The Future of Energy

Carlo Rubbia

IASS, Institute for Advanced Sustainability Studies Potsdam, Germany

GSSI-INFN, Gran Sasso Science Institute

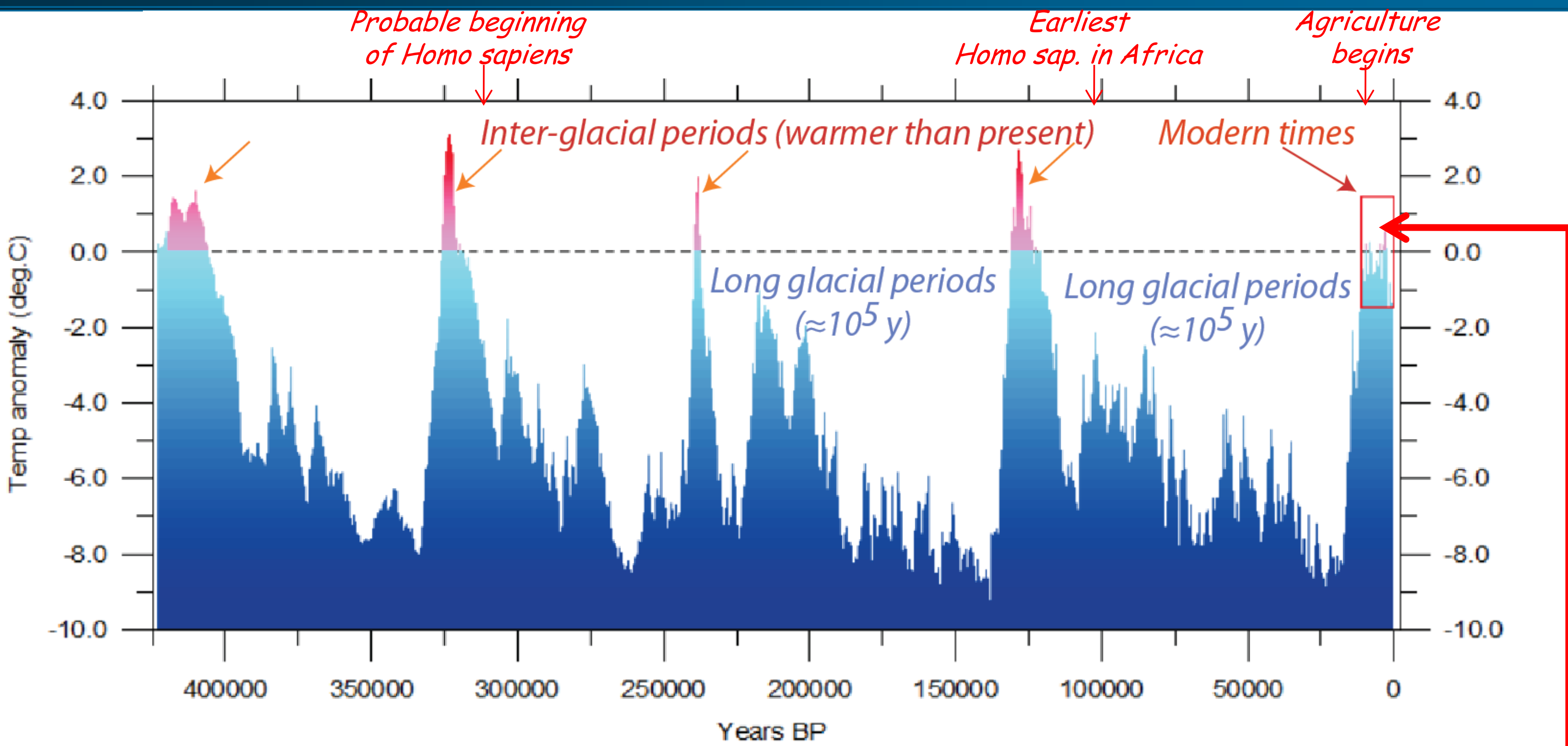
L'Aquila, Italy

ABSTRACT

- The need of stability of the climate
- The existence and limits of an Anthropogenic Era
- Can some Geo-engineering method eliminate the global warming?
  - Carbon capture and sequestration
  - Stratospheric Sulphur cooling
- The future role and the practical limits of Renewable Energies
- Some innovative methods to curb energy related emissions
  - Superconducting electricity transmission from distant (renewable) energy sources
  - Natural Gas from unconventional new sources
  - Energy from Natural Gas but without CO_2 emissions
  - Fossil Methanol as a new liquid carrier for transportation
- Conclusions

The need of stability of the climate

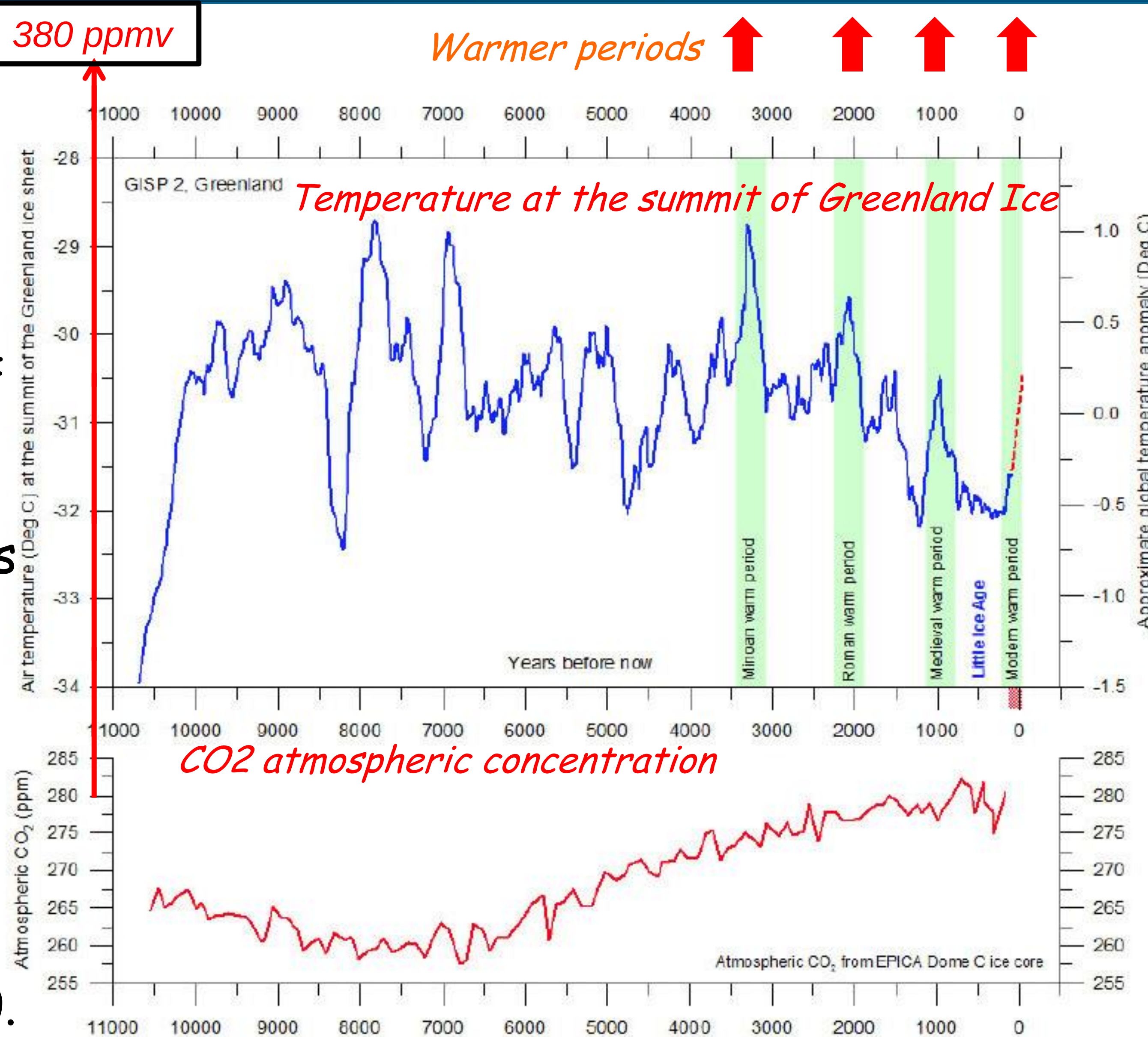
A necessary premise for civilization



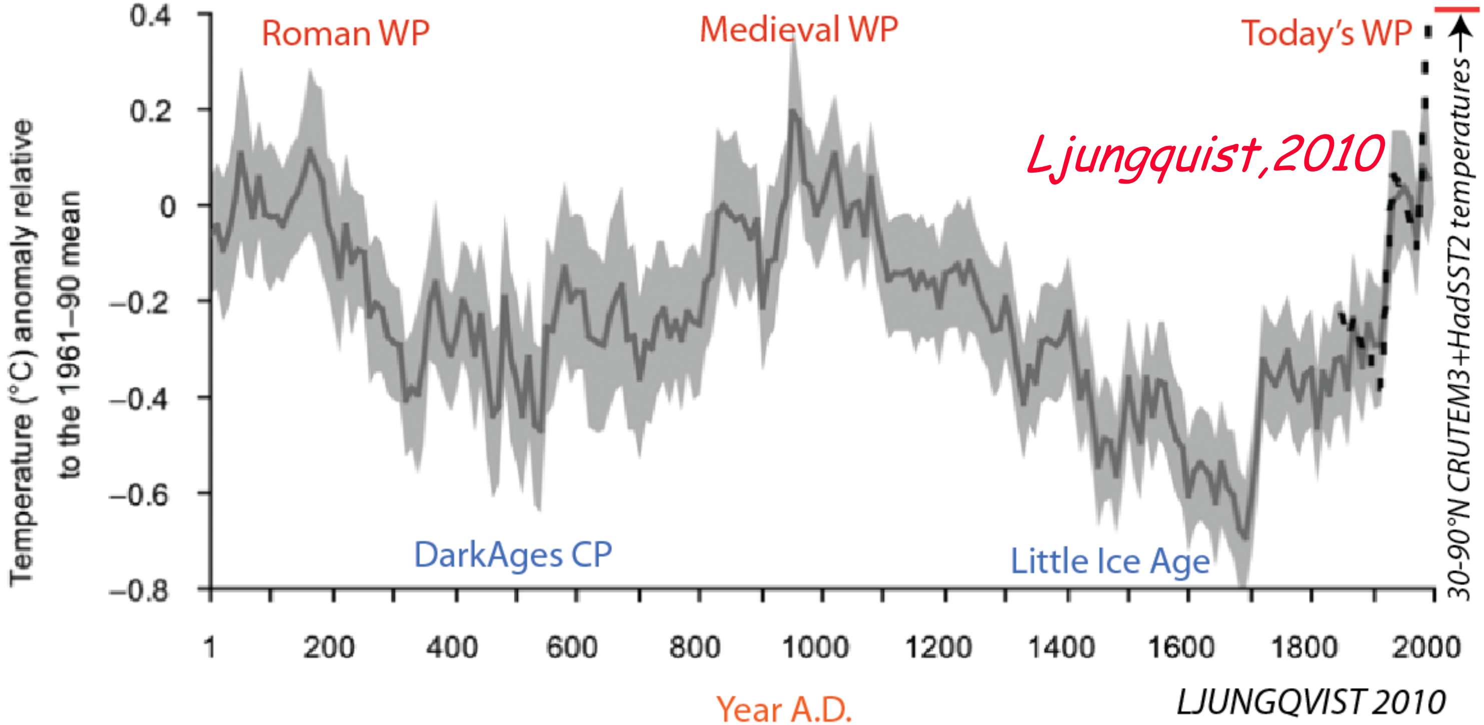
- Reconstructed global temperature over the last 420'000 years based on the Vostok ice core from the Antartica (Petit et al. 2001)
- It has been the last inter-glacial period during the last 10'000 years which has permitted to sustain the development of the human civilization.

Temperatures and CO_2 concentrations over the last 10'000 y

- The upper curve shows the temperatures at the summit of the Greenland Ice. The beginning at the left represents the end of the last glaciation (≈11'000 y).
- The lower curve shows the CO_2 concentration. *No evident correlation is between the two.*
- Presently the CO_2 concentration is 380 ppmv from 280 ppmv by the middle of 1900.

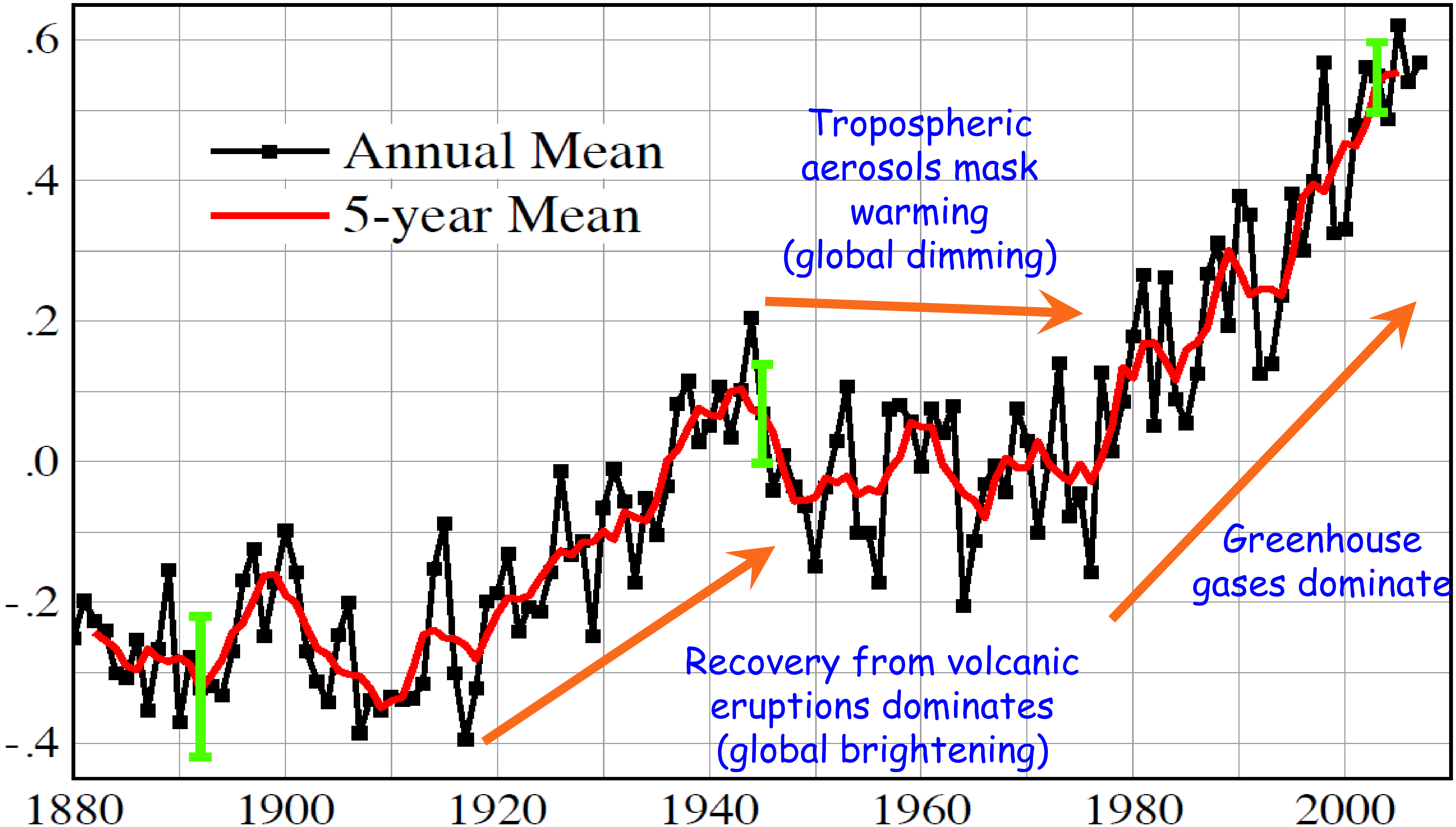


2000 years of temperatures in the 30-90° North hemisphere



- Earth's climate has changed *naturally* between cooler and warmer conditions on a millennial timescale.
- Extra-tropical Northern Hemisphere (90–30° N) decadal mean temperature variations (dark grey line) relative to the 1961–1990 mean temperature with 2 standard deviations bars

The recent presumably troposphere related effect (C°)?



Temperature variations over the last century

The existence and limits of an Anthropogenic Era

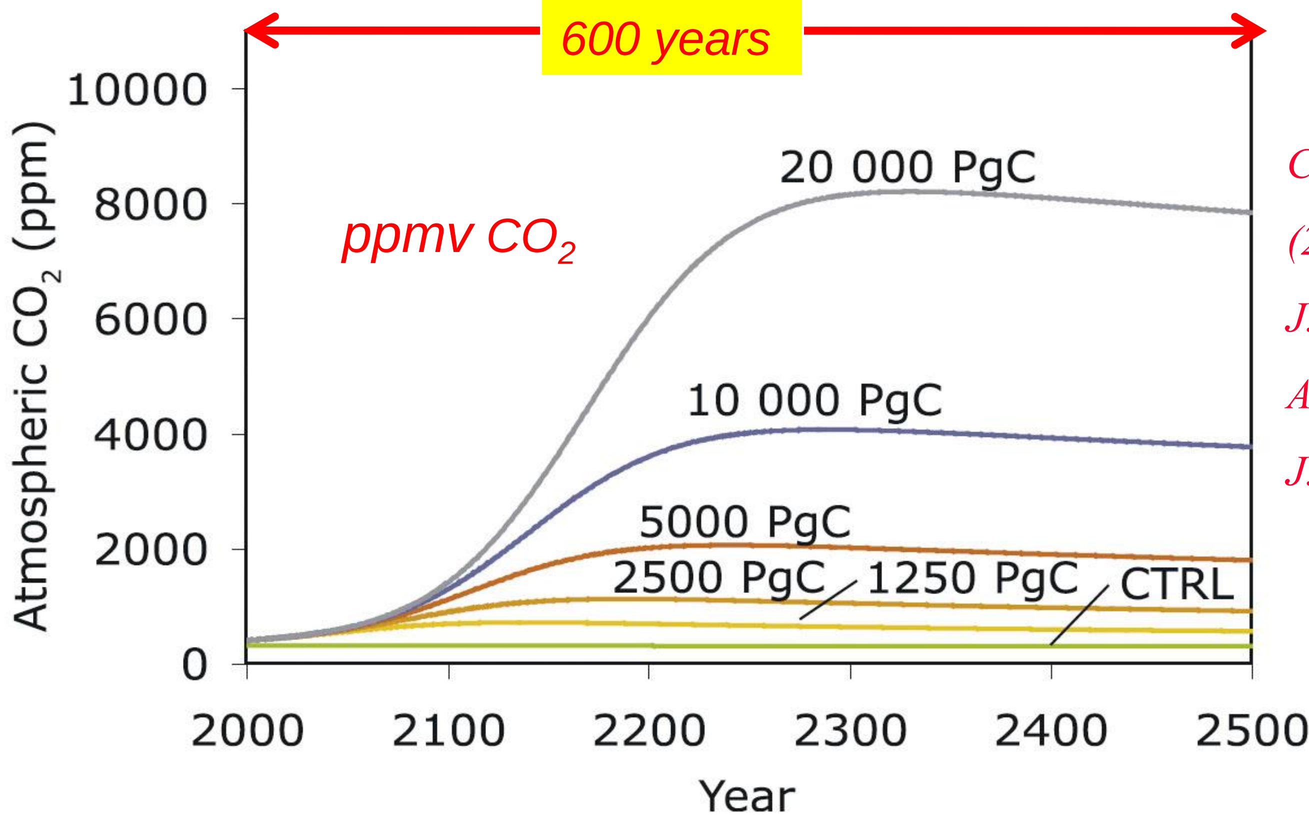
A new phenomenon: the emergence of Anthropogenic Era

- The permanence of the warm period after the last inter-glacial period has been essential to create and to sustain life and civilization as they are today, an essential element for survival that we must preserve at all cost.
- As well known, we are presently facing a new phenomenon, coined by Eugene Stoermer and popularized by the Nobel Laureate Paul Crutzen, the emergence of a man made Anthropogenic Era: for the first time human activities strongly influence the future of the earth's climate.
- For instance, since 1750, about one million of millions tons, 1000 Gtons, of CO_2 have been injected into the air, to which many other pollutants have to be added.
- The first signs of an Anthropogenic Era have been already detected. These effects must be urgently curbed to avoid the irreversible effects of a major climatic change.

Energy related new technologies: The only key to success

- The current worldwide energy supply is based mainly on the availability of fossil fuels and they will remain indispensable in the decades to come.
- The transformation to energies with lower emissions and a quantitatively significant management of CO_2, are amongst the most important technological challenges of our times.
- In order to curb environmental changes, it is necessary to proceed simultaneously on two parallel lines:
  1. a more efficient and friendly utilization of fossils fuels, curbing the effects of their anthropogenic emissions;
  2. the development and progressive utilization of the renewable energy sources.
- Both novel methods of energy production are presumably the only practical way out to the Anthropogenic warming threat

The incredible duration of CO_2 in the biosphere



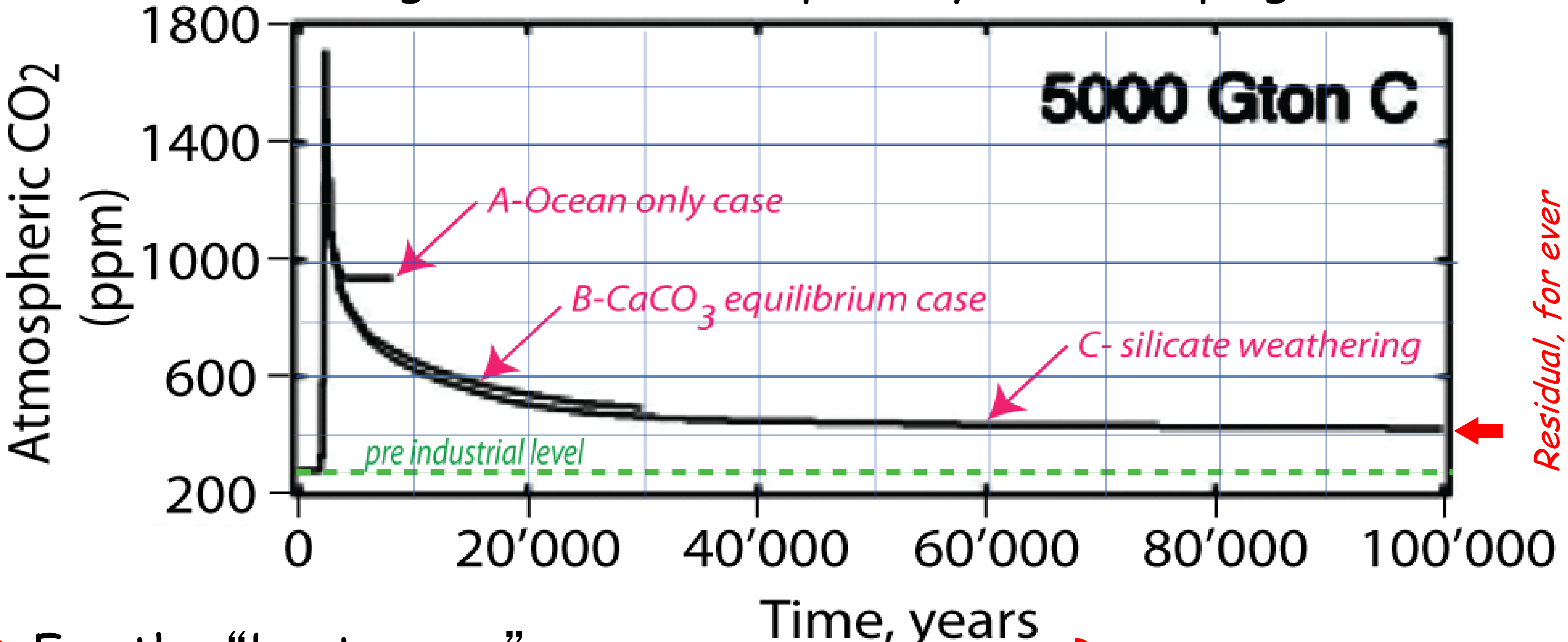
Caldeira, K., and M. E. Wickett (2005), J. Geophys. Res., 110, C09S04.

