Hydrogen at crossroads between science and politics

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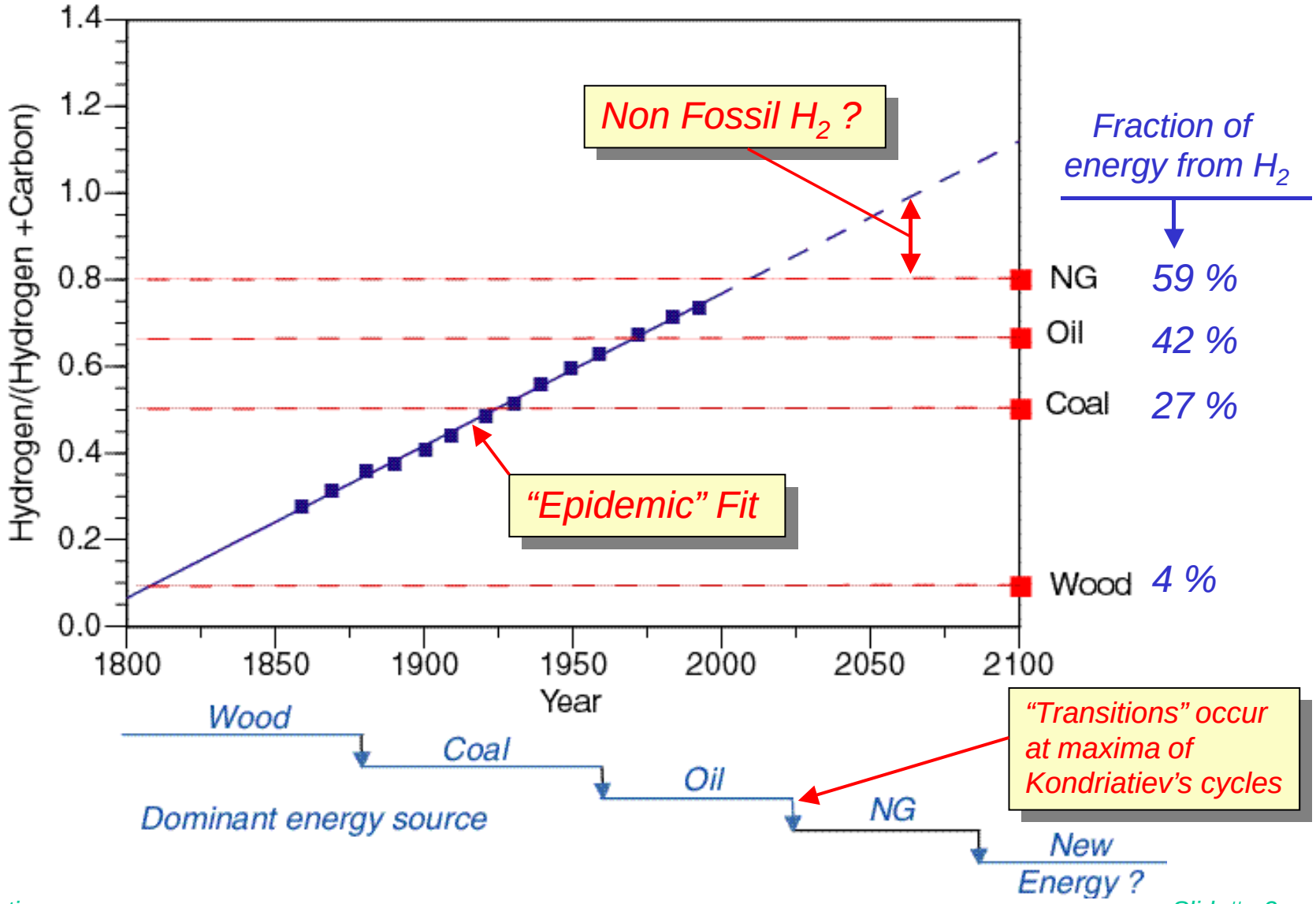
Hydrogen… an old “love story”

- One of the visionary predictions of Jules Vernes:

> « Je crois qu'un jour l'eau servira de carburant, que l'hydrogène et l'oxygène qui la constituent, utilisés seuls ou ensemble, fourniront une source inépuisable d'énergie et de lumière, d'une intensité dont le charbon n'est pas capable. Je crois aussi que lorsque les ressources en charbon seront épuisées, nous nous chaufferons grâce à l'eau. L'eau sera le charbon du futur. »
>
> *Jules Vernes, 'L’île mystérieuse', 1870*

- About 8 million ton of hydrogen are produced yearly in the EU, however primarily destined as a feedstock or an intermediate chemical.
- The old « town gas », a gas produced starting from coal « reforming » and widely used in the past, was made of ≈ 50% hydrogen, the rest being CO.
- *All fossils contain some hydrogen*, which contributes to generating heat.
- Such a fractional hydrogen content in the average fossil fuel mix has grown constantly over the last 150 years.

Evolution of Hydrogen content in world's fuel mix



Political issues…..

