MRS Materials Research Society

«ETTORE MAJORANA» FOUNDATION AND CENTRE FOR SCIENTIFIC CULTURE

TO PAY A PERMANENT TRIBUTE TO GALILEO GALILEI, FOUNDER OF MODERN SCIENCE AND TO ENRICO FERMI, THE "ITALIAN NAVIGATOR", FATHER OF THE WEAK FORCES

E-MRS European Materials Research Society

International School of Solid State Physics

Materials for Renewable Energy

Erice (Italy), May 28th – June 2nd 2010

Energy - the big picture

Augustin McEvoy

Erice, Sicily

28th. May 2010

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

DYESOL GROUP of COMPANIES

Global leaders in Dye Solar Cell Technology

Earth
Air
Fire
Water

- Energy
Sources

Nuclear
Wind Turbines
Biomass
Hydro

- Energy processes

Energy & power - for our world, 1 TW

N Lewis

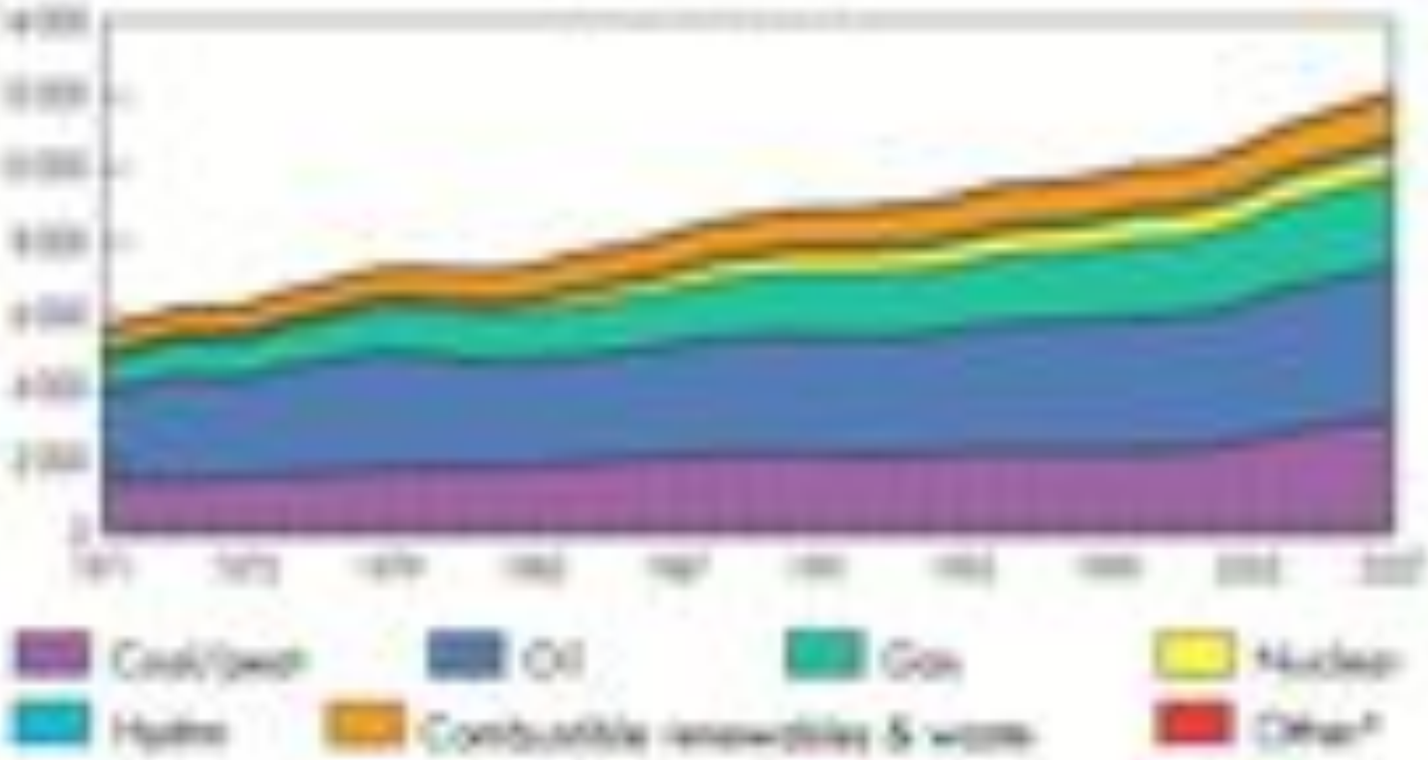
Power	1	10^3	10^6	10^9	10^{12}
	1 W	1 kW	1 MW	1 GW	1 TW