Archer, D. (2005), J. Geophys. Res., 110, C09S05

- The mean lifetime of CO_2 in the atmosphere is about 30–35 kyr
- As a comparison, the lifetime of Pu-239 is 26 kyr, associated with the today's public negative perception of nuclear energy.
- A mean atmospheric CO_2 lifetime of order 10^4 years is contrast with the "popular" perception of only few hundred years.

Coal reserves will be burnt during many centuries

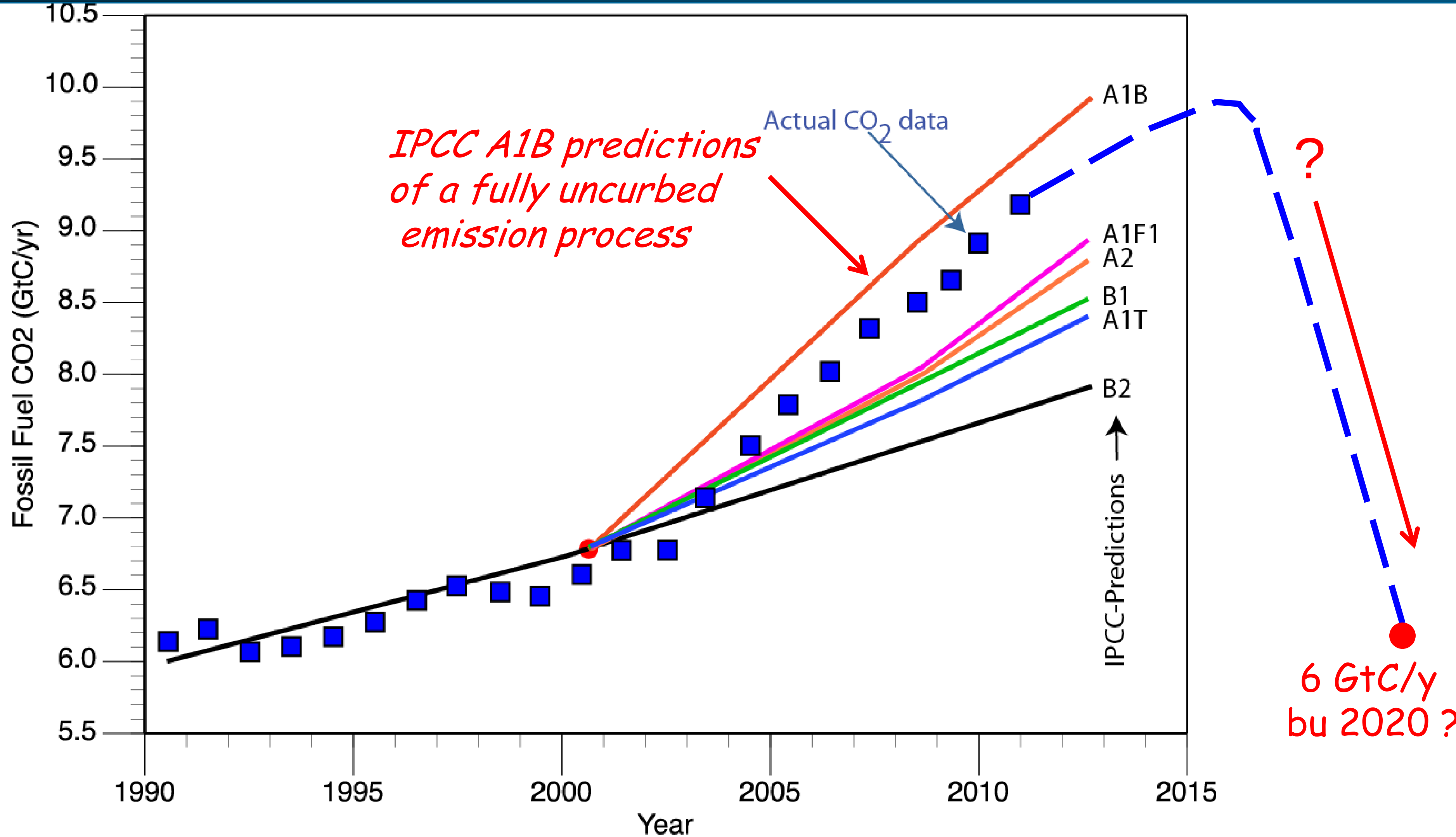
- A major fraction of energy may be produced with new methods, *but* Coal burning will continue especially in developing countries



- For the "best guess" case :
  - After 1'000 years 17-33% of fossil C
  - At 10'000 years 10–15% of fossil C
  - At 100'000 years 7% of fossil carbon.

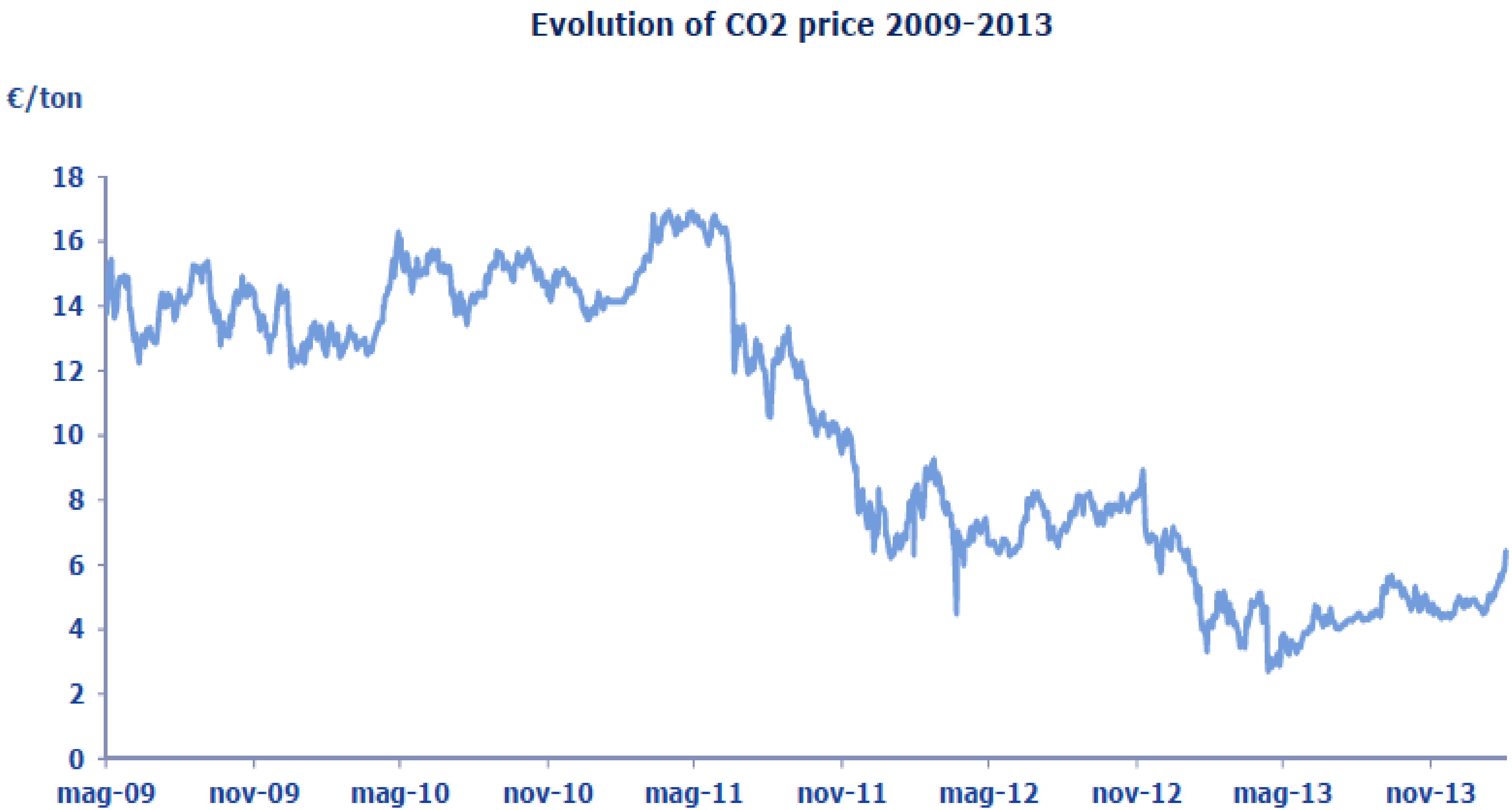
In practice, "for ever"

Man made fossil CO_2 emissions are rising at a rapid pace

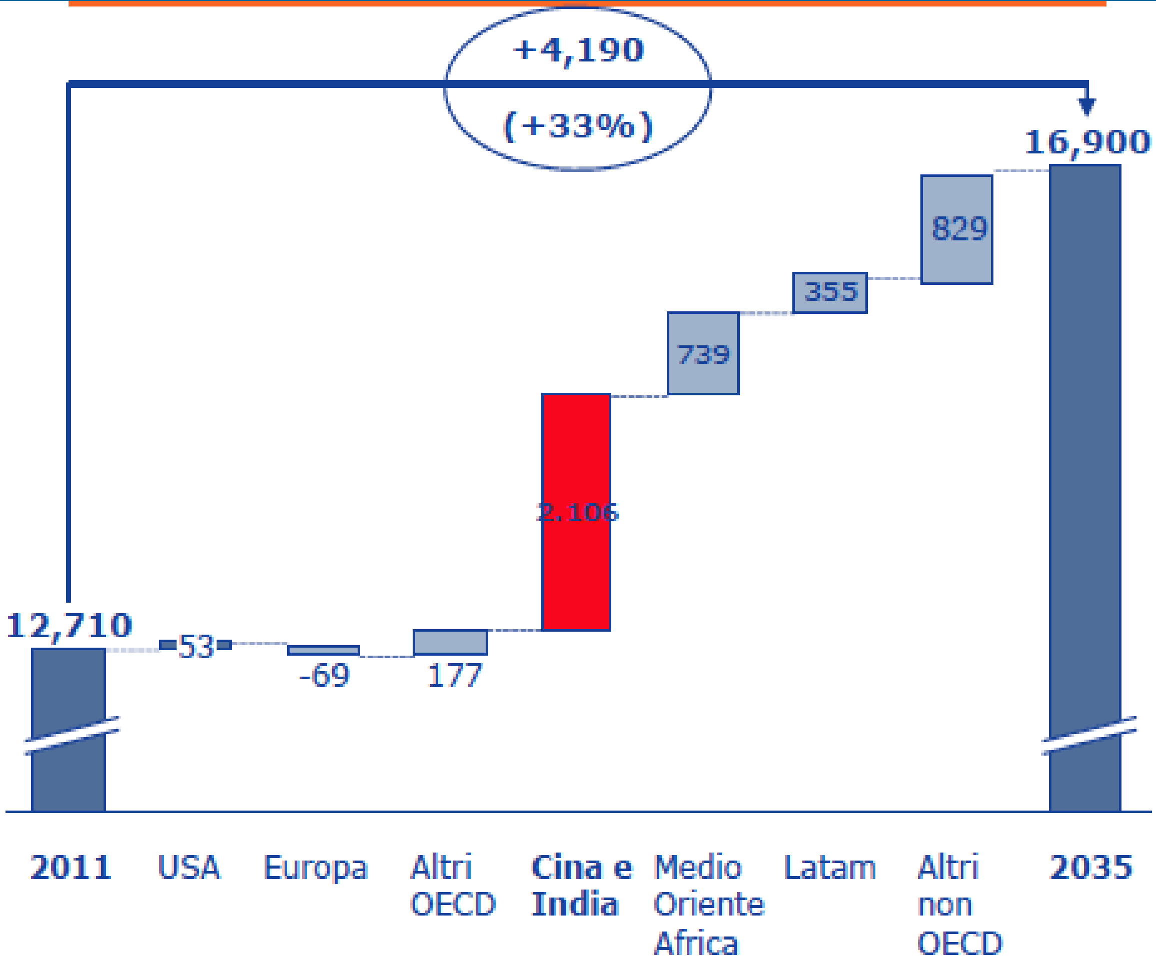


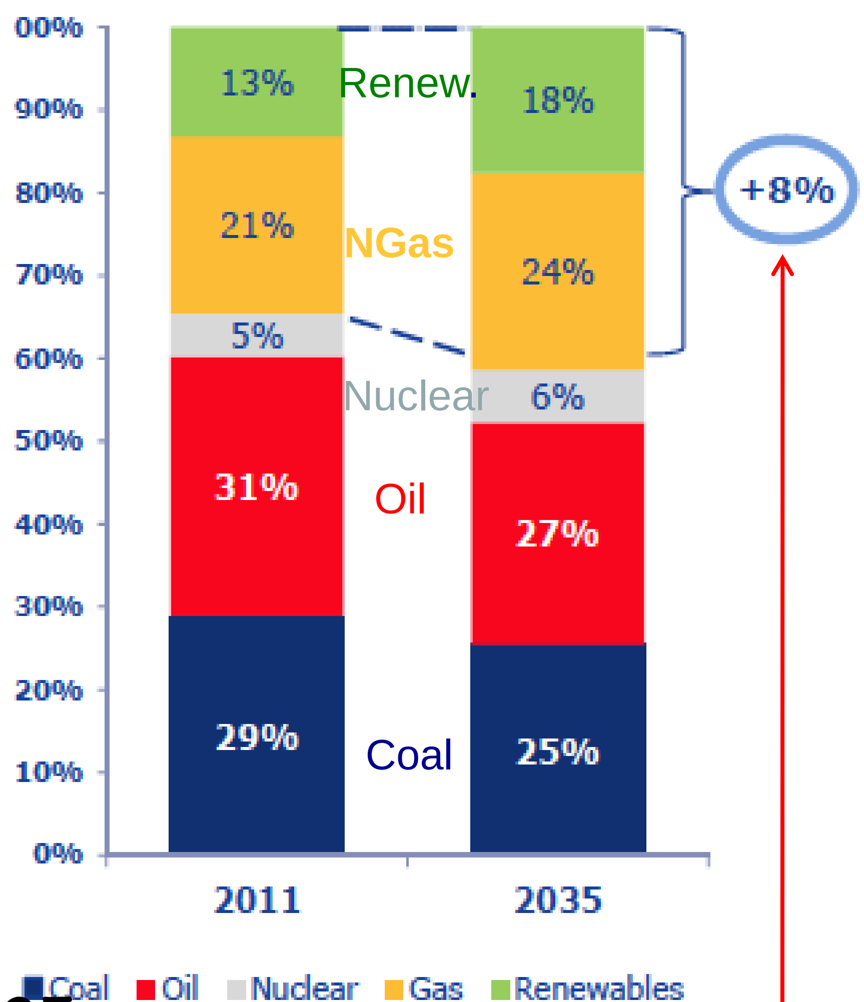
- From about 6 GtC/y in 1995, we are now at 9.5 GtC/y. By 2020 and at the present rate CO2 will reach ≈ 12 GtC/y.

Collapse of CO_2 prices



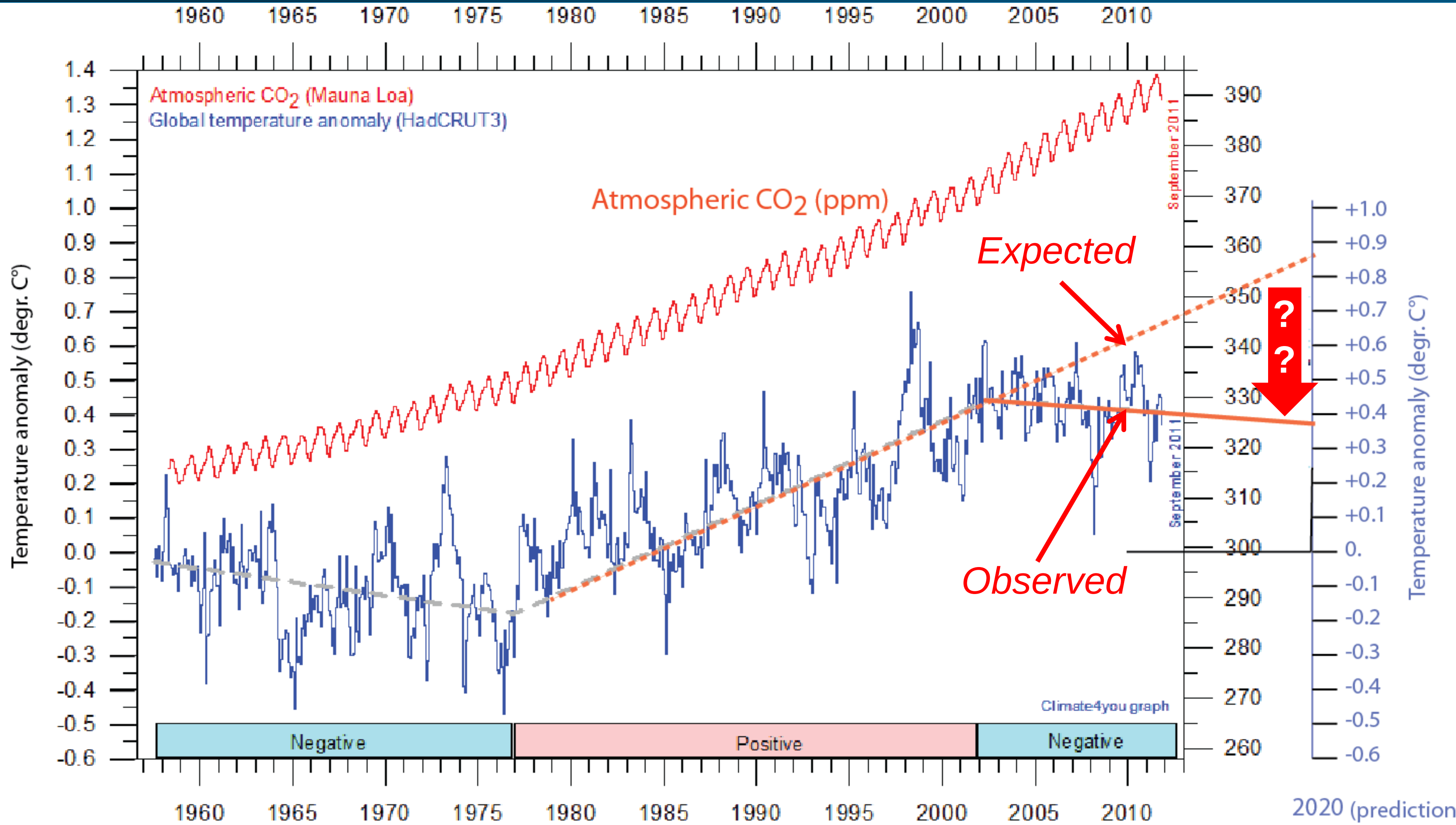
Predicted energy growths during the next 25 years





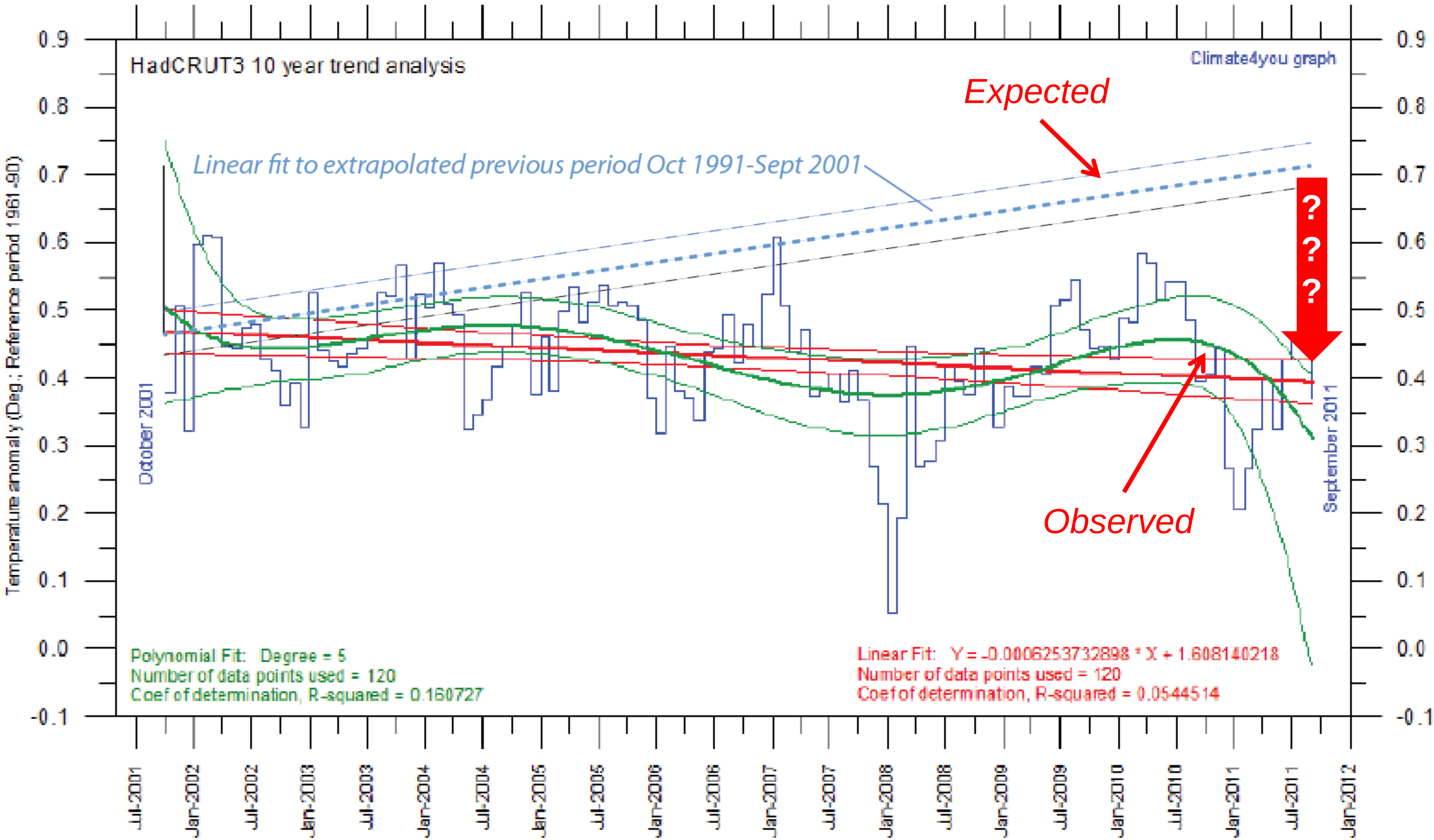
- World wide predicted growths over 25 years
- Continuation of a massive burning of fossils
- Small contribution from renewables (including hydro)

Has the Anthropogenic warming recently slowed down ?