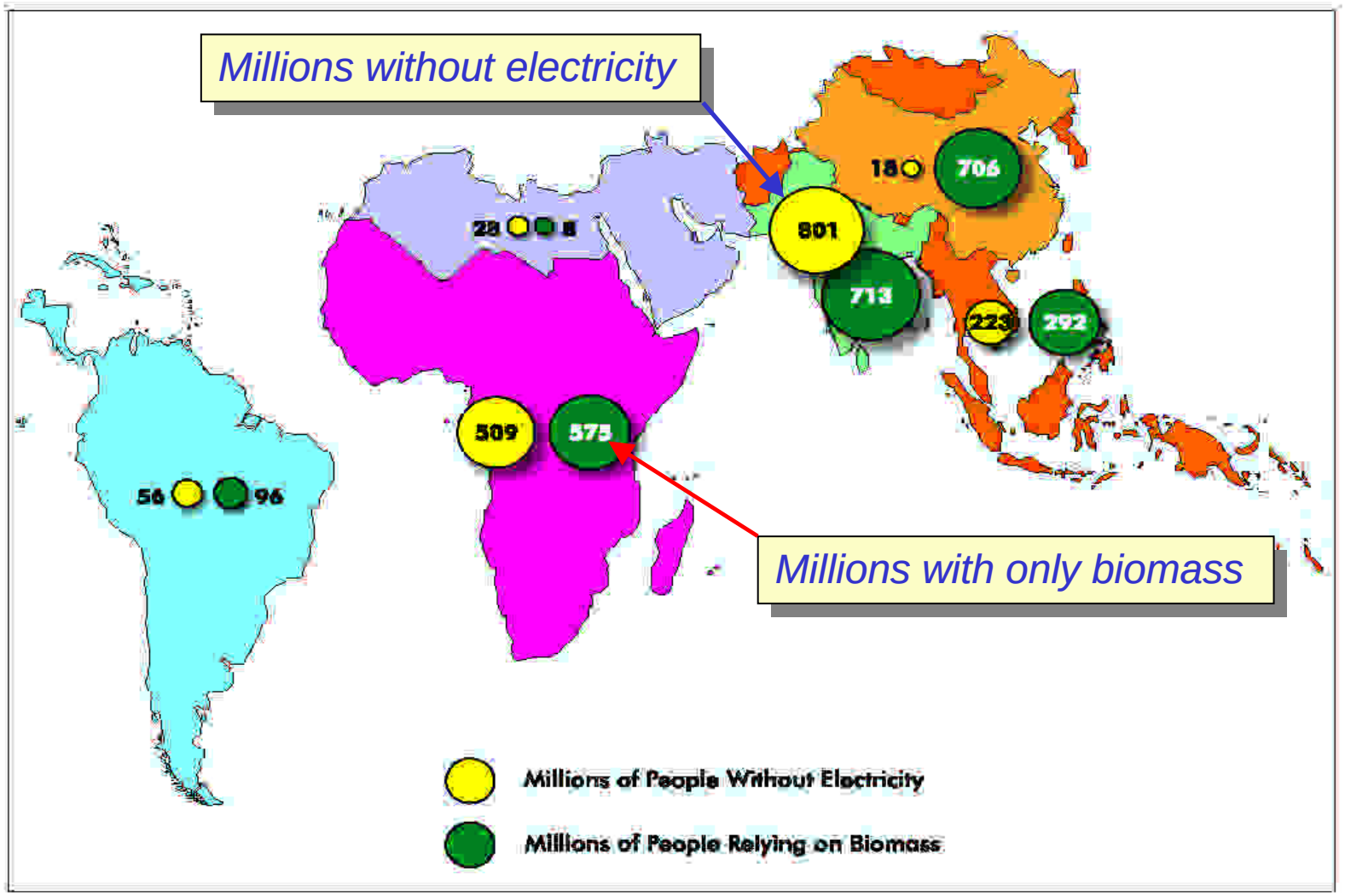
Energy is necessary

- Availability of energy has been an essential ingredient of human civilisation. In the course of history, pro-capite consumption has grown about 100 fold above the bare body metabolism, covered by food.
- The planetary energy consumption has been growing steadily since 150 years at a constant rate of +2.3 %/year.
  - ⇨ Human activities are about to double the endogenic energy of the planet Earth, i.e. the sum of the natural geo-thermal heat coming from the Earth's core and of the tidal energy coming from the Moon and the Sun.
  - ⇨ This energy is however only 1/10000 of the one received from the Sun by the Earth's surface.
- Energy consumption is directly related to wealth: energy intensity, the ratio between energy consumption and GNP, though slowly decreasing with technological progress, is indeed roughly the same both for advanced and developing countries.

Energy and poverty

- According to IEA's World's Energy Outlook 2002, about 1.6 billion people - a quarter of the current world's population - are without electricity, which precludes the great majority of industrial activities and the related job creation.
- The majority (4/5) of these populations live in rural areas in the developing countries, mainly in Asia and Africa.
- About 2.4 billion people rely almost exclusively on traditional biomass as their principal energy source. Incidentally, in many of these countries, the level of solar flux is such that it could potentially become a new primary energy source, provided it is harnessed with a simple and cost effective technology.

Global energy poverty

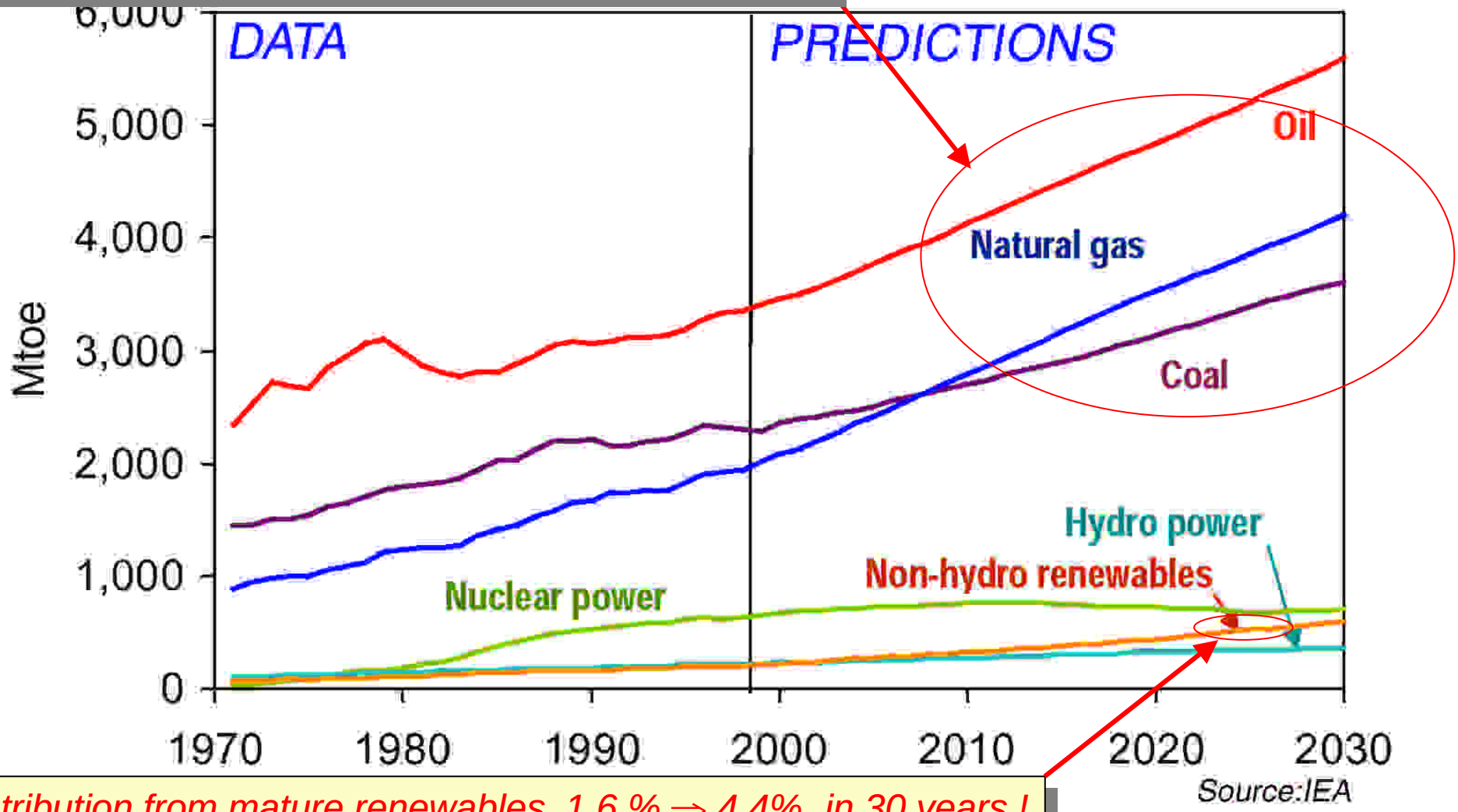


Source: IEA analysis.

