's talks at the EEUU).
- It is clear, however, that in order to achieve this, new ways must be found to make it feasible.

Hydrogen is only an energy carrier

- However, hydrogen is not a natural energy source on our planet (in contrast to the sun and stars) and it may be presently generated for instance from natural gas or coal.
- Handling of this volatile and explosive gas is difficult, dangerous and costly, necessitating high pressure equipment and the use of special materials. No infrastructure exists for it and its costs, without a doubt, will be prohibitive.
- Even with the greatest care, any leaks would represent extreme explosion hazards, limiting wide use by consumers.
- The new sources of H2 must avoid the associated production of CO2 in the process, since its increase in the atmosphere is considered a major man made cause for global warming.

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The best alternative to

complement Oil:

Hydrogen + CO2 -> Methanol

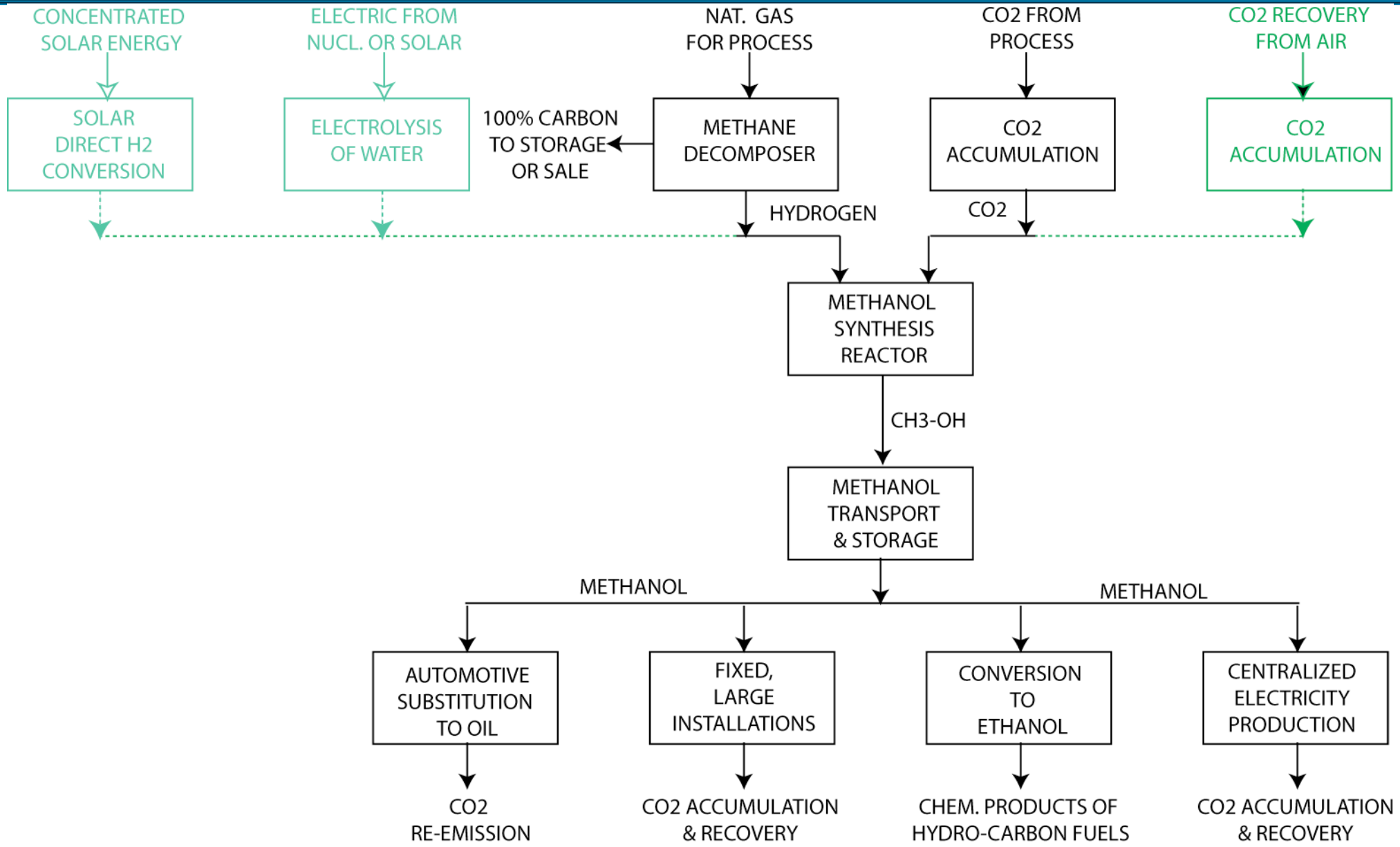
CO2 recovery and substitution

- CCS at the required amount of sequestration may be at the end a costly illusion and create false sense of security about climate warming. A better use of CO2 should be encouraged.
- Assume that we recover CO2 as a chemical material and to recycle it from some conventional source of concentrated CO2 waste.
- For instance, CO2 and hydrogen could be combined to produce methanol and water, with methanol being a liquid substitute to gasoline in nearly all transport applications.

$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O \qquad CH_3OH + 3/2O_2 \rightarrow CO_2 + 2H_2O$$

- If due to distributed sources, the produced CO2 will have been already "paid for" by the savings due to the CO2 conversion in the previous application (two for one).
- If in a concentrated source, it could be indefinitely recycled.

