The Abdus Salam International Centre for Theoretical Physics

2245-1

Joint ICTP-IAEA Advanced School on the Role of Nuclear Technology in Hydrogen-Based Energy Systems

13 - 18 June 2011

Hydrogen in the Global Energy System

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Hydrogen in the Global Energy System

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Setting the Scene

Energy: #1 priority for humanity in next 50 years

Problem statement: the Terawatt Challenge

- Security of Energy Supply
- Global Climate Change
- *(competitiveness)*

Addressing the challenge: decarbonisation of energy system

- Supply
- Demand
- Changing energy landscape

Role and contribution of hydrogen technologies

Additional slides

Humanity's Top Ten Problems for next 50 years

1. **ENERGY**
2. WATER
3. FOOD
4. ENVIRONMENT
5. POVERTY
6. TERRORISM & WAR
7. DISEASE
8. EDUCATION
9. DEMOCRACY
10. POPULATION

2004	**6.5**	**Billion People**
2050	**~ 10**	**Billion People**

R.Smalley, the Terawatt Callenge, Nobel prize chemistry 1996

Problem Statement

" Energy is the single most important technological challenge facing humanity today. Nothing else in science or technology comes close in comparison."

… if we don't cure cancer in 20 years, like it or not the world will stay the same. But with energy, we are in the middle of doing ***the biggest experiment that humans will have ever done, and we get to do that experiment exactly once. And there is no tomorrow***, because in 20 years that experiment will be cast in stone. If we don't get this right, we can say as students of physics and chemistry that we know that the world will, on a timescale comparable to modern human history, never be the same.

Nathan S. Lewis, CalTech, 2007

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Additional slides

The energy challenge

1. RISING DEMAND

2. SECURITY OF SUPPLY

3. ENVIRONMENT AND SOCIETY

Fossil fuels will continue to play and important role in energy production

- Population growth
- Economic growth
- More affluent society

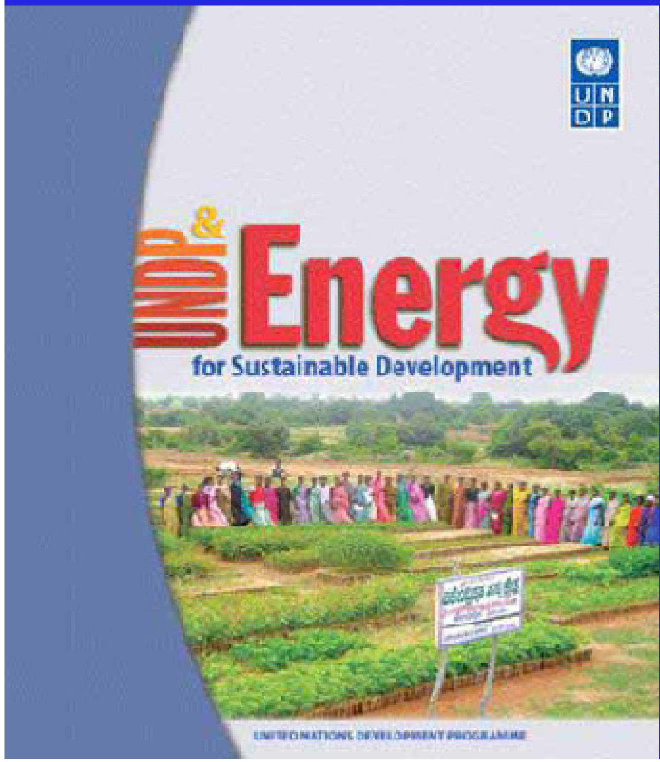
- End of 'easy oil'
- More unconventionals
- Resource nationalism

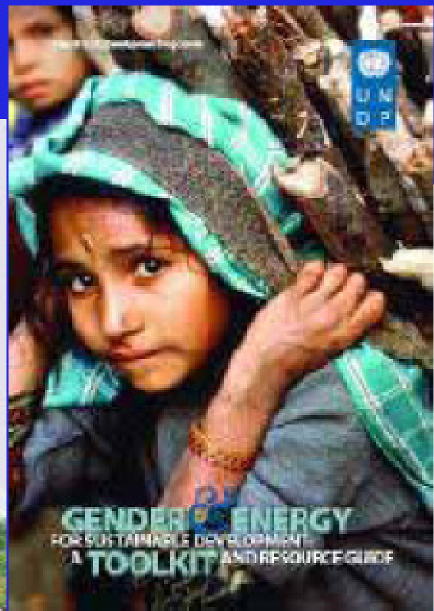
- Sustainability
- Global warming
- CO_2 consequences

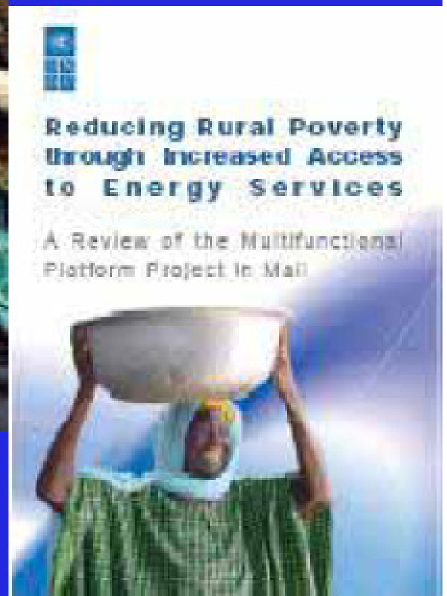
Mitigation measures have to be taken

Rising demand - 1

2 Billion Poor – No Electricity
2 Billion Poor – Biomass Heating

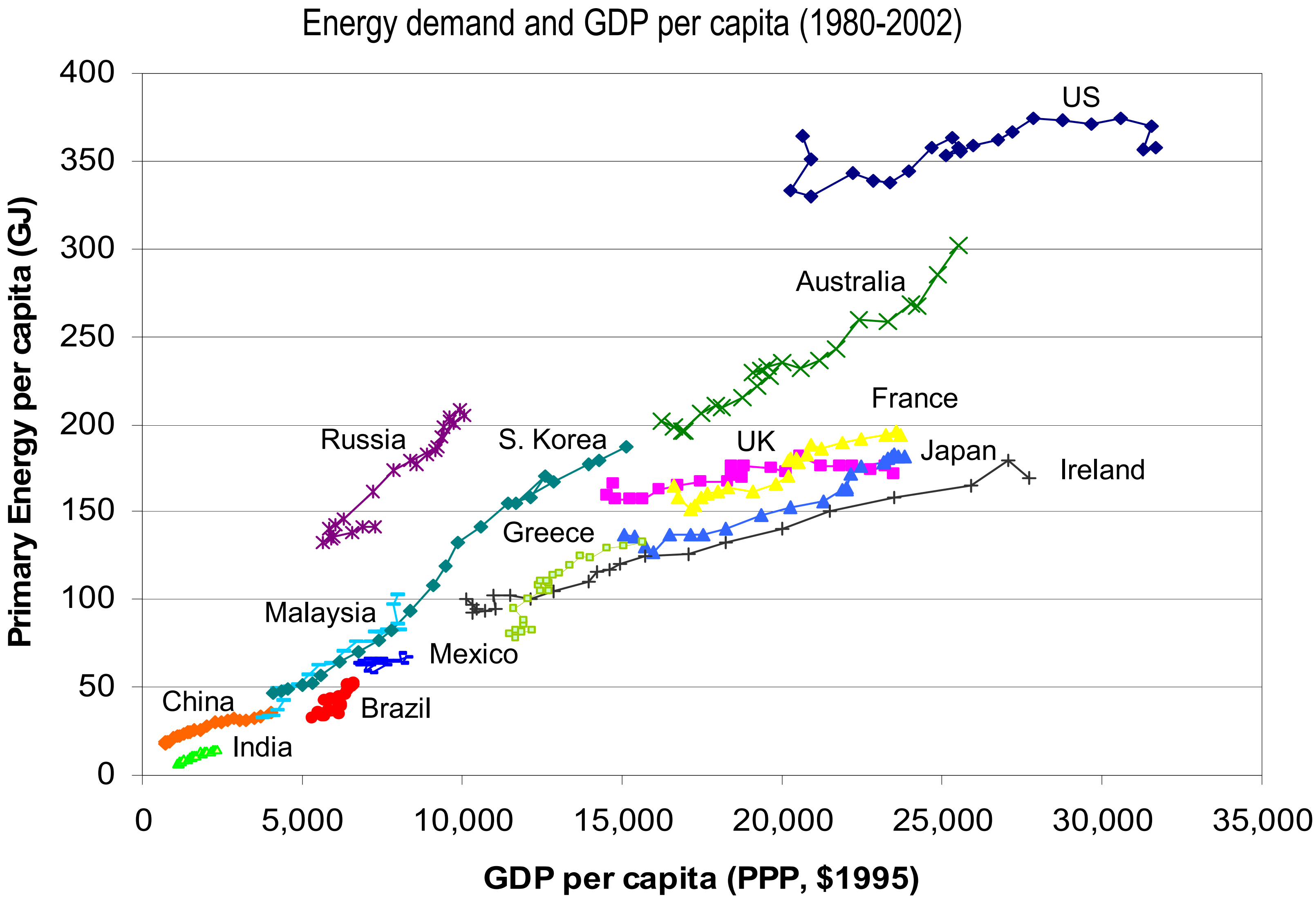






http://www.undp.org/energy

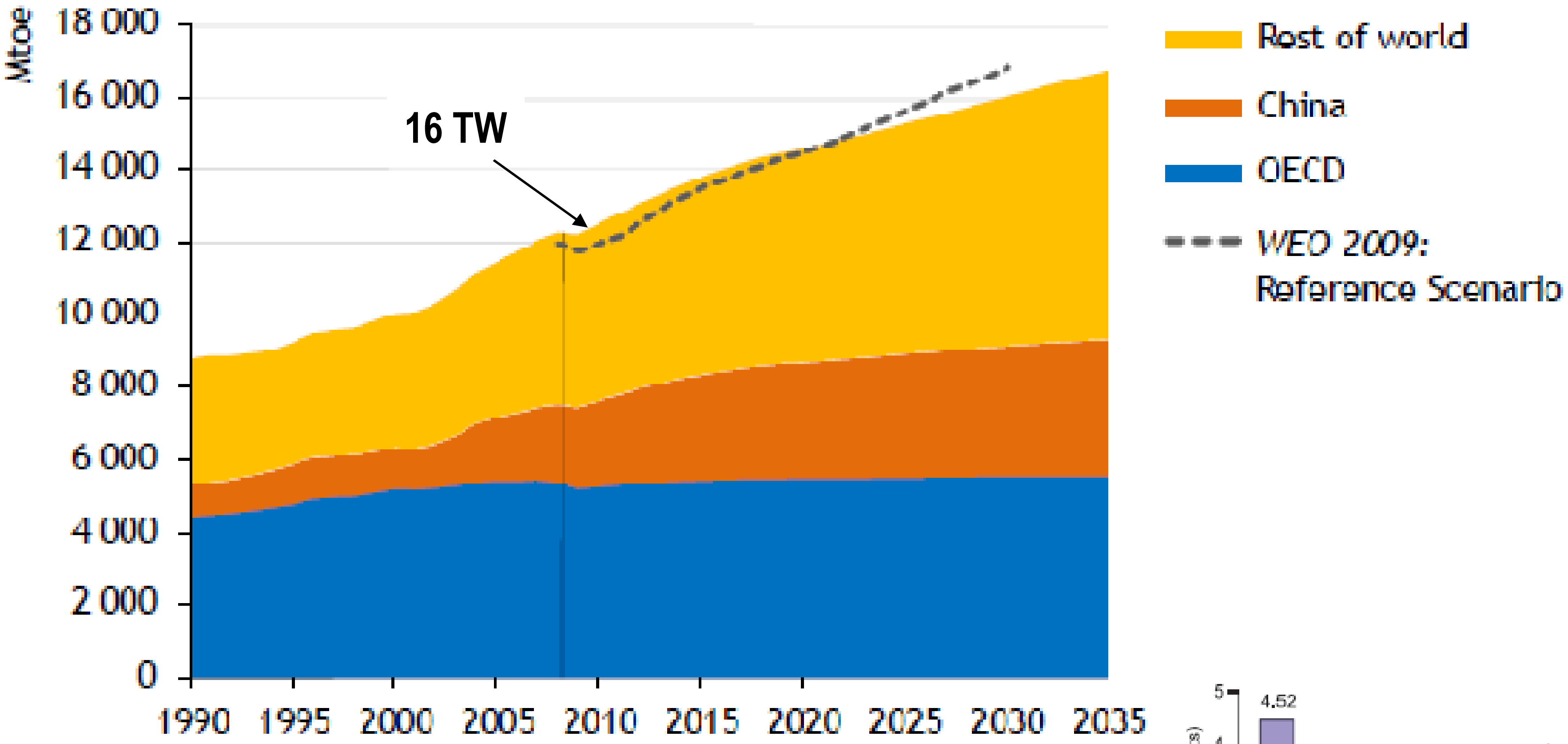
Rising demand - 2



Source: UN and DOE EIA, Slide courtesy of Steven E. Koonin, Chief Scientist, BP, plc

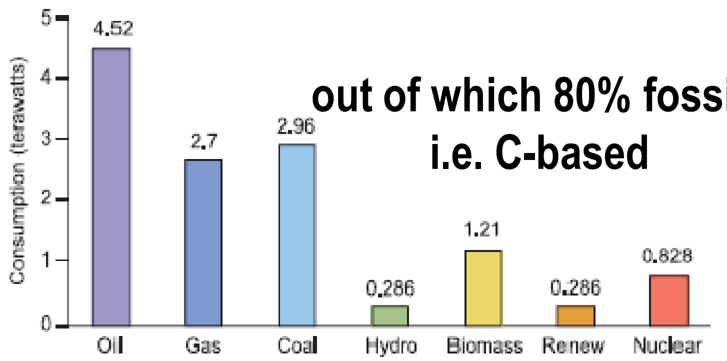
PPP = Purchasing Power Parity - A rate of exchange that accounts for price differences across countries allowing international comparisons of real output and incomes.