Most needy areas have huge solar potentials !

IEA's forecast of world's primary energy demand

Continued growth and persisting dominance of fossils



Contribution from mature renewables, 1.6 % ⇒ 4.4% in 30 years !

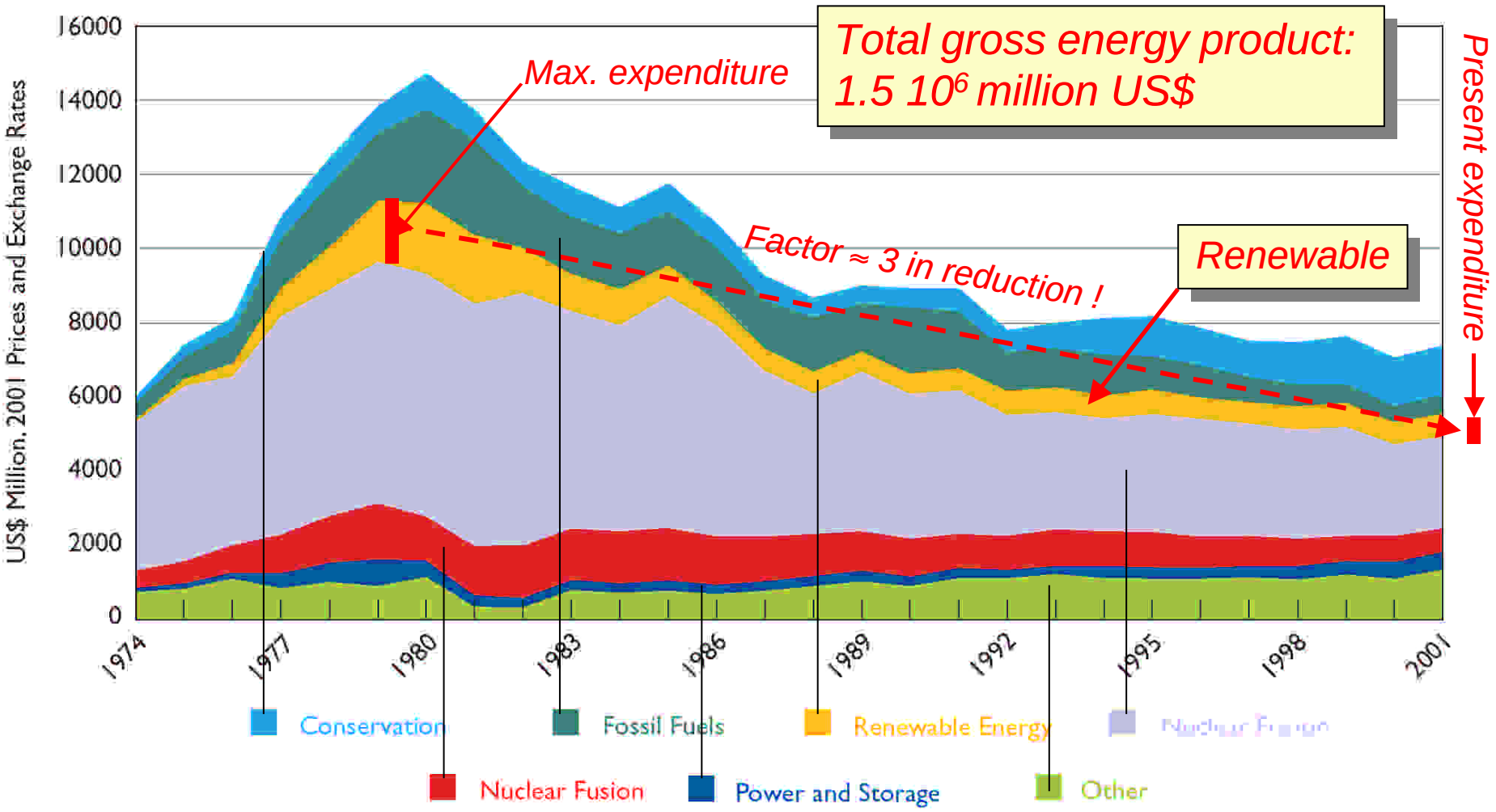
A series of forecasted disasters

- The IEA "business as usual" scenario will have serious consequences, namely:
  - ⇨ *Climate changes* of vast proportions are inevitable, with particularly serious consequences in developing countries, which are less prepared to compensate its effects.
  - ⇨ Sustainable development could be hampered by problems related to *security of oil and natural gas supplies*.
  - ⇨ The problem of *world poverty* will be amplified and perpetuated by the inevitable increases of the price of fossil fuels, due to increased demand and the related necessity of massive investments, especially for natural gas.
- Such a scenario can be avoided only by modifying some of the basic assumptions, in particular *the one forecasting that no really innovative technology will be developed in the next decades at such level as to have a substantial impact*.

Urgent need to foster the development of truly innovative, alternative renewable energy technologies

The solution can be found, but only by means of new investments in science and technological innovation…..