Energy
1 J =
1 W for 1 s

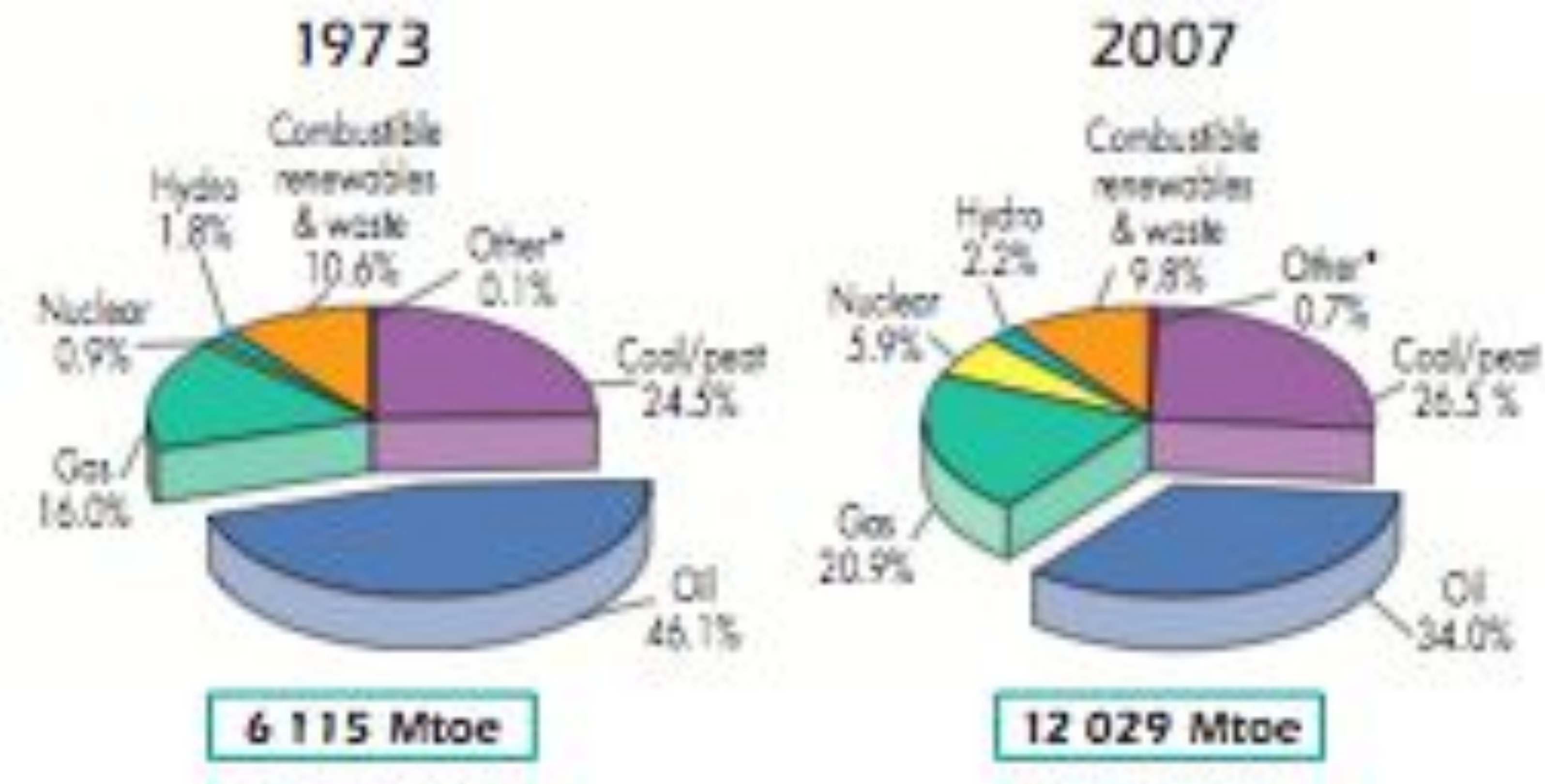
TOTAL PRIMARY ENERGY SUPPLY

World

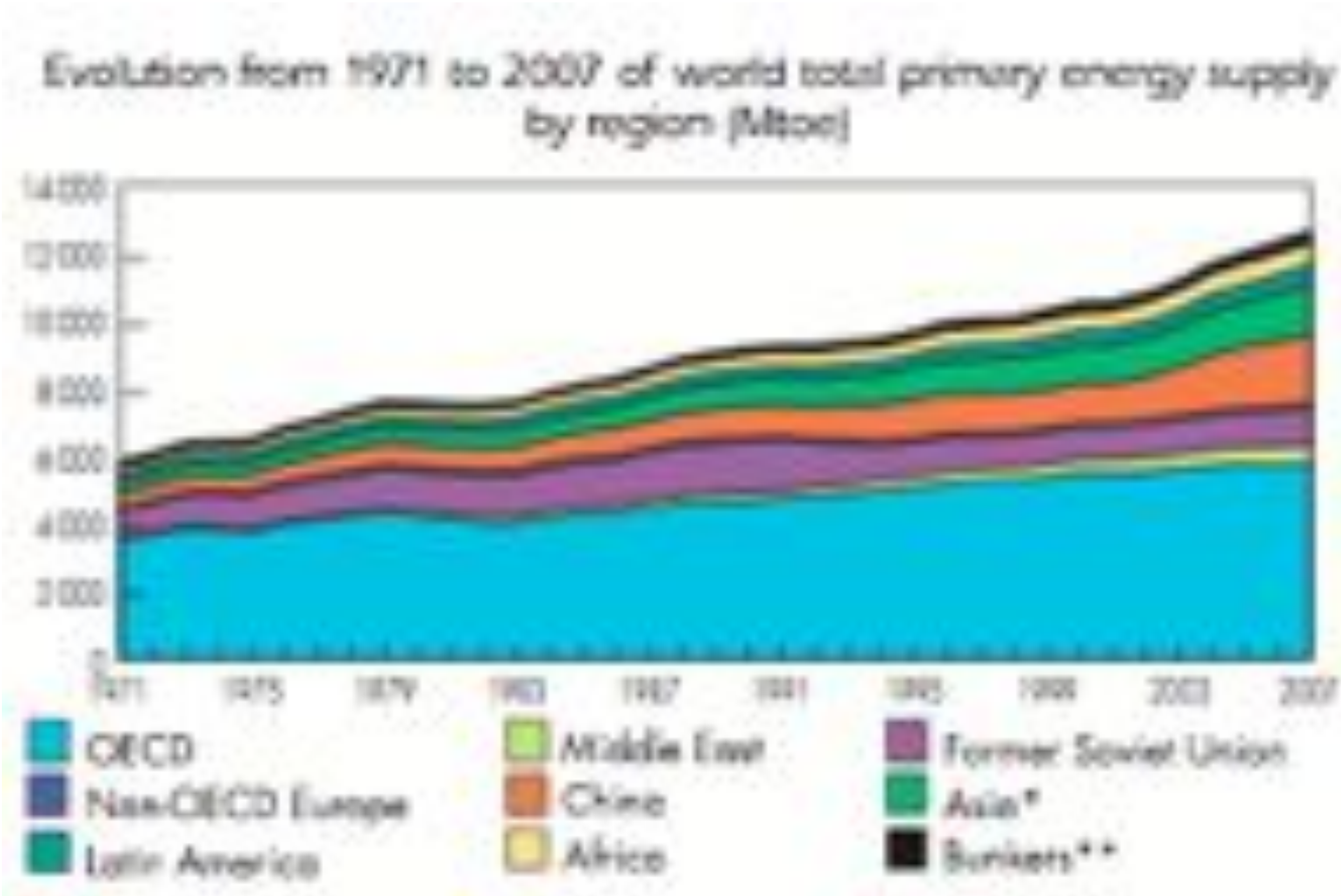
Evolution from 1971 to 2007 of world total primary energy supply by fuel (Mtoe)