Alternate processes with CO2 preservation (Summary)

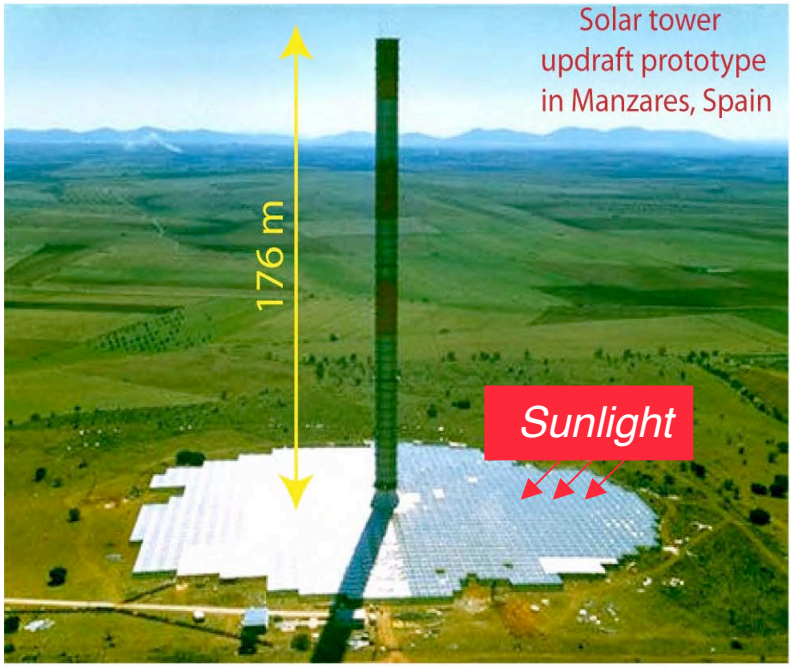


Conclusion: the future for transportation is methanol !

- Methanol is a bulk commercial chemical which can be obtained in many ways. A promising new method could be some already recovered CO2 reacting with hydrogen.
- Compared to H2, methanol is a convenient liquid product.
- Methanol is an excellent fuel in its own right and it can be blended with gasoline or used in the "methanol fuel cell", producing electricity directly combined with air.
- Methanol can be converted to ethylene, the key material to produce hydrocarbon fuels and their products.
- Therefore it would be able to replace oil both as a fuel and chemical raw material without costly new infrastructures.
- It would provide a feasible and safe way to store energy, make available a convenient liquid fuel, and provide mankind with an unlimited source of hydrocarbons mitigating the dangers of global warming.

Recovering spent CO2 back from the atmosphere ?

- According to this alternative to sequestration,the atmosphere of the planet would act as a temporary storage and transport.
- Air extraction is an appealing concept, because it separates the location of the CO2 source from its disposal. CO2 can be recovered from any product (including cars, airplanes, flames, fires, heating, etc), located far away from the sources.
- These dedicated sinks should behave like "synthetic trees", removing the CO2 of the air (≈360 ppmV).
- A solar tower ("solar chimney") is a air collector and a central updraft tube generating a strong convective flow through a chemical sorbent, called amine. Cold CO2 and amines combine. CO2 is recovered at high temperature



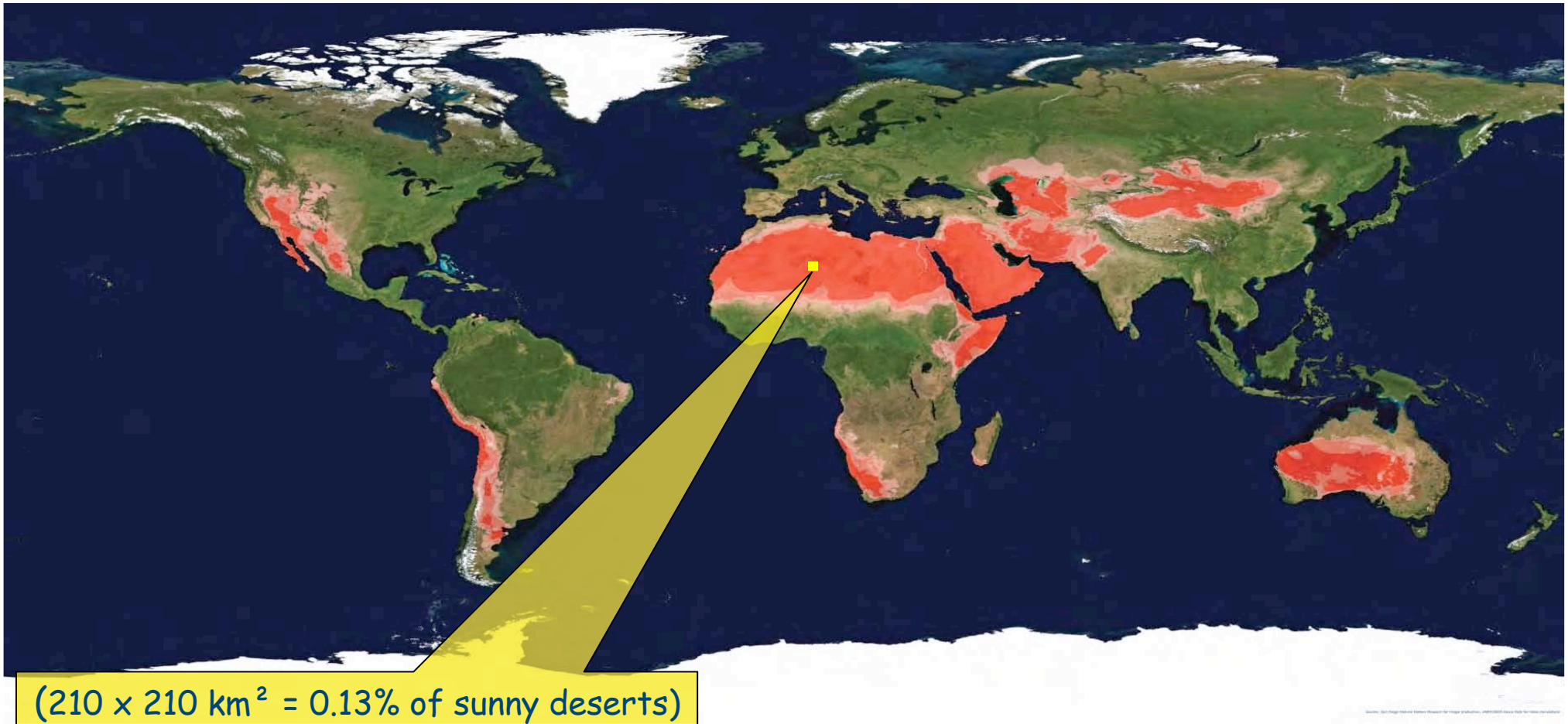
(Haaf et al. 1983, Schlaich et al, 1990)

Concentrated Solar energy:

a bright future for electricity

and hydrogen production

Solar energy in the “sunbelt”