Governments Energy R & D budgets

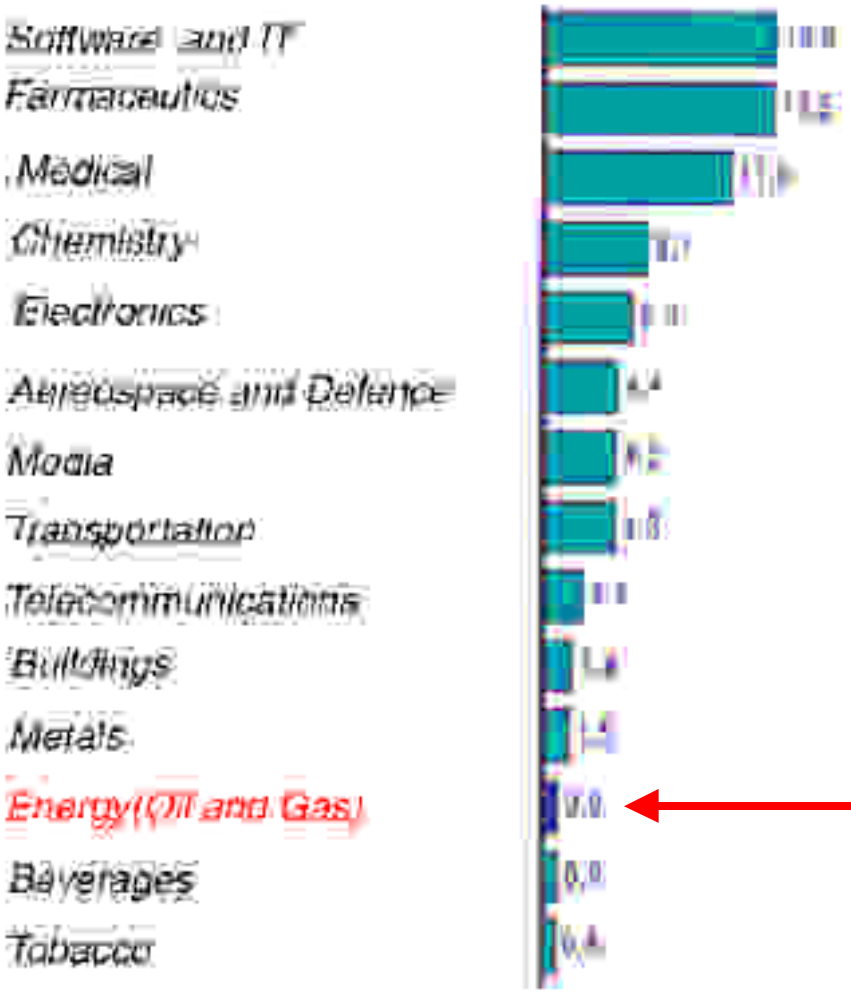


Source: Data reported to the IEA by IEA Member countries

The trend must be reversed !

World's R & D as fraction of corresponding income

Public + Private Funding



The R & D investments in the Energy sector are at the same level as the ones typical of domains with the least aspirations for innovation

Which is the way out ?

- The necessity of a significant increase of R & D funding is urgent, since the penetration of any new energy technology is generally very long.
- I would like to recall three major alternatives :

  ⇨*Clean coal combustion, virtually without emissions — through* CO_2 *sequestration.*

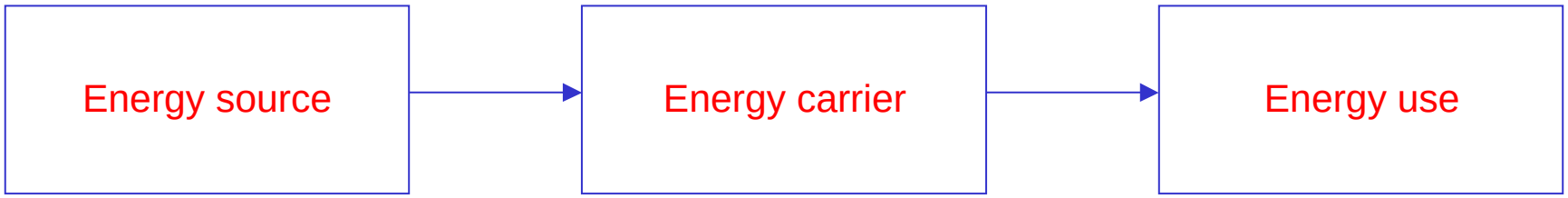
  ⇨*A new type of renewable energy, at a low cost and continuously available, for instance based on concentration of solar light.*

  ⇨*New nuclear, based on "breeding", either from Fission or Fusion*

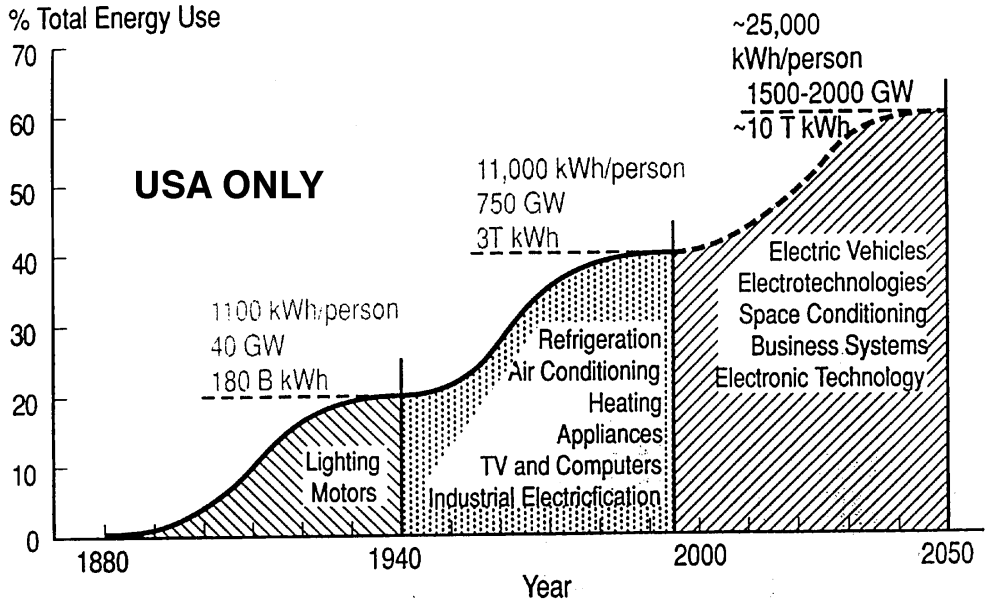
- In all these options, hydrogen will have a fundamental role as energy carrier, complementary to electricity, both without emissions at the point of utilisation.

The “energy carriers”

- In the energy sector we may split the process in three distinct phases:



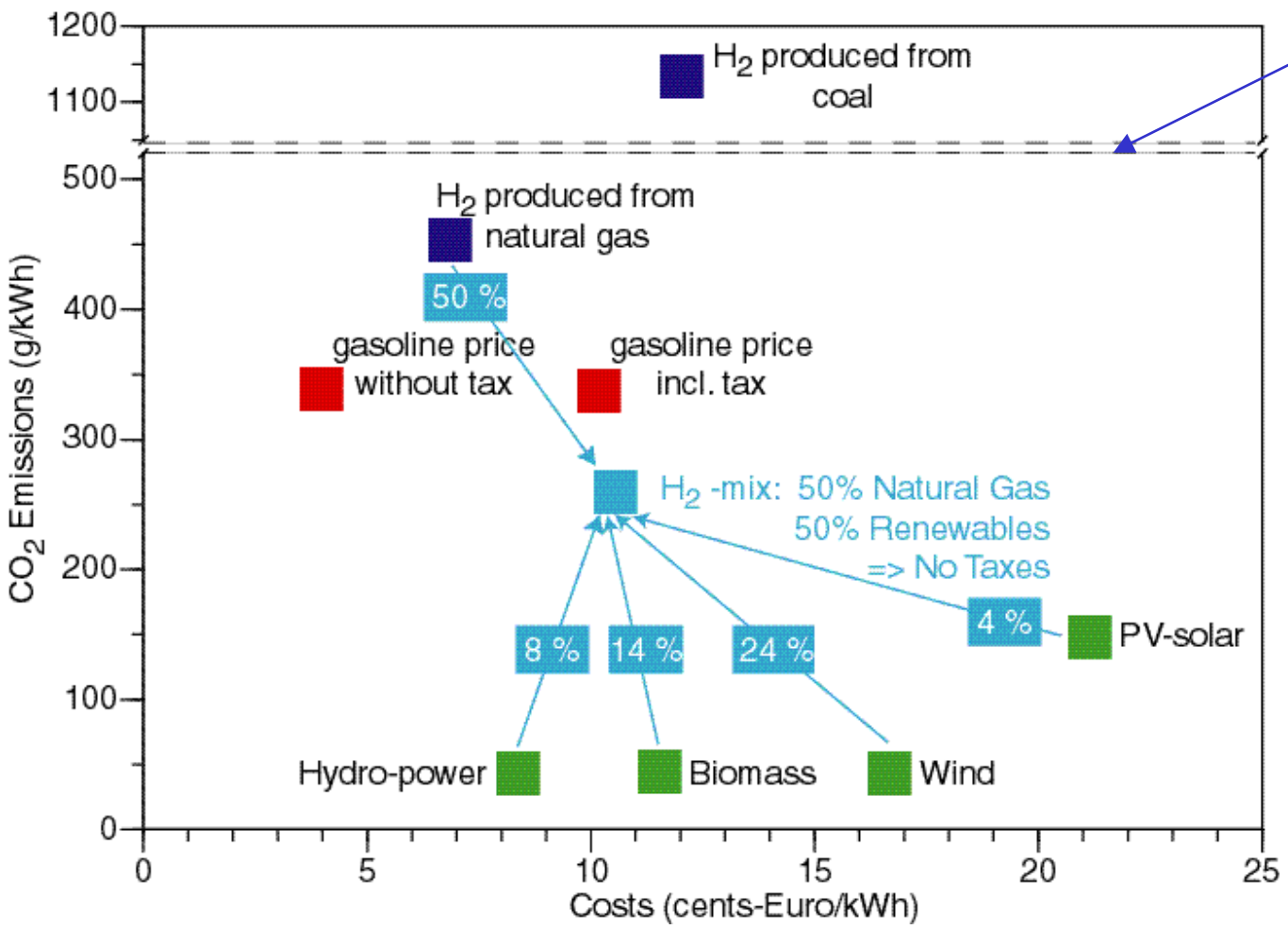
- Amongst energy carriers, only two characterize themselves for zero emissions, including greenhouse gases, *at the point of use*:
- Electricity: its penetration is growing rapidly with technological progress →
- Hydrogen (EU production ≈*10^7 t/year*):
  - ⇨ vastly used, but primarily as a feedstock in chemical production,petroleum refining, metals treating and electrical applications;
  - ⇨ only a small use as a “carrier”, mainly for space applications.



Today's hydrogen supply

- The EU production of hydrogen is presently close to 8 million ton/year.
- If used as a fuel,it would represent the energetic equivalent of
  - ⇨168 million barrels of oil
  - ⇨ 30 billion litres of gasoline,*enough to fuel 15 ÷ 25 million cars.*
- The production process is primarily steam methane reforming, with some partial oxidation of fossil fuels and of electrolysis. *These are commercialized, well proven technologies.* However*:*
  - ⇨Costs are high compared to other fuels.
  - ⇨There is large production of $CO_{2.}$
- In order to estimate the practical consequences of the use of hydrogen *at the level of present technologies,* we consider the case of transportation, for which we may consider both :
  - ⇨Hydrogen fuelled combustion engines
  - ⇨Electric cars with fuel cells
- The key diagram is the cost of fuel vs. the level of emissions of CO_2 (at production)

Costs and emissions for transportation

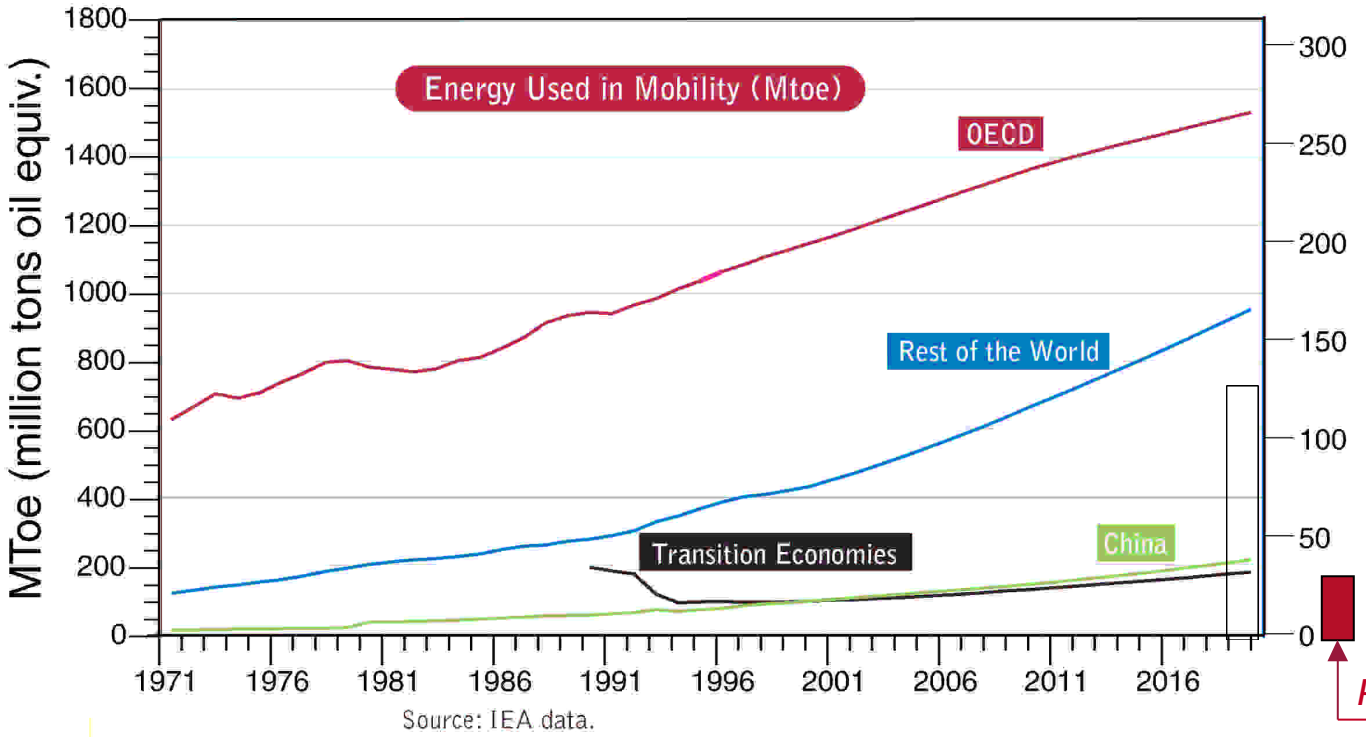


Note change of scale

Hydrogen from a fossil-renewable 50-50 mix has still a substantial CO_2 emission and unattractive cost

World's energy demand for mobility

- By 2020, *transport* is likely to account for more than *half of the world's oil demand* and roughly *one-quarter of global energy-related CO_2 emissions*, and result in considerable *local* air pollution.
- Transport will grow faster than any other end-use sector and oil consumption in transportation has become a serious concern in the context of both increasing *oil-import dependence* and *environmental impact*.