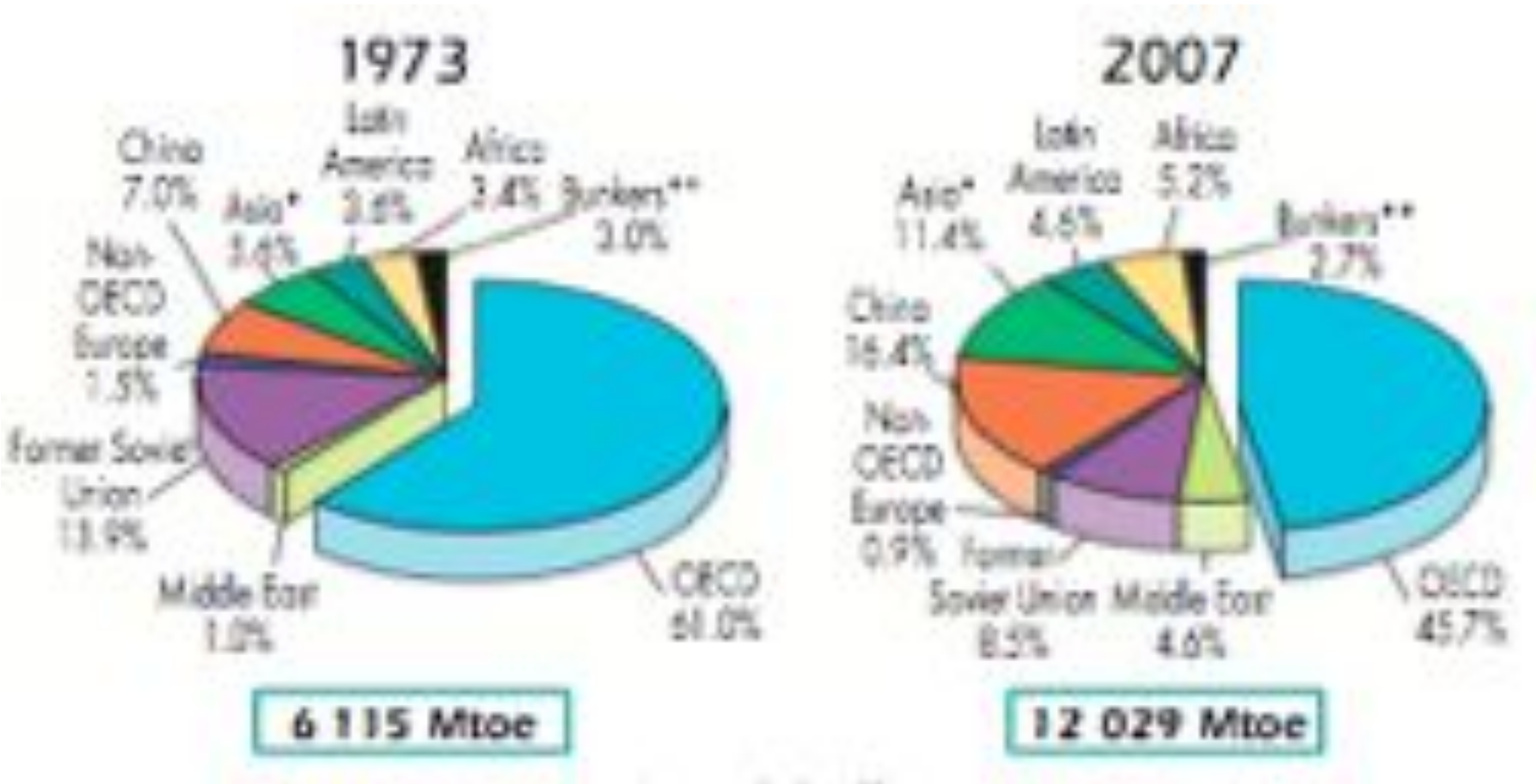
Fuel shares, 1973 - 2007



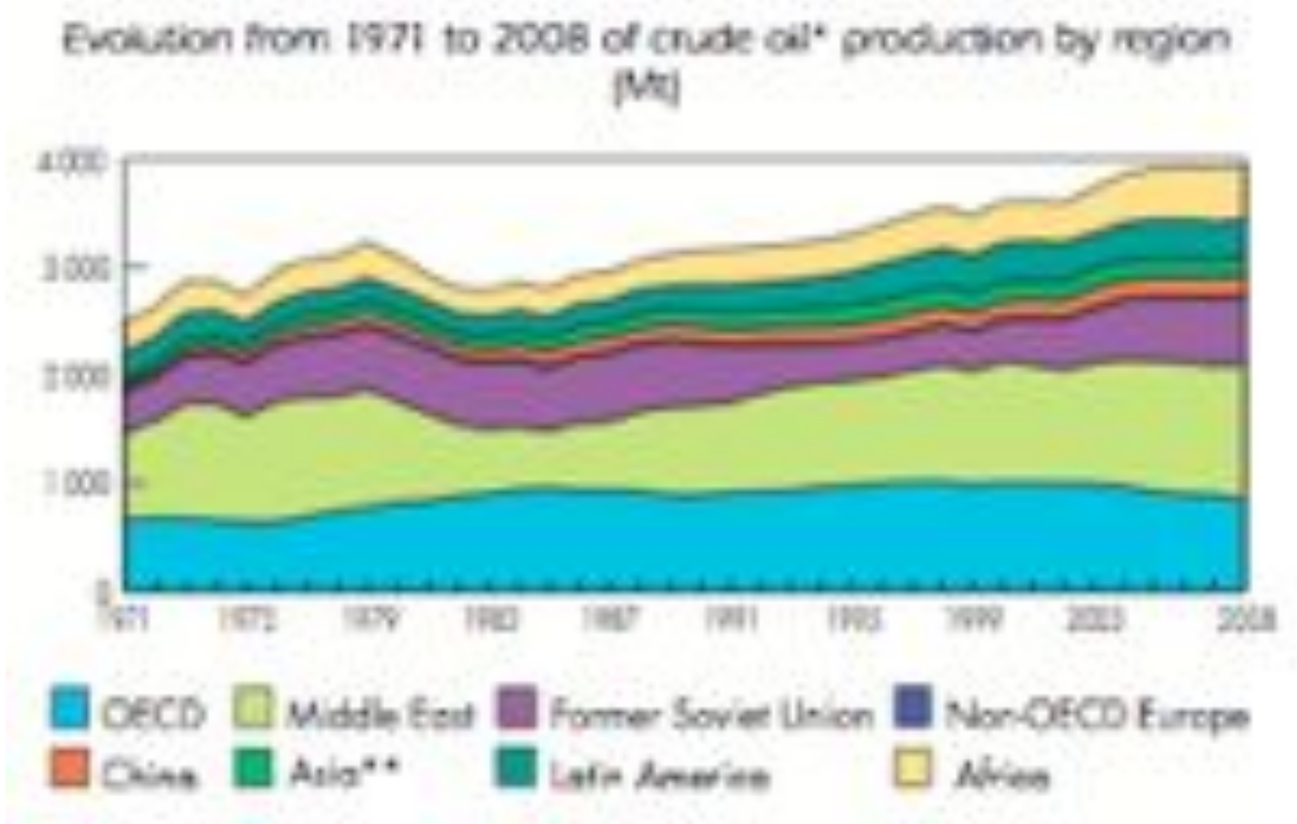
World total energy supply



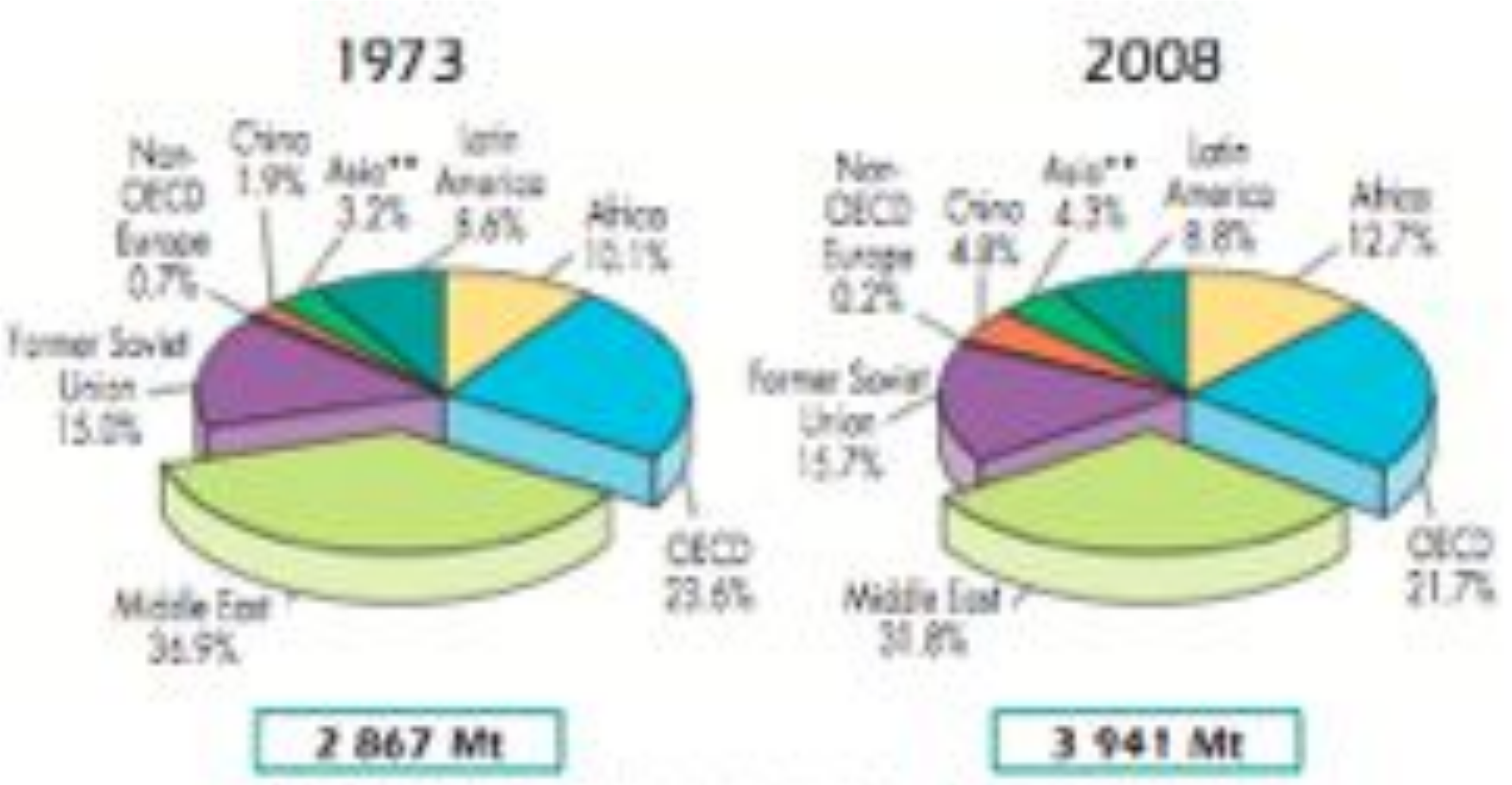
Regional shares of primary energy supply