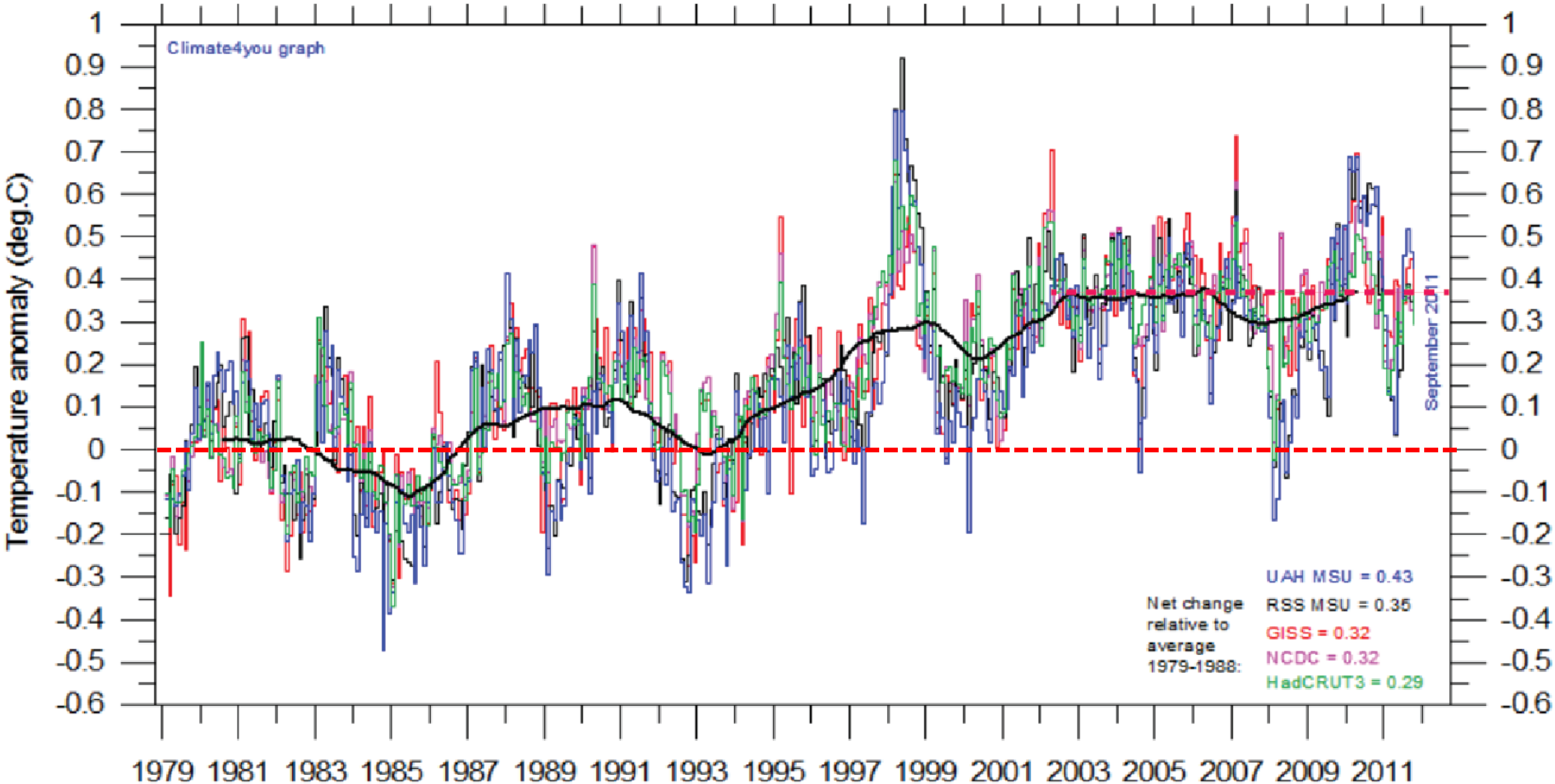


- Average temperature and CO_2 emissions over the last 10 years *show a small temperature drop rather than a significant rise !*

Has the CO2 warming slowed down ? (cont.)



Five independent global estimates



Superimposed plot of all five global monthly temperature estimates shown above. As the base period differs for the different temperature estimates, they have all been normalised by comparing to the average value of their initial 120 months (10 years) from January 1979 to December 1988. The heavy

From the press: a bad news or a good news?

- Hadcrut3 data until Jan 2013. The data show no appreciable change

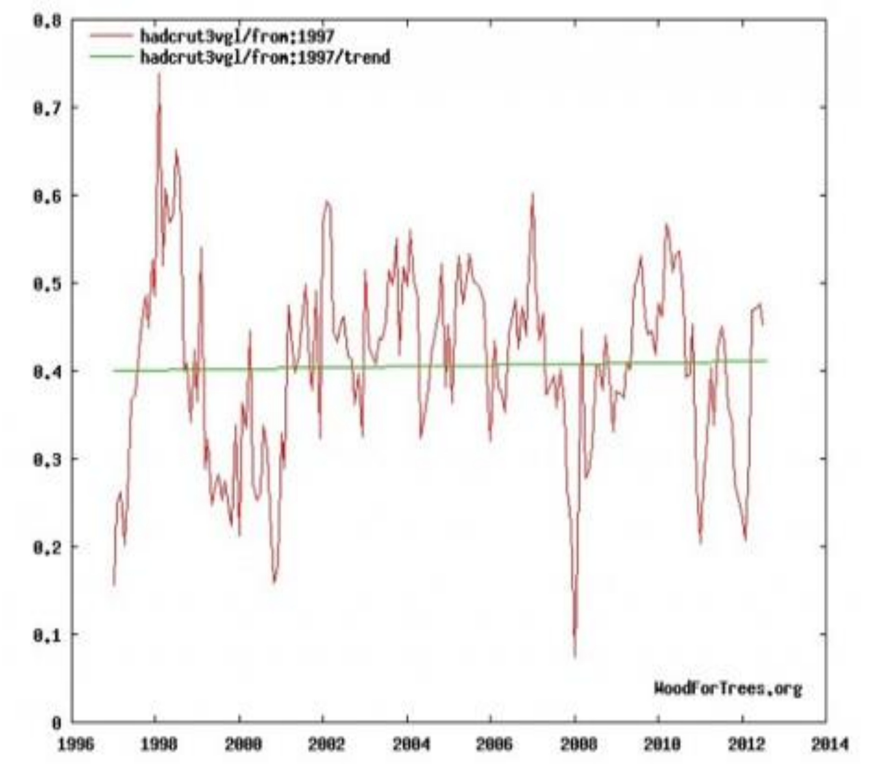
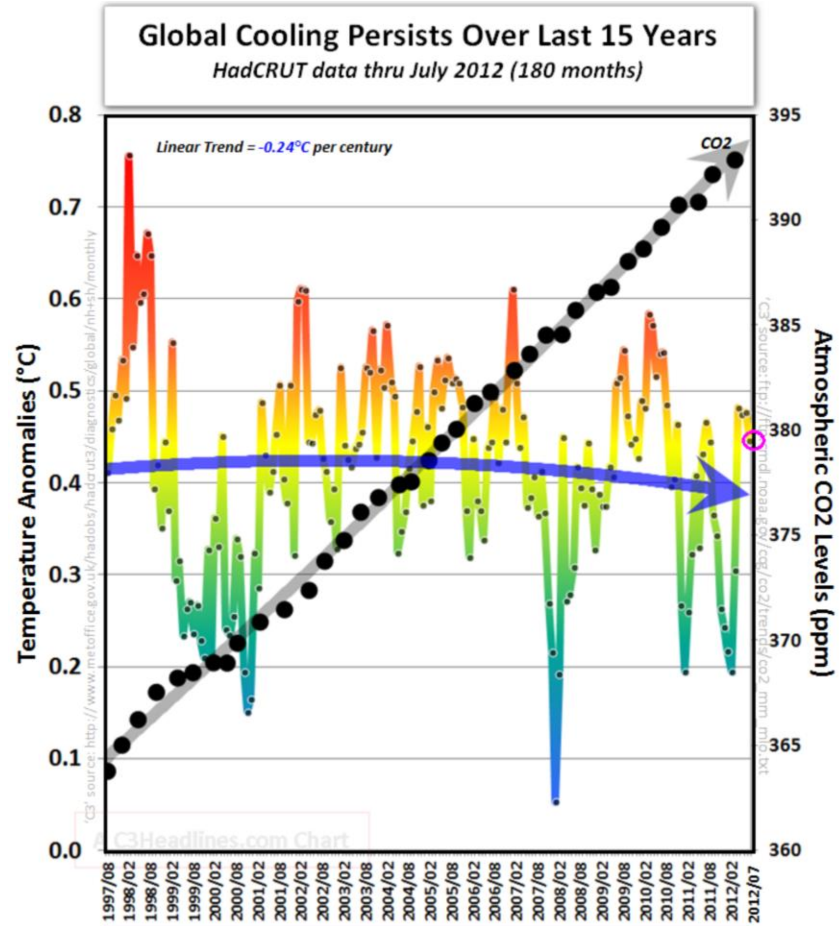
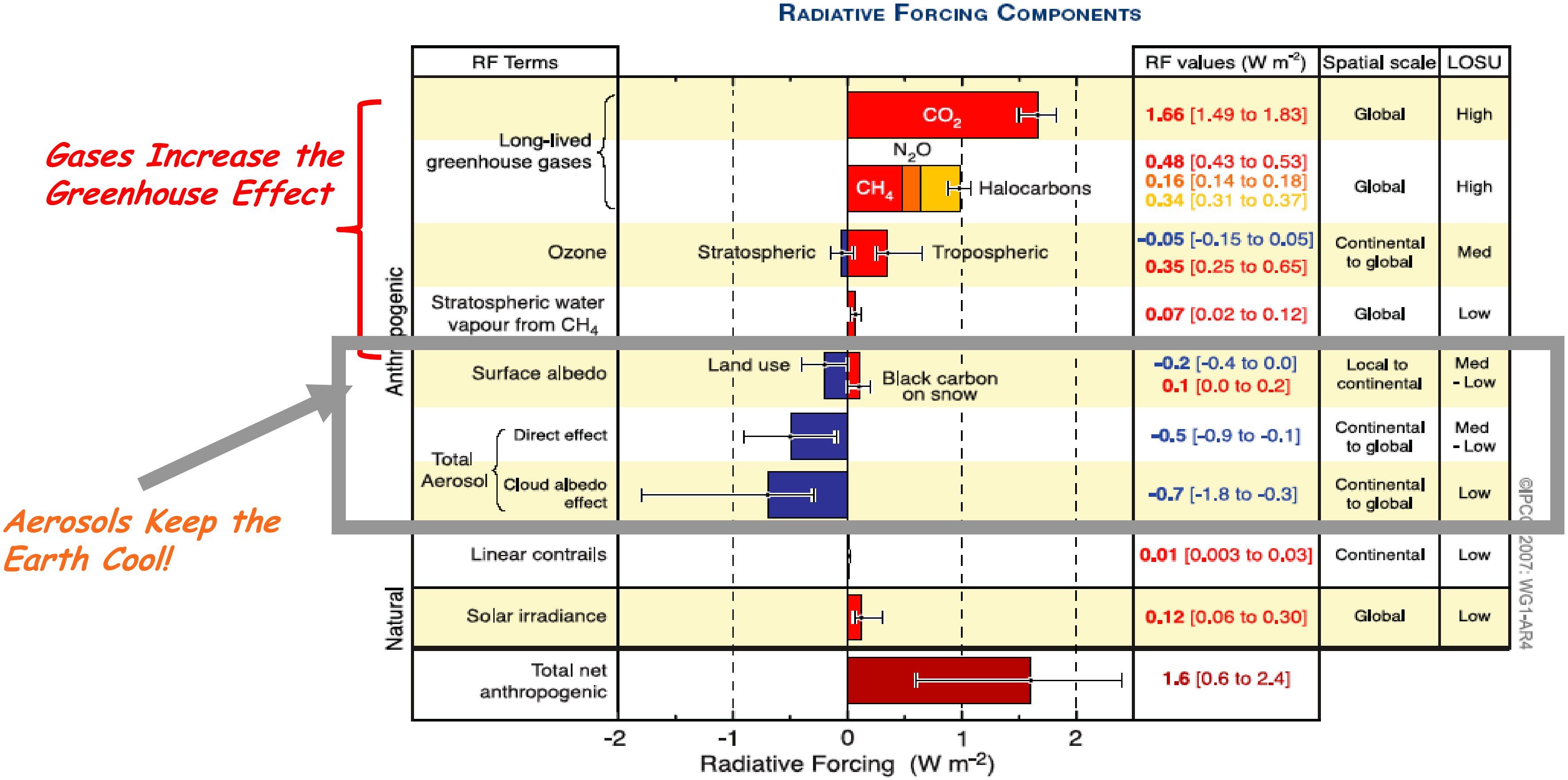


Figure 1: HadCRUT temperature data 1997 until today (red curve). The trend line (green) shows no significant increase. This temperature plateau has now been going on over 16 years. Source: Real Science based on woodfortrees.



HadCRUT global temperature and atmospheric CO2 levels plots over last 180 months. Light blue and grey curves are 2nd order polynomial fits - global warming to cooling. (As of July 31, 2012.)

The apparent climatic stability is misleading ….



- Aerosol particles and other effect cool the Earth and *on a shorter timescale are contrasting with the CO_2 warming*.
- **BUT** this will not last for ever, due to the longer CO_2 lifetime.
- ***Anthropogenic warm-up may be active and hiddenly growing !***

And, in the meantime, the Arctic Sea Ice snow cover !

- Reducing the amount of ice cap increases the surface of the Arctic waters with a consequent increase of ice melting.

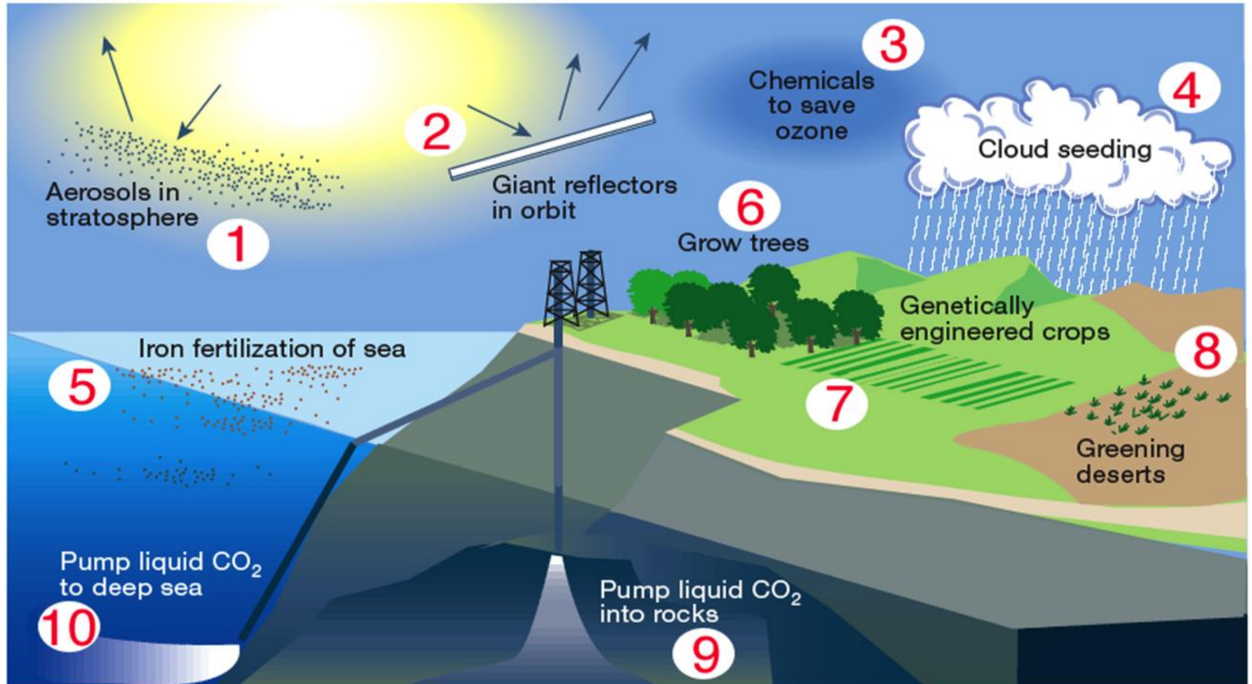
Can Geo-engineering compensate the effects of the fossil emissions ?

1) Carbon capture and sequestration

2) Aerosol stratospheric Cooling

Geo-engineering attempts to compensate CO_2 emissions ?

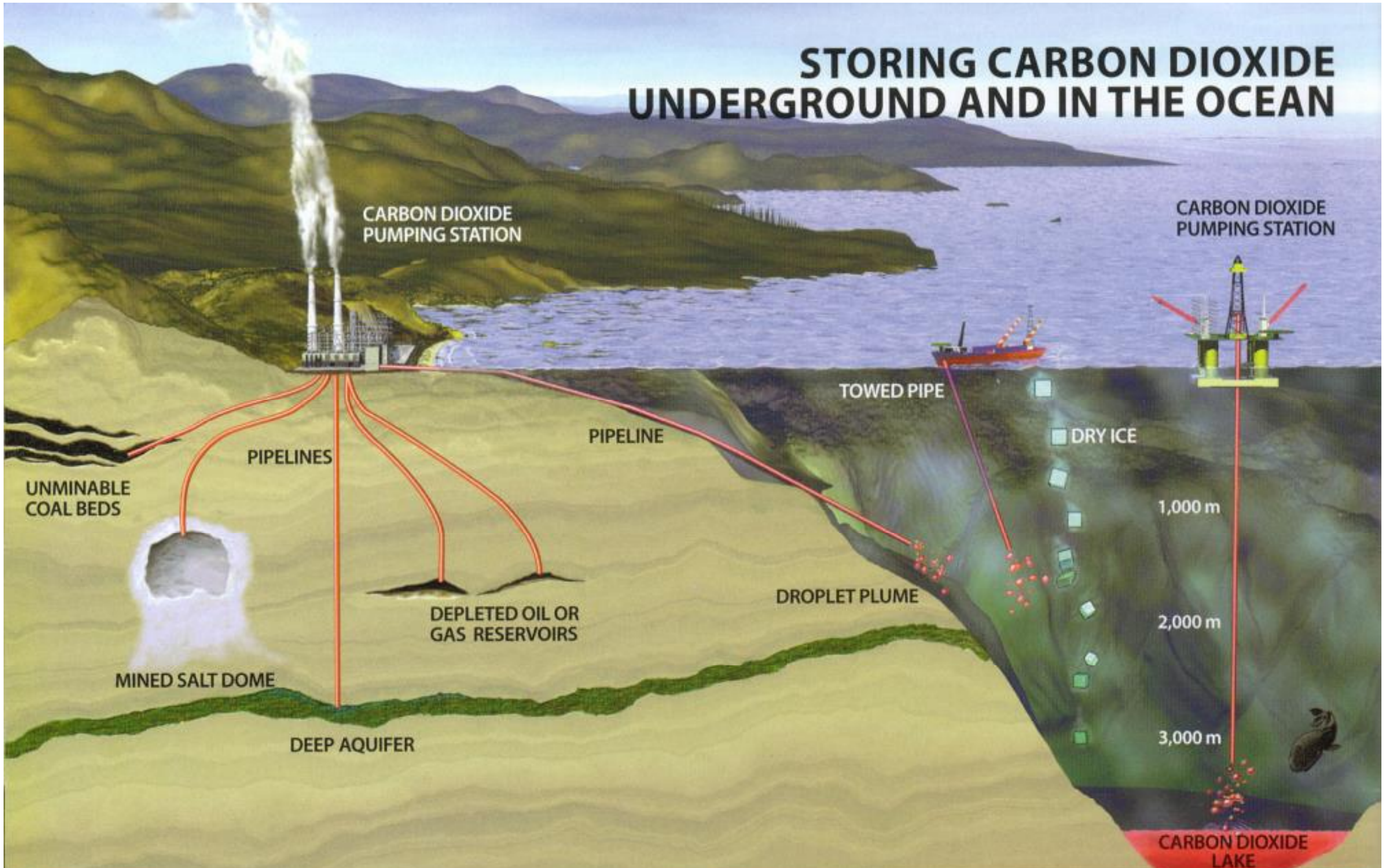
1. *Aerosols in the stratosphere*
2. *Reflectors in orbit*
3. *Ozone preservation with chemicals*
4. *Cloud seeding*
5. *Iron fertilisation of sea*
6. *Grow trees*
7. *Genetically modified crops*
8. *Greening deserts*
9. *Pump liquid CO_2 into rocks*
10. *Pump liquid CO_2 to deep seas*



Schematic representation of various climate-engineering proposals (courtesy B. Matthews).

- Many of these ideas are unrealistic at the first sight, like for instance the proposal for huge reflectors in space (2)
- Notwithstanding they evidence the extreme difficulty in facing the consequences of growing fossil emissions.
- These considerations should foster a serious debate on maybe other, truly innovative ideas on the planetary scale.

: Carbon sequestration and storage [CSS, Herzog 2000] ?