A gradual substitution with hydrogen and fuel cells is highly welcome. About 130 Mt of hydrogen should be sufficient in order to replace one half of the OECD demand of 2020. The present OECD hydrogen production is about 1/5 of such a level.

Present OECD total H_2 production

Summing up:

- *Present day hydrogen production methods are inadequate to sustain the generalisation of a hydrogen carrier in an economically acceptable way* , even assuming that problems related to delivery, storage and fuel cells are all solvable.
  - ⇨ Some savings may come from the increased demand: however even a market of 100 million hydrogen fuelled cars (≈1/2 of all EU cars) will require about 40 million ton/y of hydrogen, only ≈ 5 times the present EU production. *Reductions in prices due to an increased demand may be significant, but not determinant.*
  - ⇨ *CO_2 emissions with fossil derived hydrogen are likely comparable or even higher than the ones of today's cars.* A massive sequestration programme is conceivable, but it will add further costs and it will only postpone the problem, since the stored CO_2 will have eventually to be evacuated later on.
- The success of a hydrogen energy carrier depends on the advent of *entirely new methods* of production (1) with a *lower cost* and (2) *without CO_2 emissions* :
  - ⇨ *Exotic* new methods (biological systems, photo-chemical processes, etc.)
  - ⇨ Direct conversion of *solar concentrated heat*
  - ⇨ High temperature *nuclear reactors*

Thermo-chemical or thermo-physical water splitting

Thermo-chemical production of Hydrogen

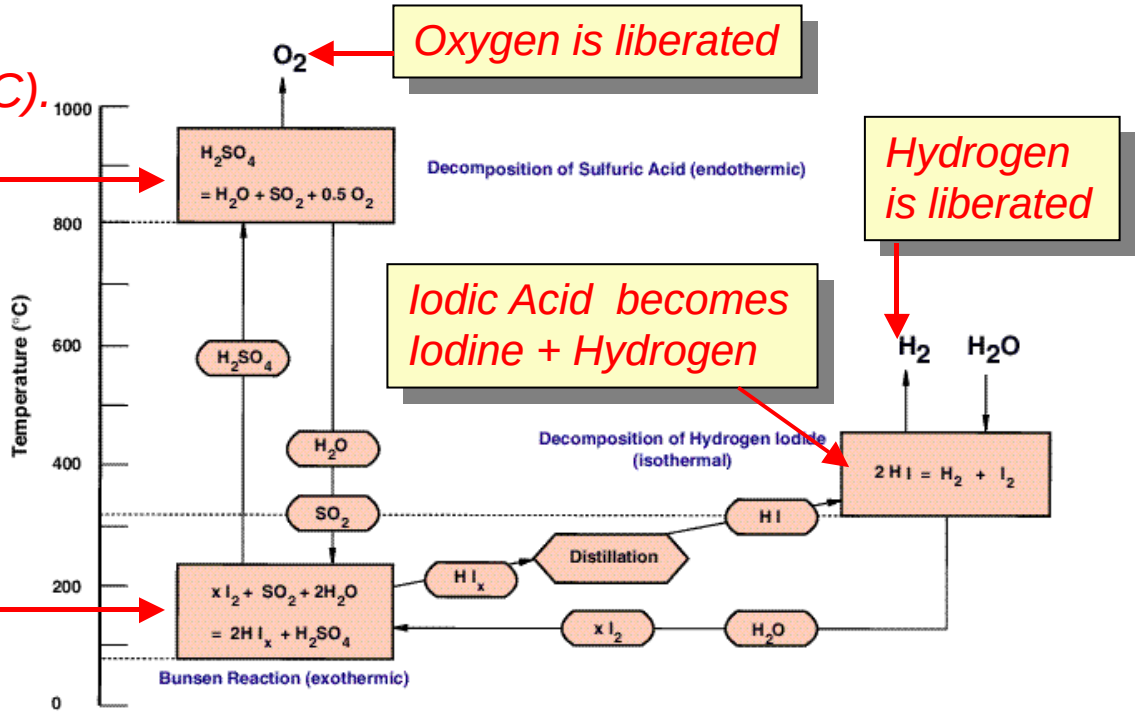
- The basic concepts were developed in the eighties in association with *nuclear heat*, but they have been more recently extended to solar heat.
- Spontaneous, direct water splitting in hydrogen and oxygen, at the expenses of supplied thermal heat occurs at prohibitive temperatures (≈ 3000 °C). In order to achieve hydrogen production at lower temperatures, *a chain of intermediate chemical reactions is necessary.*
- A number of interesting processes, have been reported, successful at the laboratory scale.

The Sulphur-Iodine process (850 °C).

Efficiency is high: ≈ 50 % of heat is transformed into hydrogen's chemical energy !