Petroleum production

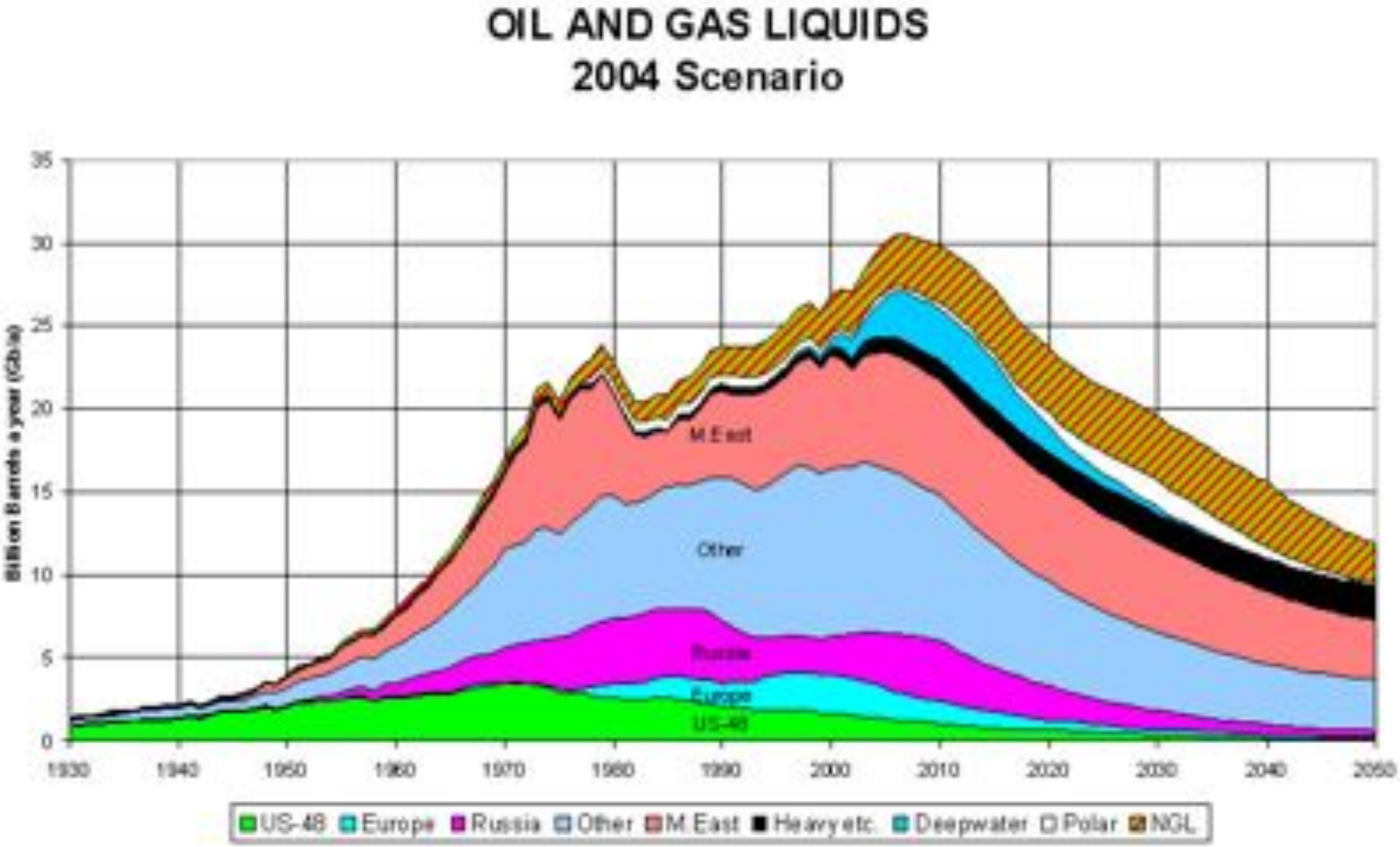


Petroleum production - regional

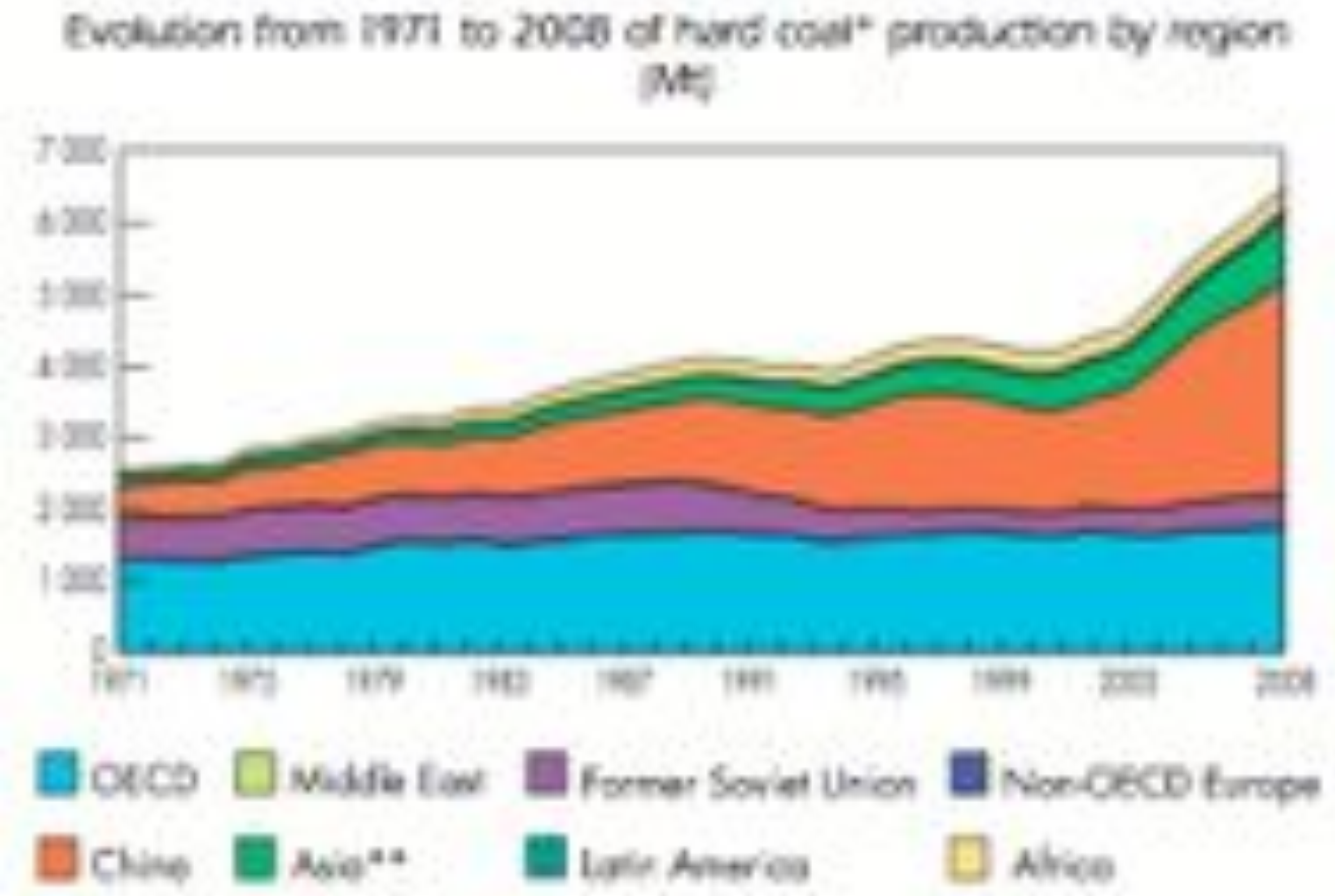