STORAGE UNDERGROUND	ADVANTAGES	DISADVANTAGES	STORAGE IN OCEAN	ADVANTAGES	DISADVANTAGES
Coal Beds	Potentially low costs	Immature technology	Droplet Plume	Minimal environmental effects	Some leakage
Mined Salt Domes	Custom designs	High costs	Towed Pipe	Minimal environmental effects	Some leakage
Deep Saline Aquifers	Large capacity	Unknown storage integrity	Dry Ice	Simple technology	High costs
Depleted Oil or Gas Reservoirs	Proven storage integrity	Limited capacity	Carbon Dioxide Lake	Carbon will remain in ocean for thousands of years	Immature technology

Herzog, H., Eliassou, B., Kaarstad, O.: Capturing Greenhouse Gases, Scientific American vol. 282, No. 2, pp. 72-79, February 2000

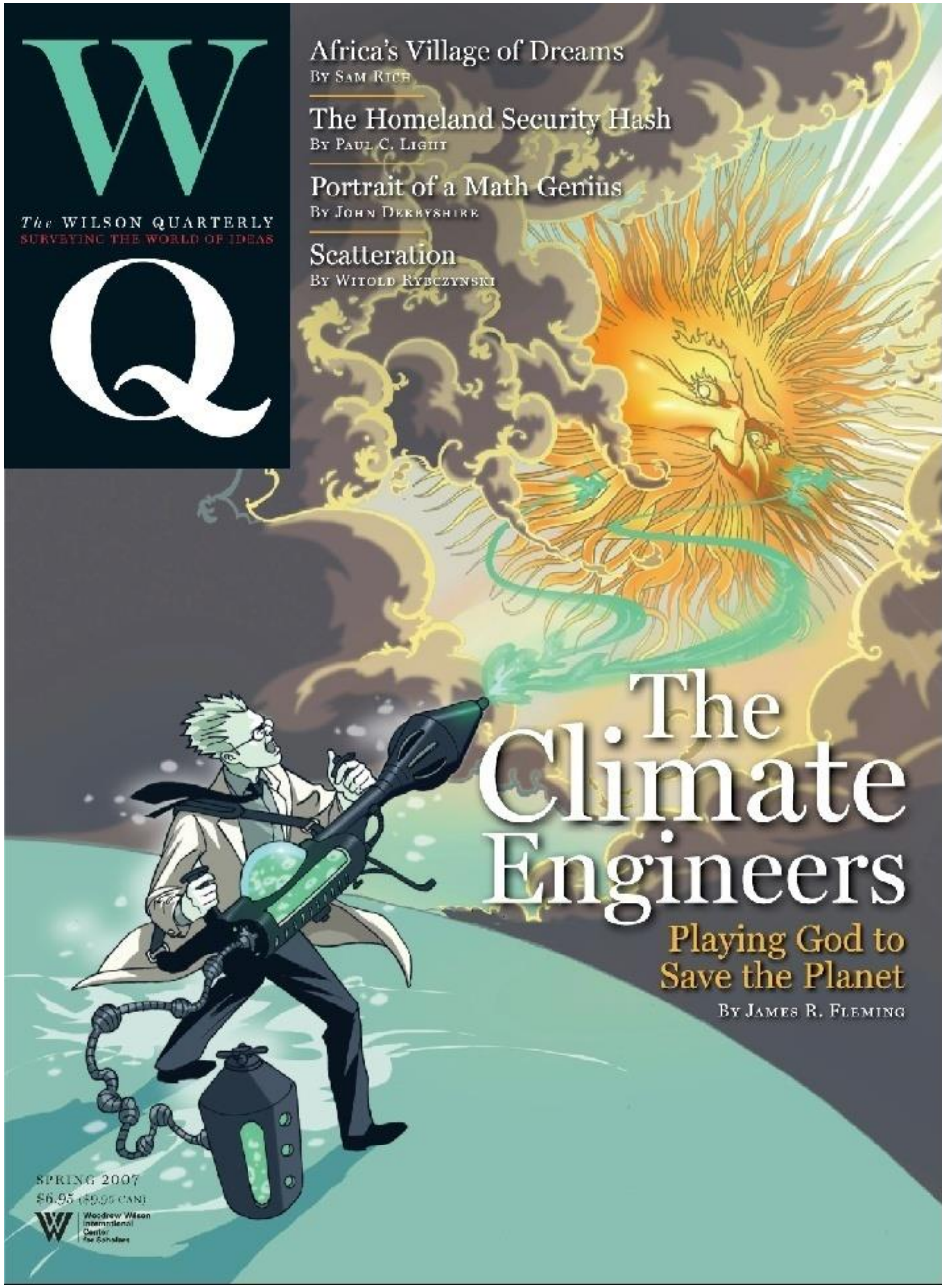
Compensating the effects of fossils: CO_2 sequestration ?

- Much discussion and substantial studies have been going on on the possibility of a substantial CO_2 sequestration underground or under the seas.
- In our view this alternative is unrealistic, since:
  - Its very long lifetime: we need CO_2 wells safely under pressure for >>10^3 years: sequestration is not elimination
  - Only a limited fraction of the collected CO_2 offers the necessary premises to ensure potential recovery. But in order to maintain 550 ppm by 2100 with the option "Business as usual" –according to IPCC– ≈ 2×10^{12} ton must be stored.
  - The additional costs of accumulating, transporting and storing safely away for millenia such a large quantities of CO2 are extremely large and without sufficiently defined profit returns.

Safety considerations

- The degradation processes for the sealed wells and the behaviour over long times are difficult to predict.
- If the likelihood of leaks from a CO_2 reservoir is similar to that of hydrocarbon reservoirs during production, leaks (> 10 t/day) are expected to occur at about 10^{-3} per reservoir year. But we need CO_2 wells safely under pressure for $\gg 10^3$ years .
- The expanded CO_2, if promptly emitted, will be very cold and hence remain close to the surface of the escaping area.
- Although not toxic, above some %, CO_2 act as a powerful brain vein dilatator. In a few minutes, unconsciousness occurs at 15 % of relative concentration and immediate death at 30%. Deaths start being observed already at 9%.
- In 1986, at lake Nyos a volcanic CO_2 leak of 2.4×10^5 ton has killed all 1746 people < 15 km from the source. In order to ensure 550 ppm by 2100 with the option "Business as usual" – according to IPCC– we must accumulate CSS with $\approx 2\times10^{12}$ ton.

Aereosol Cooling ?



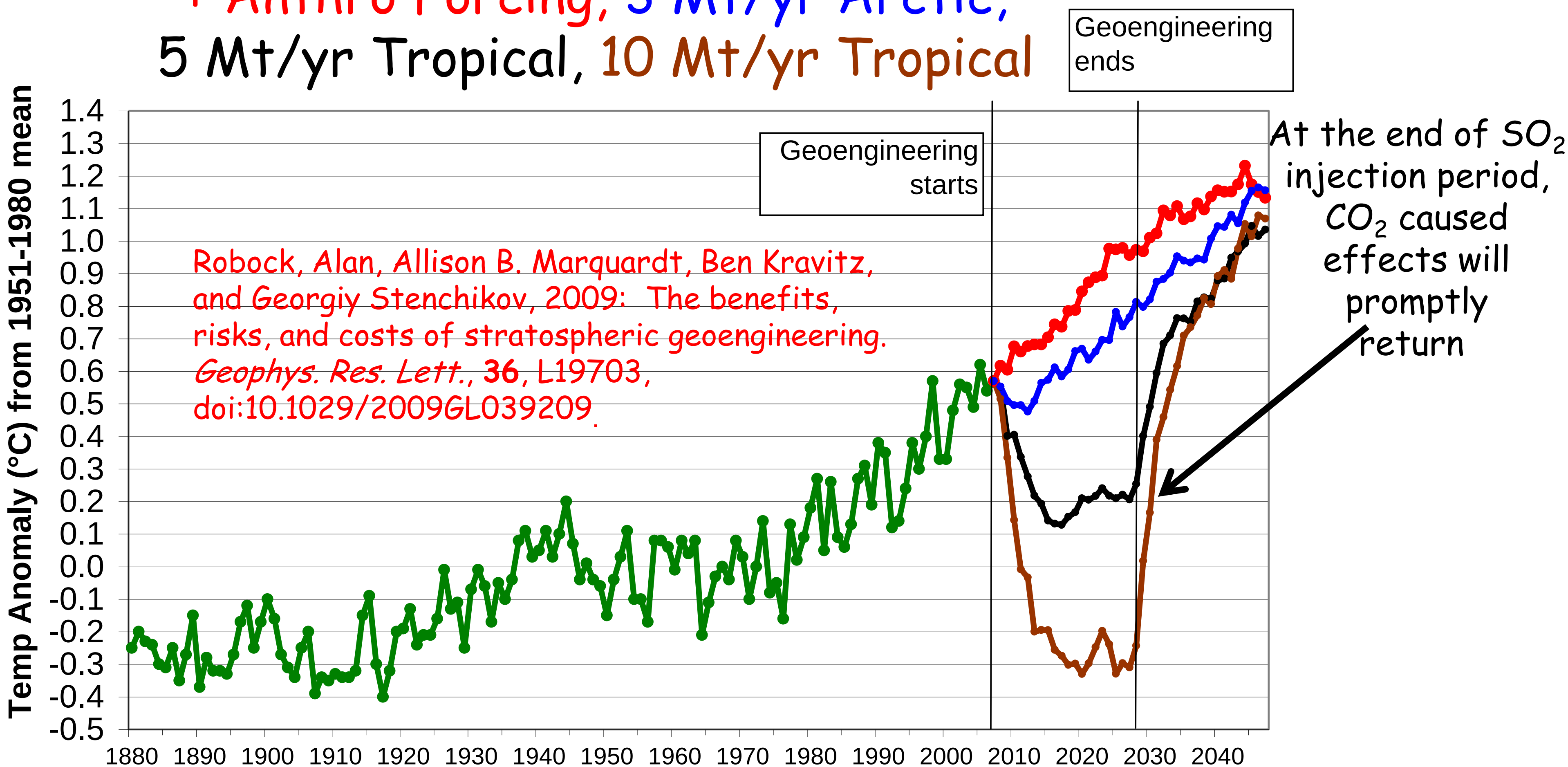
In response to New York Times Op-Ed
"How to Cool the Globe"
by Ken Caldeira, October 24, 2007

Aerosol SO_2 cooling ?

- If there were a way to continuously inject SO_2 *into the lower stratosphere at a level of ≈ 1/1000 of the CO_2 emissions, it would produce a very large, compensatory global cooling.*
- Tropical SO_2 injection would produce sustained cooling over most of the world, with more cooling over continents. Winds will spread them around and produce global cooling, like tropical volcanic eruptions have.
- Arctic SO_2 injection would not just cool the Arctic, where they will keep sea ice from melting, while any negative effects would not affect many people.
- Solar radiation reduction produces larger precipitation response than temperature, as compared to greenhouse gases.
- BUT both tropical and Arctic SO_2 injection might disrupt the Asian and African summer monsoons, reducing precipitation to the food supply for billions of people.

SO2 injections in the stratosphere

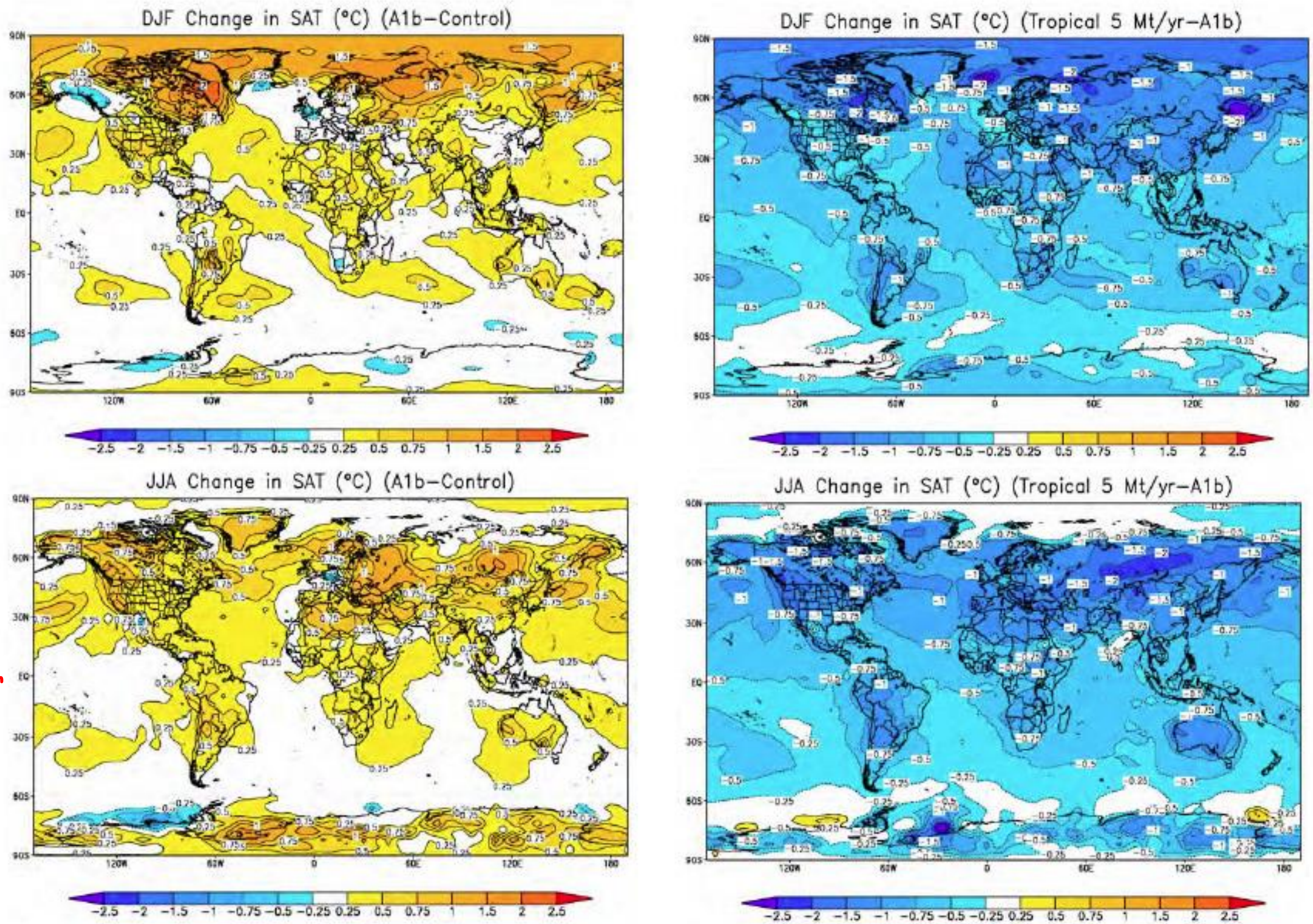
GISS Global Average Temperature Anomaly
+ Anthro Forcing, 3 Mt/yr Arctic, 5 Mt/yr Tropical, 10 Mt/yr Tropical



Aereosol tropical injection after 10 y

NH winter and 5 Mt/y after 10 y

NH summer and 5 Mt/y after 10 y



Without aerosol cooling

With aerosol cooling

Practical way to inject stratospheric aerosols

KC-135 Stratotanker

Ceiling: 15 km

Payload: 91 tons gas

Cost: $39,600,000
(1998 dollars)

http://upload.wikimedia.org/wikipedia/commons/a/a8/Usaf.f15.f16.kc135.750pix.jpg

http://www.af.mil/shared/media/photodb/photos/021202-O-9999G-029.jpg

With 3 flights/day,
operating 250 days/year

would need 15 planes
to deliver 10^6 tons of gas per year
to Arctic stratosphere.

Some dramatic secondary effects of high altitude eruptions

- In the past 2000 years there have been three major high altitude natural eruptions :
  - 939 Eldgjá, Iceland –
  - 1783-84 Lakagígar (Laki), Iceland (14.7 km^3 of lava)
  - 1912 Novarupta (Katmai), Alaska

***M. C-F. Volney**, Travels through Syria and Egypt, in the years1783, 1784, and 1785, Vol. I*, Dublin, 258 pp. (1788)

- *" The inundation of 1783 was not sufficient in Egypt. In 1784, the Nile again did not rise, and the dearth became excessive. The famine carried off, at Cairo, nearly as many as the plague; the streets, before full of beggars, now afforded not a single one: all had perished or deserted the city." By January 1785, 1/6 of the population of Egypt either died or left the country".*
- The beginning of the French revolution was strongly influenced by the famine related to the Laki eruption.
- Famine devastated India as the monsoon failed in summer 1783
- There was also the Great Famine in Japan in 1783-1787, which was locally exacerbated by the Mount Asama eruption of 1783.

Socio-economic considerations

- Volcanic eruptions inject mostly SO_2 but it is preferable to produce H_2S which would oxidize and form H_2SO_4 droplets with water. However, H_2S is toxic and flammable.
- Using airplanes would not be costly, especially with existing military planes, but there are still questions about whether desirable aerosols could be created. No means have been studied so far on how to inject aerosol precursors (gases).
- Crude estimates show it would cost a few billion dollars to build a system, cost a few billion dollars per year to operate and take less than a decade to implement.
- Schemes perceived to work will lessen the incentive to mitigate greenhouse gas emissions.
- Even if it works, whose hand will be on the thermostat? How could the world agree on an optimal climate?
- Who has the moral right to advertently modify the global climate ?

The role and the limits of Renewable Energies

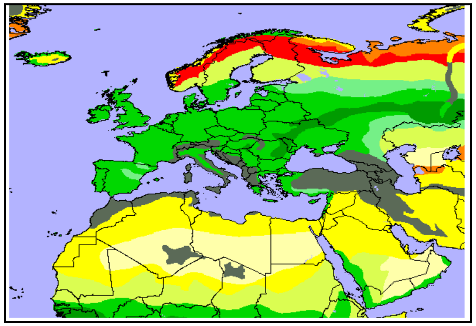
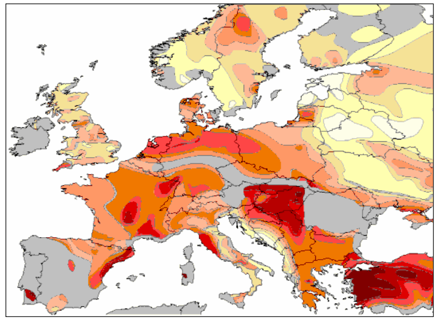
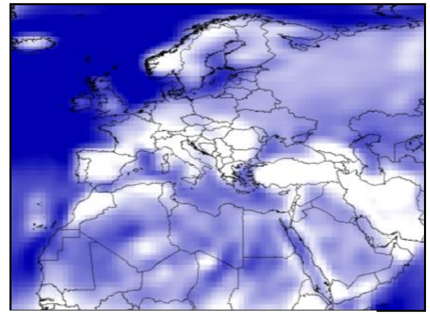
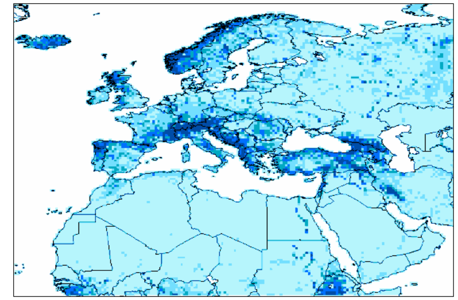
Renewable energies: how quickly may they grow?

- 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

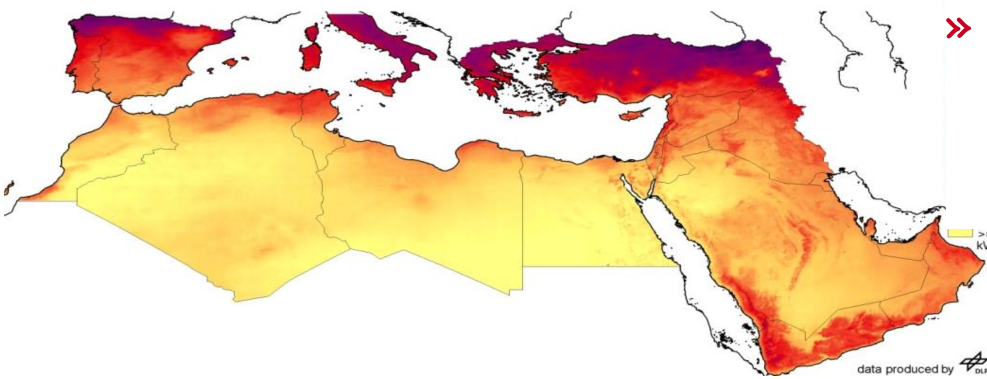
$\approx 1\ GWh_{el}/km^2/y$	$\approx 1\ GWh_{el}/km^2/y$	$\approx 30\ GWh_{el}/km^2/y$	$\approx 30\ GWh_{el}/km^2/y$

$890\ TWh_{el}/y$	$750\ TWh_{el}/y$	$1700\ TWh_{el}/y$	$1090\ TWh_{el}/y$

Economic potentials

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



Economic potentials > $600\ 000\ TWh_{el}/y$

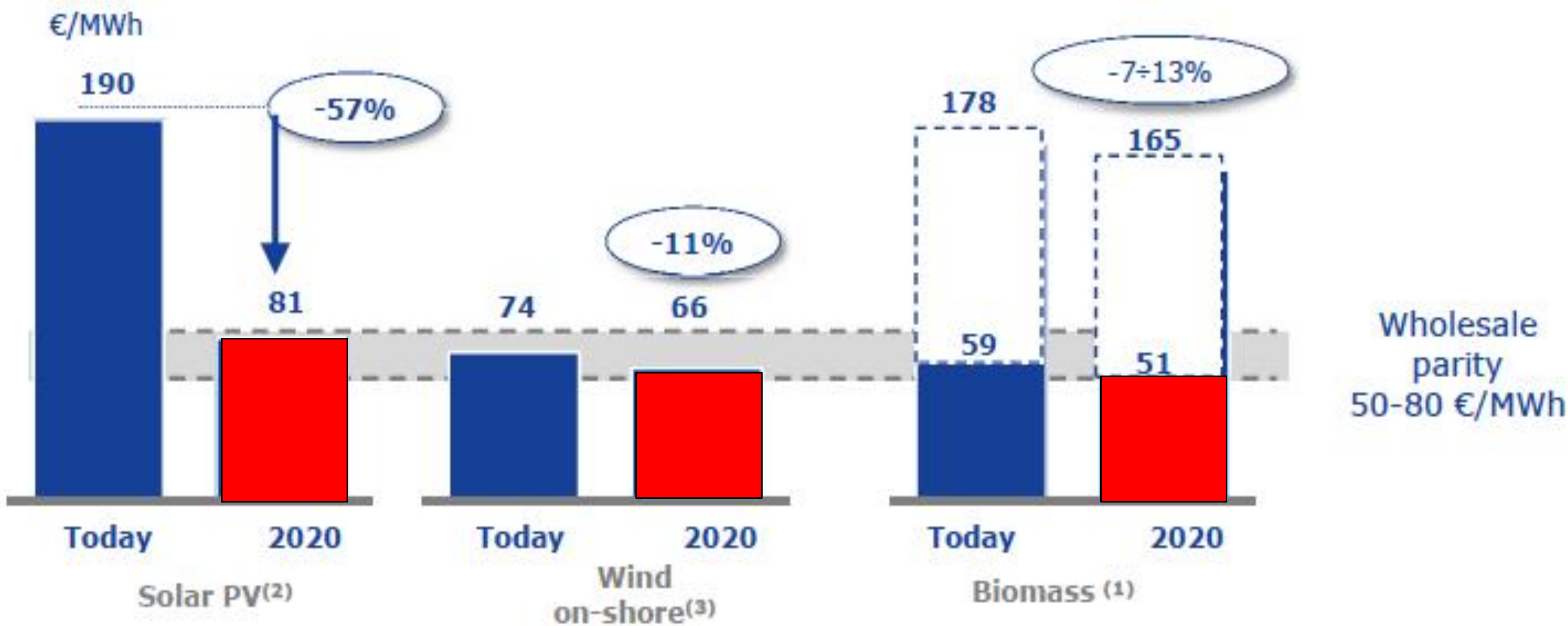
Demand of electric power:

» 7 500 TWh/y Europe + Desert 2050

» 35 000 TWh/y world-wide 2050

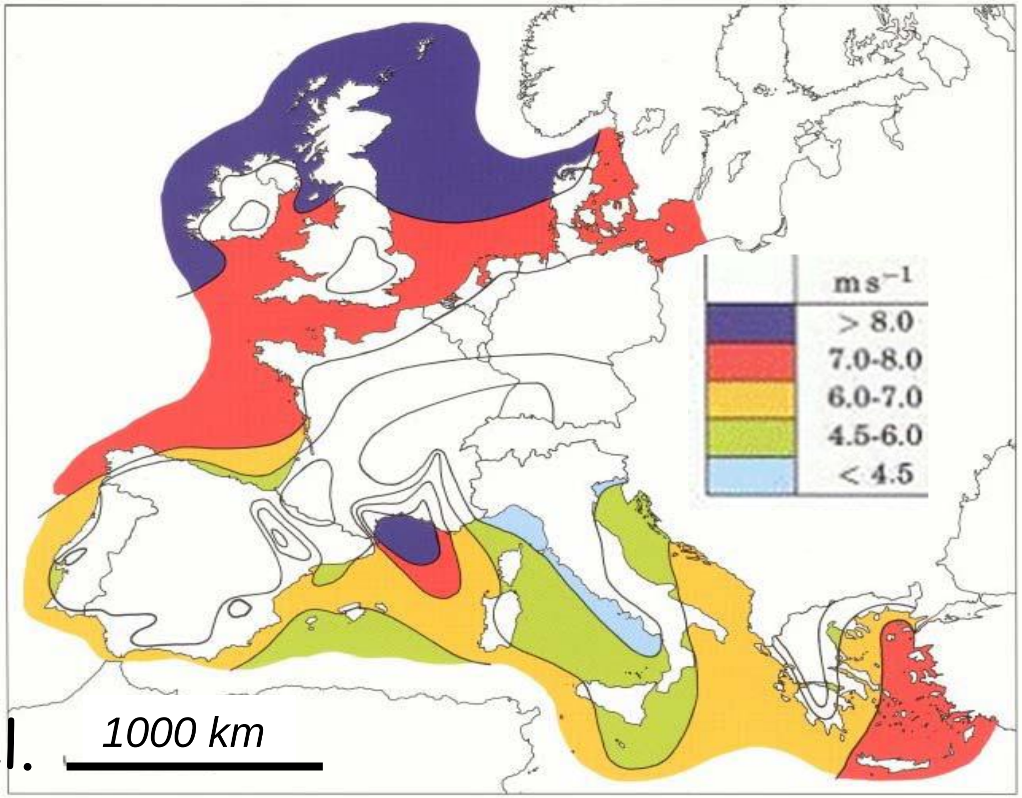
Gerhard Knies, ISES-Rome CSP WS 2007

Paths to innovation and renewable energies



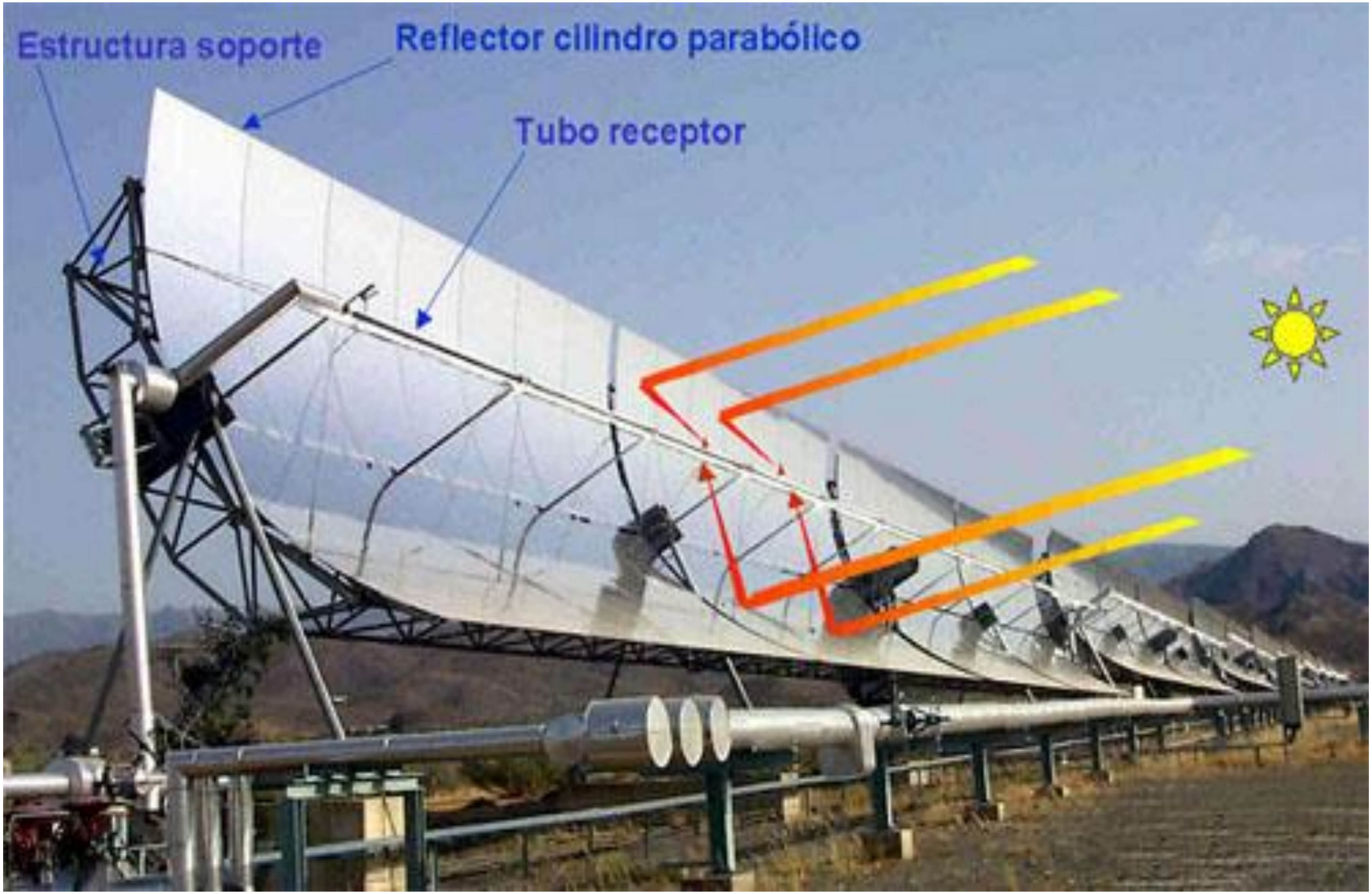
A new role of renewable energies in Europe: wind

- In line with the commitments taken by the Member States for 2020 and beyond, wind energy will indeed become the most prominent renewable resource to be used in Europe to contribute to GHG emission abatement.
- A fair share of this wind capacity will be growingly installed offshore for several reasons*: higher resource level, lack of promising sites onshore and growing public opposition against future onshore wind parks.*
- Transmission lines will need major innovations in order to keep costs at a manageable level.

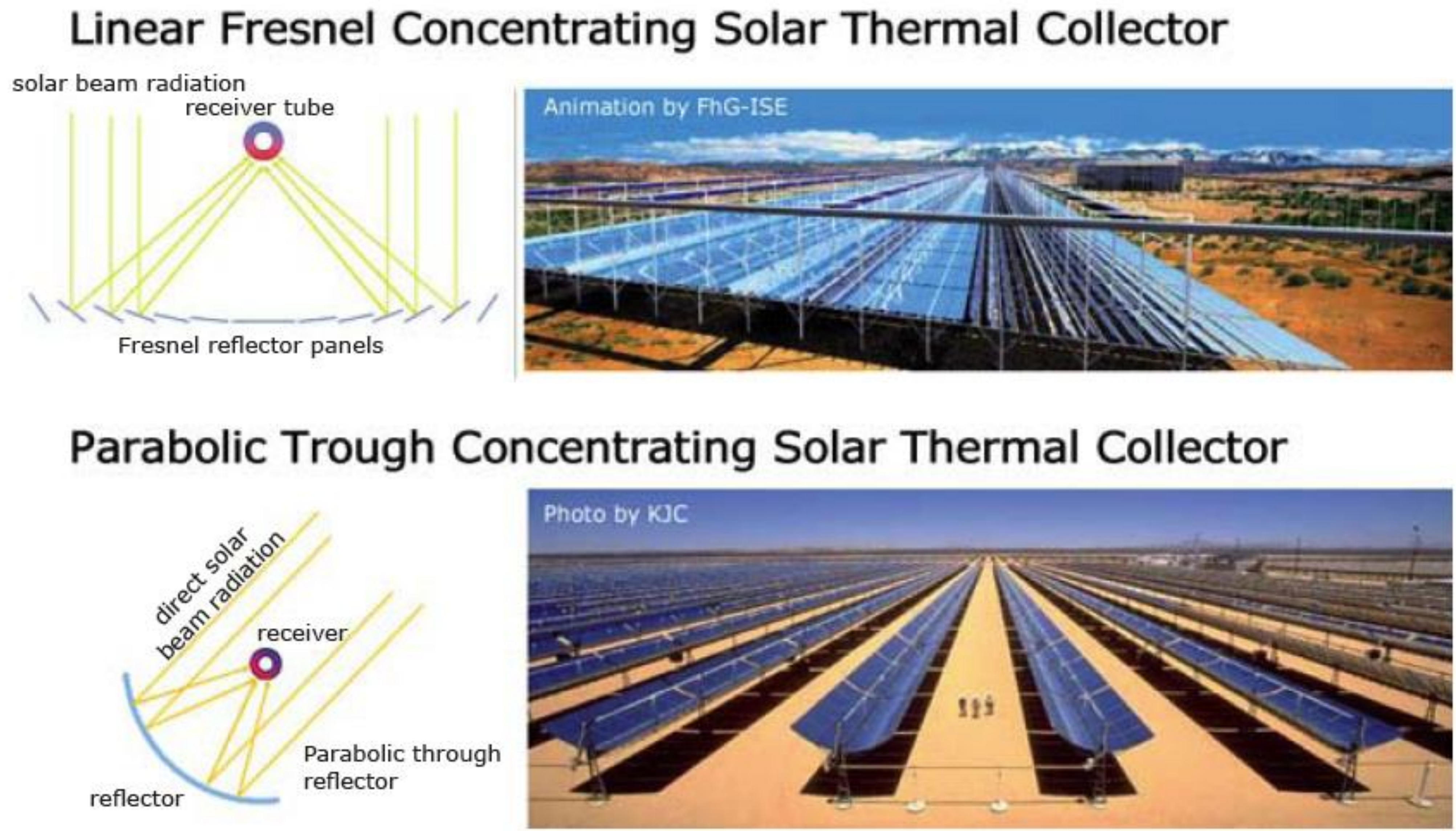


Average wind speed in European open seas (at a 10m height). Source: Ocean Grids around Europe - Frederik Groeman, Natalia Moldovan & Peter Vaessen - KEMA - November 2008.

Principle of modern CSP

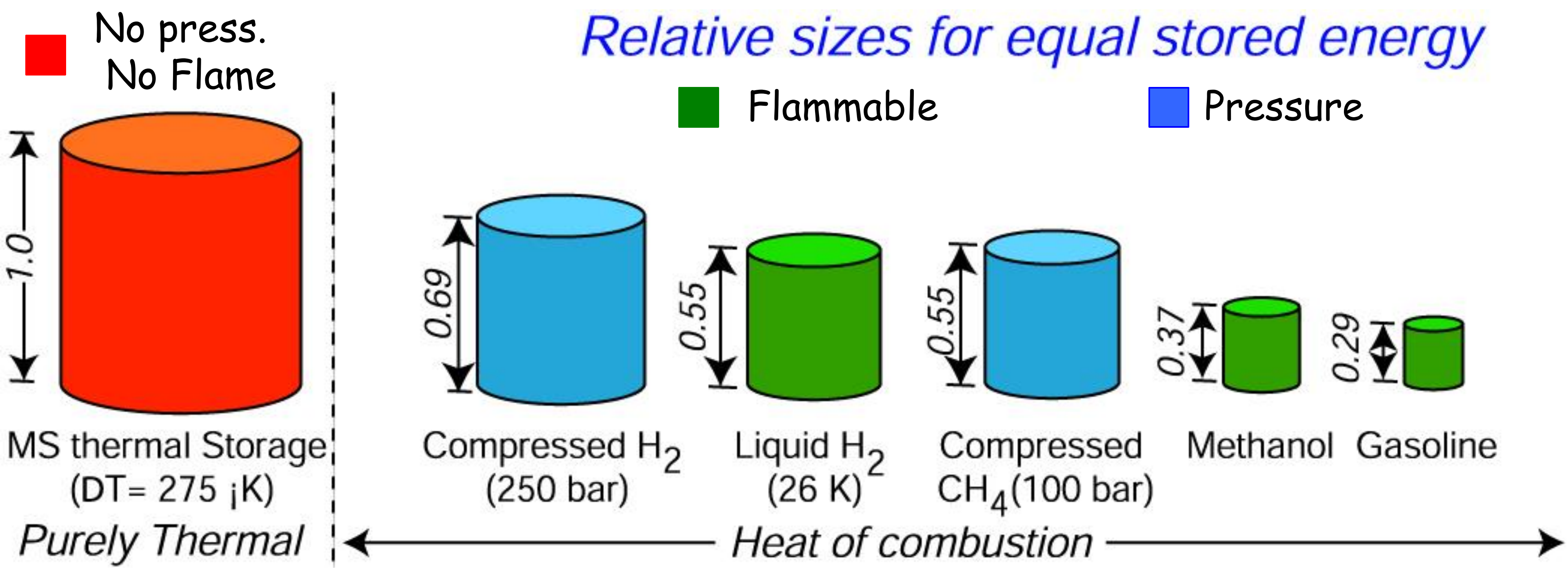


Fresnel lens vs parabolic through ?



The thermal storage of energy from a CSP

- Indeed any primary main form of energy, in order to be realistically capable to counteract fossils and their emissions must be available *whenever it is needed by the user and not according to the variability of the source*.
- It is possible to insure the continuity of utilisation of CSP plant with the addition of a thermal liquid storage, in the form of a cheap molten salt.



Comparing to Hydro: Thermal storage efficiency per unit mass is equivalent to a gravitational water drop height of 72.68 km!

Key problems of renewable energies

- *The best energy is always the cheapest energy*: the cost of renewables must be strongly reduced in order to ensure its cost competitivity with fossils and nuclear.
- *Energy must be available when it is needed:* the variability of solar, wind must be curbed with the help of an energy storage.
- *Renewable energies are mostly generating electricity*, when compared with fossils which produce thermal heat.
- There is an important difference between total energy/p which should be reduced and of electricity/p which will be increasing.
- Renewable energies require much *wider surfaces of collection* located in specific locations in which production is optimal.
- Electricity and very high powers (GWatt) must be *transported and over much longer distances* than today, comparables to the ones possible today for NG and oil.

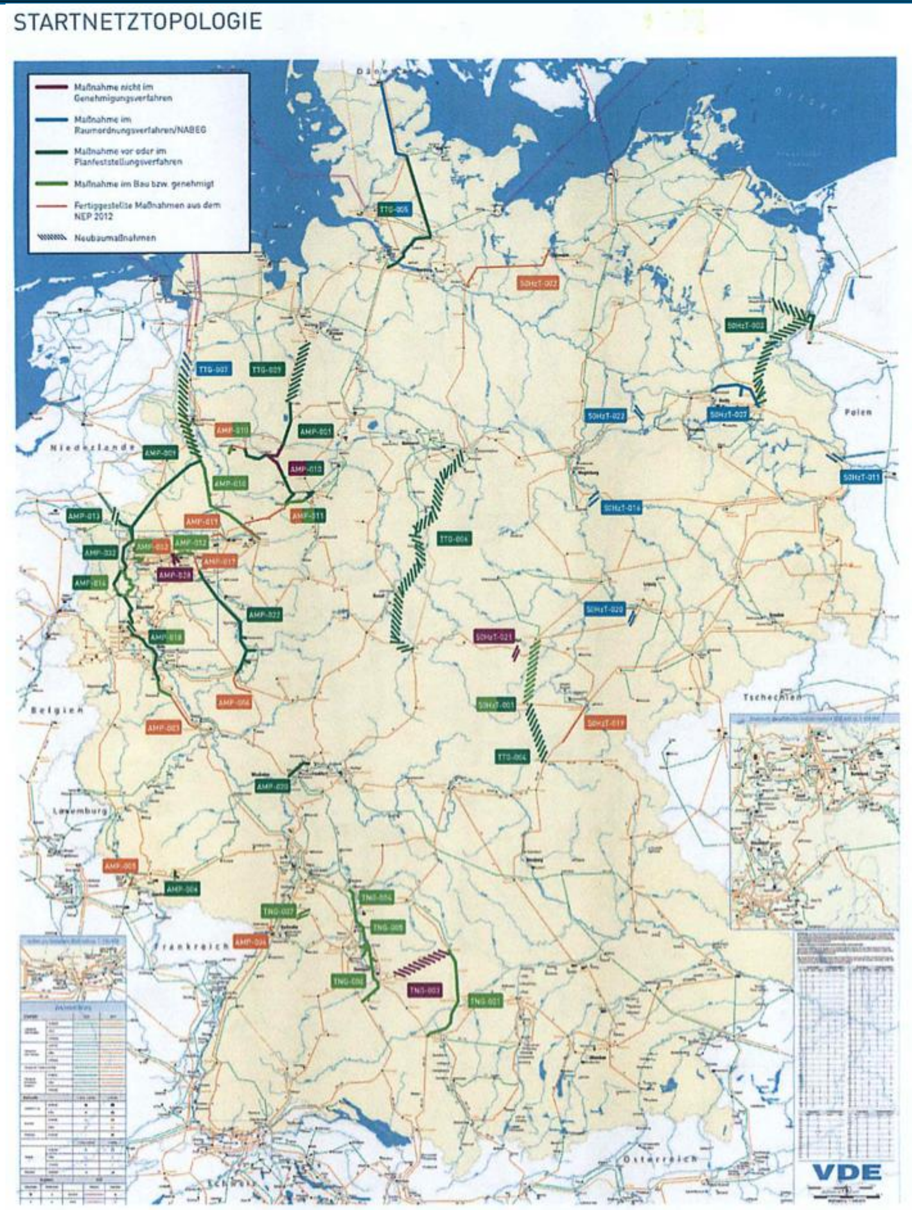
Some novel methods to curb the emissions under study at IASS

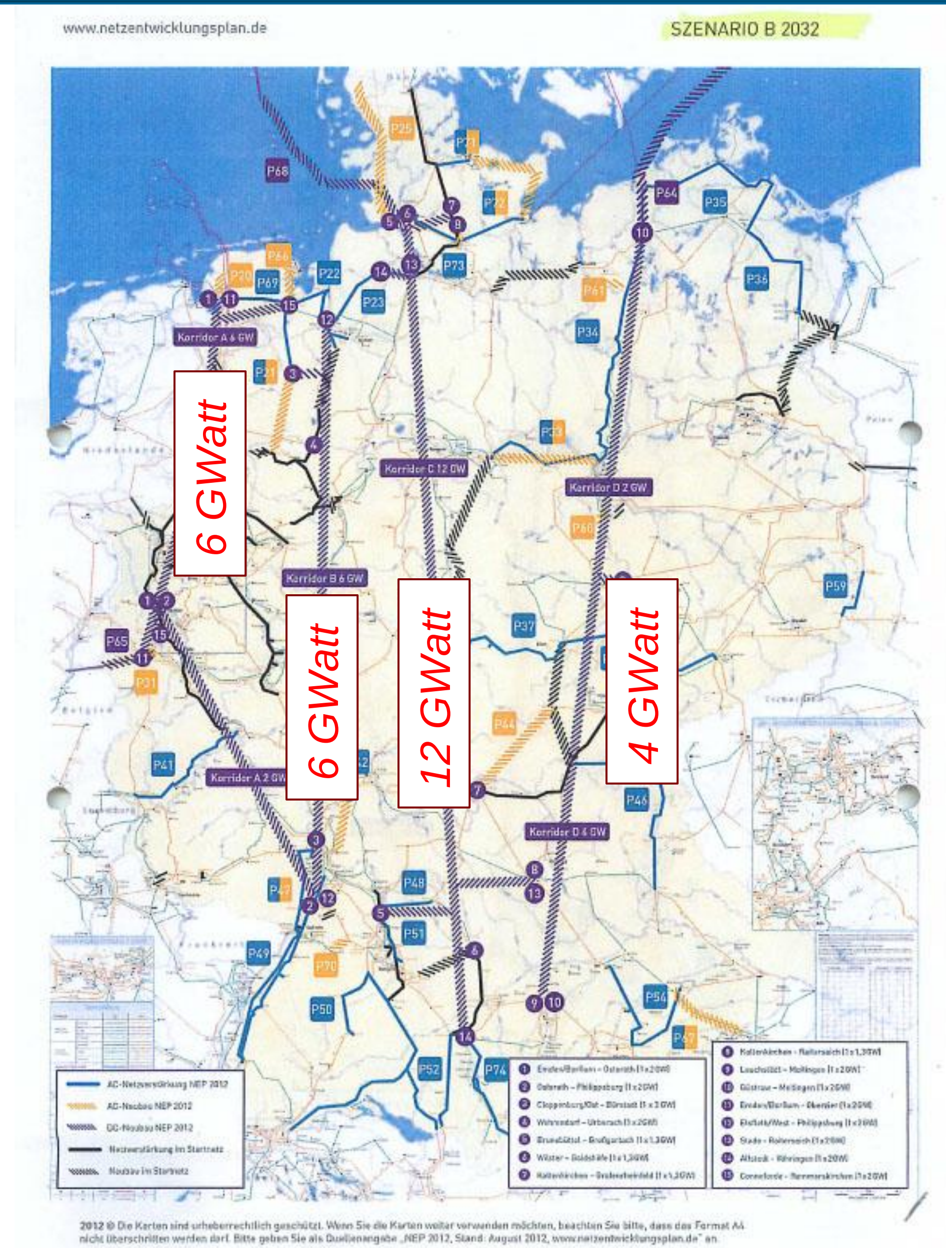
1) Superconducting electricity transmission
2) Unconventional Natural Gas sources
3) Natural Gas with no CO2 emissions
4) Fossil Methanol for transportation

1.-Long-distance energy transport

- Remote renewable energy sources require an efficient transfer of electrical energy over long distances.
- High power lines may have lengths of more than 4000 km

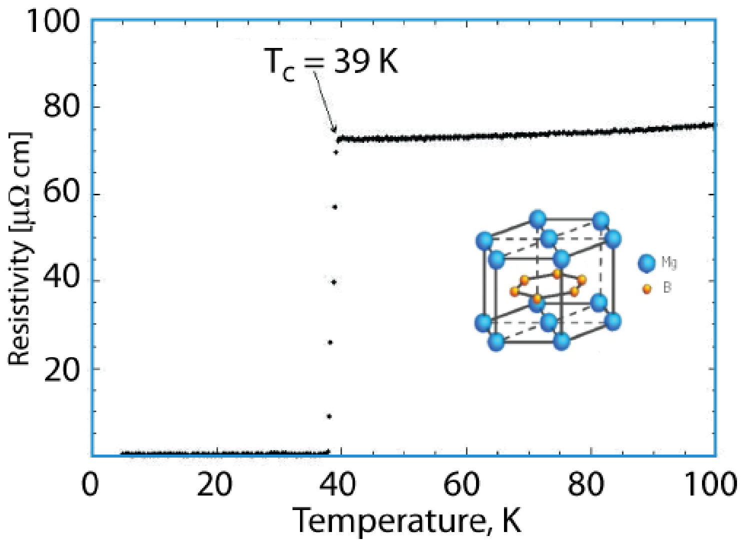
Evolution of German electricity system

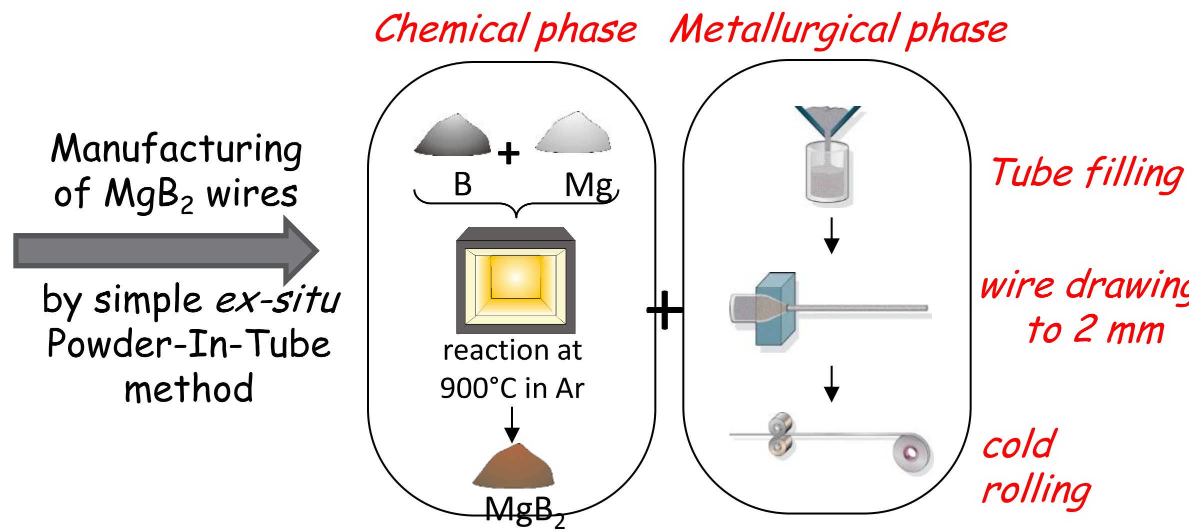




The new choice in long power lines:MgB_2

- In January 2001 superconductivity was announced of a simple new compound, the Magnesium Diboride, MgB_2.
- MgB_2 is under development and relatively small quantities of cable have been manufactured so far at the laboratory scale.