Rising demand - 3



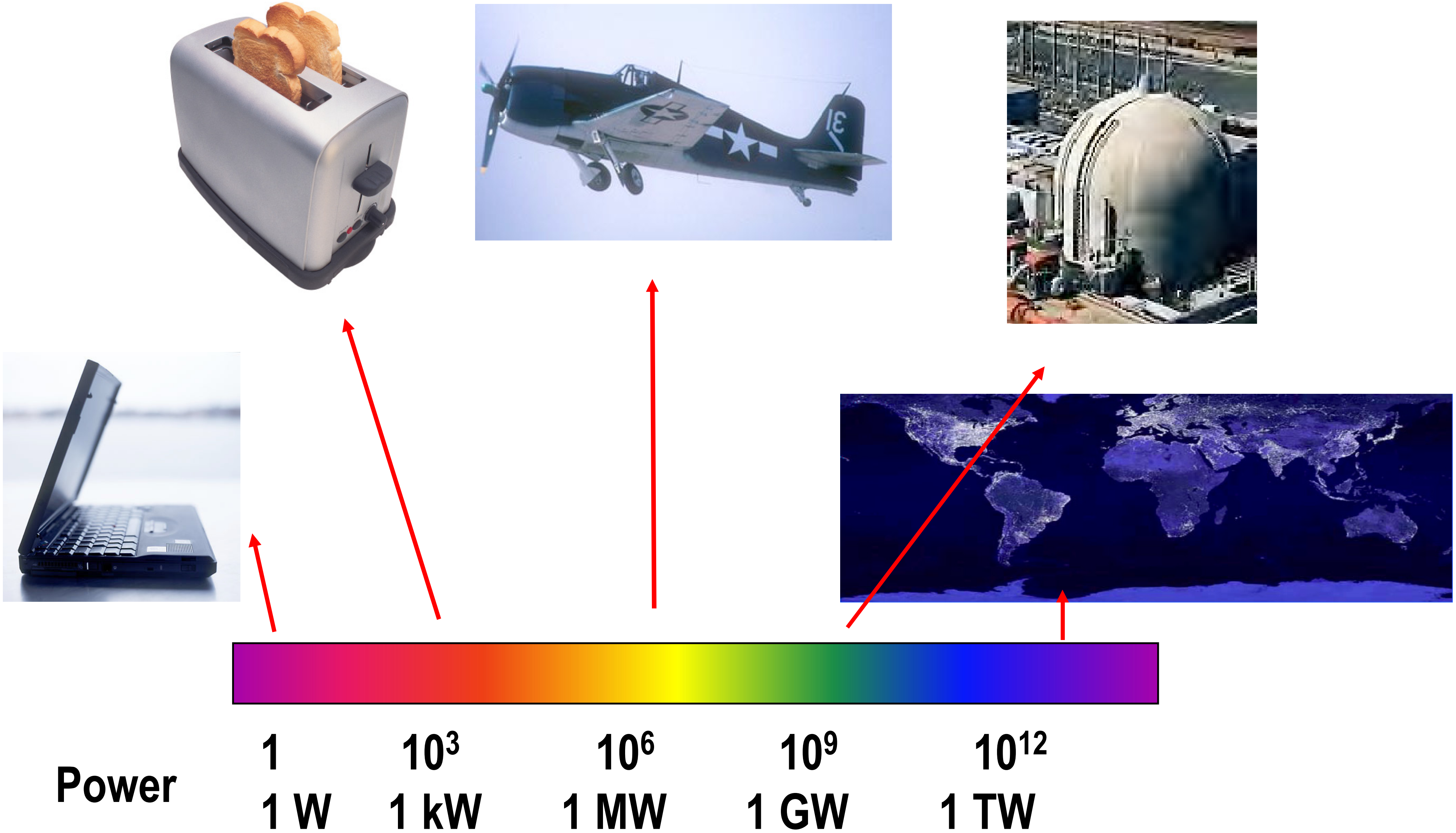
IEA WEO 2010

note: scenarios ≠ predictions !

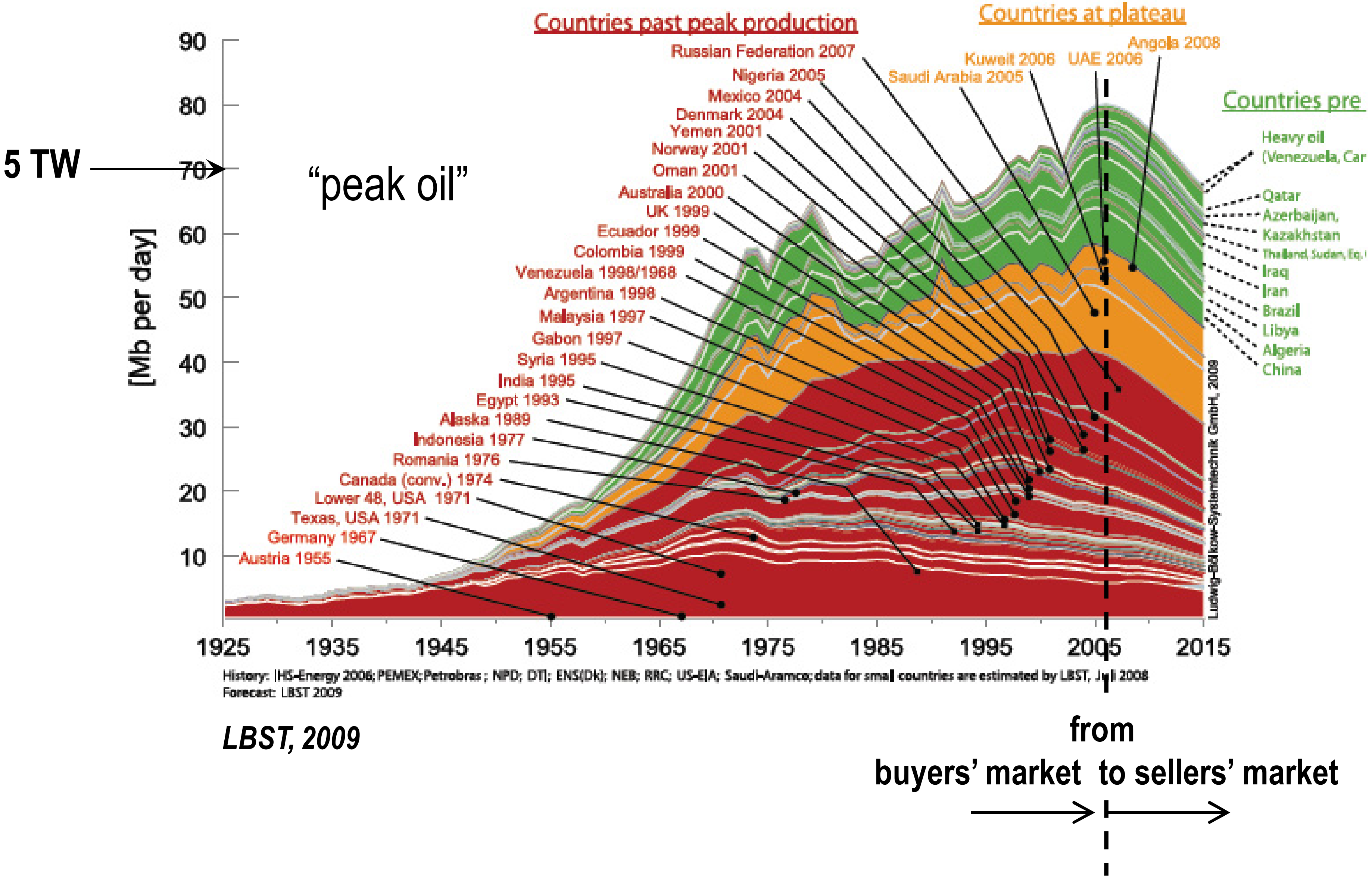


out of which 80% fossil, i.e. C-based

The Terawatt Challenge

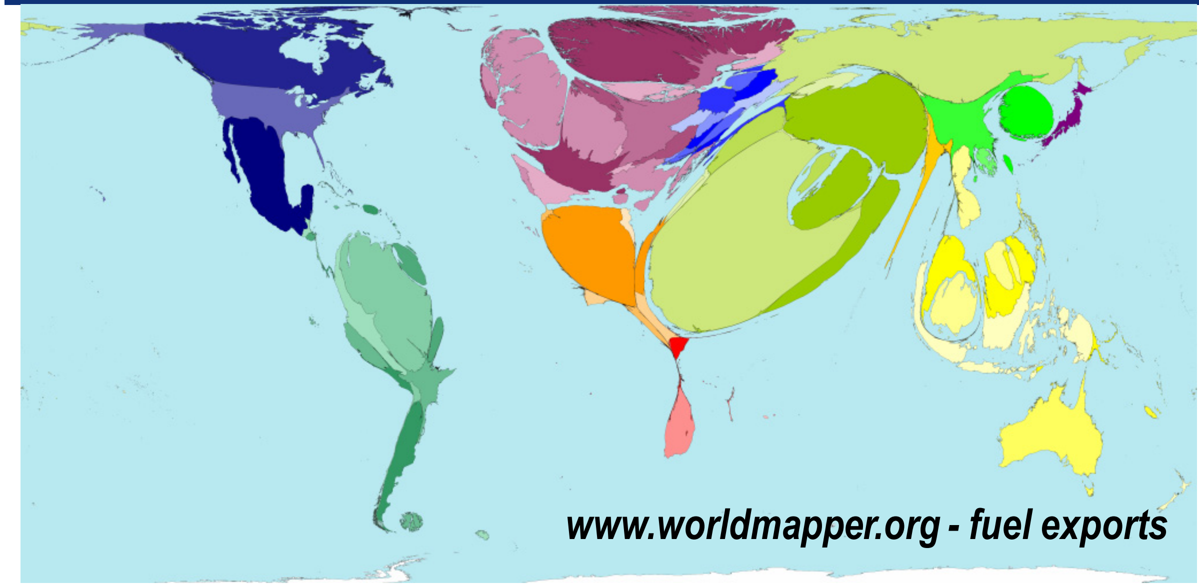


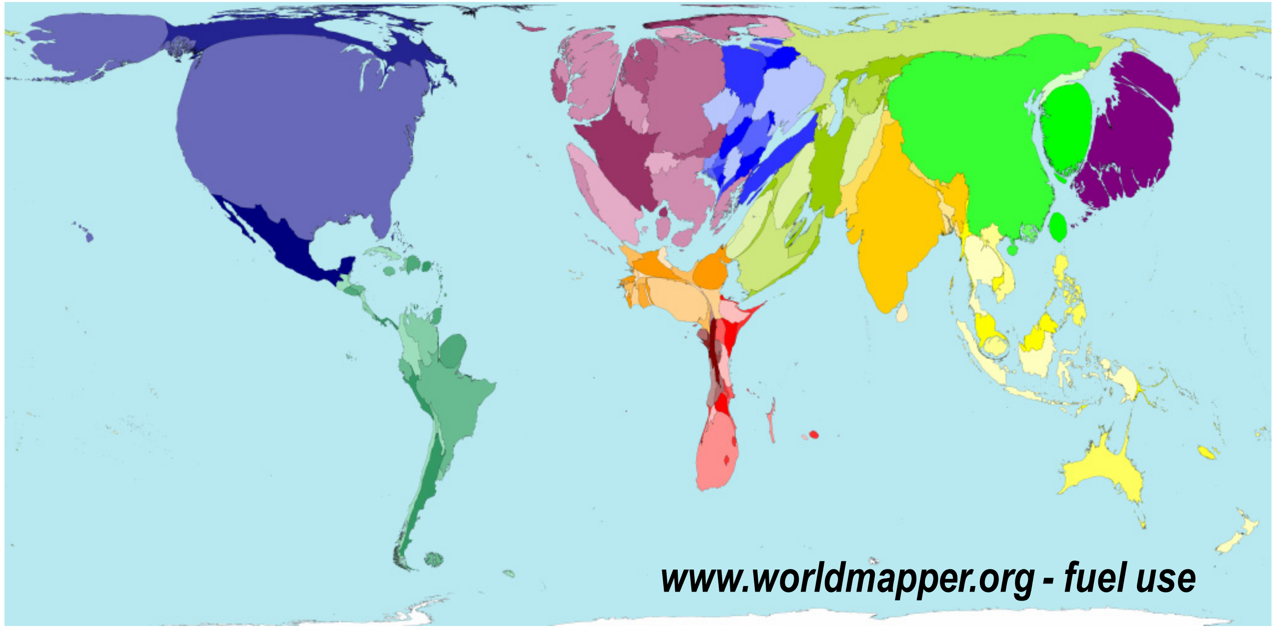
Security of supply - 1- fossil resources are finite



LBST, 2009

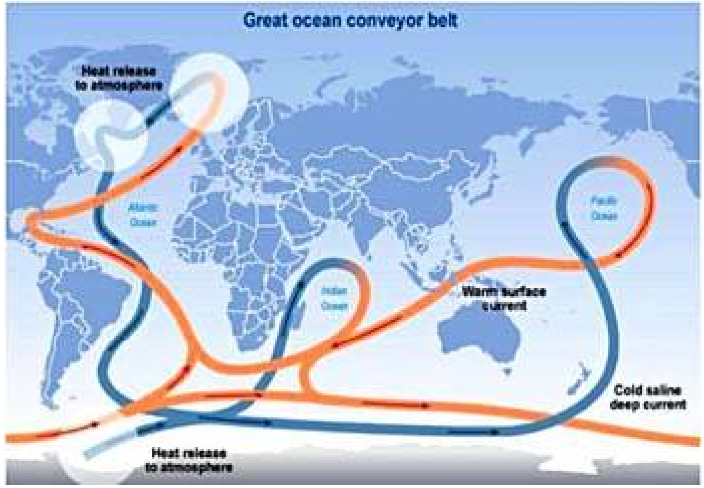
Security of supply - 2 - resources unevenly distributed





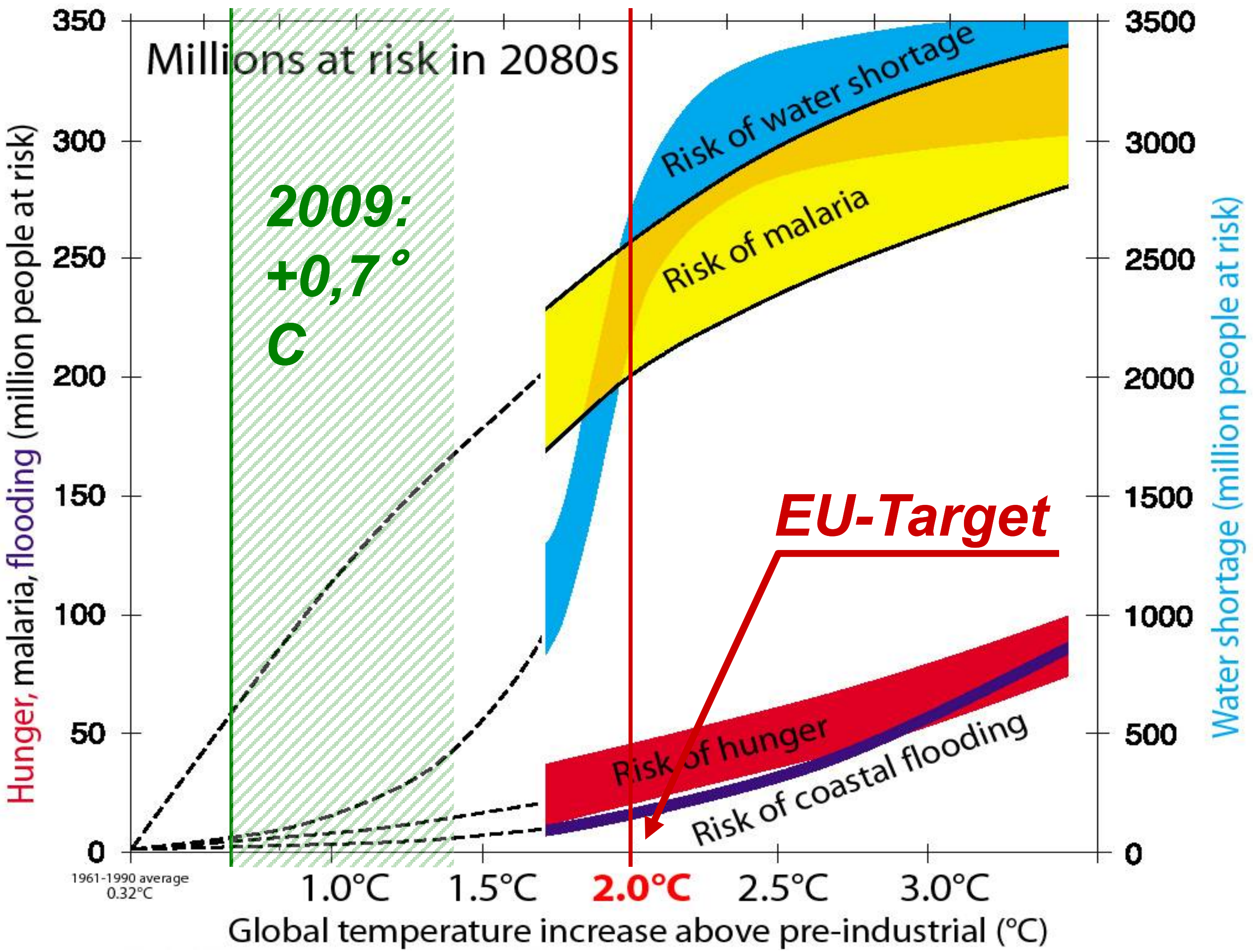
Global Climate Change

2010



? 2100 ?