“Peak oil” - very close?

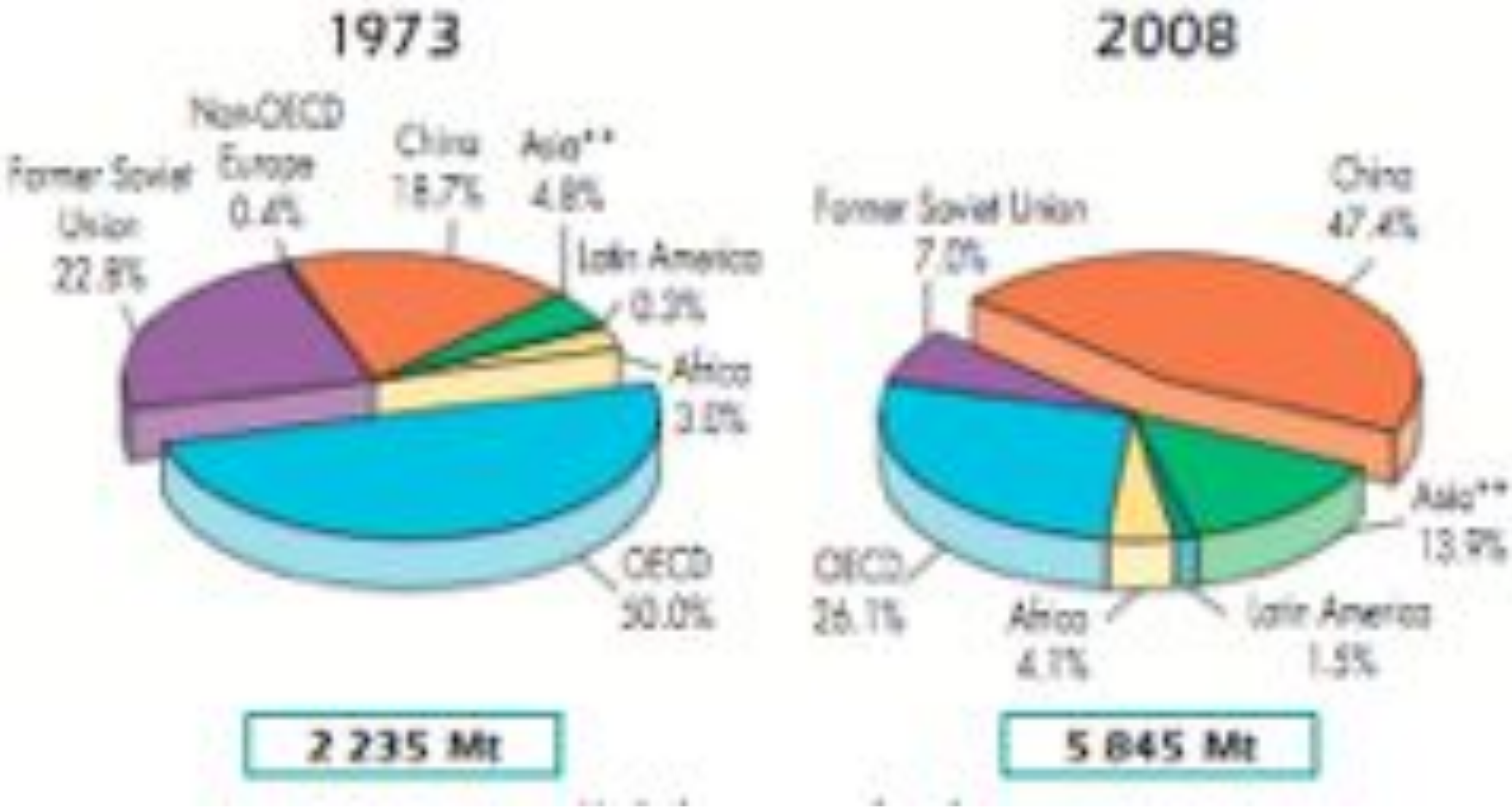
But beware “prophets of doom” -
we have had them before,you know!