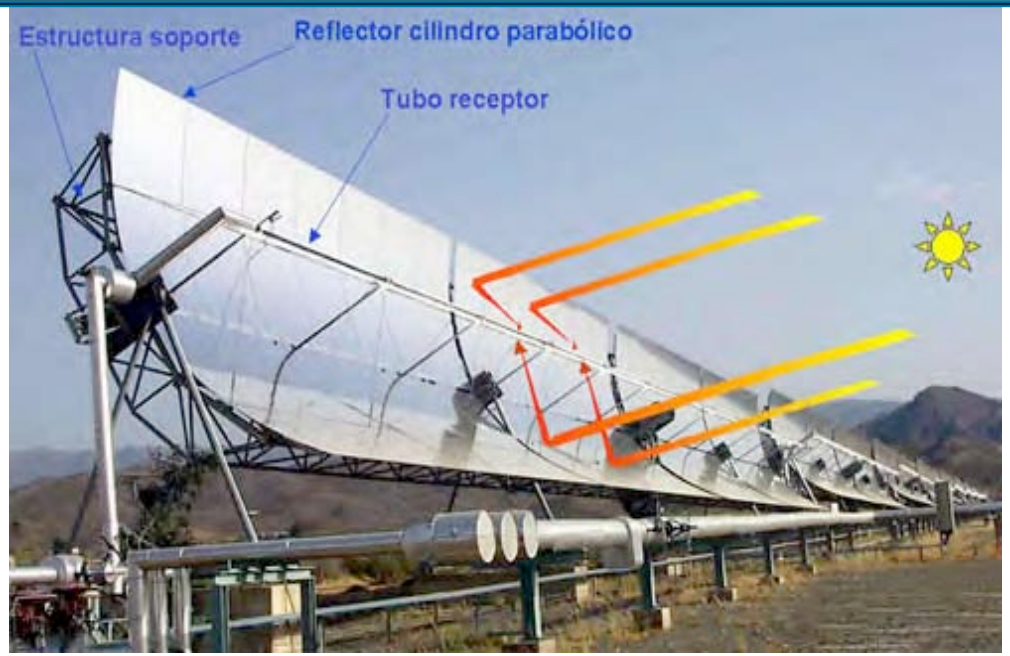
(210 x 210 km² = 0.13% of sunny deserts)
is receiving a yearly averaged solar energy equal to today's global energy consumption (15 TW x year)

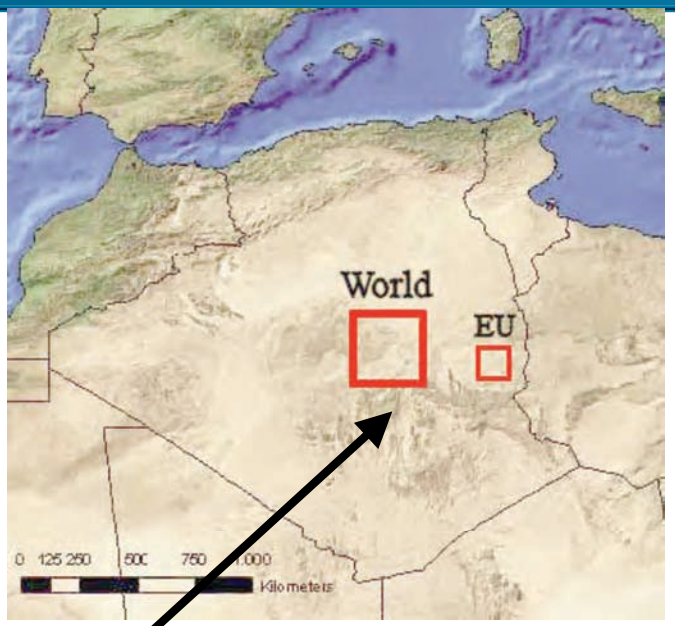
Gerhard Knies, ISES-Rome CSP WS 2007

High efficiency conversion of CSP solar into high temperature heat (450-650 °C)
The "great transformation" from fossils to solar