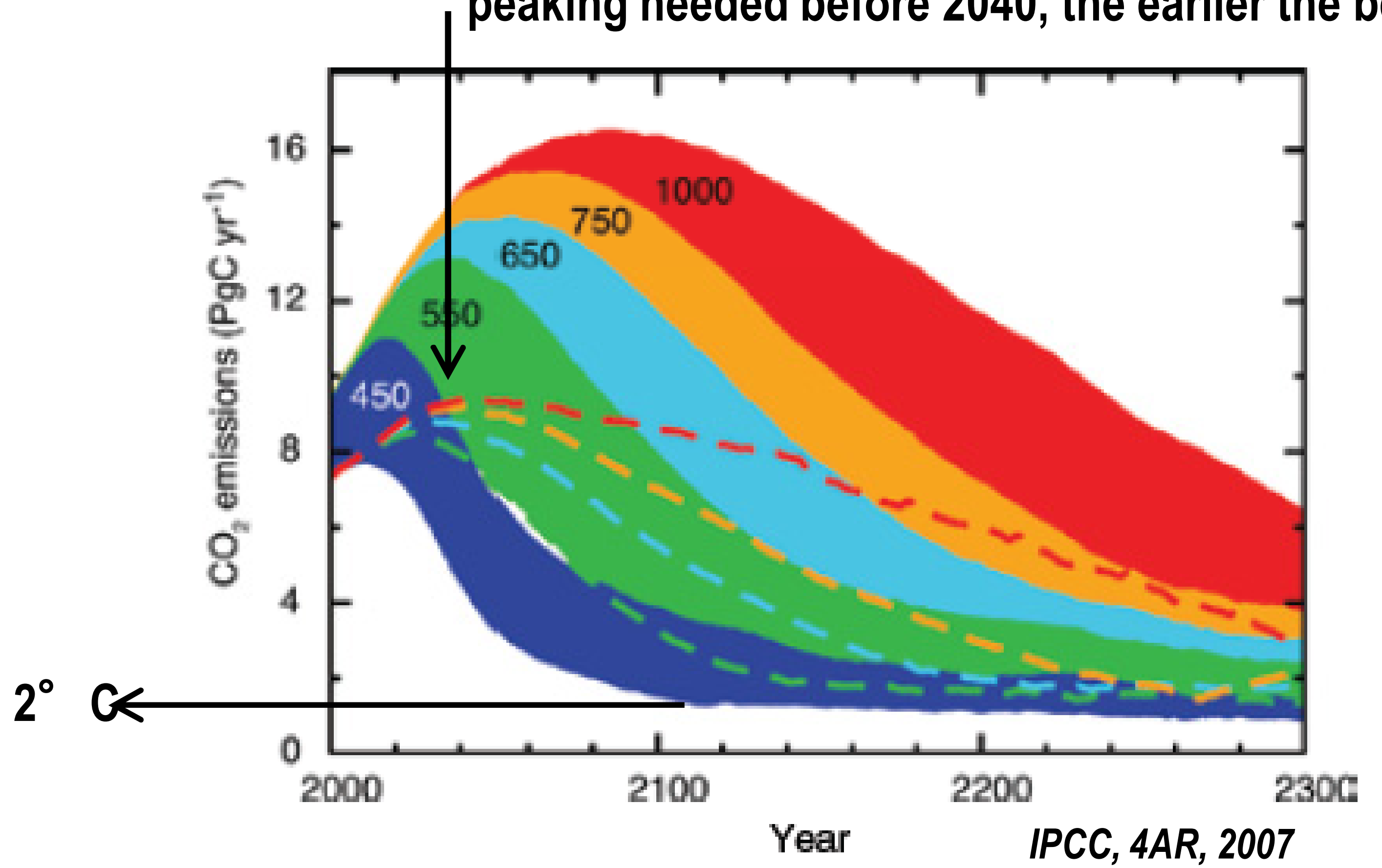
Climate Change is a top issue for the EU…



IPCC, Parry et al., 2001

from max. +2° C to max. CO_2 concentration

peaking needed before 2040, the earlier the better



IPCC, 4AR, 2007

Figure 3. Estimates of greenhouse gas emissions needed to achieve stabilization at a range of concentrations and temperatures (from Reference 5, p. 792). The dashed lines indicate the lower end of the estimated range needed to achieve stabilization at the respective values. The range of values reflects the uncertainty in predicting stabilization based on emissions profiles and the associated climate feedbacks.

Kaya Equation

CO_2 Emissions = Carbon content of energy x Energy intensity of economy x Production per person x Population

needs to be reduced by factor of 7.5

needs to be reduced by factor of 12

needs to be reduced by factor of 5

assume reduction by 80% until 2050

decrease by factor 2.5 (-1.8% per year)

increase by factor 1.65 (1% growth per year)

increase by factor 1.5

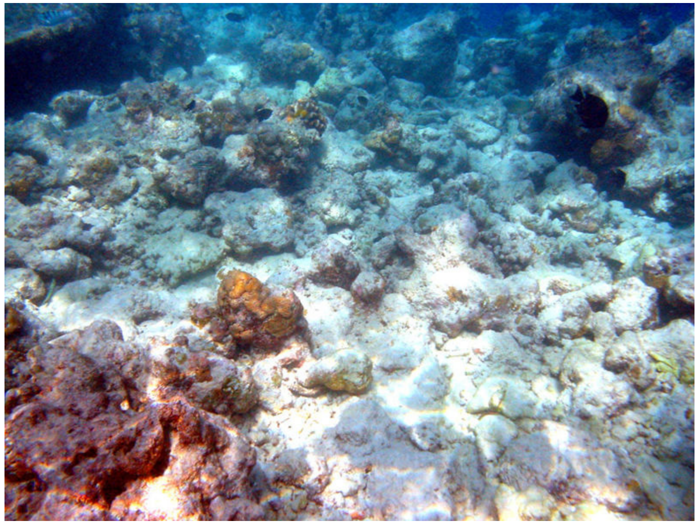
necessitates very strong expansion of ”carbon-free” energy sources

Do not forget: CO_2 is not all!!

permafrost thaw

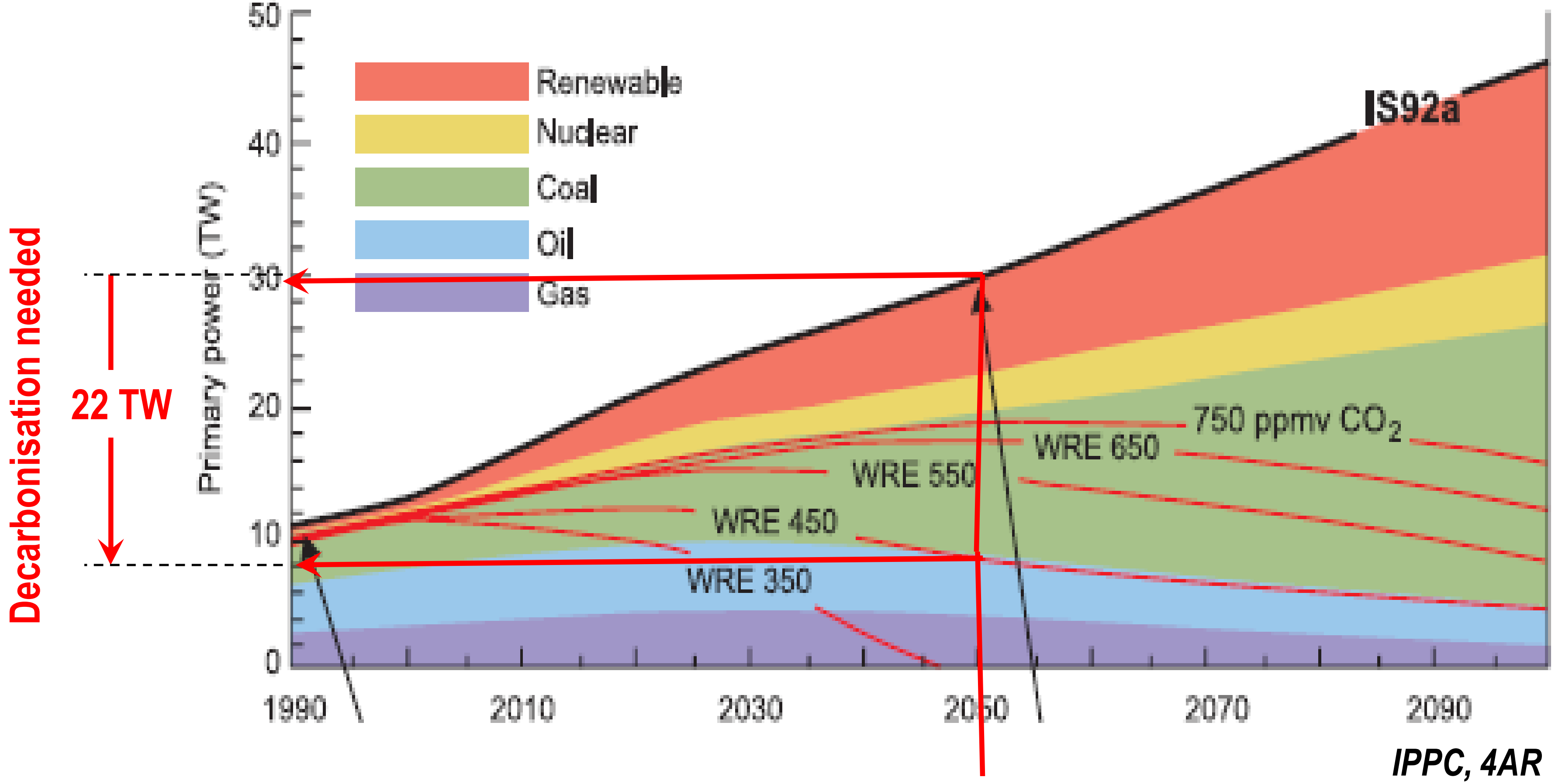
release of CH_4, much more powerful greenhouse gas

coral bleaching



food chain effects ….

What does 450 ppm imply?



IPPC, 4AR

1) **max. 8 TW carbon-based energy, i.e. <u>half</u> of today**
2) **needed carbon-free power = approx 1.5 times <u>total</u> power produced at present**

10 TW nuclear = 10000 plants of 1 GW in next 40 years = 2 new plants every 3 days!

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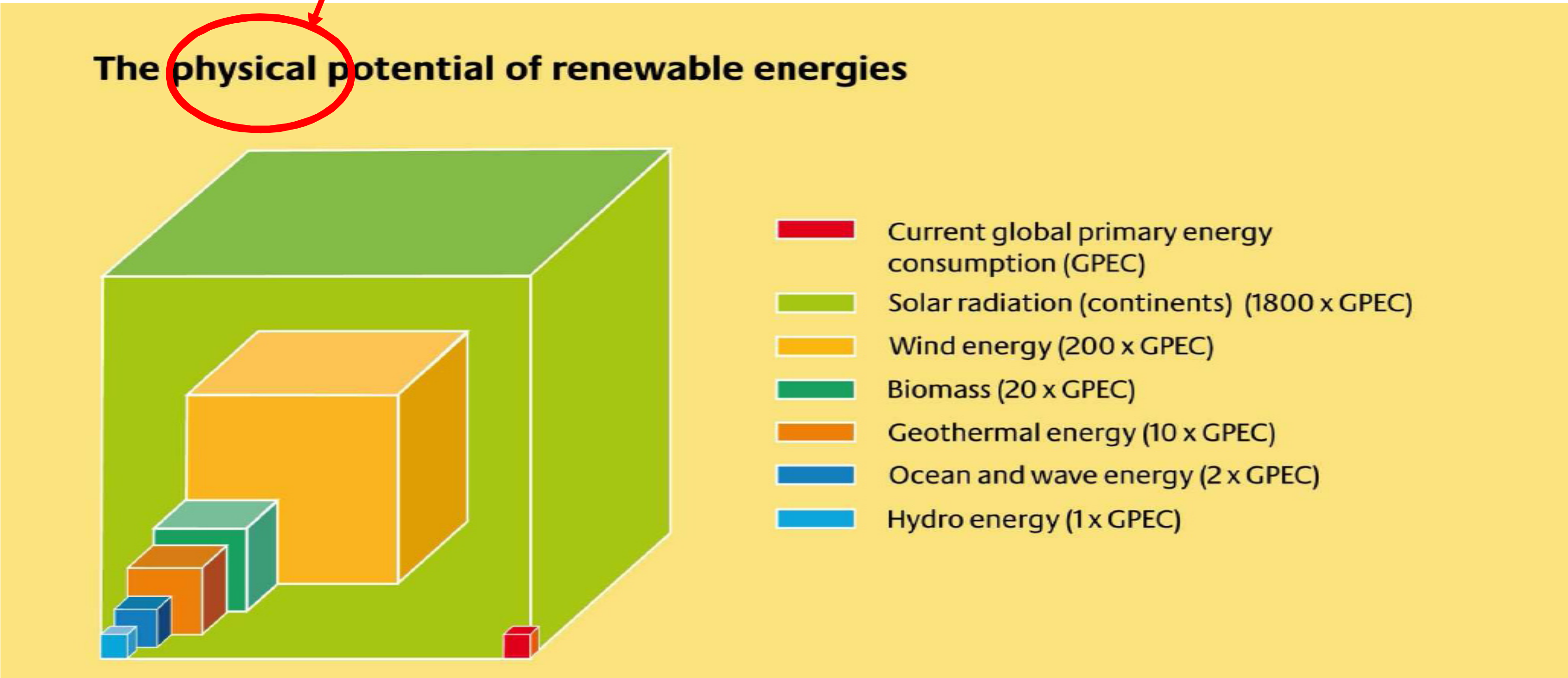
Role and contribution of hydrogen technologies

Additional slides

Decarbonisation: 22 TW through renewables?

Note: not practical potential for electricity generation!



Nitsch, DLR, 2007

1) physical potential is sufficient!