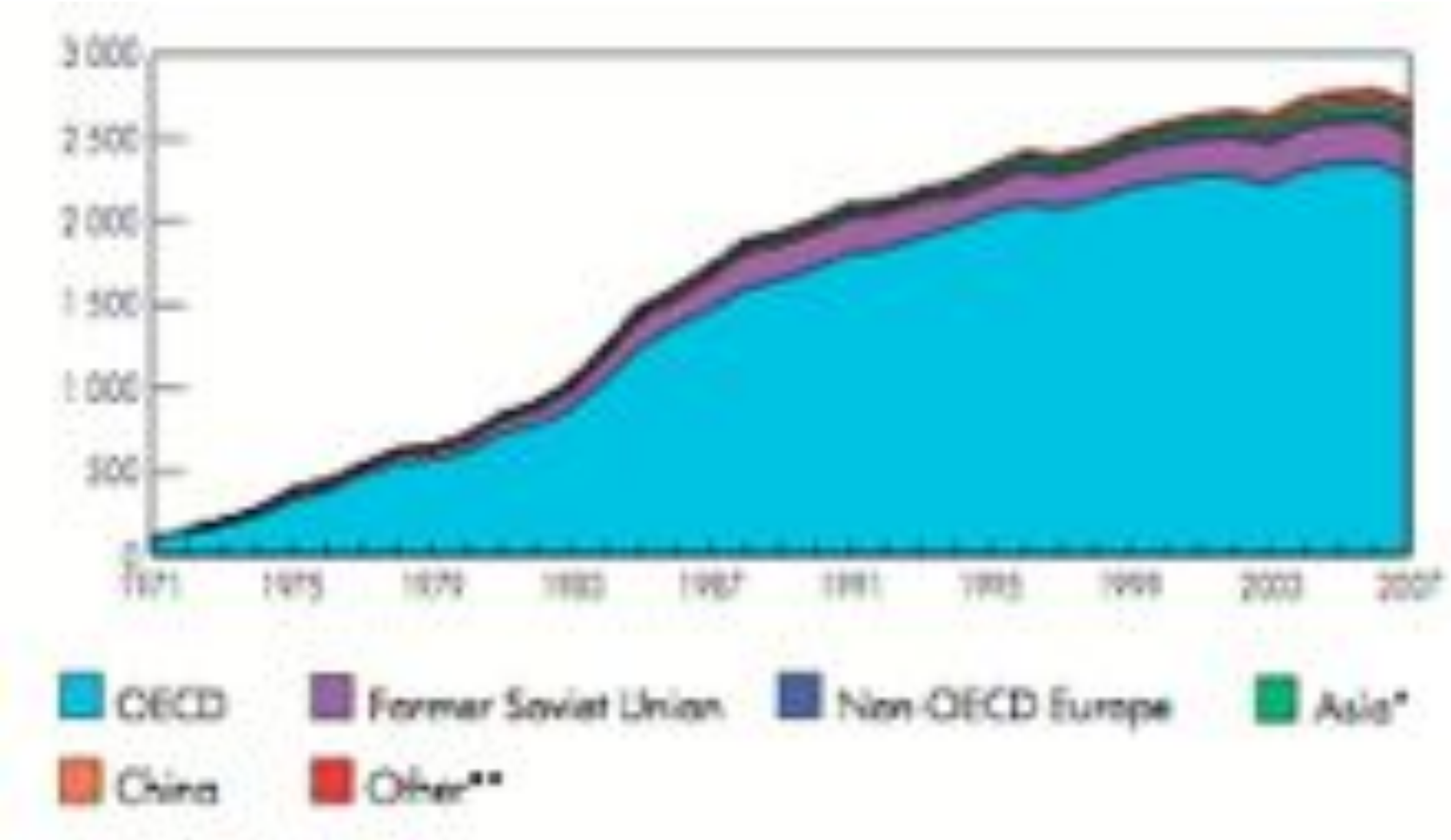
Hard coal production



Where coal is mined

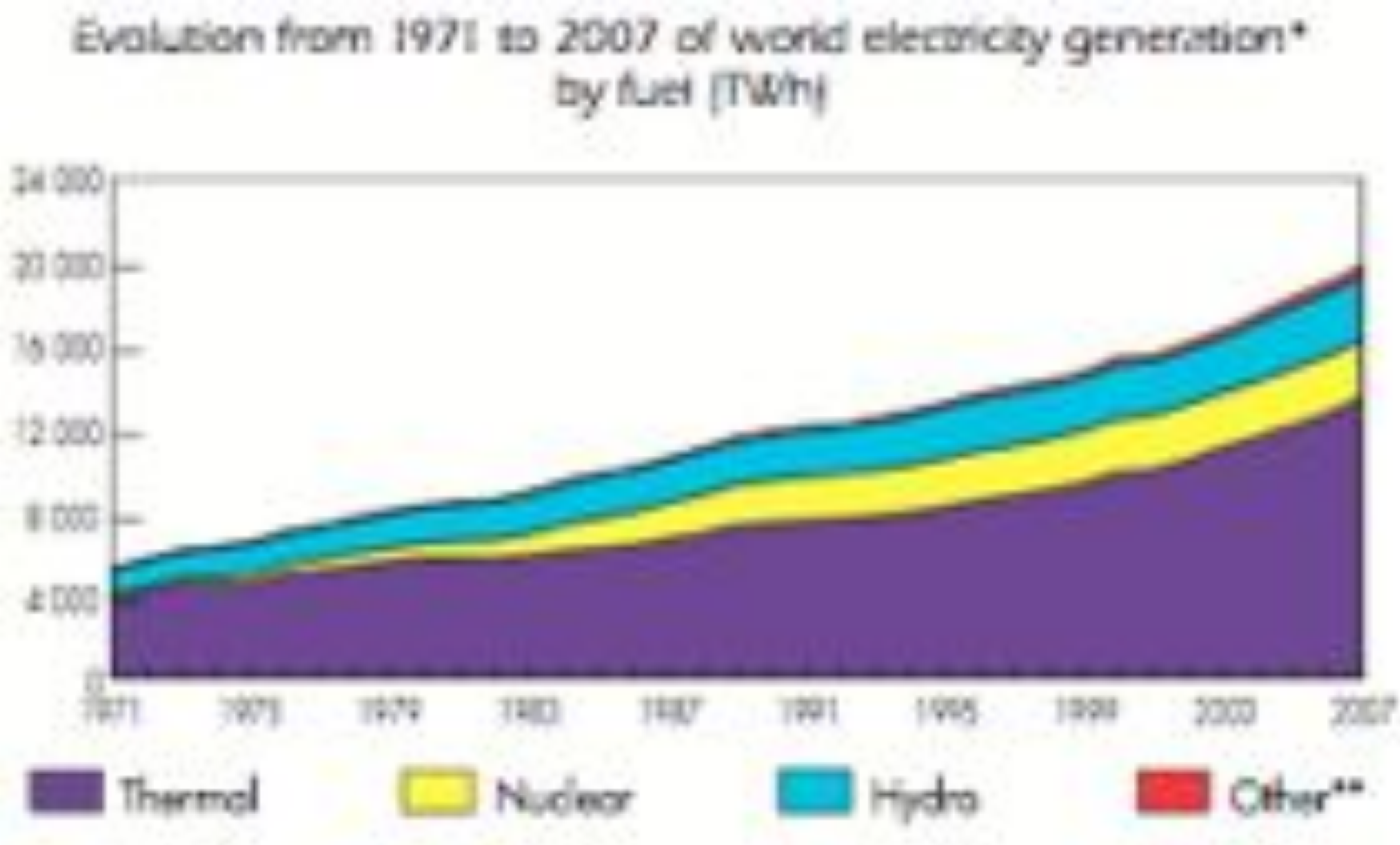