- An extremely simple method of producing the cheap chemicals and of drawing the wire, in analogy with Nb-Ti.
- Wire unit length today up to 20 Km in a single piece, easily scalable by increasing billet size/length.
- Conductor cost at 20K, 1T:now 1.5 €/kAm; in 3 y 0.5 €/kAm

Long-distance transport with superconducting electric line

MgB_2 Cable Design

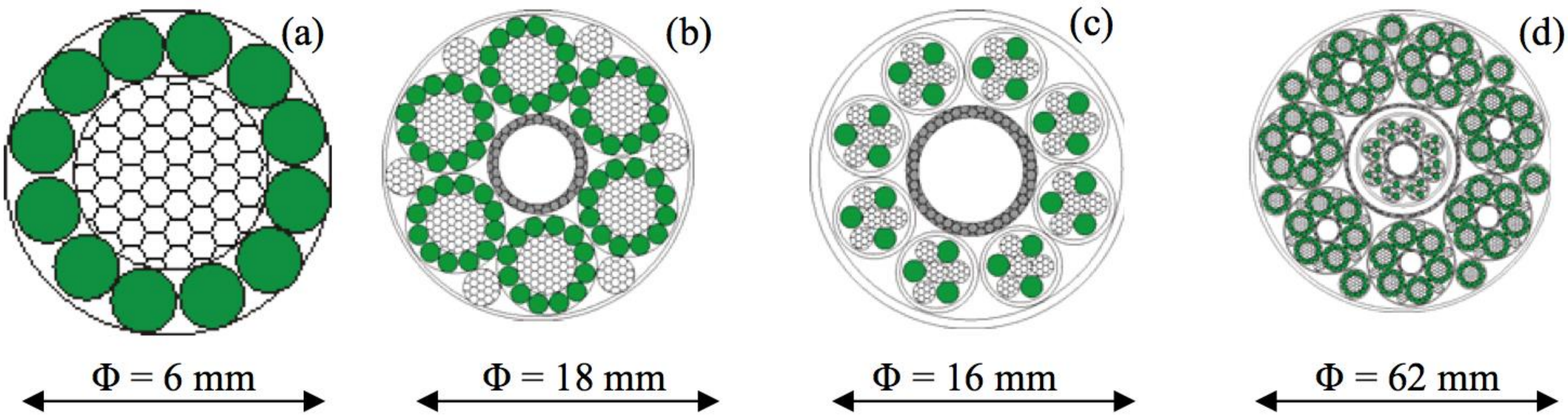


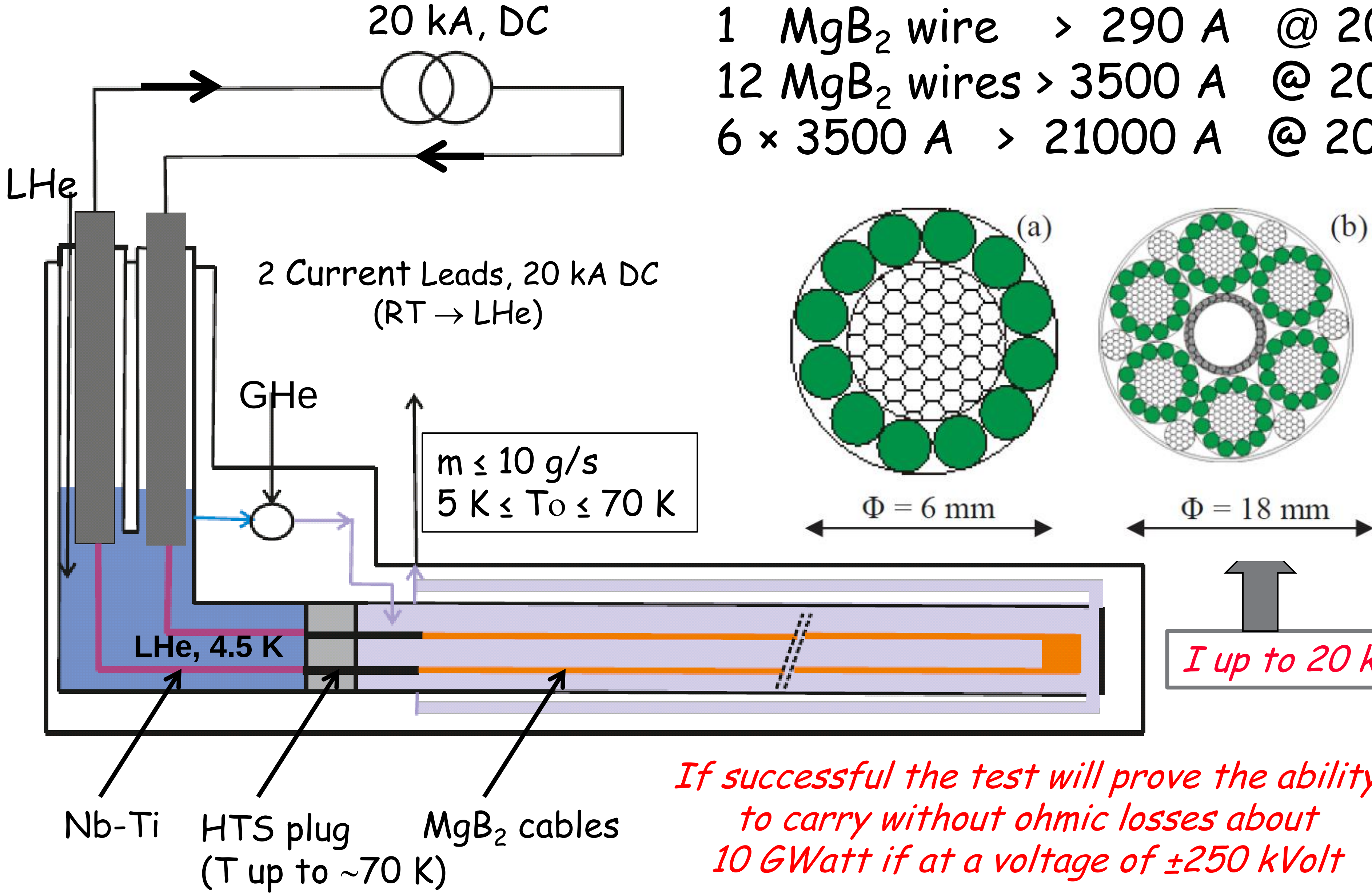
Figure 1. Layout of: 3 kA cable (a), 14 kA cable (b), group of 8 × 0.6 kA cables (c), configuration of 7 × 14 kA, 7 × 3 kA and 8 × 0.6 kA cables (d). The MgB_2 is shown solid, the copper is shown hatched.

1 Sub-cable → 12 MgB_2 wires
I_c (16 K) ~ 5100 A

6 Cables
I_c (16 K) ~ 21000 A

Conceptual design of the 20 m tube with MgB_2 cable

1 MgB_2 wire > 290 A @ 20 K
12 MgB_2 wires > 3500 A @ 20 K
6 × 3500 A > 21000 A @ 20 K

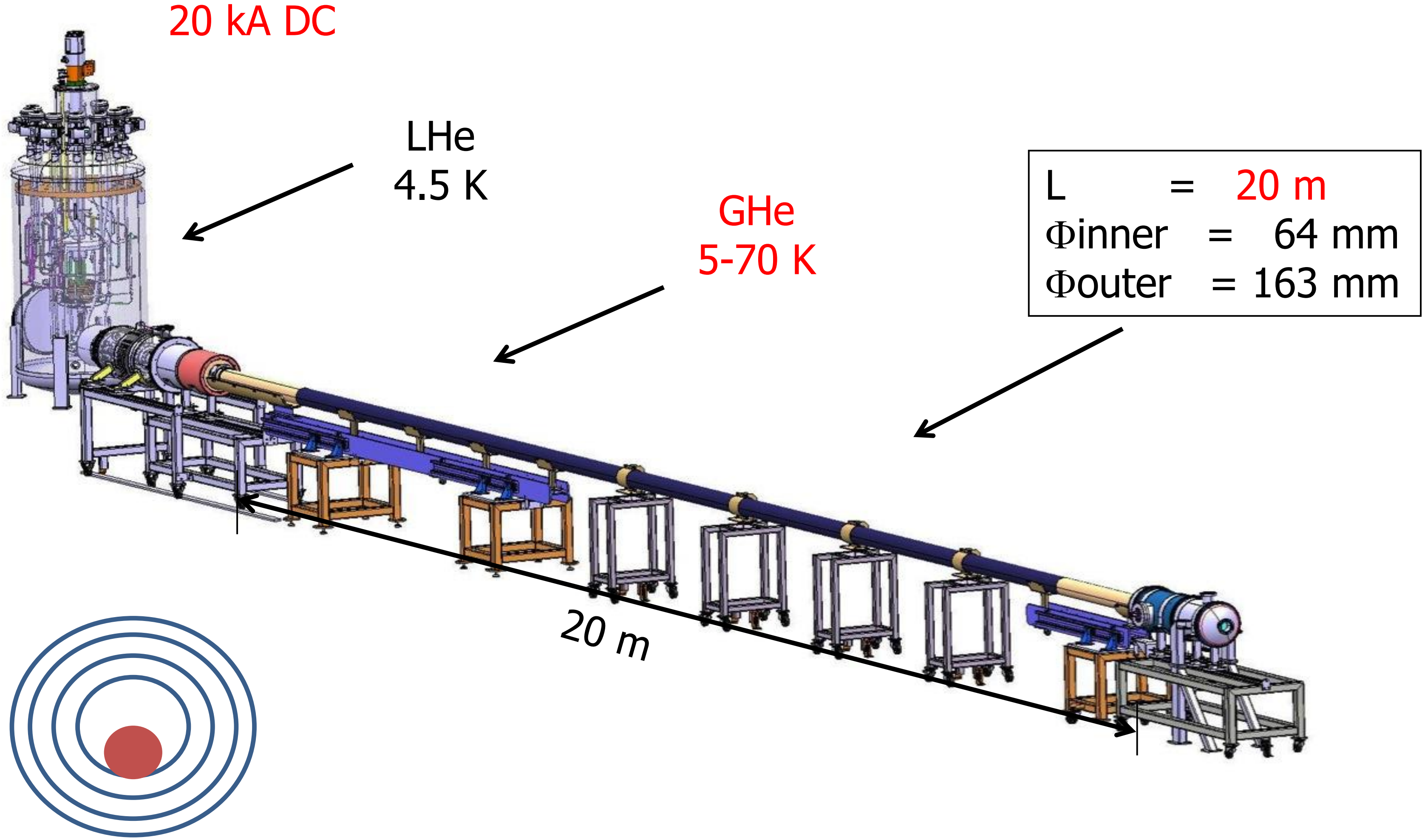


I up to 20 kA

If successful the test will prove the ability to carry without ohmic losses about 10 GWatt if at a voltage of ±250 kVolt

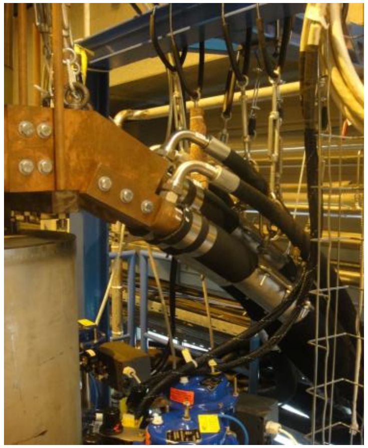
Long-distance transport through superconducting electric line

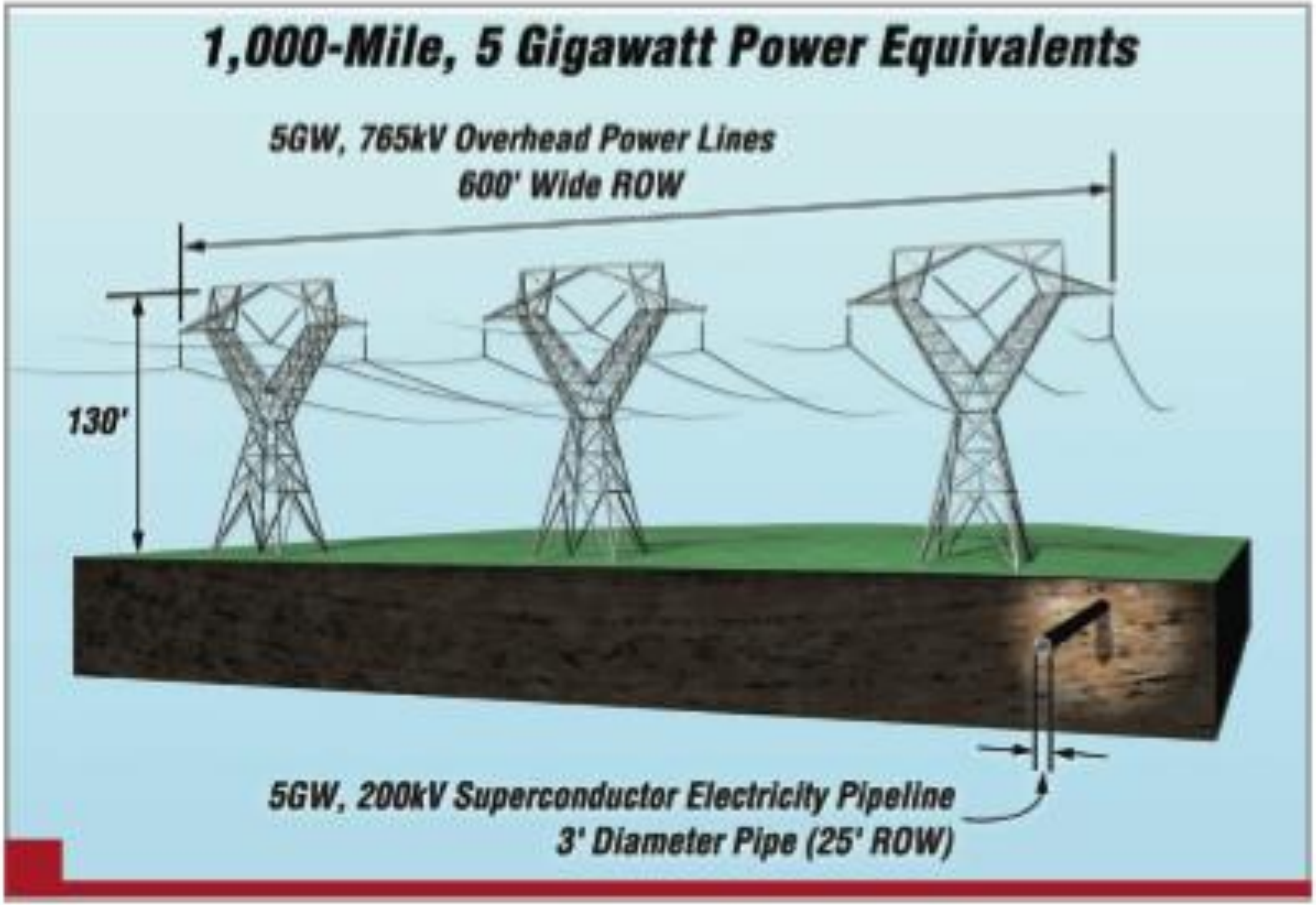
CERN SC Test Station (20 kA, 5-70 K)



MgB_2 powerline programme IASS/CERN

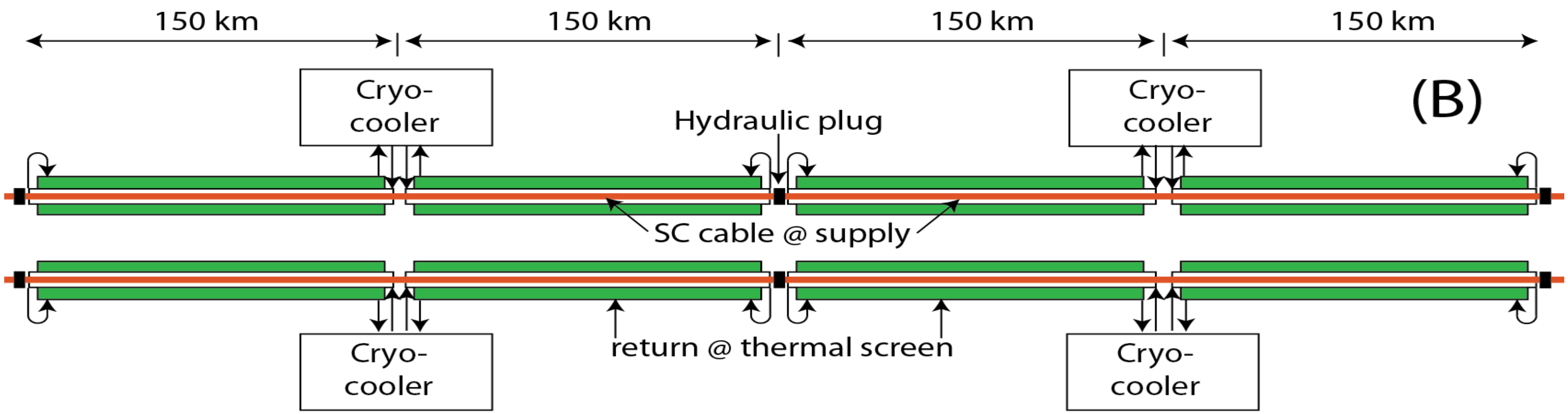
Presently fully operational and collecting data

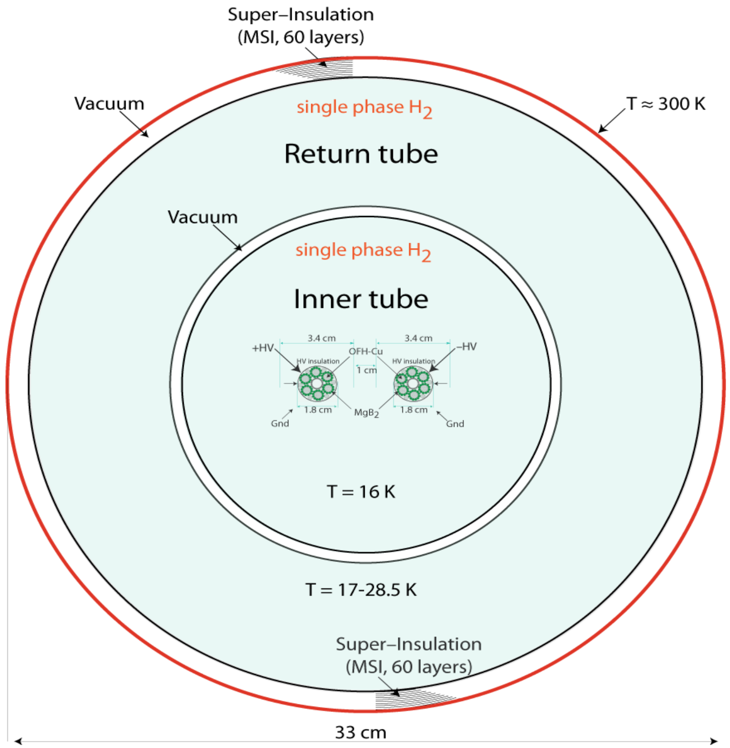



1,000-Mile, 5 Gigawatt Power Equivalents
5GW, 765kV Overhead Power Lines
600' Wide ROW
130'
5GW, 200kV Superconductor Electricity Pipeline
3' Diameter Pipe (25' ROW)

Cooling and electric concept for MgB_2 Transmission Line

I = 20 kA
V = ±125 kV



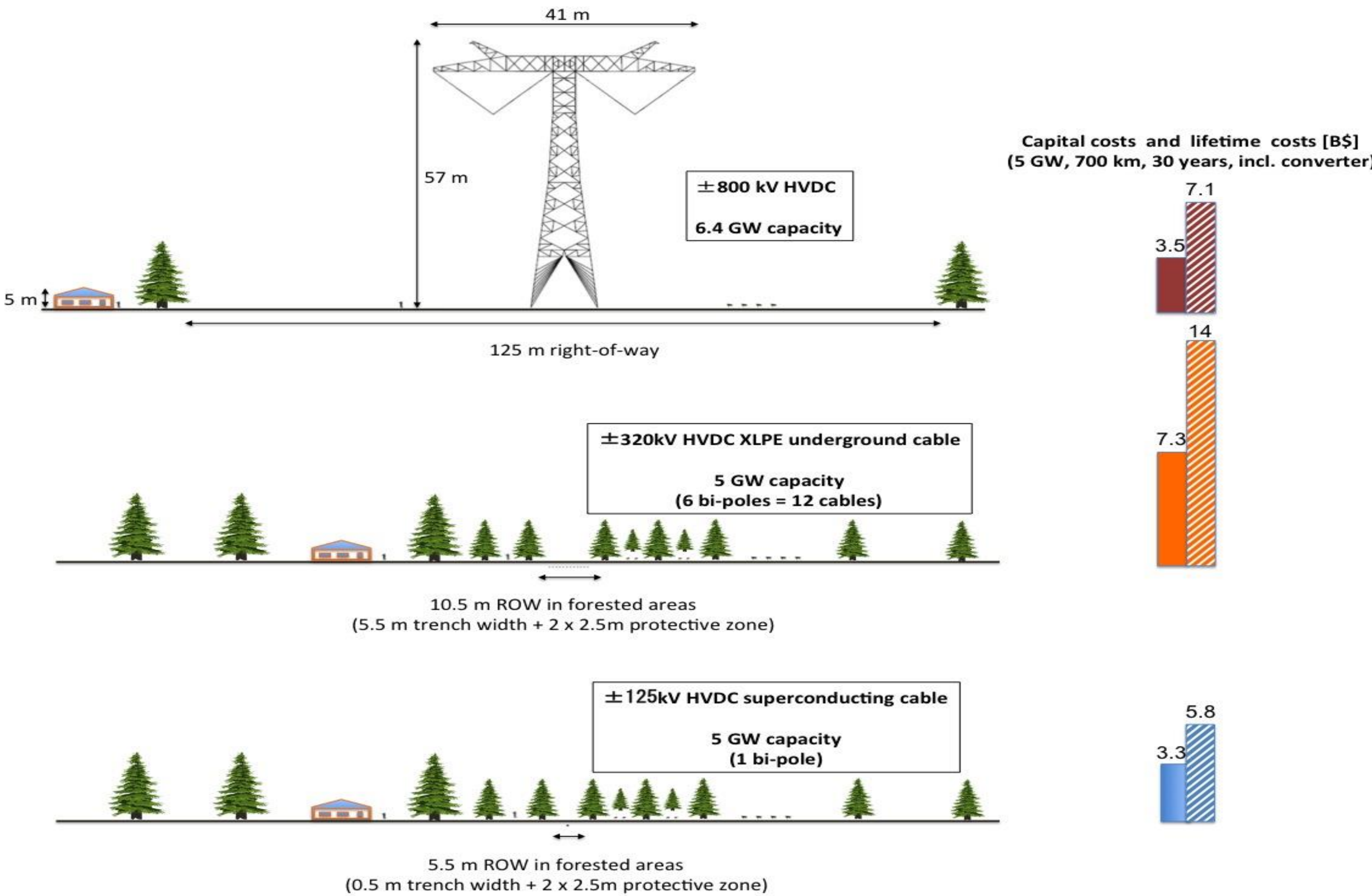


NG pipeline for same but thermal energy
90 cm diameter
Pressure 100 bar

33 cm diameter
Pressure 20 bar

- Typical underground trench which could be used to install a Superconducting electric high power line.
- Superconducting electricity power lines could be located along existing transportation rights of way.
- A single 5 GWatt SC line at ±100 kV is much smaller and cheaper than 16 XLPE underground cables at ± 320kV.