2) however, exploitation = technology + costs + other factors specific to the nature of the renewable energy source

Renewable energy potential

technological

storage grid

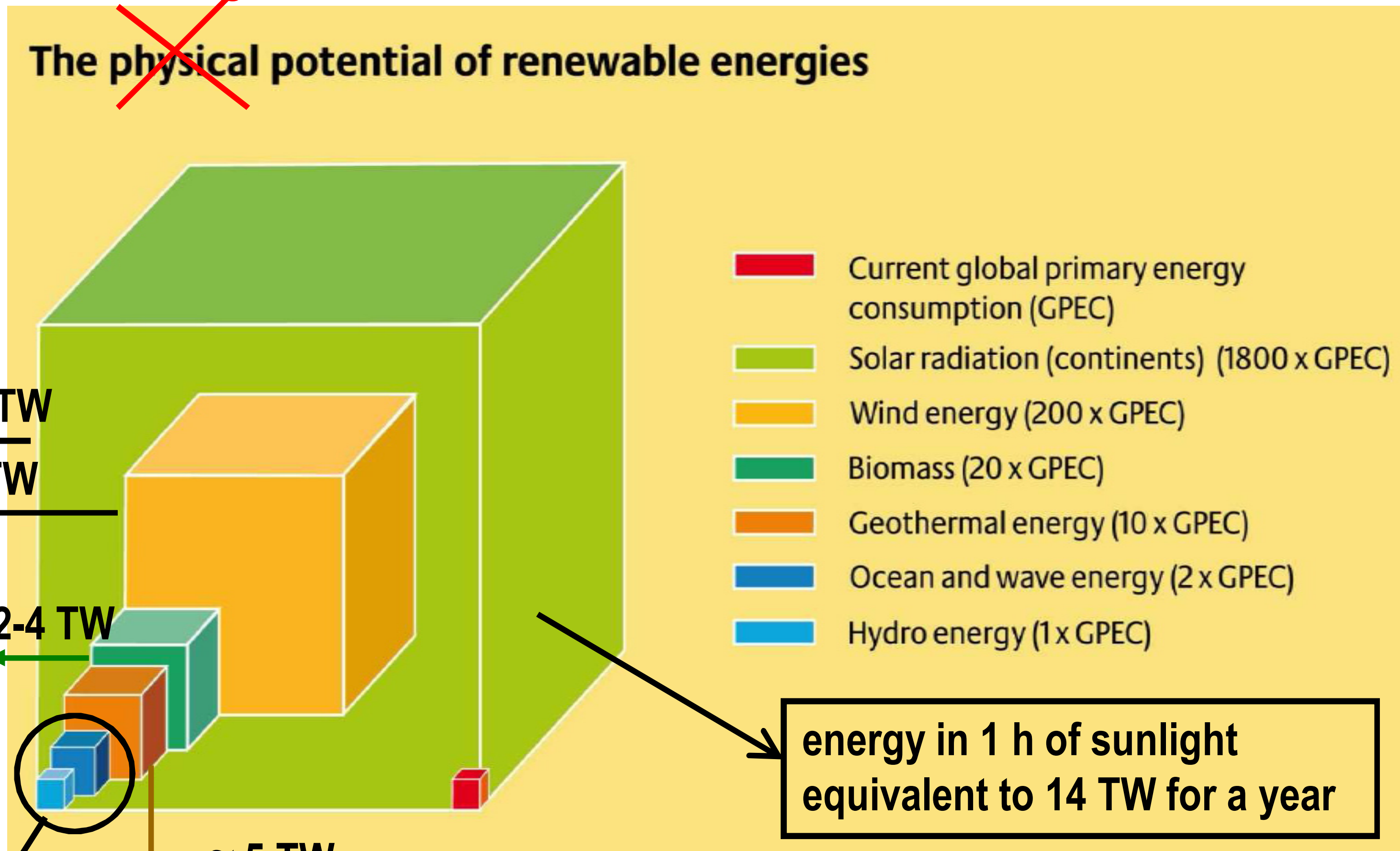
- intermittency
- remoteness
- NIMBY

>10 TW

2 TW

- surface area
- competition with food
- sustainability
- logistics
- fresh water needs
- energy & materials input

2-4 TW



energy in 1 h of sunlight equivalent to 14 TW for a year

≈ 5 TW

too little

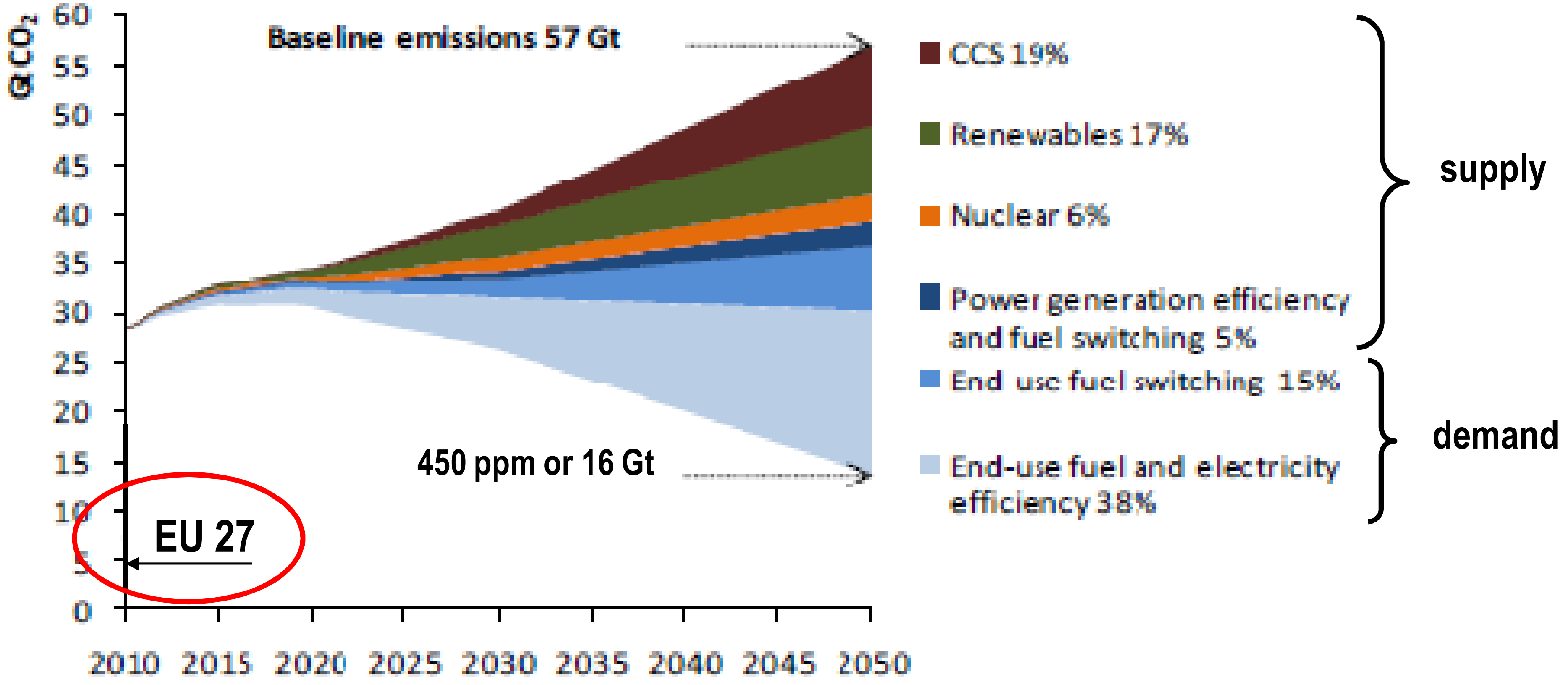
- drilling technology breakthrough
- largest potential in oceans

but electricity cannot be stored

in addition: cost considerations
RES << 22 TW

N. S. Lewis, Powering the Planet, 2007

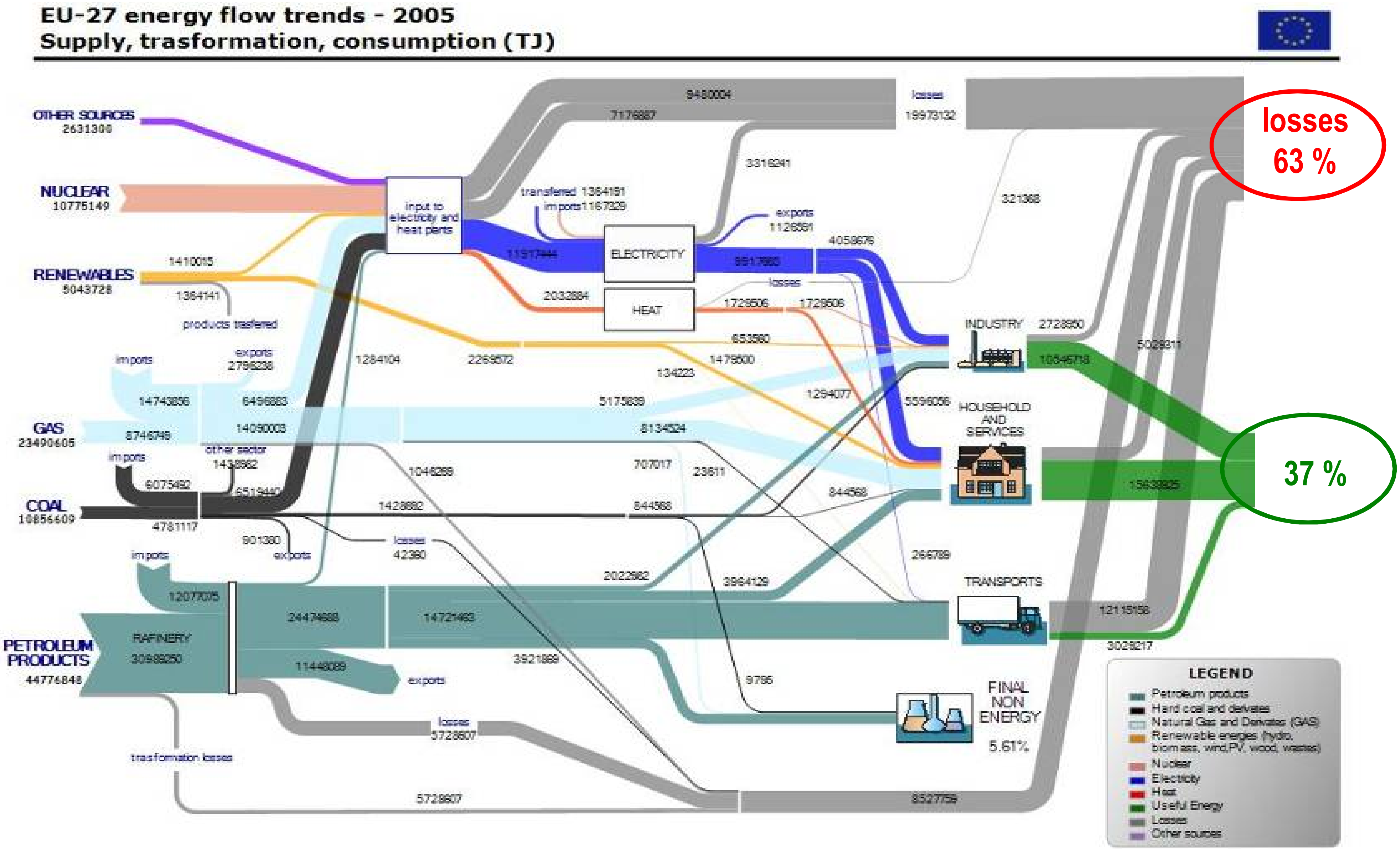
Decarbonisation requires supply and demand measures



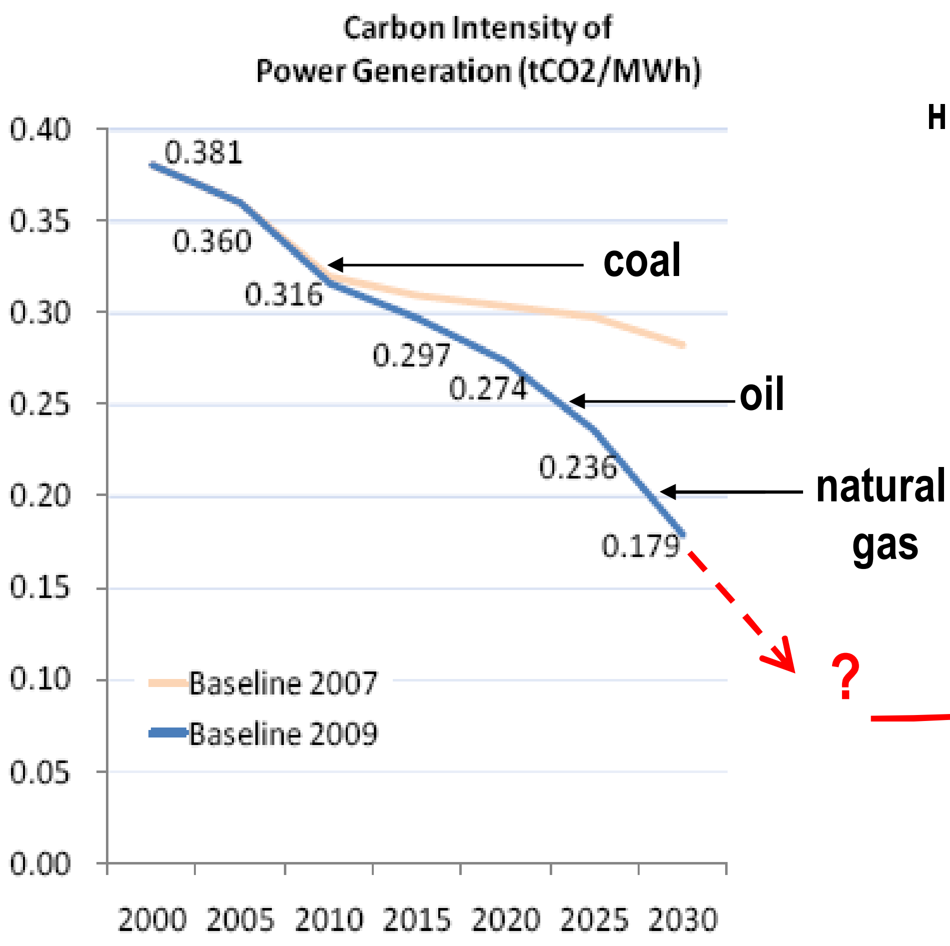
IEA WETO 2010

1) lowest cost contribution: EFFICIENCY, through technology + behavioural change
2) wide range of generation technologies needed
3) EU contribution small