Nuclear - no CO_2, but stagnation for >20 years

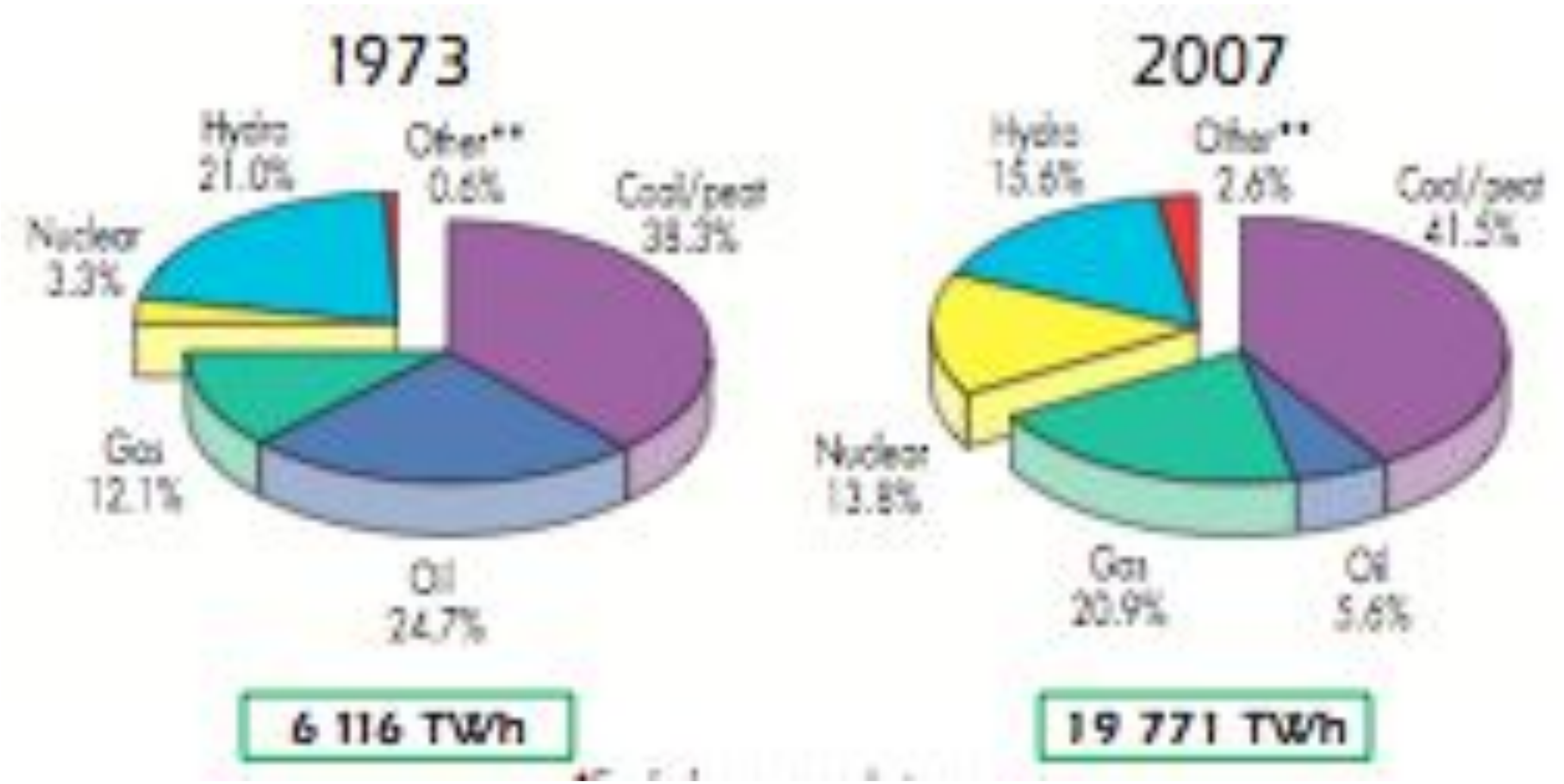


Major fuel user - electricity.