Cost comparison for 700 km length and 5 GW capacity

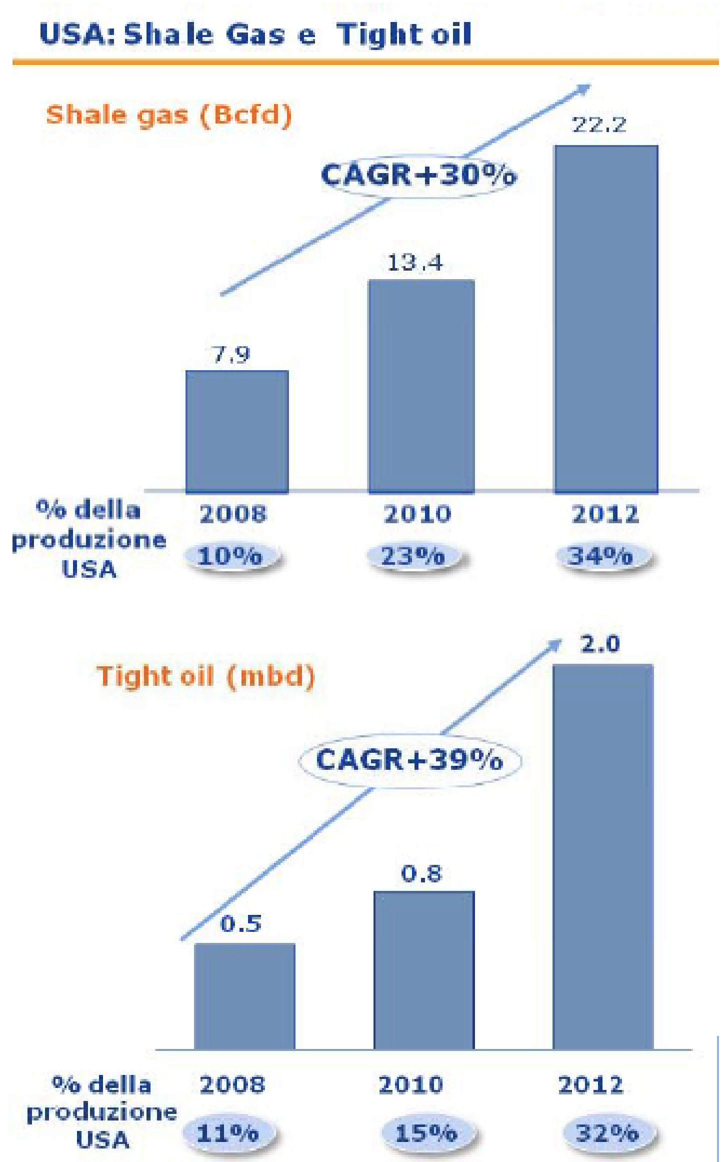


2.-Unconventional Natural Gas resources

- The process of progressive de-carbonization of fossils goes necessarily through an increased use and consumption of NG.
- NG (methane) it is the fossil fuel with the highest de-carbonization, whose full combustion produces 2.5 times less CO_2 than coal for the same energy.
- NG could represent a practical alternative to the presently growing exploitation of Coal as main source of energy.
- In addition to ordinary NG production several other unconventional sources are being developed.
- Alternatives as for instance the transformation of Coal into a substitute Oil are possible and economically viable (Fisher & Tropf) *but at a huge multiplication of CO_2 emissions (≈1/2 ton for each barrel of oil).*
- New methods may be developed which would introduce *additional substantial reductions in the GHG emissions*

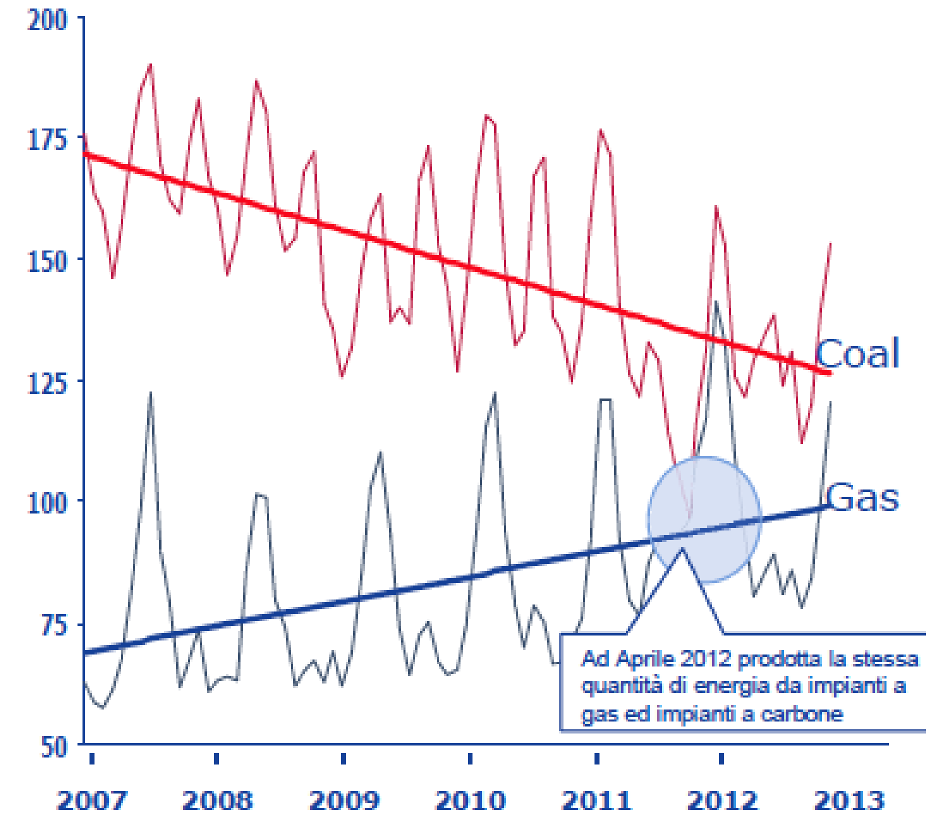
The shale revolution in the US

APRIL 2011



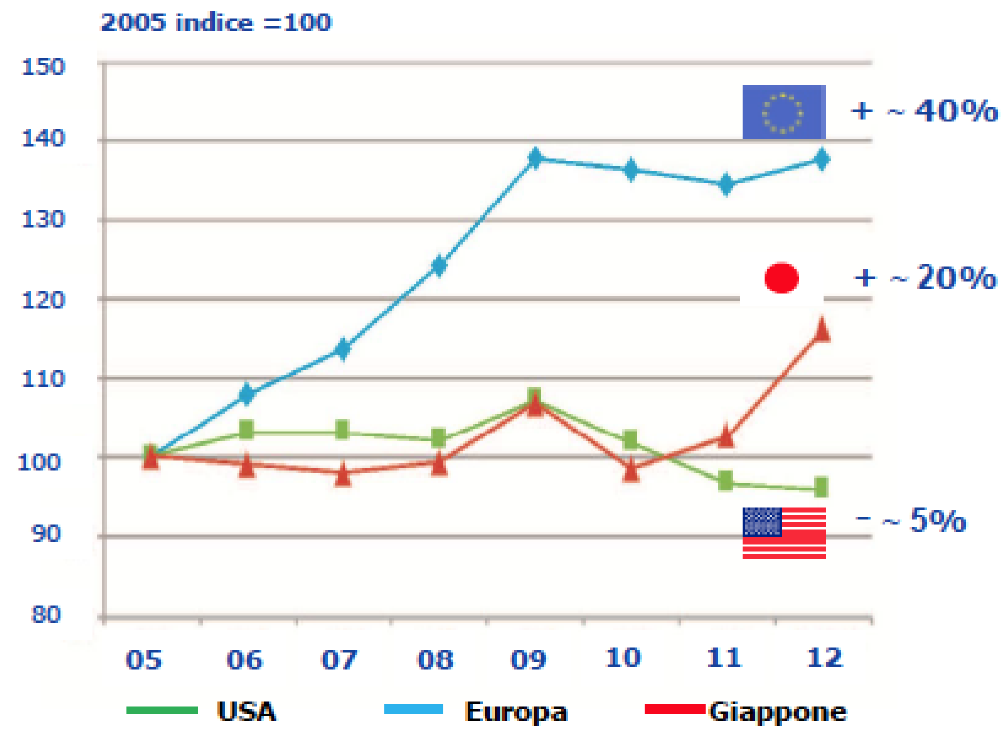
Coal and gas in the US

Electricity production in the US (TWh)

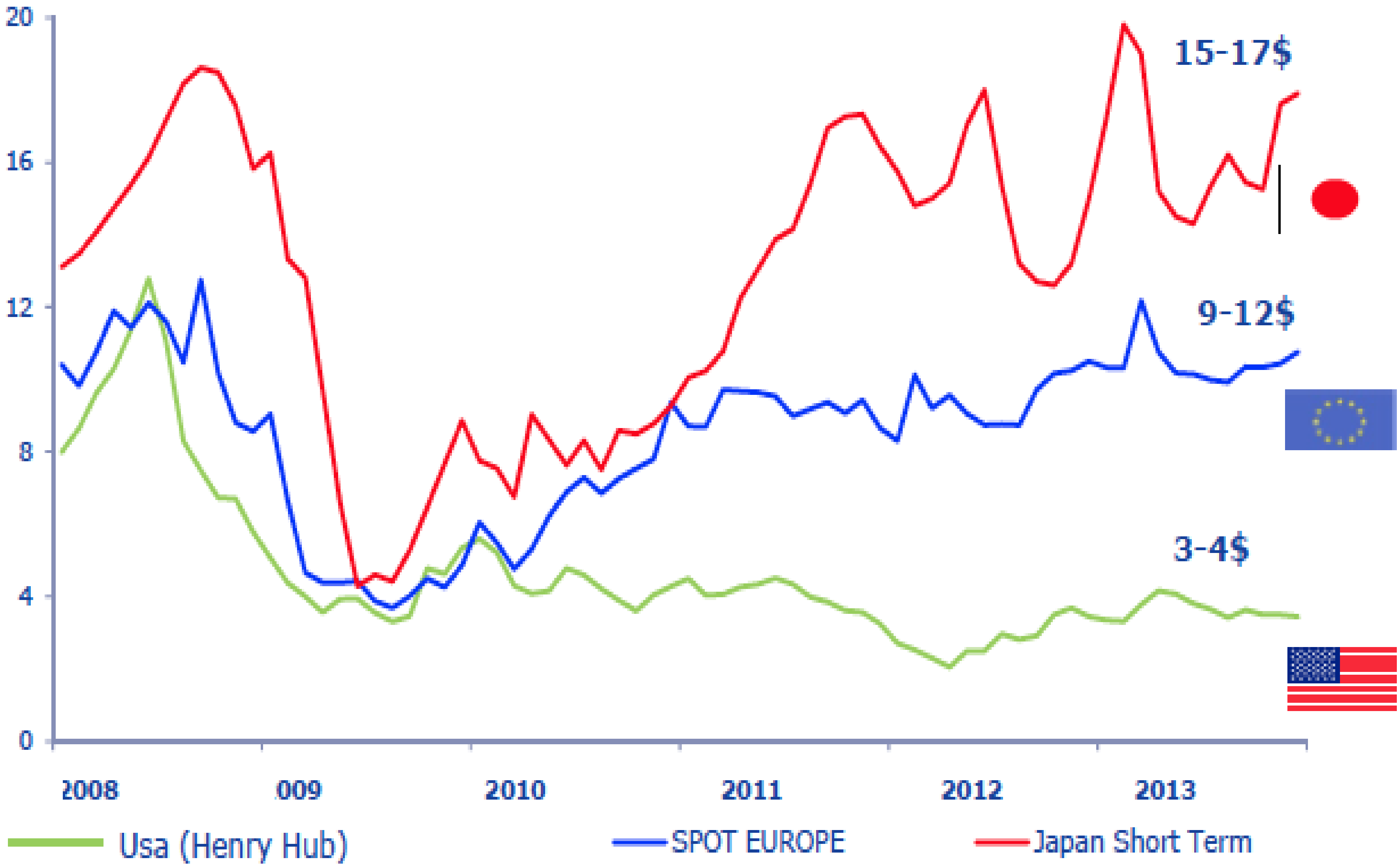


Fonte: US eia

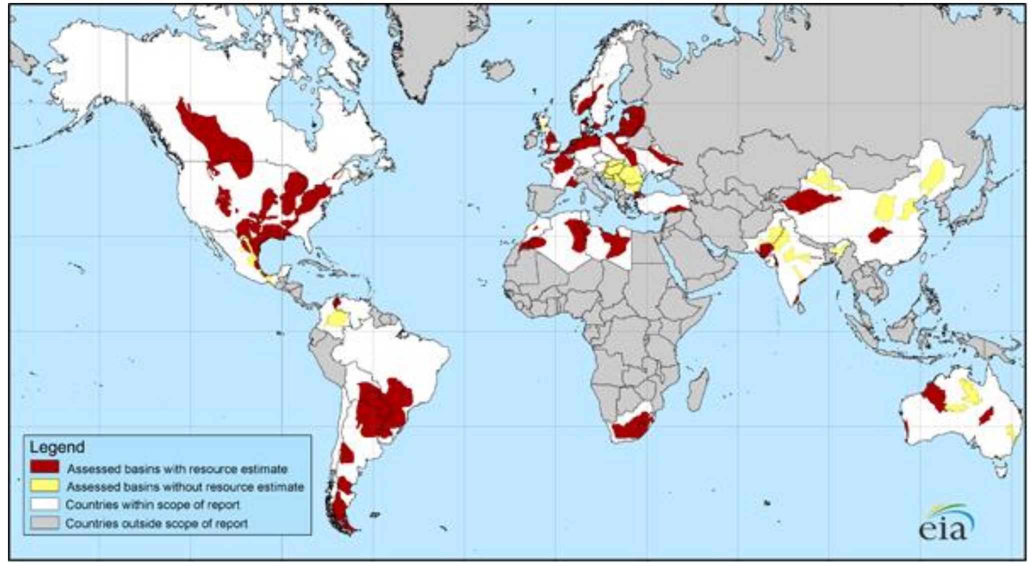
Prices of electricity for Industry



Behaviour of NG prices worldwide

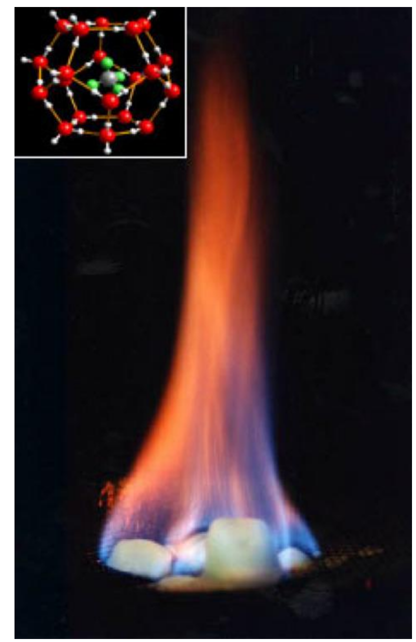


Unconventional NG sources ?



- In 2000 Shale gas provided only 1% of U.S. natural gas production; by 2010 it was over 20% and the U.S. government predicts that by 2035 46% of the United States' natural gas supply will come from shale gas.
- Methane hydrate is the most abundant natural form of clathrate, a chemical substance in which molecules of water form an open solid lattice that encloses, without chemical bonding, appropriately-sized molecules of methane.
- At high pressure methane clathrates remain stable up to 18 ° C. One litre of methane clathrate contains as much as 168 litres of methane gas.

"Burning ice"

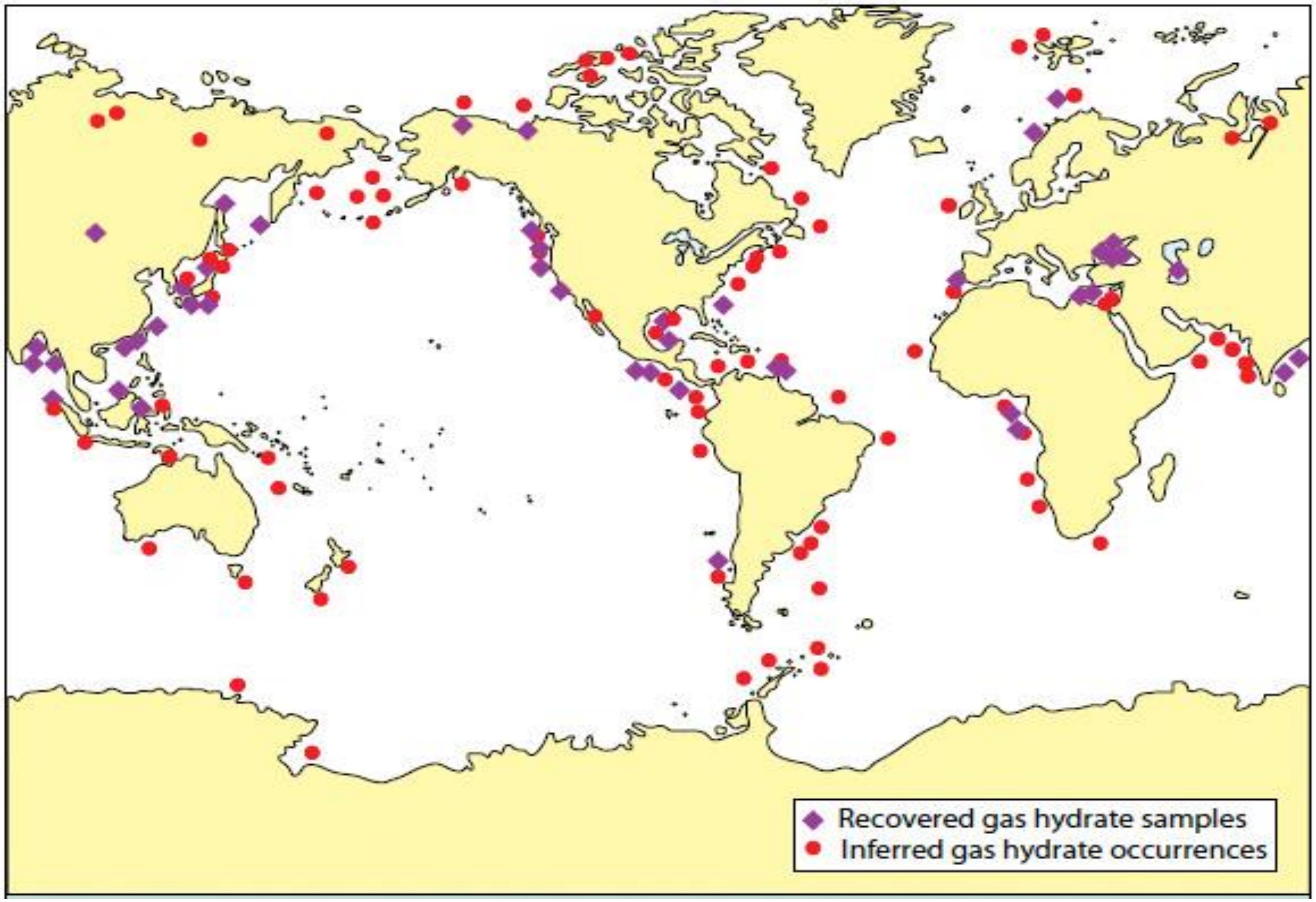


Natural Gas production from Clathrates ?

- The subject appeared to be purely academic until recently when scientists realized that, given the ubiquity of both methane (the common by-product of bacterial breakdown of organic matter) and water in nature, methane hydrate could be present in vast quantities in any environment with suitable pressures and temperatures.
- Methane clathrates are common constituents of the shallow marine geosphere and they occur both in deep sedimentary structures, and as outcrops on the ocean floor.
- The potential amount of methane in natural gas hydrate is enormous. Estimates range from 3,000, 10,000, or even to as much as 74,000 Gtons of methane carbon. Recent estimates of methane on the sea floor range from 650 to 3200 Gtons.
- As a comparison the total estimates for conventional Natural Gas and Oil are of the order of a few hundred Gigaton.

Locations where clathrates have been observed

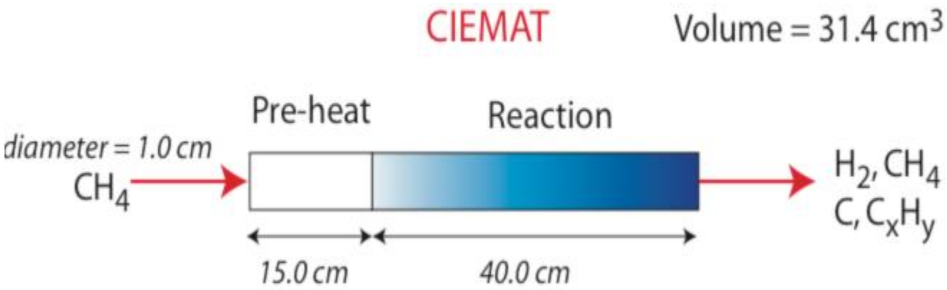
Reservoirs of methane, located globally within 2000 m of the solid surface and observed in a large number of locations are of major interest as a potential novel energy resources.