Sulfuric Acid is heated to 850 °C, where it splits into Oxygen and SO_2

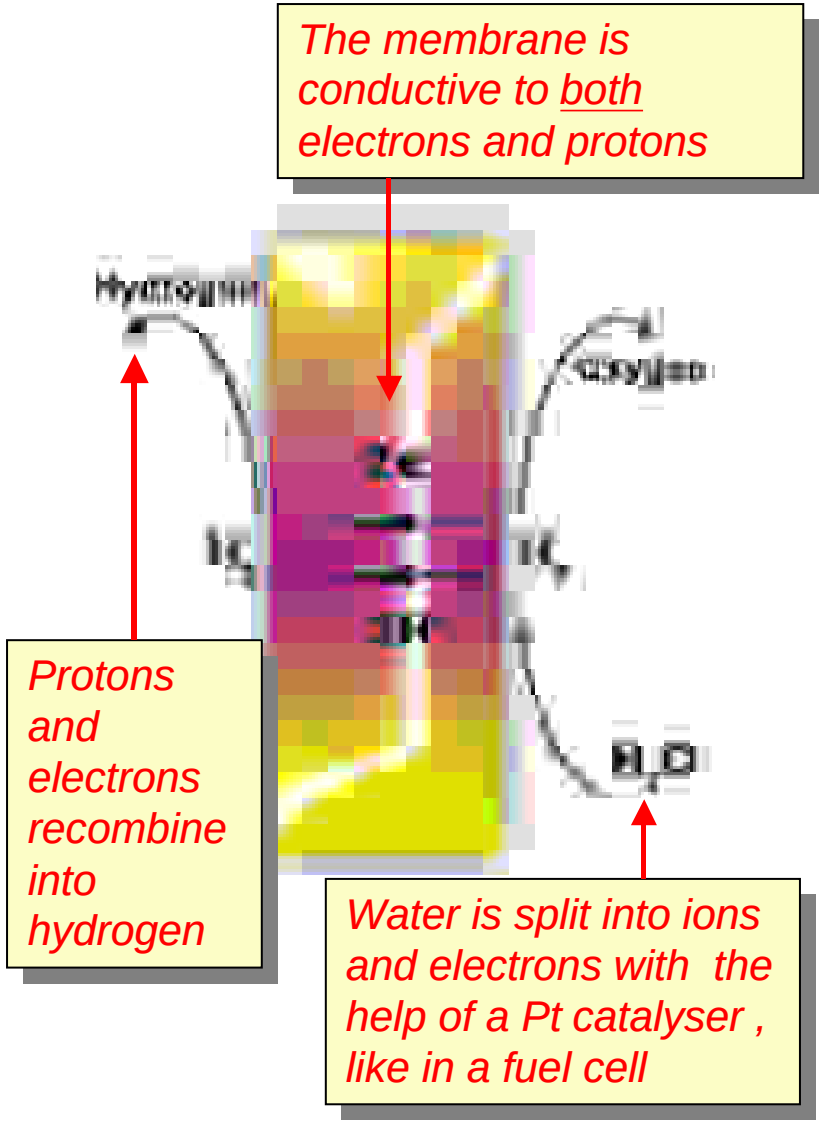
SO_2 is converted again into Sulfuric acid by Iodine transformed into Iodic acid (HI)



Thermo-physical production of Hydrogen

- The technology is very similar to the one of fuel cells, in which hydrogen is split into protons by a catalyser and transported by an ion conducting membrane.
- The key elements are:
  - ⇨ A *catalyser* which splits water into ions and electrons at a reasonable temperature (≤ 1000 °C) .
  - ⇨ A *ceramic membrane* conducting both electrons and protons, which recombine into hydrogen on the other side.
- The method is extremely simple and promises to be very cheap.
- The conversion efficiency promises to be very high.

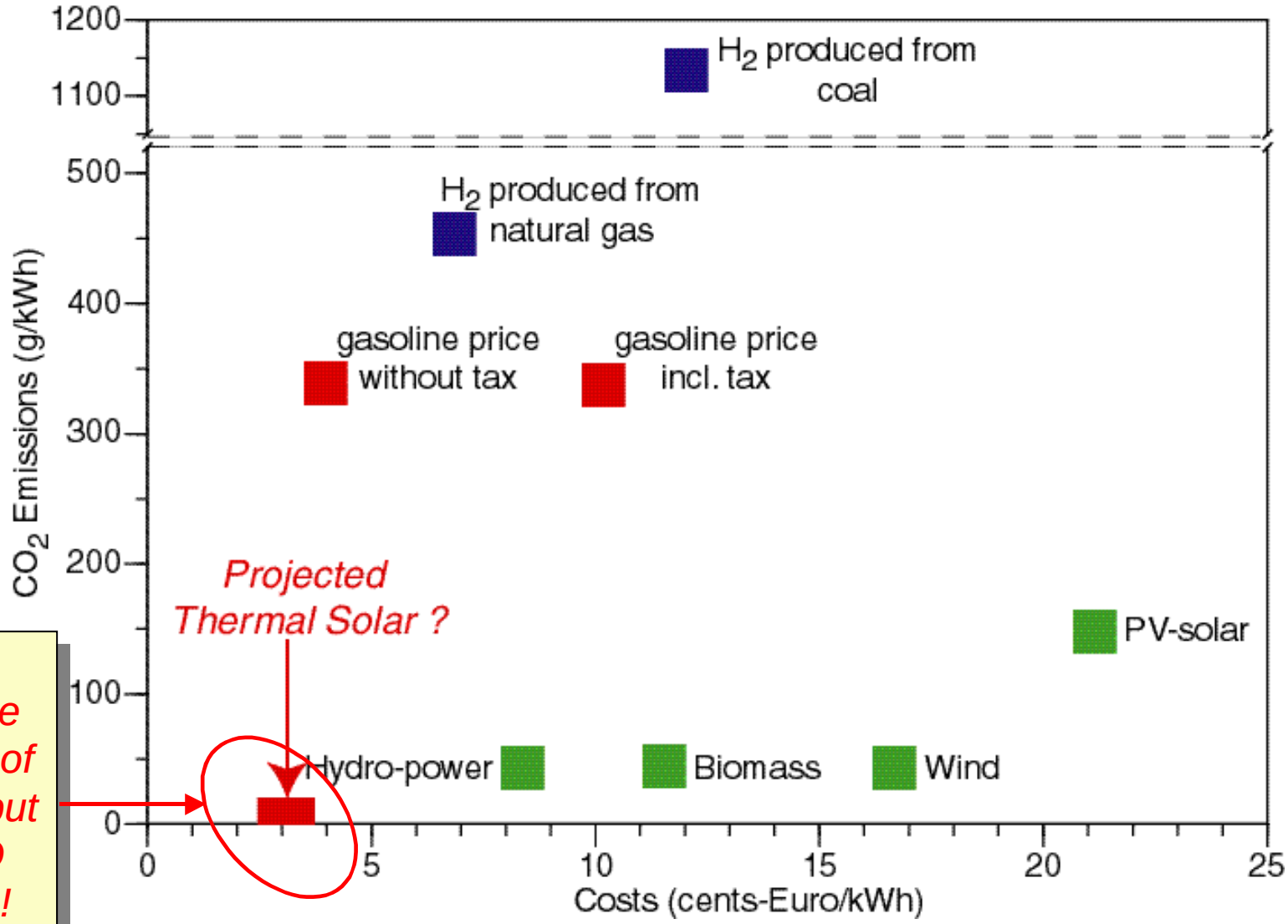
In my view this is a major breakthrough, which must be vigorously pursued