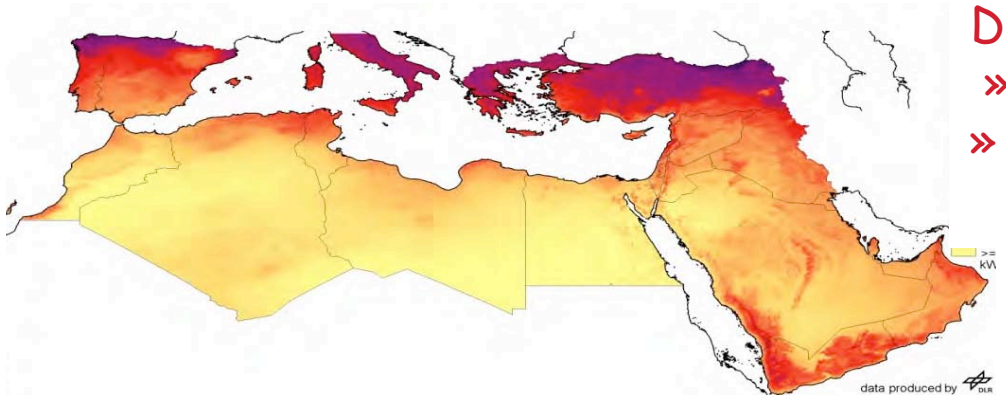
Geneva, March 2009

Principle of modern CSP





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



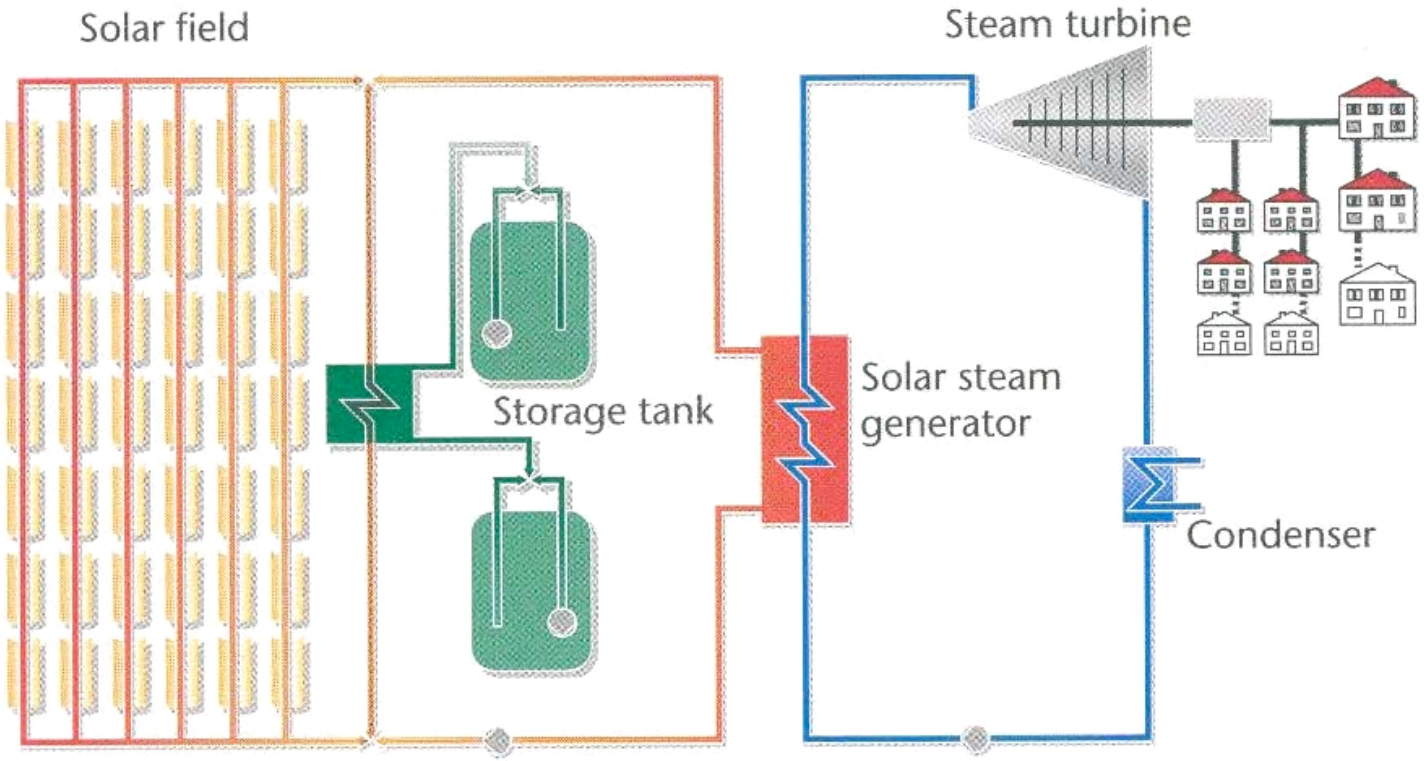
Economic potentials > 600 000 TWh_{el}/y

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

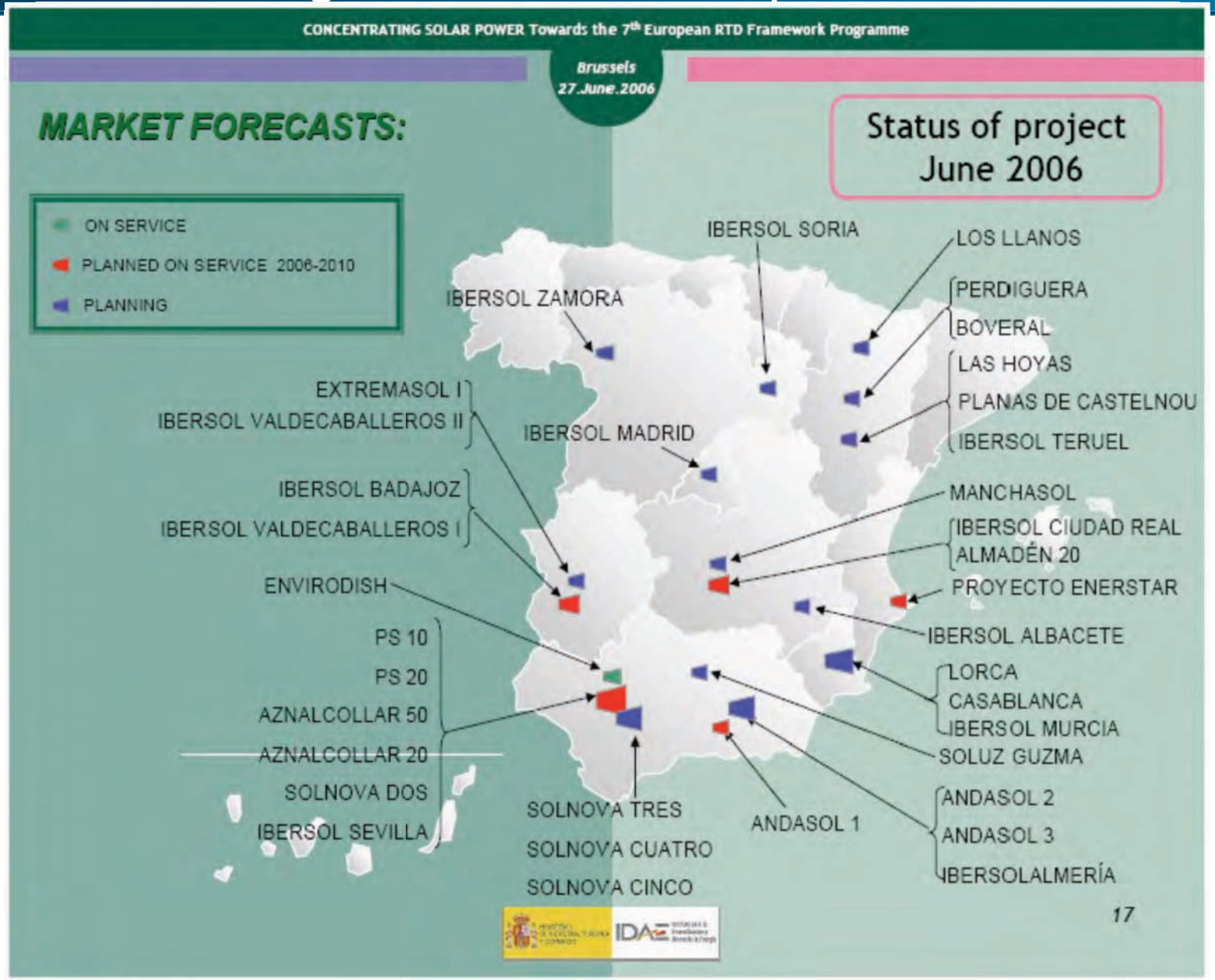
CSP modern power plant

- Utility scale plant with conventional power block
- 2000 - 7000 full load hours using thermal storage
- LECs today: 13 - 20 ct/kWh, future: 5 - 10 ct/kWh