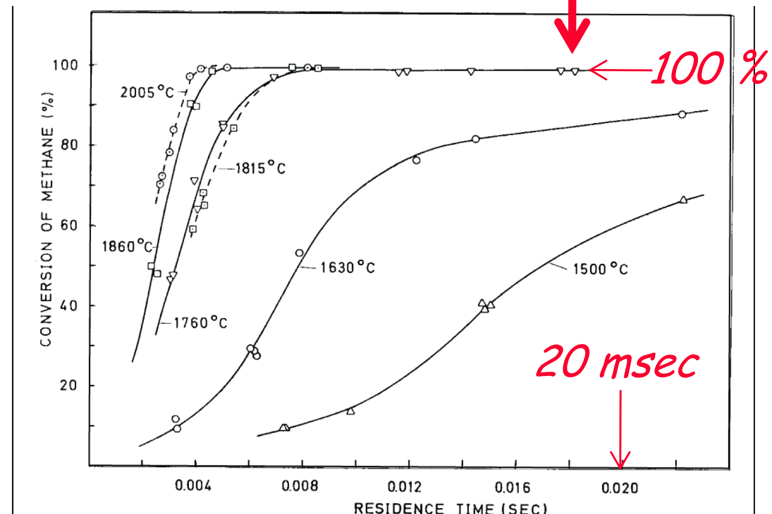


3.- Burning Natural Gas without CO_2 emissions?

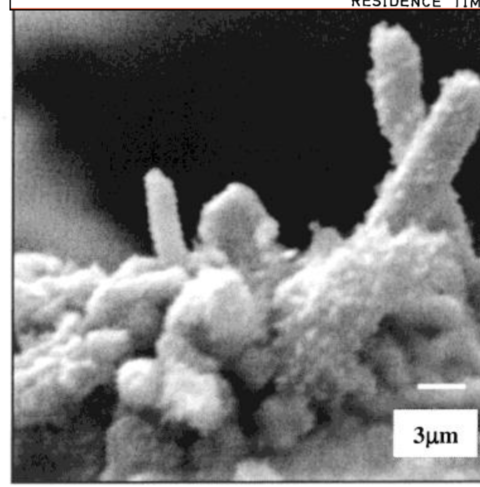
- The process is the spontaneous thermal decomposition (TDM) at sufficient temperature of methane to hydrogen and black carbon: $CH_4 \rightarrow 2H_2 + C$
- Cracking methane with no CO_2 emissions uses no more energy than the existing SRM reforming process, which however produces as much as 4 tons of CO_2 for each ton of Hydrogen.
- The black carbon can either be sequestered or sold on the market as a materials commodity, or reduce costs by marketing the carbon as a filler or construction material
- The absence of CO_2 in the TDM process is the main reason for its development.
- A specific pre-industrial development is on going as a collaborative effort of our Institute (IASS) with leading German research institutions.

Early (2005-09) studies on spontaneous thermal dissociation





- The device is a simple graphite tube heated at very high temperature
- Natural gas is introduced at high temperatures and flow rates in the reactor to activate pyrolytic dissociation.
- A dense black smoke streamed from the outlet end of the reactor tube and it was found to consist of carbon black and hydrogen.
- Carbon black particles are extremely fine and difficult to filter.
- Carbon black must be recovered and separated (bag or precipitator).



Typical nanotube structure from NG

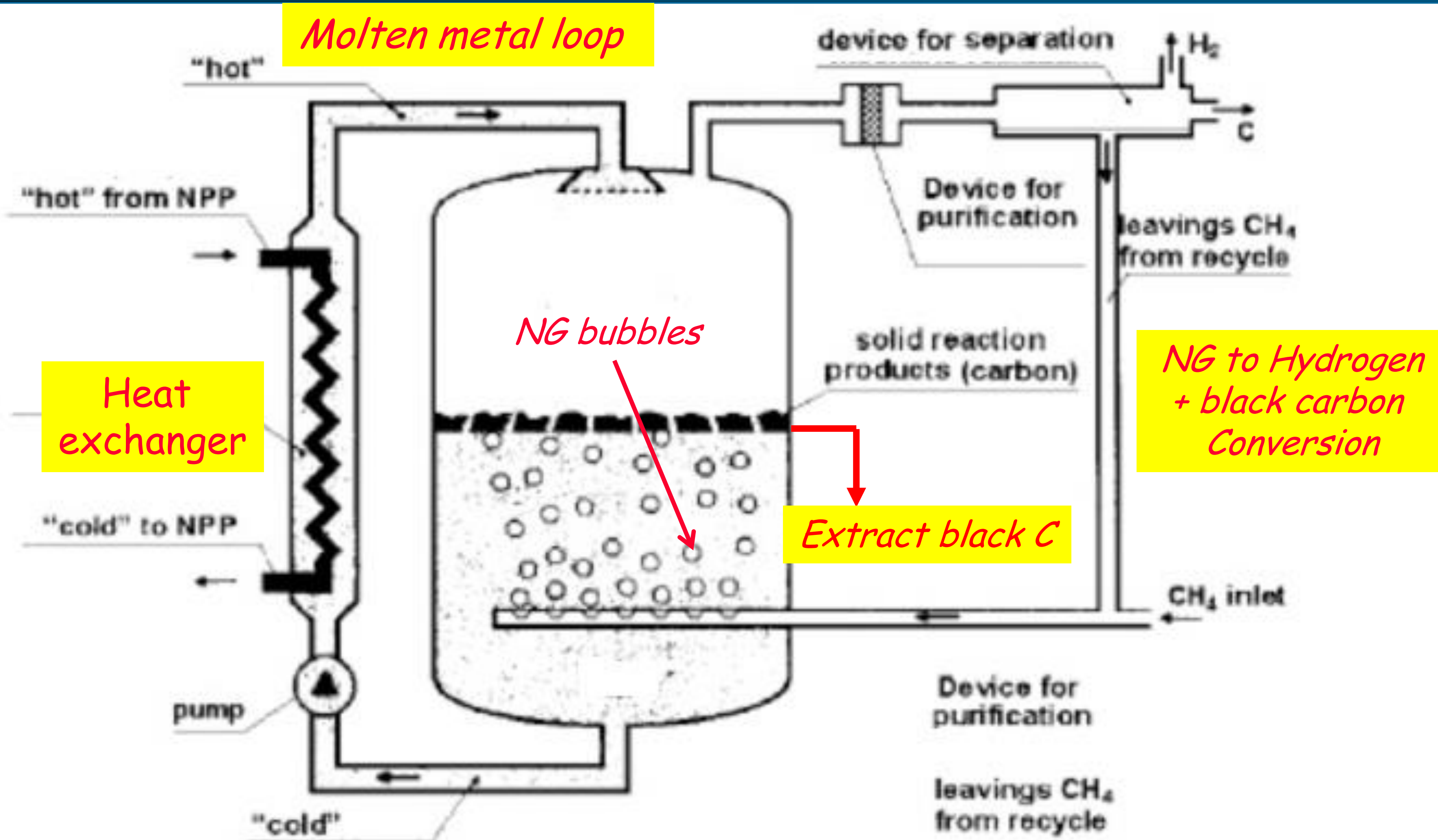
Comparing reforming and pyrolysis of NG for H_2 production

Reforming and CO2 sequestration

Spontaneous pyrolisis without CO2 emissions

Item	SRM–Reforming	TDM–Pyrolysis
Reaction chemistry	$CH_4 + 2H_2O = CO_2 + 4H_2$	$CH_4 = C + 2H_2$
Mols H_2 per mol CH_4	4	2
Endothermic Ht of reaction Kcal/mol CH_4	60	18
At 80% Thermal Eff. process heat in Kcal/mol H_2	18.8	11.3
Process Thermal Efficiency for H_2 Production–%	75	58
CO_2 Emission Mols CO_2/mol H_2	0.43	0.0
Lbs CO_2 Gas/MMBTU	155	
Lbs C Solid/MMBTU	0	49
Process Unit Operations	1. Reformer 2. Shift 3. CO_2 separation	1. Pyrolyzer 2. CH_4 Separation if needed
Sequestration % net energy reduction	Liquid CO_2, in ocean, gas wells, aquifers = ~15%	Solid C, in land fill, mines o market = ~0%
Net Energy Efficiency %	75–15 = 60% Energy Lost = 40%	58% Energy Stored = 42%
By-product value	Low	High materials potential
Uncertainties	Possible Hazardous Environmental Effects	Minimal
Process development	Well developed	Needs development

Molten metals for methane decomposition



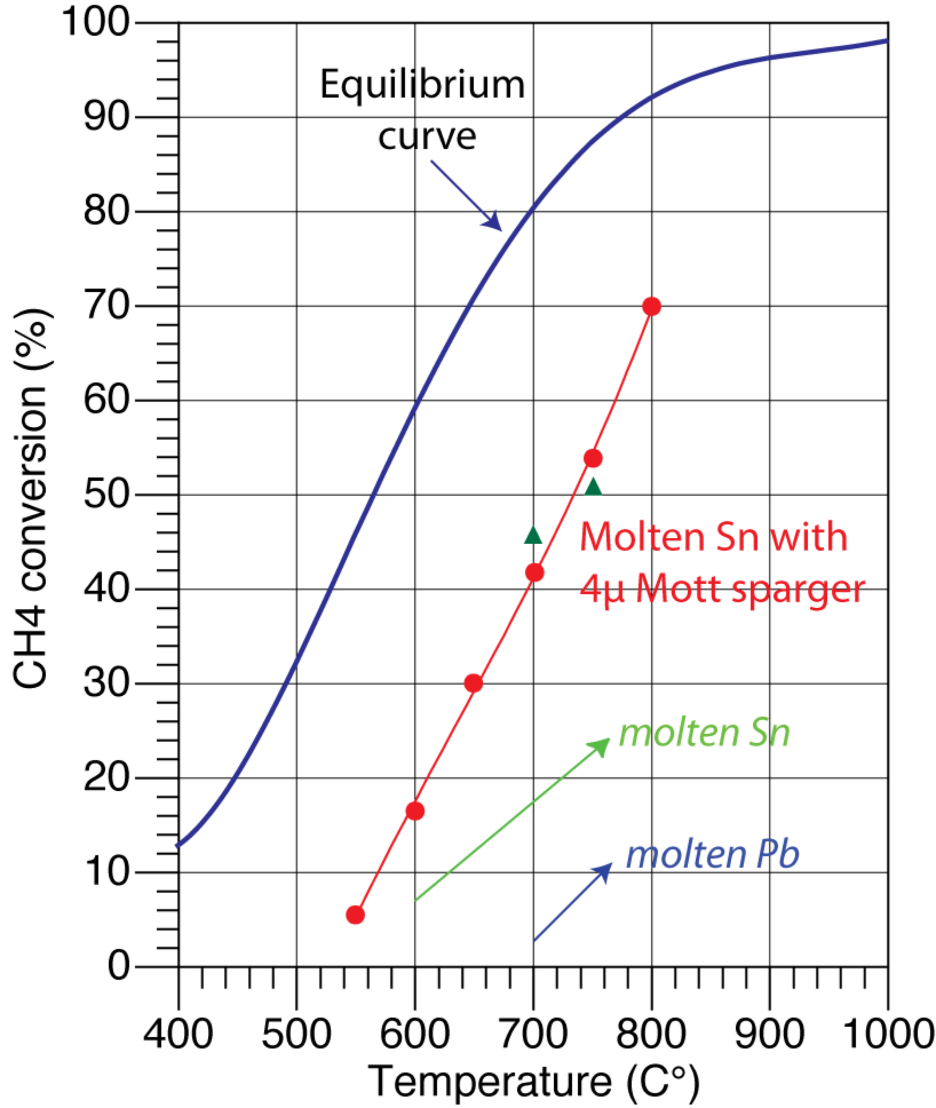
- Early decomposition through bubbling of NG through a molten metal at high temperature. Small bubbles enhance the NG to hydrogen conversion.

Collaboration with Karlsruhe Institute of Technology (KIT)

- The (table top) project is based on the Implementation of liquid metal technology to the production of H_2 from NG without CO_2 emissions.
- Selection of structural materials:
  - Compatible with liquid metals, as Lead or Tin
  - High temperatures (approximately 900 °C)
  - Compatible with Hydrogen production.
- Bubble formation in ceramic sponges and a liquid metal bath.
- Evaluation of the formation of Carbides or Hydrides in liquid metals.
- Removal of Carbon plugging to the structural materials
- Selection of a suitable catalyst for the process.
- Gas separation of pure H_2 from the remaining hydrocarbons and carbon
- Removal and recovery of Carbon particles from the liquid metal.

Results of NG pyrolysis with molten metals

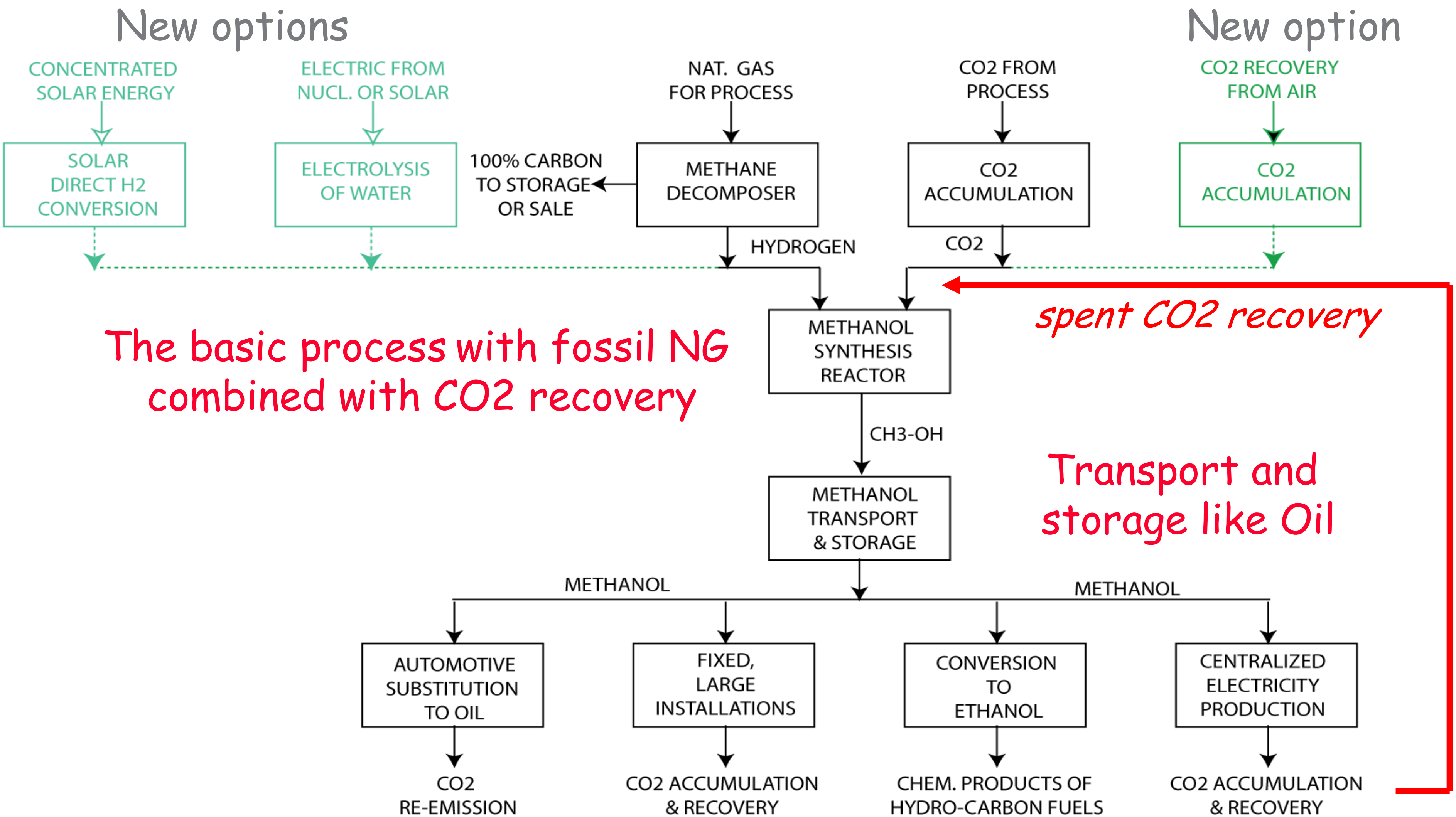
- The equilibrium curve at standard pressure is shown and it reaches 95% at 900 C° .
- Molten Pb and molten Sn are away from equilibrium conditions for ordinary boiling.
- The most efficient configuration was obtained with a Tin and SiC in a very small scale porous filter ("Mott Sparger") as consequence of the reduction of the bubble size, what produce an optimal gas/liquid contact, with a conversion of the order of 70% at 800 C° .



4.-Methanol as a “fuel” for transportation ?

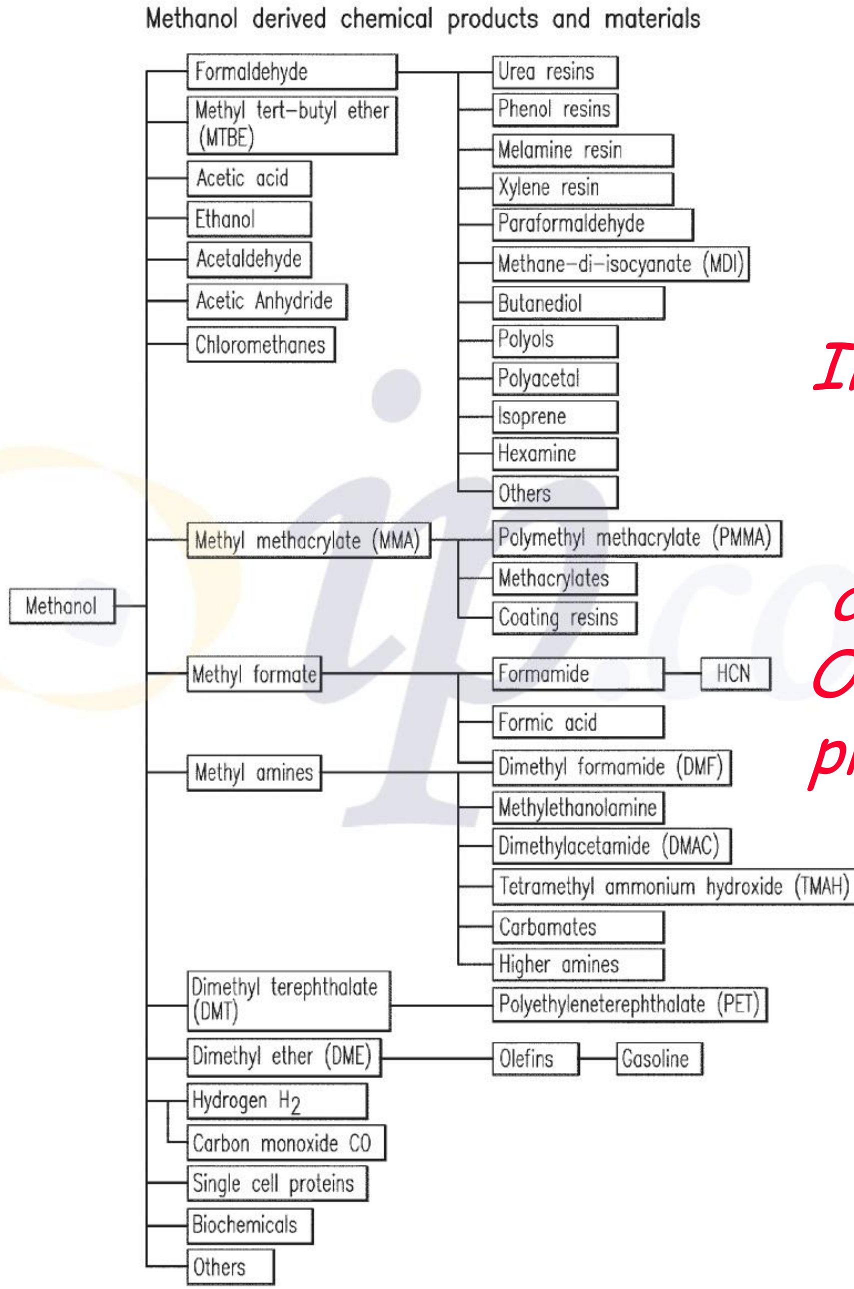
- Much has been said and much money has been spent for the hydrogen economy as a substitute for Oil.
- Hydrogen as a chemical product is already widely used in a number of fields which include for instance production of ammonia, cracking of Petrol: its production is as much 4% of the one of Oil, mostly out of NG production.
- Notwithstanding, fundamental problems will have to be solved if hydrogen gas is ever to become *directly* a practical, every day *transportation fuel* that could be filled into the engines as easily and safely as gasoline is today.
- The chances that lay ahead seem prohibitive. In many people’s view the necessary future substitute to Petrol for transport *must be liquid, containing H_2,O_2 and CO_2*.
- The main alternative choice is of combining H_2 + [spent] CO_2 to produce liquid methanol: $CO_2+3H_2 \rightarrow CH_3OH+H_2O$

Transforming CO_2 from a liability to an asset



Methanol derived chemical products (Olah)

A "methanol Economy" (Olah)



In practice, all chemical products associated to Oil may be also produced from Methanol

Conclusions

- A coherent energy policy is required, strategic choices have to be made, relaying on truly innovative scientific and technological developments, in order to reconcile sustainable development and economic growth with the threat of environmental decay.
- Our society will depend crucially on uninterrupted and differentiated energy supply. Therefore major steps have to be taken in order to avoid potential geo-political and price vulnerability.
- The human capital of the most educated society is decisive factor for the establishment of norms of social conduct. We must recognize the duty to society in terms of long term actions rather than of their immediate interests.
- Only through such a concentrated and coordinated effort, leadership can be targeted and the objectives of creating high quality employment opportunities and a better quality of life be met.

Macchiavelli's advice: "De Principatibus" (1523)

- *Et interviene di questa come dicono e' fisici dello etico, che nel principio del suo male è facile curare e difficile a conoscere, ma, nel progresso del tempo, non l'avendo in principio conosciuta né medicata, diventa facile a conoscere e difficile a curare. Cosí interviene nelle cose di stato; perché, conoscendo discosto, il che non è dato se non a uno prudente, e' mali che nascono in quello, si guariscono presto; ma quando, per non li avere conosciuti si lasciono crescere in modo che ognuno li conosce, non vi è più remedio."*

- *For it happens in this, as the physicians say it happens in hectic fever, that in the beginning of the malady it is easy to cure but difficult to detect, but in the course of time, not having been either detected or treated in the beginning, it becomes easy to detect but difficult to cure.*

  Thus it happens in affairs of state, for when the evils that arise have been foreseen (which it is only given to a wise man to see), they can be quickly redressed, but when, through not having been foreseen, they have been permitted to grow in a way that every one can see them. there is no longer a remedy.

"I'm starting to get concerned about global warming."

Thank you !