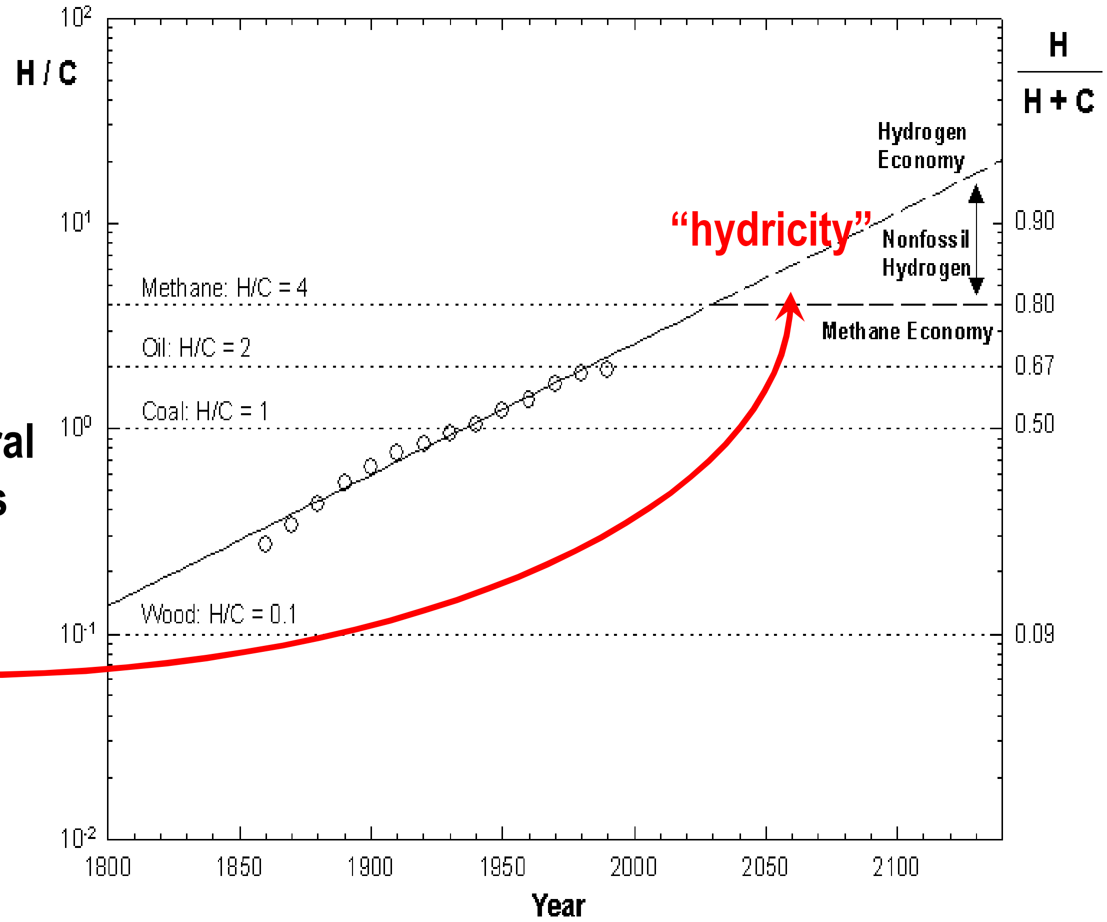
Sankey diagram - EU



Decarbonisation of EU power generation



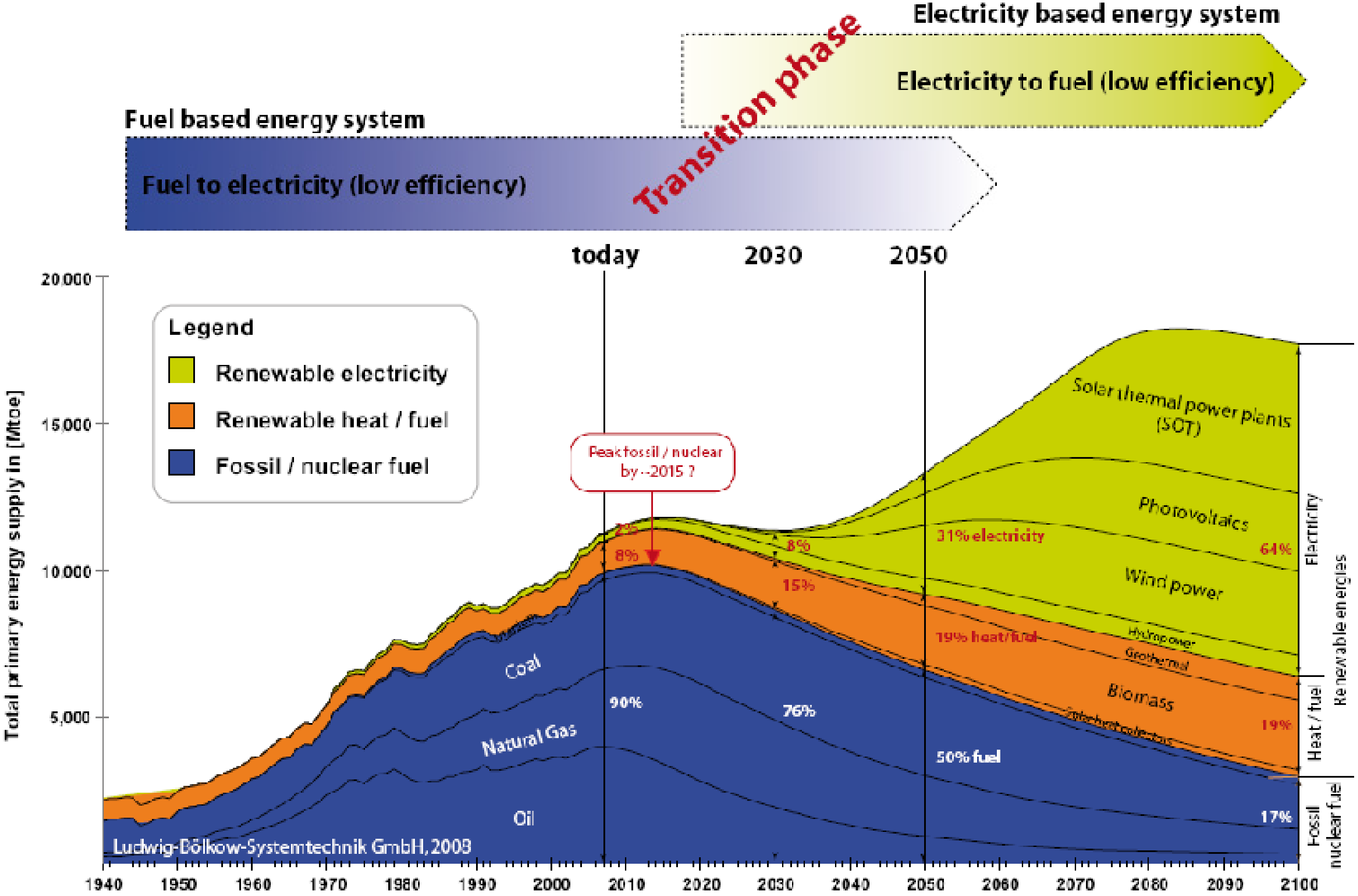
EC – trends to 2030



Nakisenovic, 2008

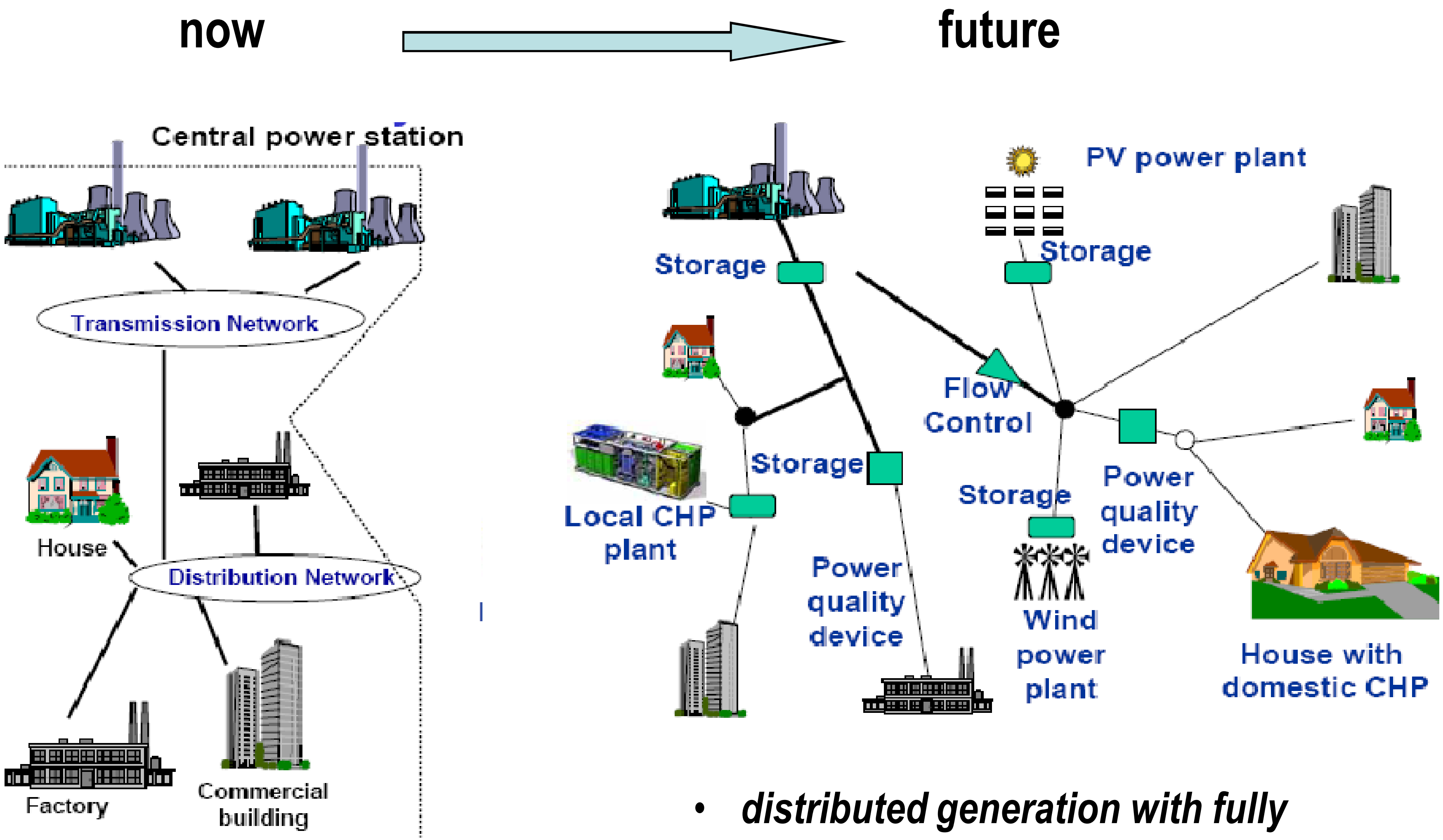
Decarbonisation is there, ***further decarbonisation requires hydrogen!***

Decarbonisation = transitioning



Source EHA

Changing energy landscape



- *distributed generation with fully integrated network management*
- *from consumers to "prosumers"*

very serious cost implications

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Role and contribution of hydrogen technologies

Additional slides

All I'm saying is **now** is the time to develop the technology to deflect an asteroid.

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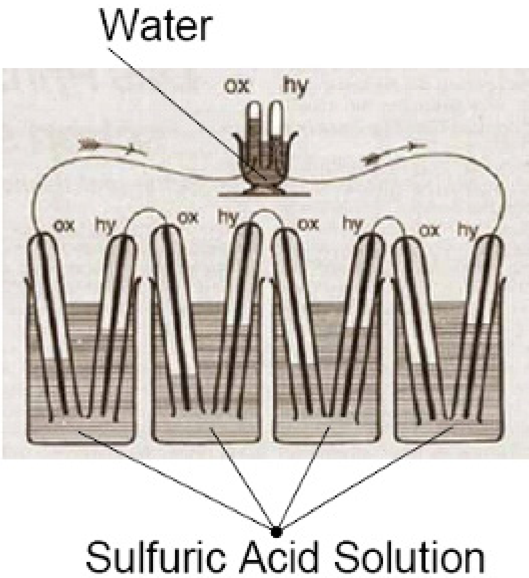
Hydrogen: enabler of CO_2 emission reduction

- H2 is a energy carrier like electricity, but not an energy source
- H2 can be produced from a variety of sources, hence contributes to diversification and security
- H2 is transportable & storable
- H2 is does not produce any emissions at point of use
- H2 can provide full range of energy services: heat, electricity & transportation

Hydrogen technologies are not new

Christian Friedrich Schönbein
(1st publication on FC 1838)

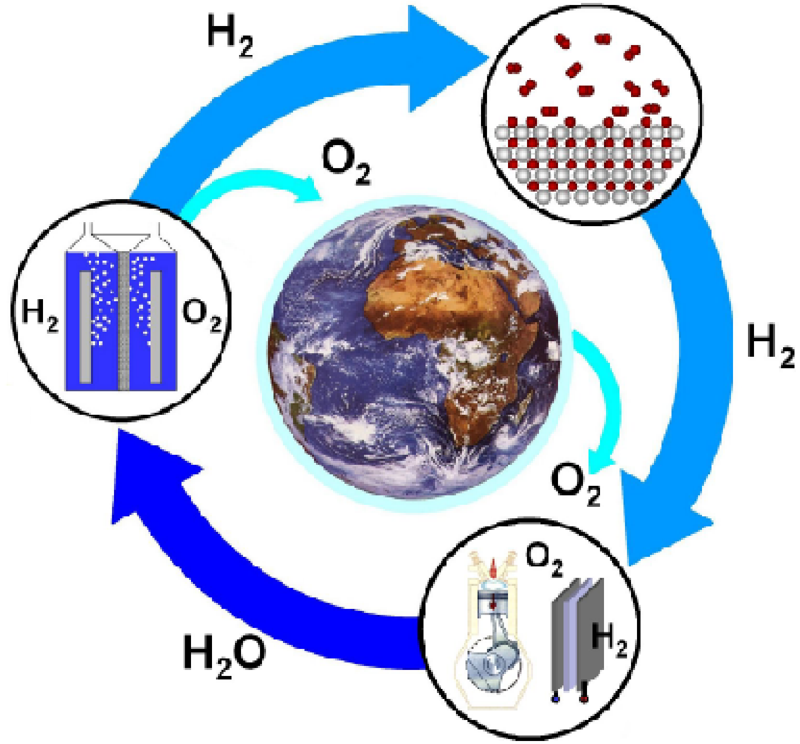


William Grove
(1st FC 1839)

Zeppelin patented in 1899

First FC commercial product:
GE 1955 for NASA

H2 – water cycle

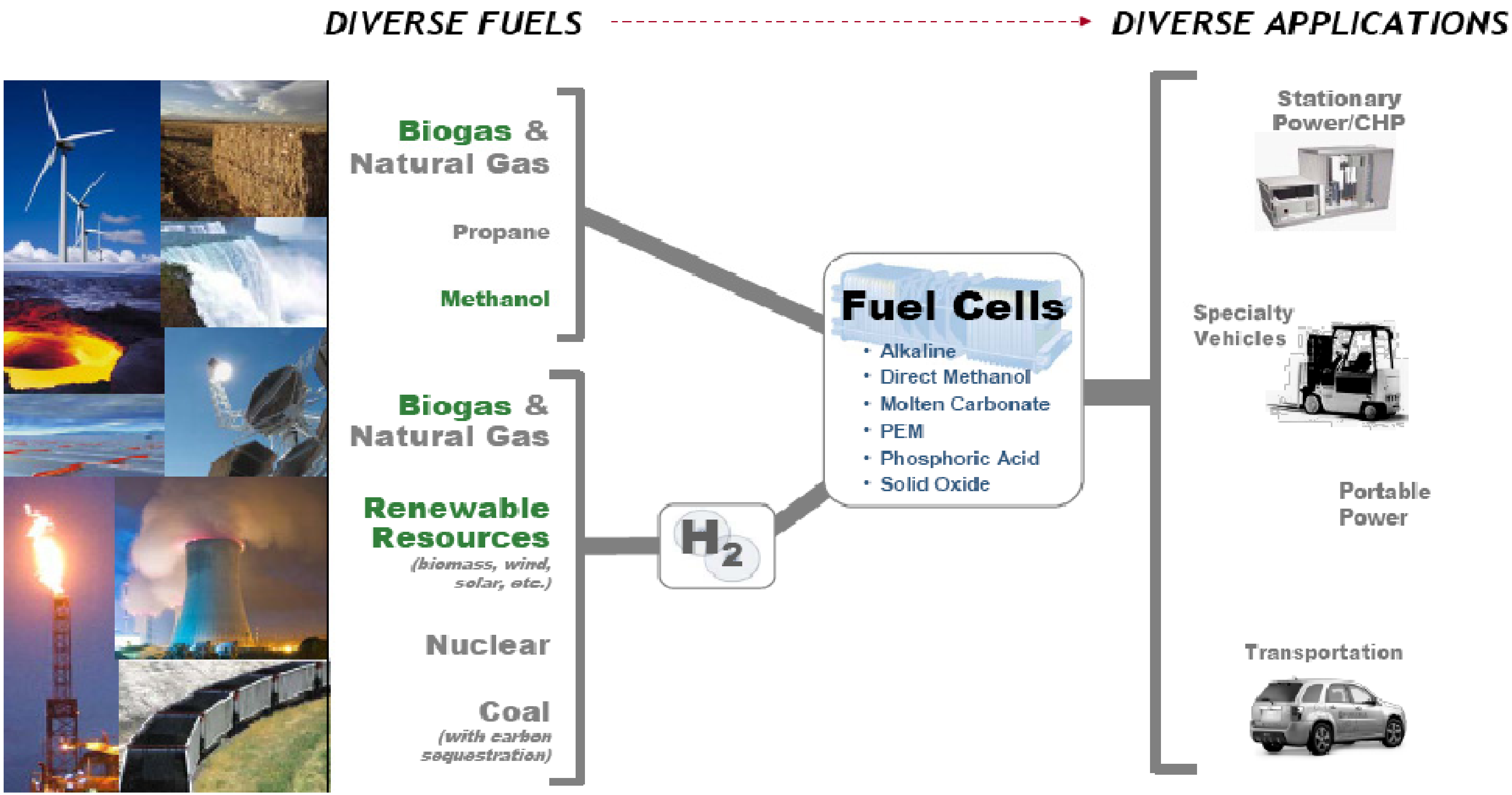


H2 is created from water by injecting energy at the point of production from any source—photons, electrons, or heat.