Looking at the future

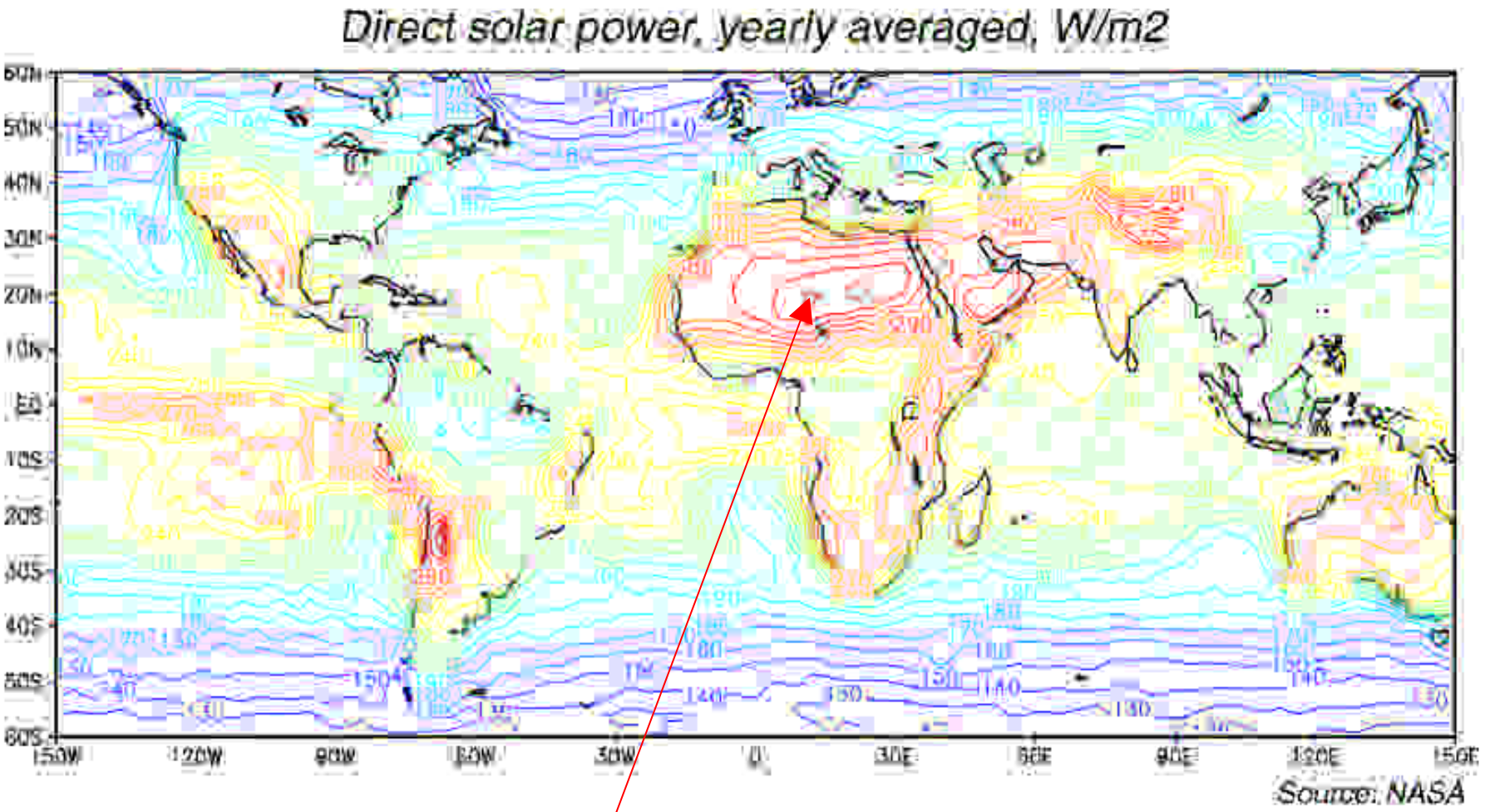
- Let us assume that we wish to power with hydrogen 100 million cars, corresponding to a yearly supply of 40 million ton of hydrogen.
- In order to achieve it without appreciable CO_2 emission, we can choose either:
  - ⇨ *Solar energy parabolic concentrators* with thermo-physical or eventually thermo-chemical hydrogen production at ≈ 1000 °C and 50% efficiency, located in desert locations (Sahara ?) — with a direct solar flux of 2900 kWh/m^2/y. The required collector surface is the one of *a square of 36.3 km on a side*, *equivalent to a surface of a mere 13.2 m^2 for each car to be fuelled*. A typical car parking area is 3.5 x 5 =17.5 m^2 !
  - ⇨ Several 3 GWatt $_{thermal}$ high temperature, innovative, *gas cooled nuclear reactors*, each of thermal power comparable with the one of standard PWR (1 Gwatt $_{electric}$). *The number of such reactors turns out to be equal to 165, about three times the installed nuclear power of France.*
- The estimated cost of solar heat collectors — according to the new ENEA design — is about 100 €/m^2, corresponding to a heat cost of ≈ 2 €/GJ. The cost of hydrogen generation is uncertain, but it should be in the order of 2 ÷ 4 €/GJ, plus 4 ÷ 6 €/GJ for transport and distribution, totalling 8 ÷ 12 €/GJ.

Projected solar thermal hydrogen ?



Cost comparable to the one of gasoline, but with ZERO emissions !

Solar energy is abundantly available



On a square meter in good insolation location, it 'rains" yearly the equivalent of ≈ 30 cm of oil

Conclusions

- *The R & D investments in the Energy sector are today at the same level as the ones typical of domains with the least aspirations for innovation:* such a persisting pattern would make the transition to a hydrogen driven economy either impossible or too slow in order to curb timely the greenhouse effects.
- *Present day hydrogen production methods are probably inadequate to sustain a generalized hydrogen carrier in an economically acceptable way*, even assuming that problems related to delivery, storage and fuel cells are all solvable. CO_2 sequestration is probably necessary, but it has extra costs.
- *Thermal splitting of water by high temperature heat is the most promising way to cut costs and to ensure virtually zero CO_2 emissions.* Such heat is abundantly available (1) from *solar energy* in a vast fraction of the planet, though it may be realized elsewhere with (2) high temperature *nuclear reactors*.
- *Solar hydrogen production with innovative technologies will provide a new opportunity for the southern part of Europe* (Spain, Italy, Portugal, Greece, etc.), which may become major producers of indigenous energy.
- *Solar hydrogen production will offer new opportunities for many parts of the world, where poverty is immense and land is inhospitable*.
- It is a responsibility of the wealthier countries to provide for the know-how in order to make it all possible.

- We strongly welcome and support the initiative of the EU-Commission to focus on the energy problem in general and more specifically on the future of hydrogen.
- This is well in line with similar initiatives taken elsewhere and in particular in the United States.
- 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 avoid potential geo-political and price vulnerability.
- The European Commission should play a very important role in order to foster at European level the absolutely necessary fundamental breakthroughs and catalyze innovation in a coherent international framework.
- Only through a concentrated and coordinated effort, European leadership in hydrogen and fuel cells can be targeted and the objectives of creating high quality employment opportunities and a better quality of life be met.