Parabolic trough power plant with heat storage system



The leading role of CSP in Spain: June 2006

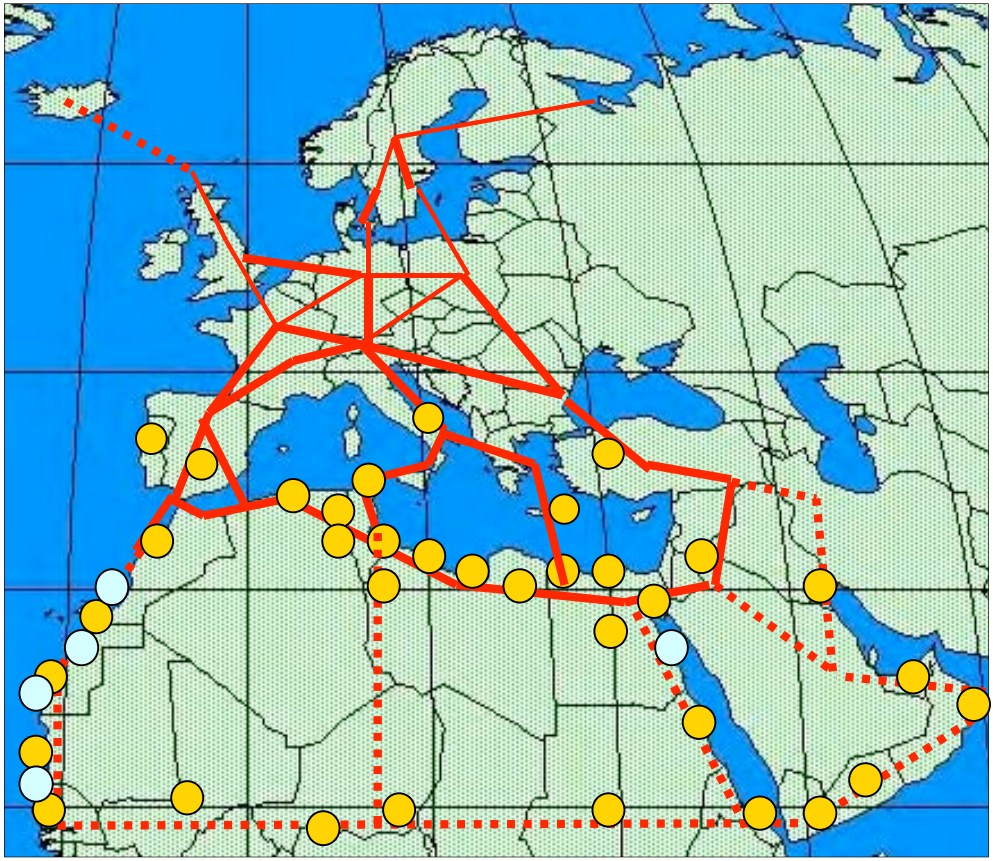


Nevada Solar 1 in the USA (2007)

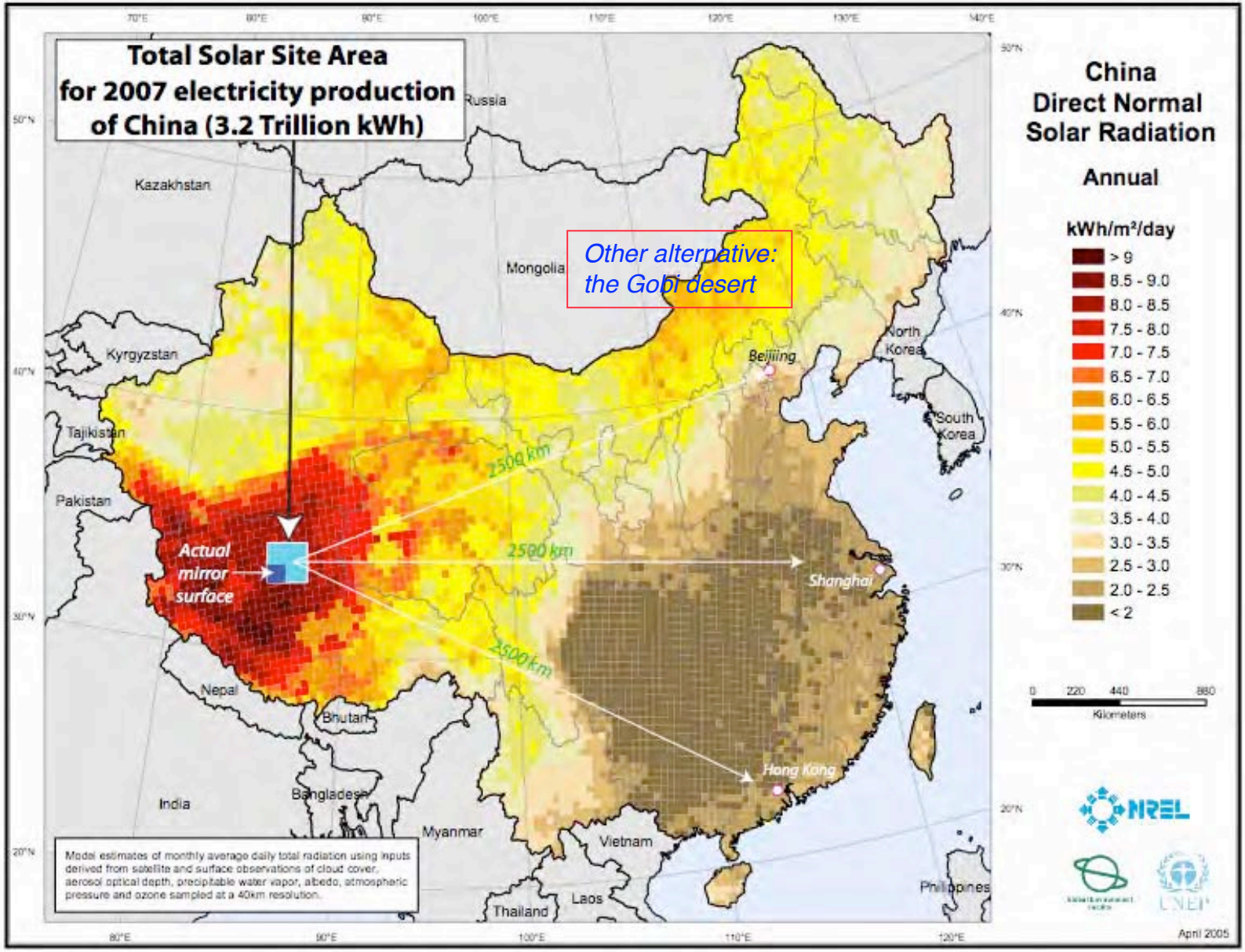
- Generating Capacity 64 MW (Nominal)
- 357,200 m2 of Solar Field
- Annual Production > 130,000 MWh
- Construction in less than 18 months,
- 1.6 million man-hours
- *Capital investment : ≈ 250 Millions USD*