Water is created from H2 when energy is released at the point of use, by electro-oxidation to electrons and heat in fuel cells, or combustion to heat in engines or turbines.

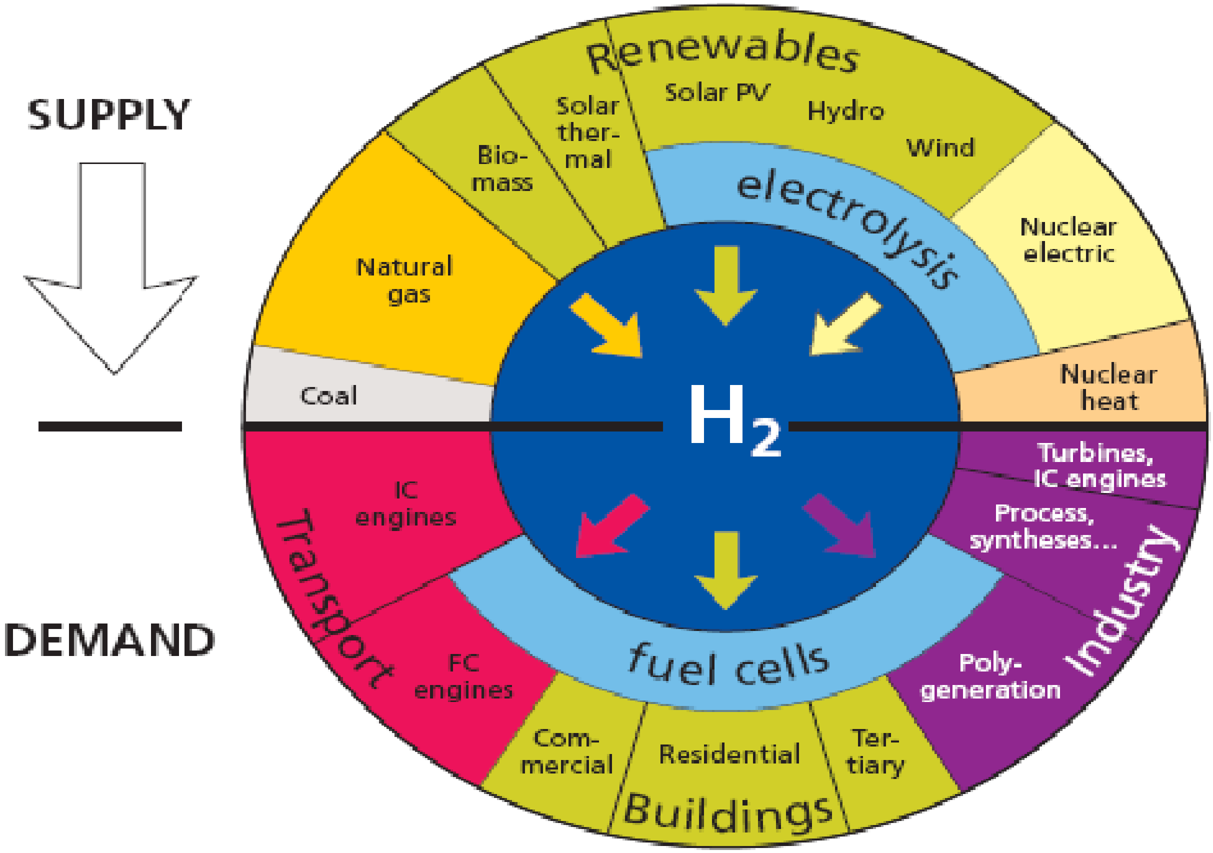
- H2–H2O cycle is closed and sustainable
- the associated energy chain can be open and depletable
- no emissions at point of use, overall use is as clean as H2 production method, sustainability is maintained if renewable energy is used to split water

Adapted from Züttel (2009), MRS Bulletin (April 2008)


DIVERSE FUELS
DIVERSE APPLICATIONS
Biogas & Natural Gas
Propane
Methanol
Biogas & Natural Gas
Renewable Resources
(biomass, wind, solar, etc.)
Nuclear
Coal
(with carbon sequestration)
H2
Fuel Cells
• Alkaline
• Direct Methanol
• Molten Carbonate
• PEM
• Phosphoric Acid
• Solid Oxide
Stationary Power/CHP
Specialty Vehicles
Portable Power
Transportation

Source DoE

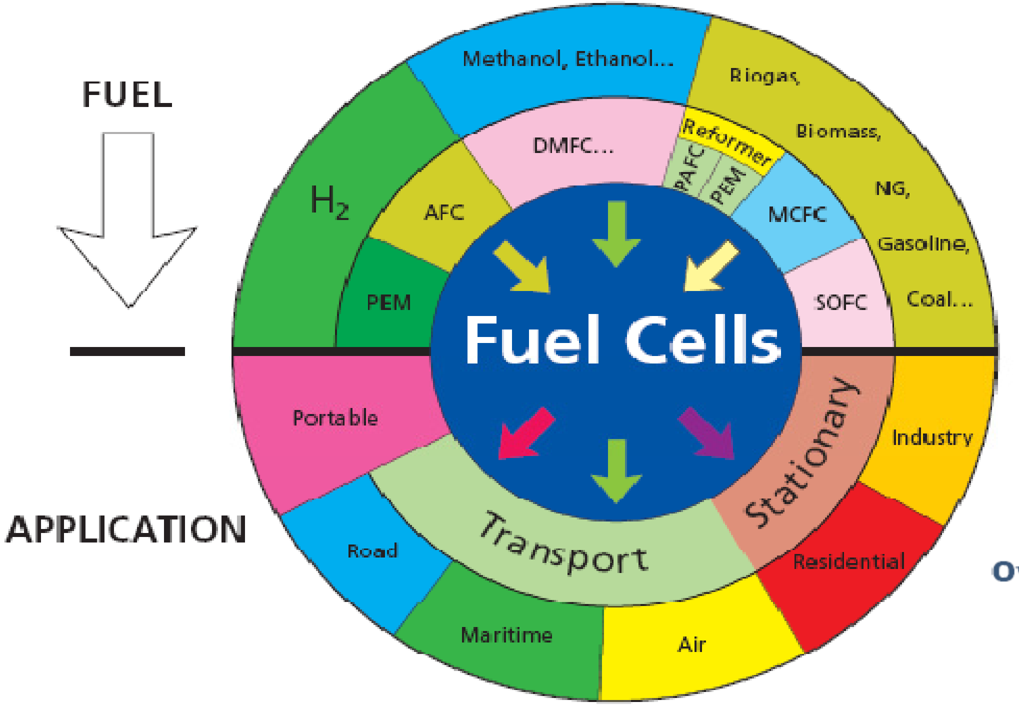
The Hydrogen Circle



Source EC: Hydrogen Vision

EUROPEAN COMMISSION

The Fuel Cell Circle



Overall Benefits

- **Efficiency:** >2x more efficient than internal combustion engines; > 80% energy efficiency possible with combined-heat-and-power
- **Fuel Flexibility:** Can use hydrogen from a variety of domestic resources (including renewable, nuclear, and fossil-fuel sources)

Transportation

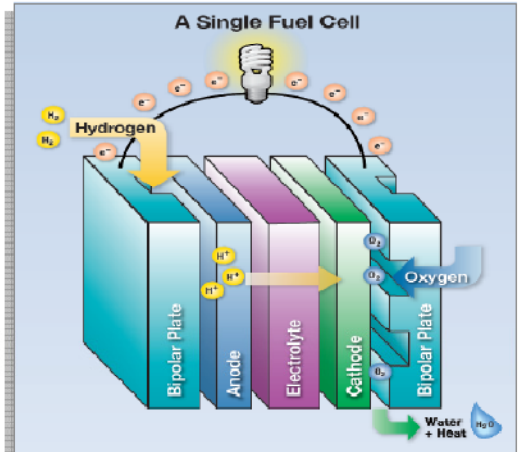
- Reduce dependence on oil
- Zero-emission vehicles

Stationary Power

- Improved reliability in electric power generation, including storage of intermittent renewable power sources
- Reduced greenhouse gas (GHG) emissions

Portable Power

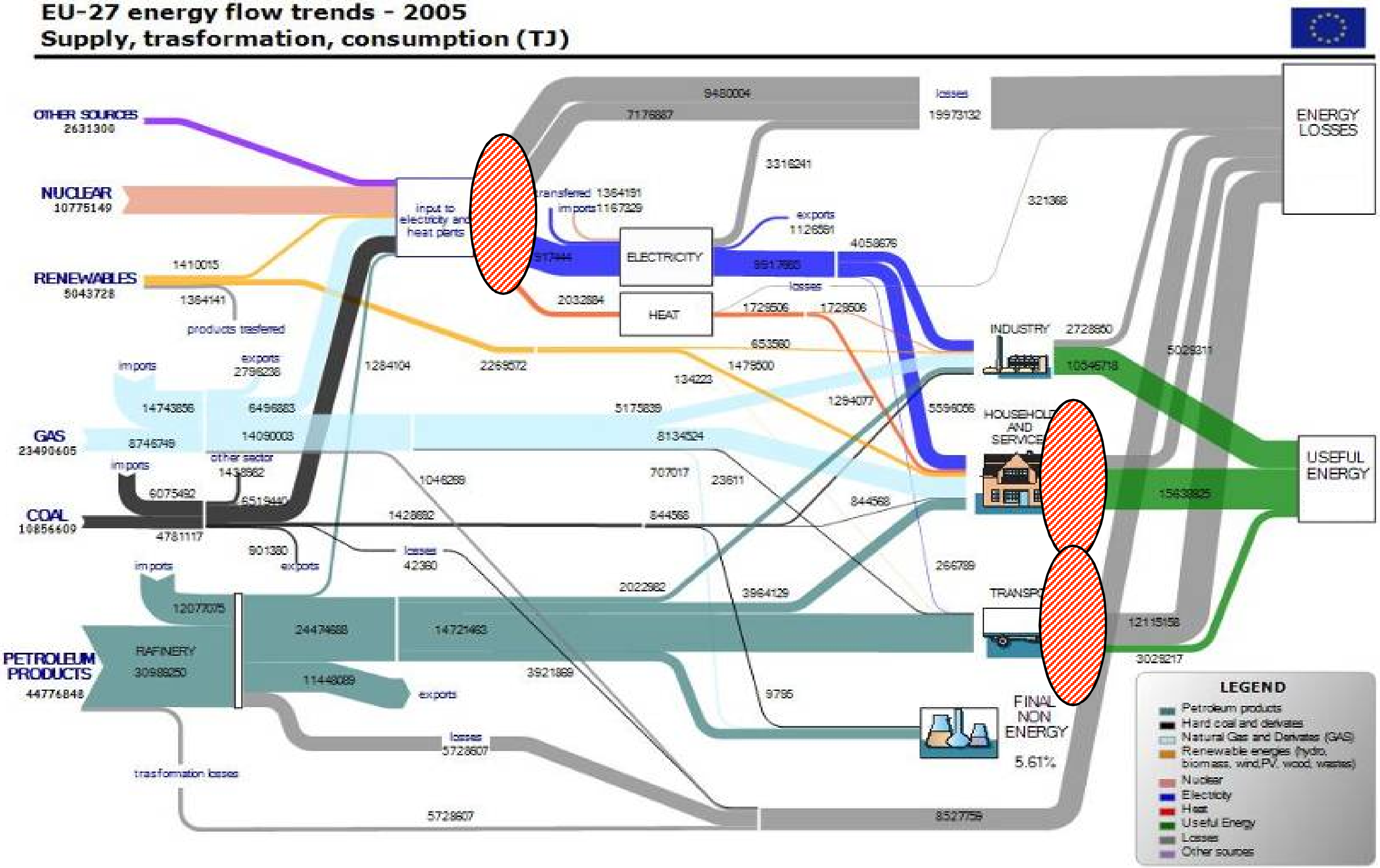
- Greater energy capacity (longer lifetime) for portable electronic devices



- Fuel cells use hydrogen and oxygen to generate electricity through an electrochemical reaction.
- The only by-products are water and heat.
- Single cells are stacked in series to produce the voltage needed to power cars, buses, homes, or portable devices.

Source EC: Hydrogen Vision

Fuel Cell Potential in the Energy Chain



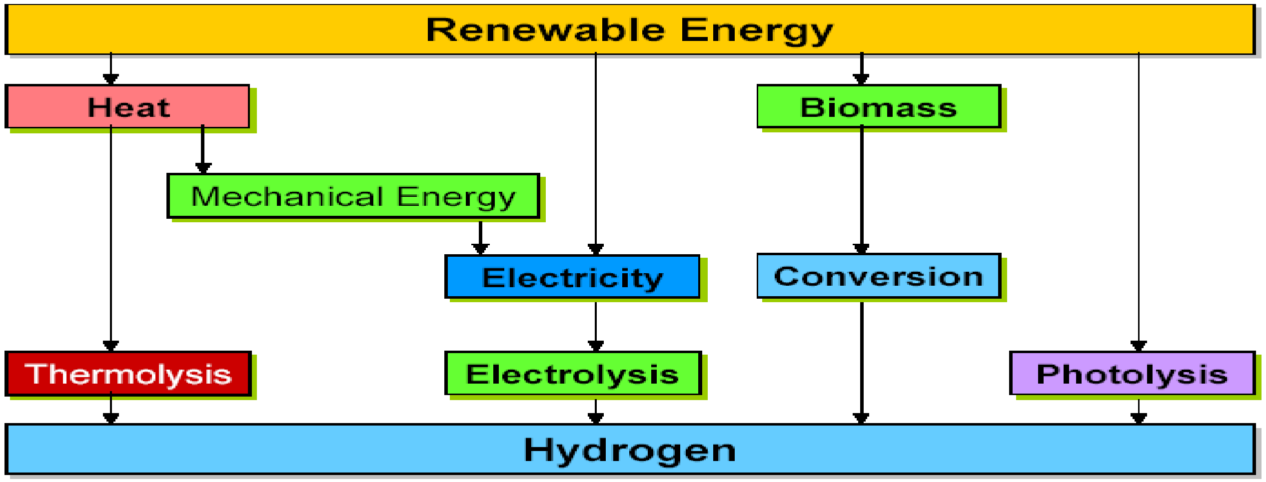
Fuel cells should be used where

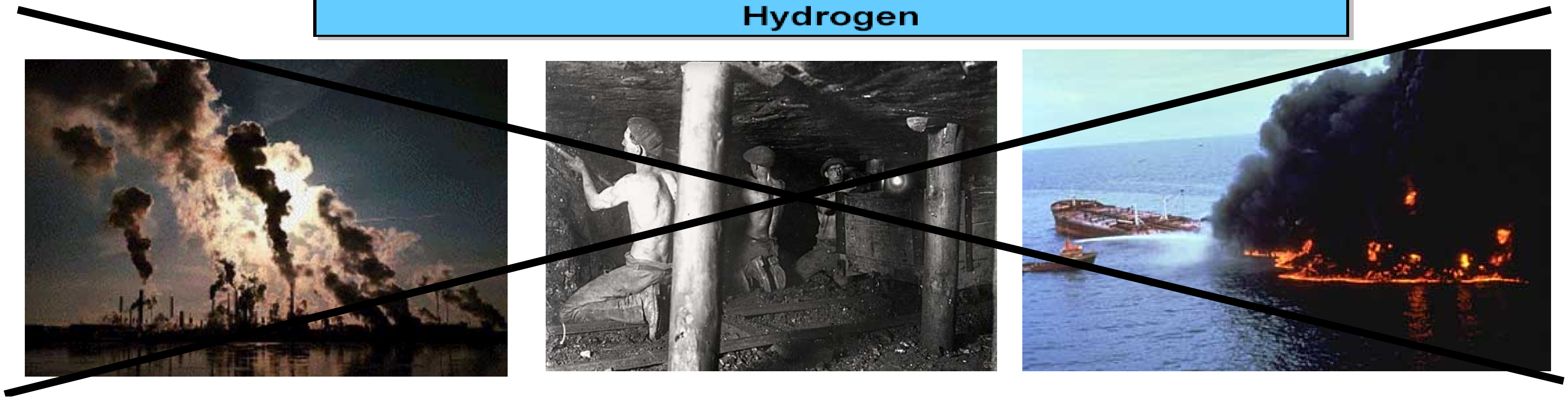
- **they create the biggest efficiency gains, and thereby carbon reductions**
- **they contribute optimally to relieving the grid: stationary applications in distributed generation**

Not all fuel cell types use exclusively hydrogen as a fuel

Hydrogen in the Energy Chain

- H2 is an energy carrier, it must be produced
- a particular H2 production pathway can only be justified if it reduces carbon emissions compared to alternatives and it must be cost-effective
- ultimate goal: zero-carbon energy cycle from generation to use









Combination of H2 from RES and FC allows realisation of the ultimate goal of zero-carbon cycle

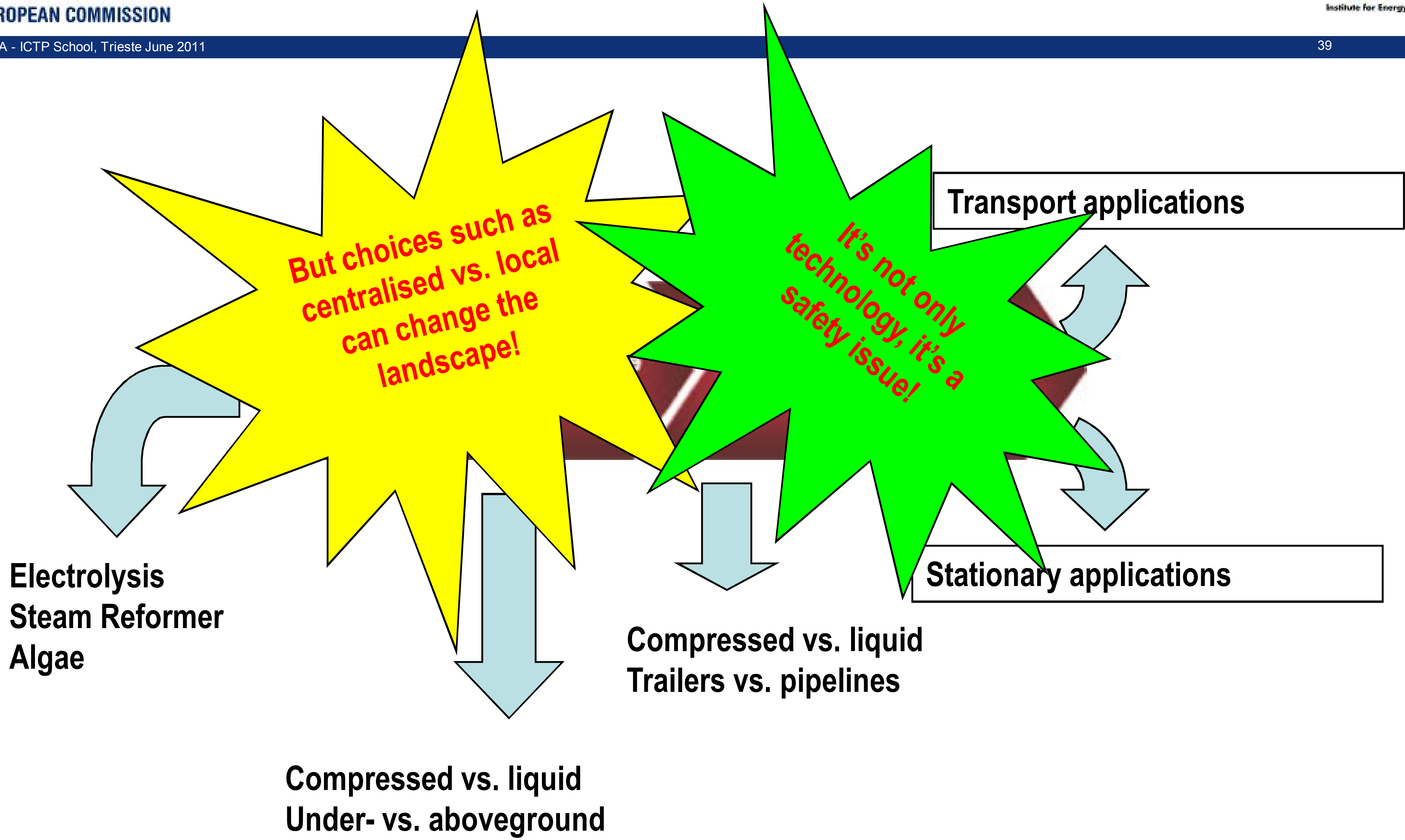




but

- RES intermittency and not enough available yet
- chain conversion efficiency (e.g. 80% electrolyser x 50% fuel cell)
- H2 storage & transport: non-negligible losses of H2 energy content

Link to 2nd presentation



Recap: the nature of the energy problem

Facts

1. Energy is the largest-ever societal challenge at global level
2. The world is NOT running out of energy, but it is running out of:
   - cheap energy sources (oil in particular)
   - environmental adaptation possibilities
   - time for a non-disruptive transition and for investments for implementing other, newer technology options
3. Technology progress is absolutely critical and there is not a single silver bullet!
4. New technology options and societal needs based on renewables require a re-vamp of the centralised power generation system
5. Technology and infrastructure choices of today determine the energy landscape of 2050
6. Hydrogen and fuel cells are part of the solution

action is needed now!

"will we look into the eyes
of our children and confess
that we had the **opportunity**, but lacked the **courage?**
that we had the **technology**, but lacked the **vision?"**

R. Smalley

Thank you for your attention!

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Additional slides – ordered according to main presentation

Time to depletion of current world reserves

Natural Gas (in cubic meters)

Total world reserves Jan. 1st 2010:	171514266542404
World usage per second:	92653
Estimated date of exhaustion:	09:25 Sep 12, **2068**

Oil (in barrels)

Total world reserves Jan. 1st 2010:	1175686472626
World usage per second:	986
Estimated date of exhaustion:	20:58 Oct 22, **2047**

Coal (in metric tonnes)

Total world reserves Jan. 1st 2010:	834684384000
World usage per second:	203
Estimated date of exhaustion:	20:05 May 19, **2140**

Uranium (in metric tonnes U-235)

Total world reserves Jan. 1st 2010:	17963
World usage per second:	0.000042222017
Estimated date of exhaustion:	23:12 Nov 28, **2144**

www.energy.eu

note: reserves (i.e. proven supply) ≠ resources

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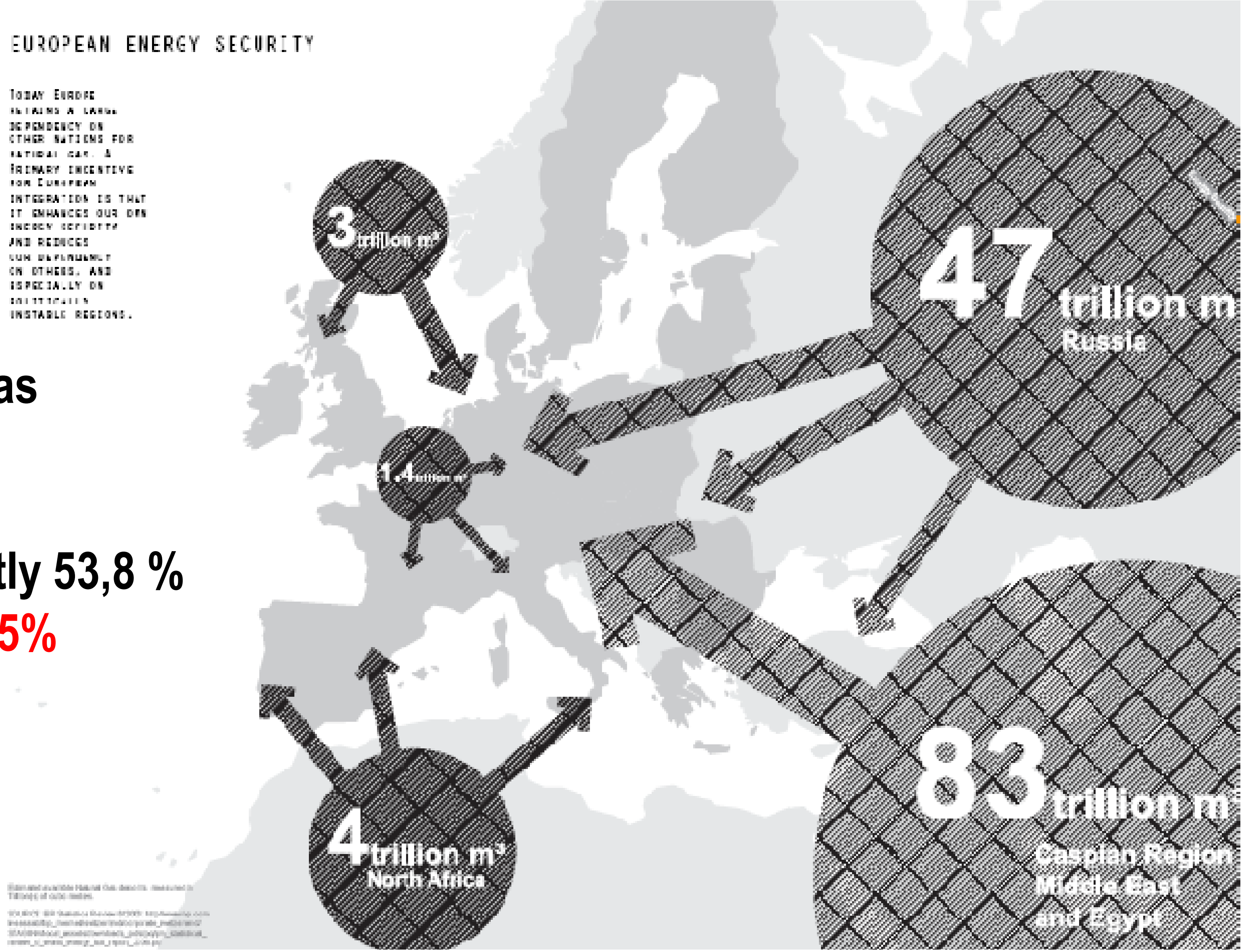
EUROPEAN COMMISSION

energy dependence of EU

Institute for Energy



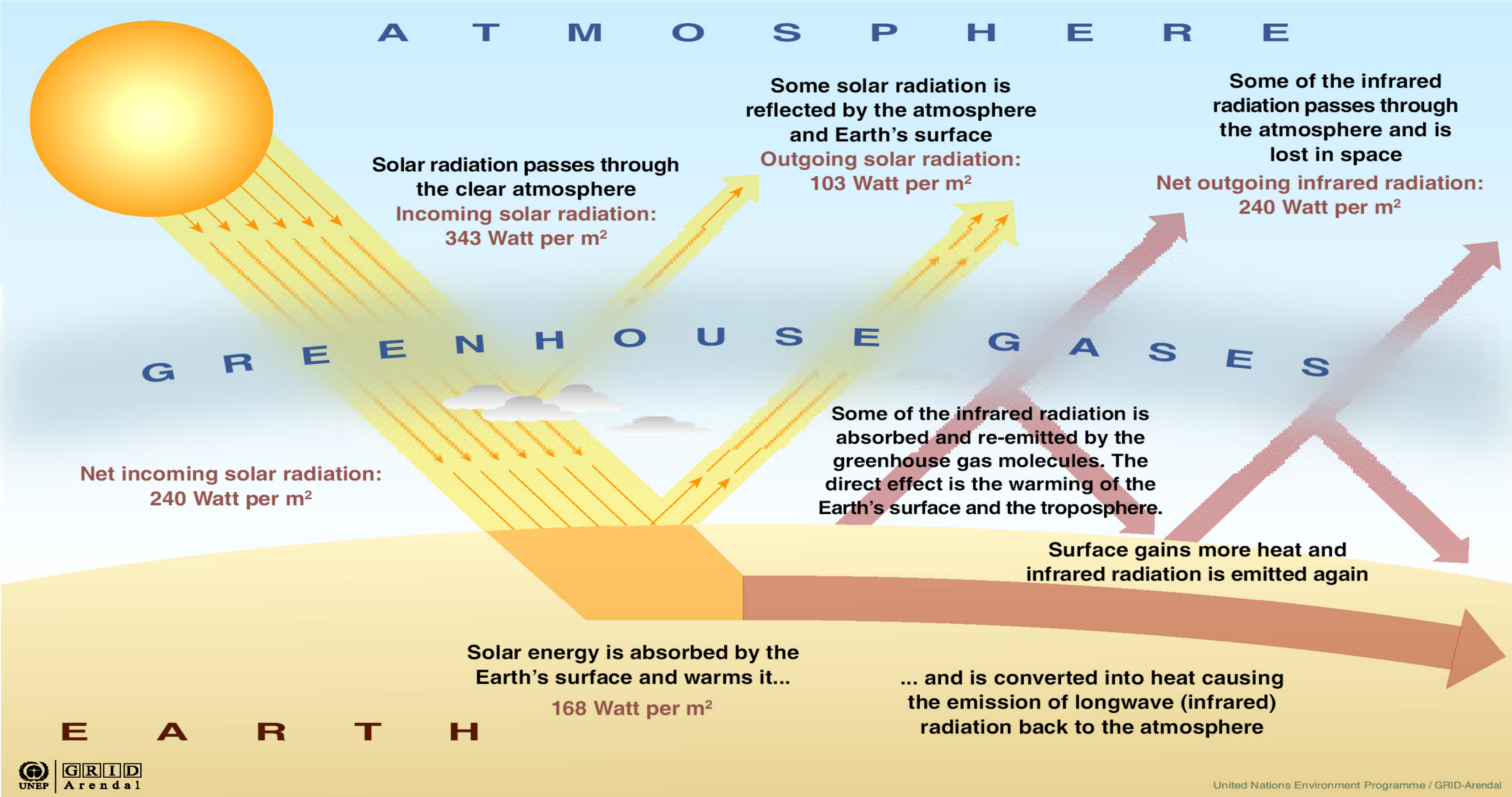
graph: gas

total:

- **presently 53,8 %**
- **2030: 75%**

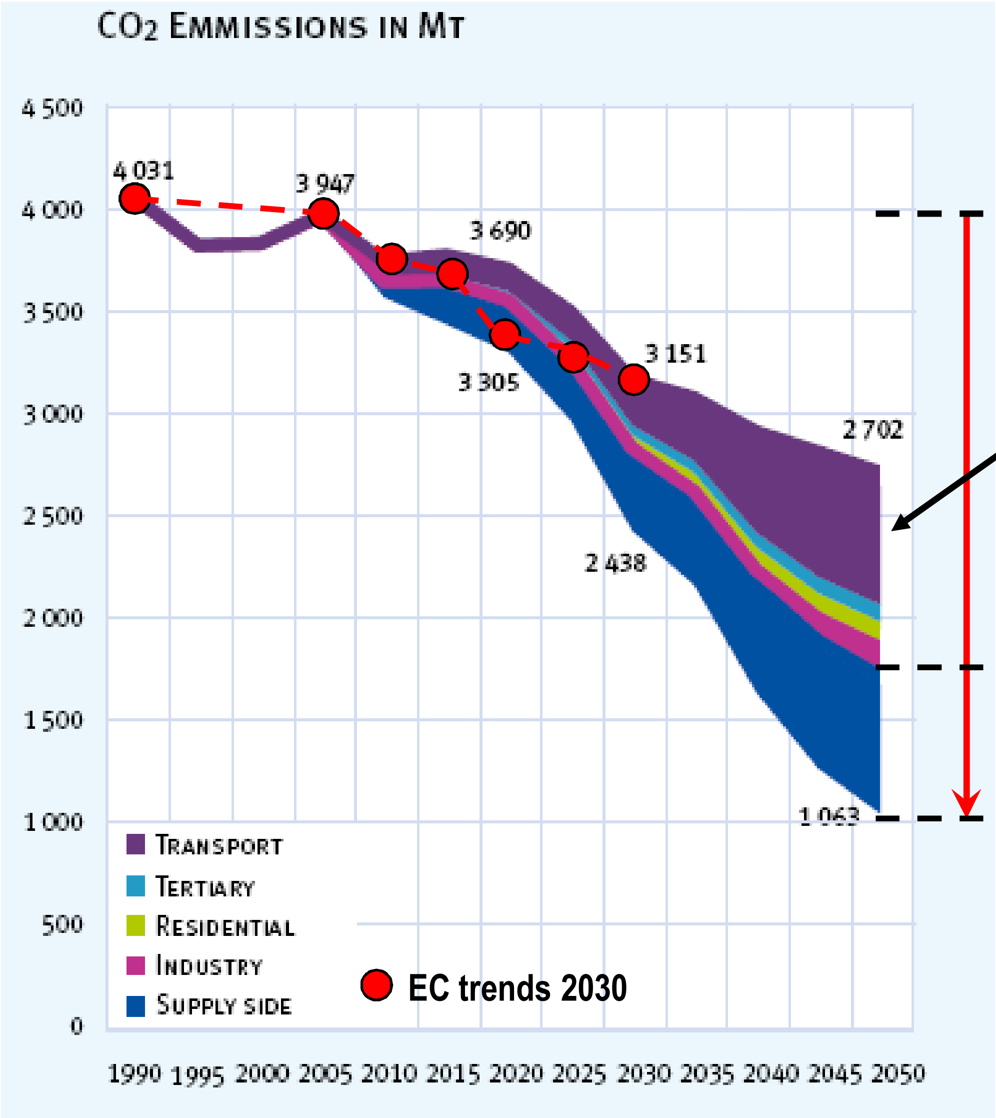
www.roadmap2050.eu

The Greenhouse Effect



Human actions – burning fossil fuels and land clearing – are increasing the concentrations of greenhouse gases. This is known as the enhanced greenhouse effect. Naturally occurring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Greenhouse gases that are not naturally occurring include hydro-fluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6), which are generated in a variety of industrial processes.

Decarbonisation path in EU



decarbonisation of transport:

- intermodality
- efficiency
- fuels

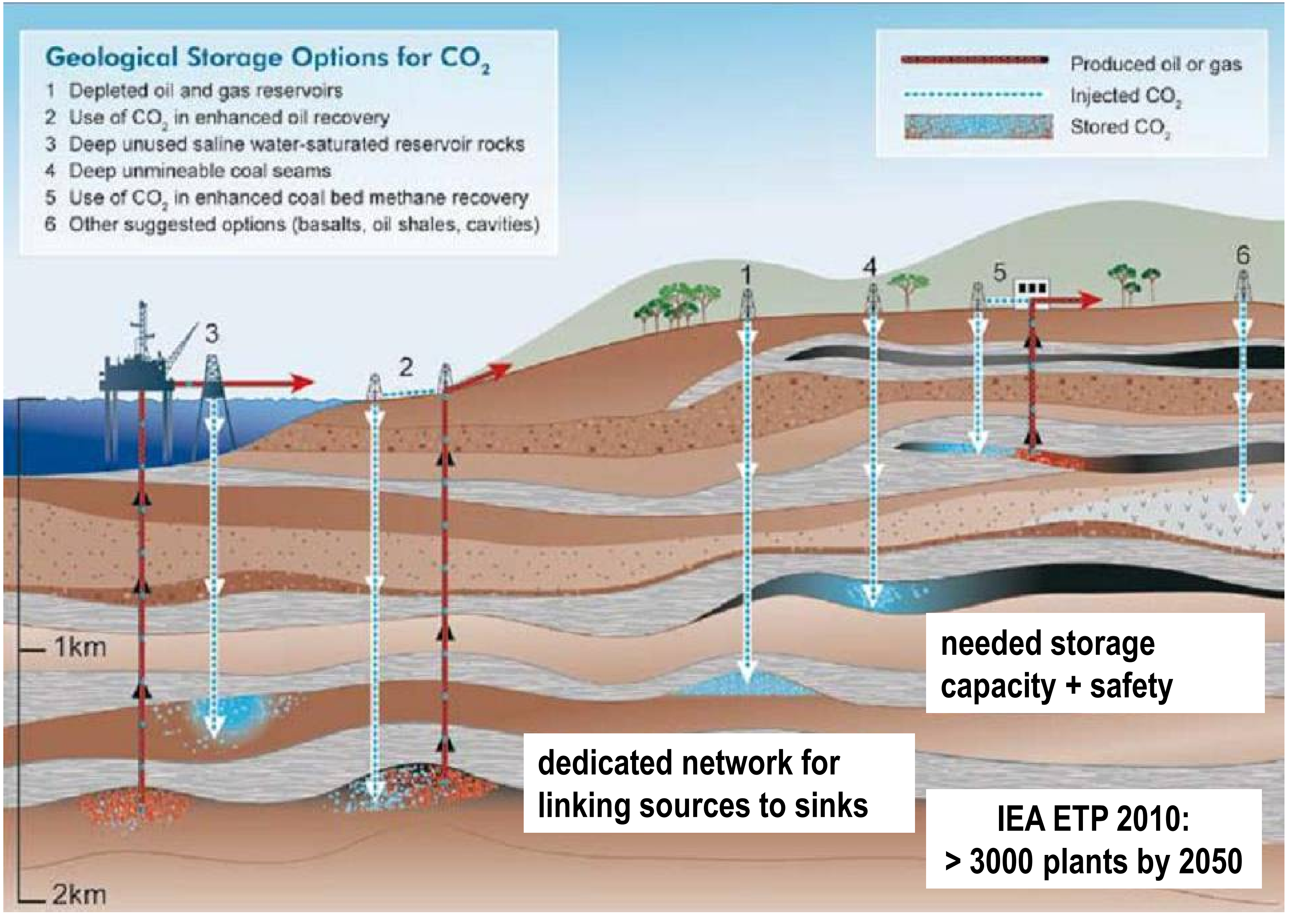
supply side: decarbonisation of power supply : RES, nuclear, CCS

indirect effects in other sectors:

- electric vehicles
- heat pumps

Power Choices 2050, Eurelectric, 2010

Decarbonisation of Supply: CCS



needed storage capacity + safety

dedicated network for linking sources to sinks

IEA ETP 2010:
> 3000 plants by 2050

Decarbonisation of the energy system – Implications

energy landscape changes:

- higher capacity, both in generation and transmission
- distributed generation from sun and wind
- more efficient final conversion

storage needs:

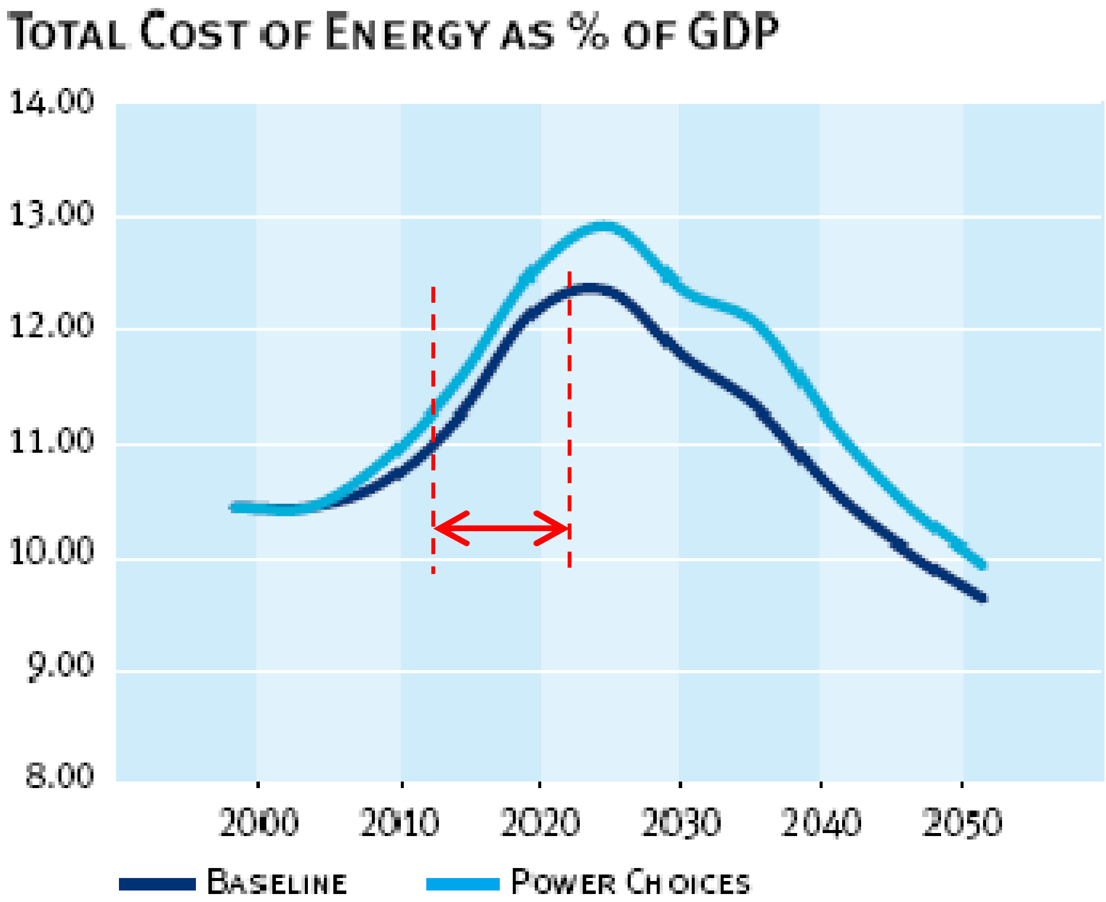
- technologies
- (secondary) energy carriers

transmission needs: matching origin to destination

- electricity: generation sites to users
- CO_2 from CCS: sources to sinks

huge investments needed!

Energy infrastructure investment needs by 2020 (EC)



decrease because of positive effects: fuel savings

Power Choices 2050, Eurelectric, 2010

H2: Hype and Hope for the future energy system

- zero-emission technology (not only CO2!)
- available from various sources "freedom fuel"
- synergy between mobile and stationary applications
- system innovation: RES + DG

(1) Consider carefully when and how to use it

- H2 from RES by electrolysis: only an option if electricity cannot be used directly
- H2 will be produced from fossil fuels and biomass in the coming decades
- H2 is not the ideal storage medium of energy
- H2 storage and transport lead to significant losses of energy

(2) Tackle the barriers to realise progress

- cost effective and reliable technologies
- H2 production costs due to efficiency penalty
- storage density as potential show-killer
- infrastructure chicken-and-egg situation
- safety perception

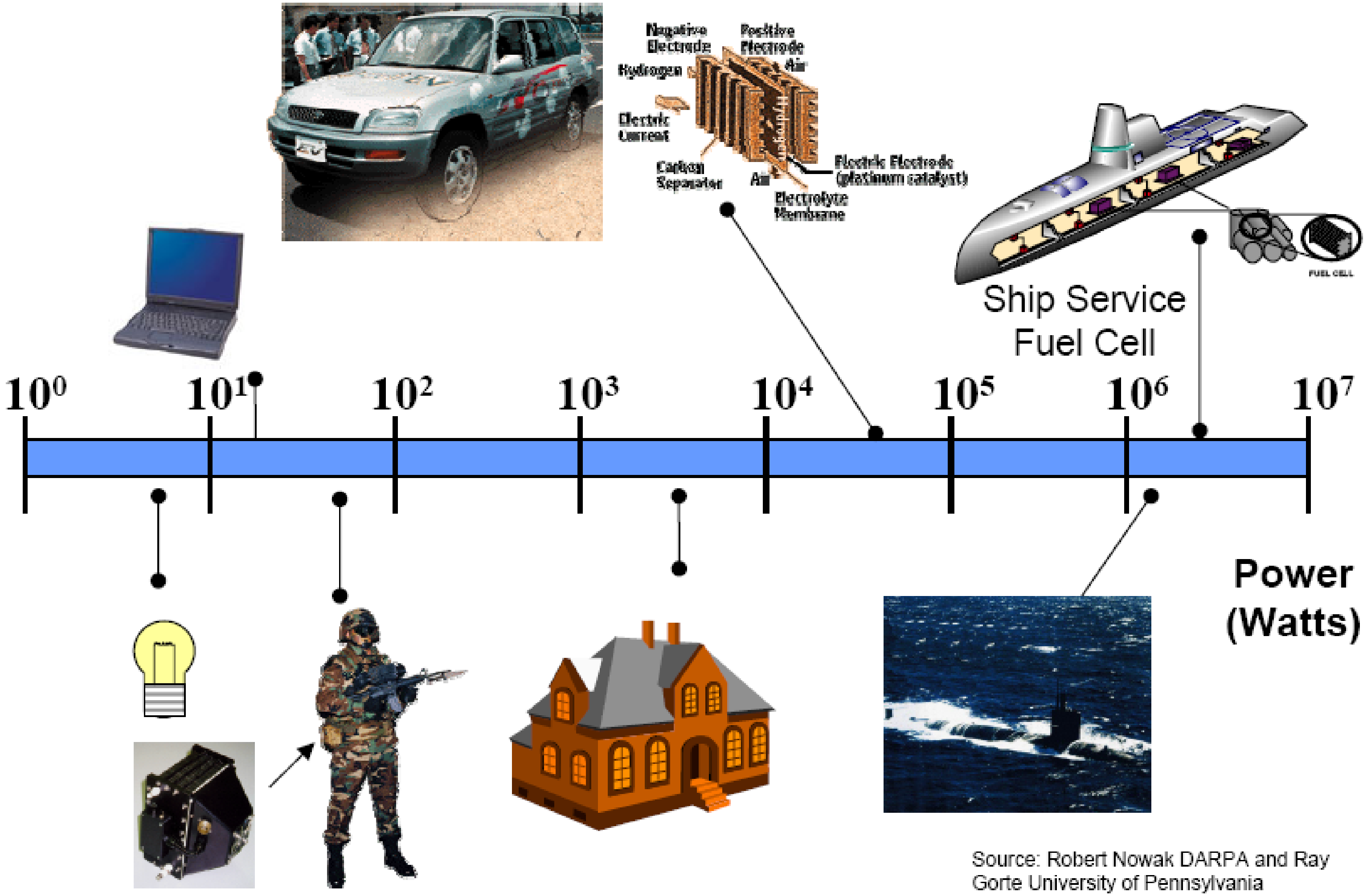
JRC input

Hydrogen Fuel Cell Demonstrations

- Residential heating & electricity (CHP)
- Back-up power (UPS)
- Portable power
- Distributed power generation
- Cars
- Buses
- Scooters
- Bicycles
- Golf-carts
- Forklifts
- Utility vehicles
- Space vehicles
- Airplanes
- Locomotives
- Boats
- Underwater vehicles
- Portable devices (laptop, etc.)

Source: UNIDO - ICHET

Fuel Cells Applications & Power Ranges



Source: Robert Nowak DARPA and Ray Gorte University of Pennsylvania