CSP Pan European Forecast for 2020-50

- The planned EURO-MED electricity interconnection permits to produce from the Sahara large amounts of solar electricity toward the Pan-European network.
- Transport of electricity from far regions to central Europe is both economically and technically feasible.

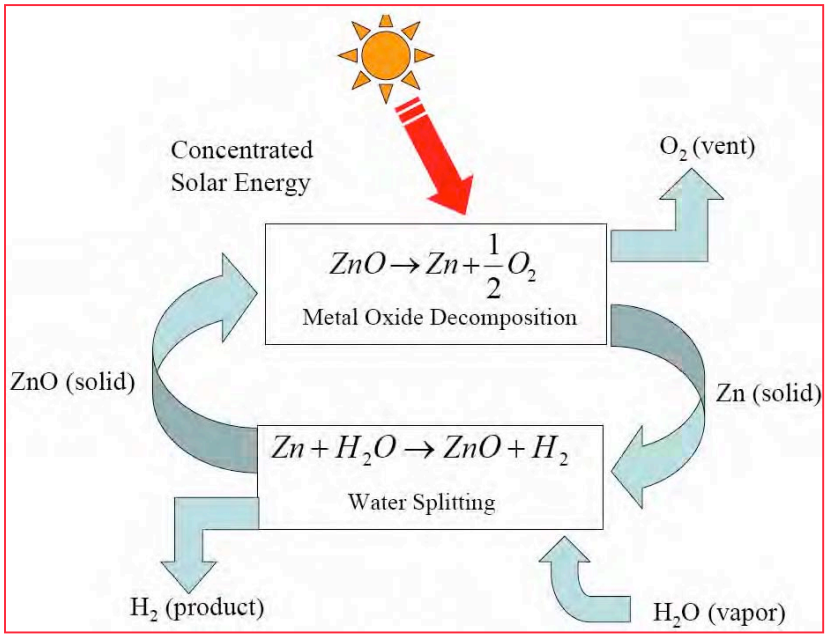


China ?


Total Solar Site Area
for 2007 electricity production
of China (3.2 Trillion kWh)
Other alternative:
the Gobi desert
China
Direct Normal
Solar Radiation
Annual
kWh/m²/day
> 9
8.5 - 9.0
8.0 - 8.5
7.5 - 8.0
7.0 - 7.5
6.5 - 7.0
6.0 - 6.5
5.5 - 6.0
5.0 - 5.5
4.5 - 5.0
4.0 - 4.5
3.5 - 4.0
3.0 - 3.5
2.5 - 3.0
2.0 - 2.5
< 2
Actual
mirror
surface
2500 km
2500 km
2500 km
Beijing
Shanghai
Hong Kong
Russia
Kazakhstan
Mongolia
Kyrgyzstan
Tajikistan
Pakistan
North
Korea
South
Korea
Nepal
Bhutan
India
Bangladesh
Myanmar
Vietnam
Laos
Thailand
Philippines
Kilometers
Model estimates of monthly average daily total radiation using inputs derived from satellite and surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone sampled at a 40km resolution.
April 2005

Direct Hydrogen production without CO2 (cont)

- Hydrogen can be produced directly from water dissociation with the help of high temperature (solar) heat.
- But a spontaneous dissociation of water into H_2 and O_2 is only possible at temperatures above 3000 °C, far too high to be of practical use. Several simple thermo-chemical processes are under development in which concentrated solar heat, at temperatures of the order 1200 °C, splits H_2O into H_2 and O_2.
- Some optimal processes are oxi-reductions of ZnO/Zn, Fe_3O_4/FeO and Fe_2O_3/Fe_3O_4. They are cycles with a high efficiency, large scale and environmentally attractive.
- The accumulated hydrogen energy in good sunny regions is in practice about 50% of the incoming solar.



New, clean energies from nuclei

able to provide resources

for millenia to come

- A serious alternative are new nuclear energies without U-235 and without nuclear proliferation : Thorium fission and D-T fusion are likely candidates, capable of supplying energy for millennia to come
- An example is fission on U-238 or Th-232 in which
  - ⇨ the totality of the natural fuel is eventually burnt
  - ⇨ the released energy for natural element *is about two hundred times greater than the one in the case of the classical, U-235 driven nuclear energy*. (F.I. 1 GWe x year = 200 ton of Natural U and ≈ 1 ton of Natural Th)
- Natural reserves are adequate for many tens of centuries at a level several times the today's primary fossil production.

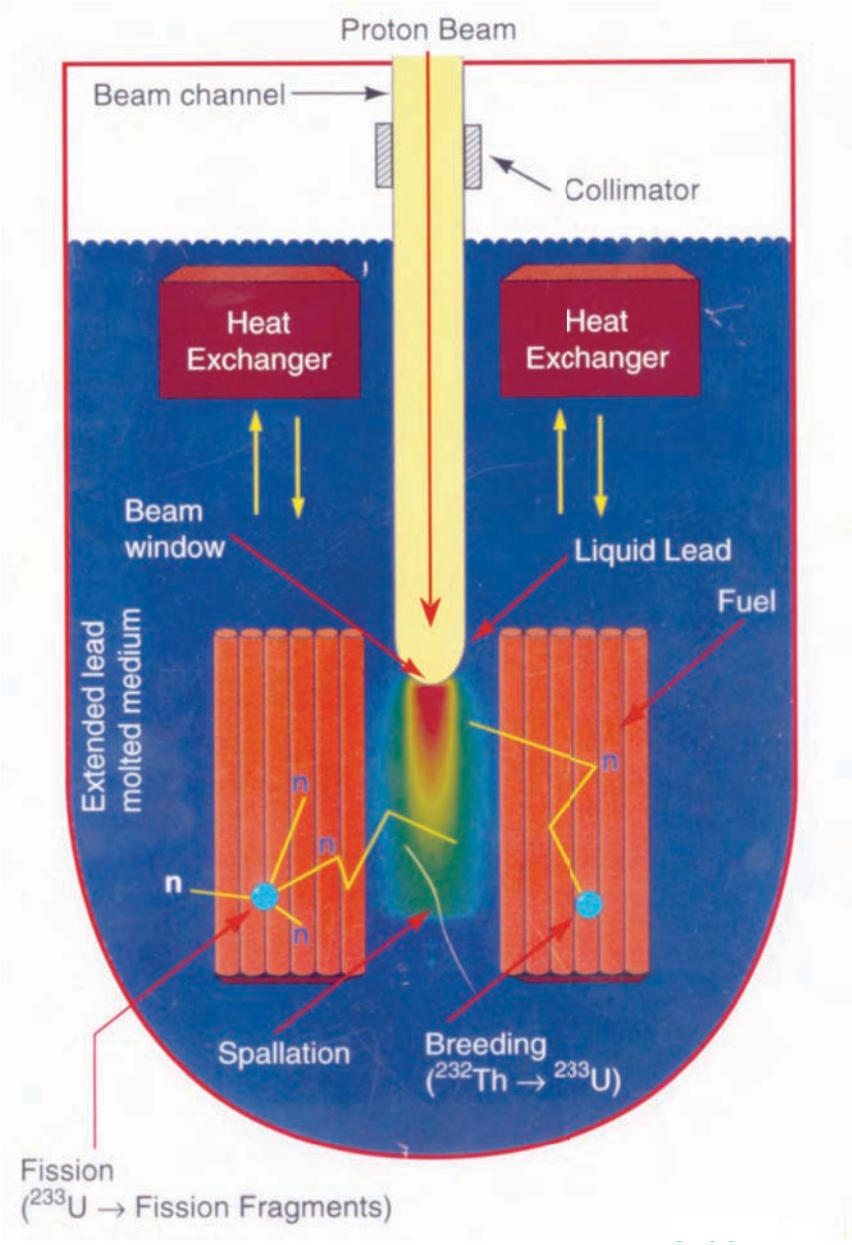
Principle of operation of the Energy Amplifier

Thorium related Fission

$$^{233}_{92}U + ^{1}_{o}n \rightarrow 2.53[^{1}_{o}n] + 2FF + 200\ MeV$$

$$^{232}_{90}Th + ^{1}_{o}n \rightarrow ^{233}_{91}Pa + \gamma \xrightarrow[(27\ days)]{\beta-decay} ^{233}_{92}U + ^{o}_{-1}e$$

$$^{233}_{92}U + ^{1}_{o}n \rightarrow ^{234}_{92}U + \gamma$$



General setup

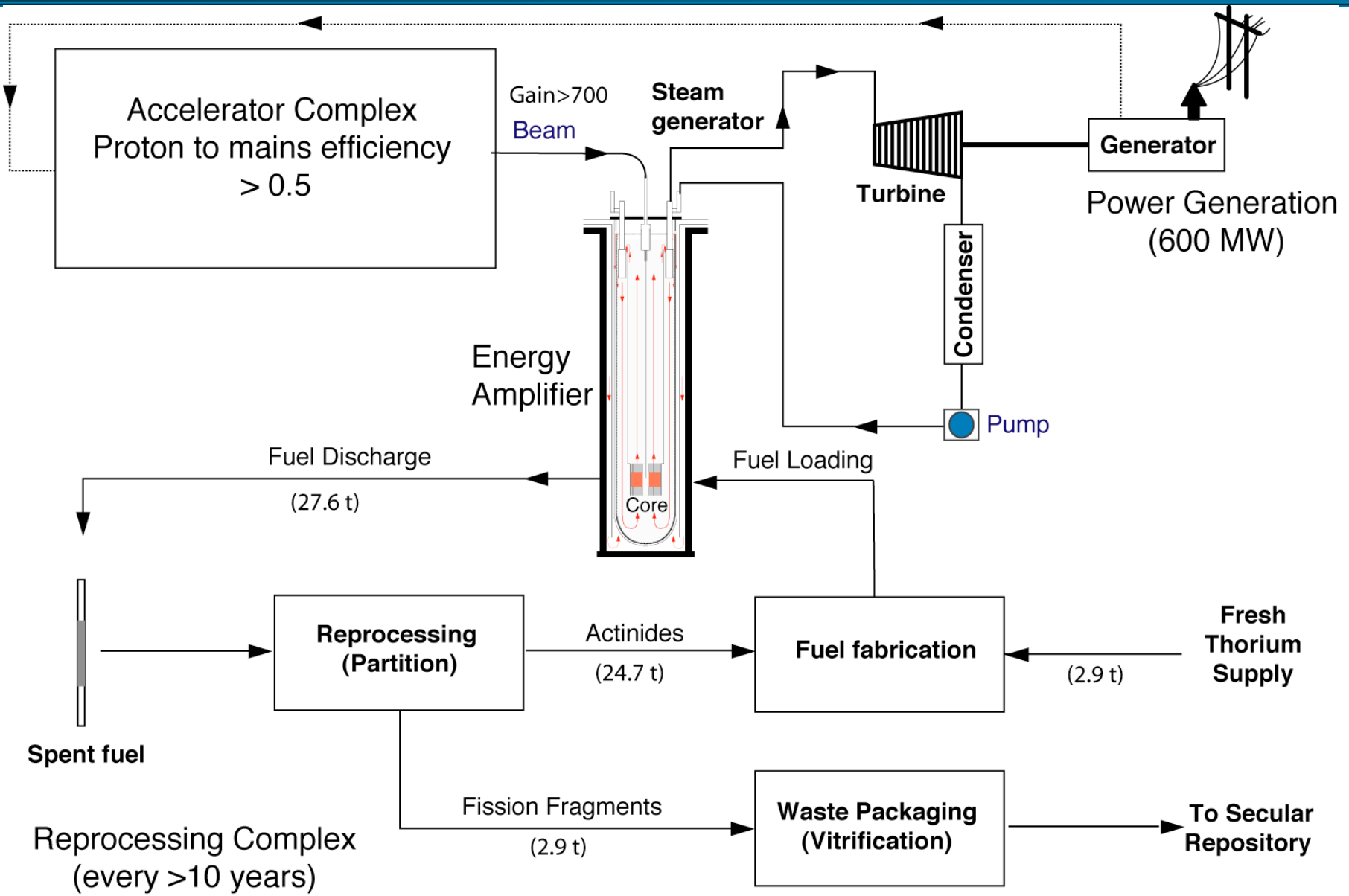
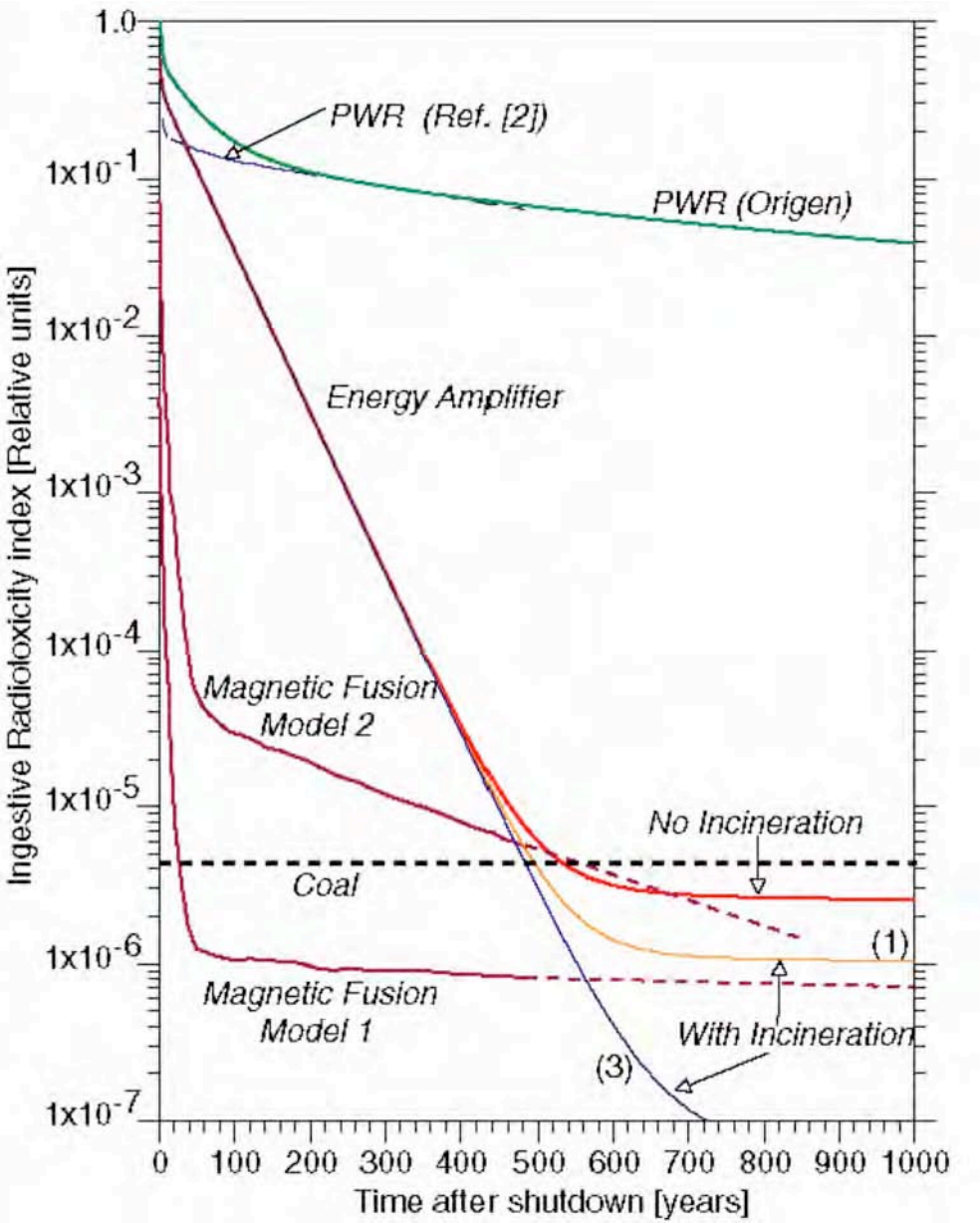


Figure 1

Residual radio-toxicity of waste as function of time



Comparing :
(1) ordinary reactor (PWR),
(2)Thorium based EA (closed cycle)
(3)two T-D fusion models

Conclusions

- The future of mankind is crucially dependent on the continued availability of cheap and abundant energy.
- It is most urgent that the use of fossils is reconciled with global warming. Burning of NG without CO2 and CO2 recovery for methanol conversion should be developed. Alternative energies must also be vigorously pursued:
- Solar Energy: particularly promising is *concentrated* solar radiation in the wide, desertic regions of the "sun belt",for electricity production and water splitting into hydrogen.
- A new Nuclear Energy without U-235 and without nuclear proliferation : Thorium fission and D-T fusion are likely candidates, capable of supplying energy for millennia to come.
- Both methods are likely to become successful in the long run: however *a vast, urgent and innovative R&D is necessary.*
- Although innovative energies may eventually be more essential for developing countries, *our technically developed society should realistically foster such a change.*

Thank you !