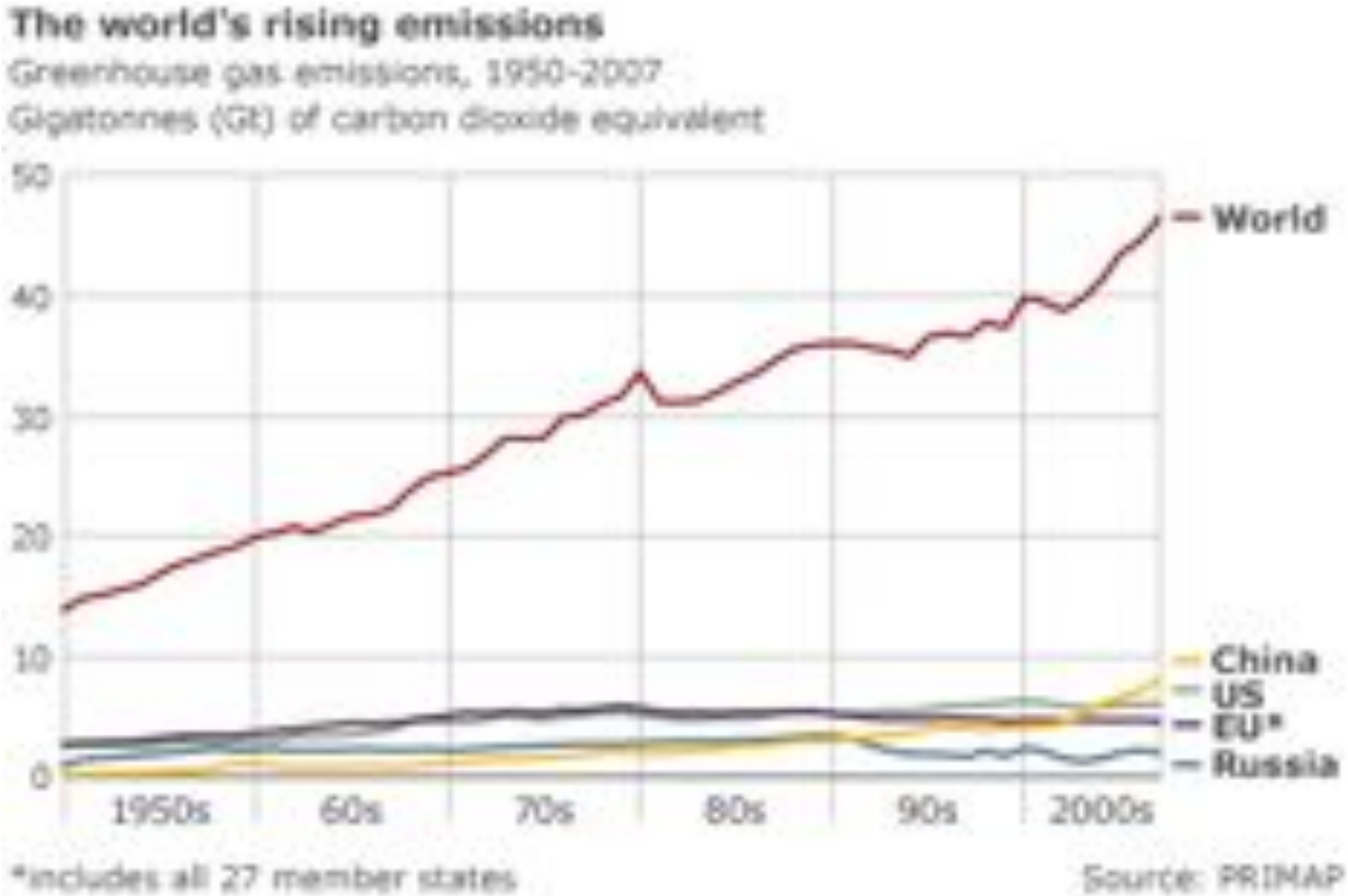
Electricity is an "*ENERGY VECTOR*"



Electricity by primary energy source



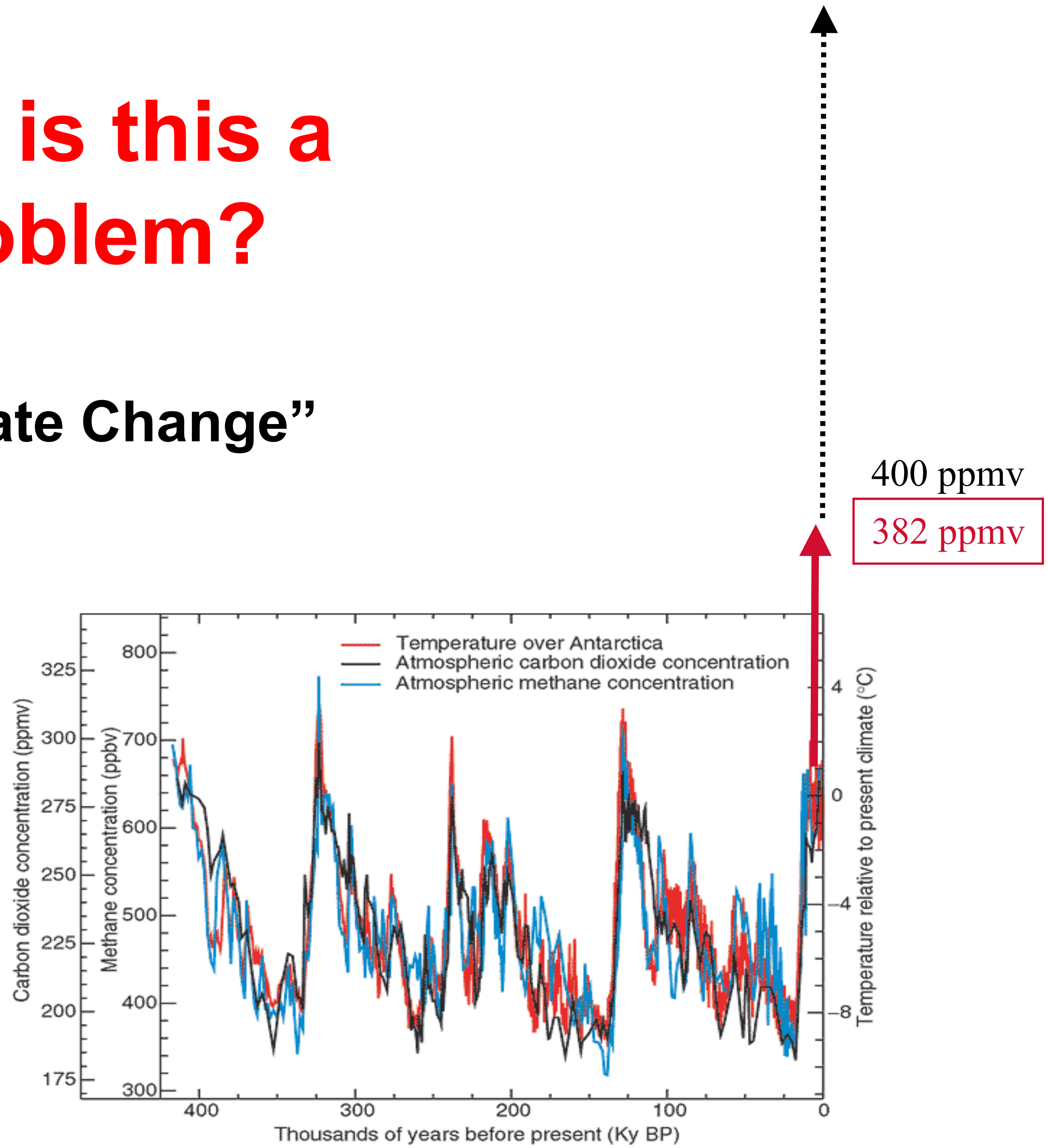
Can we go on like this?



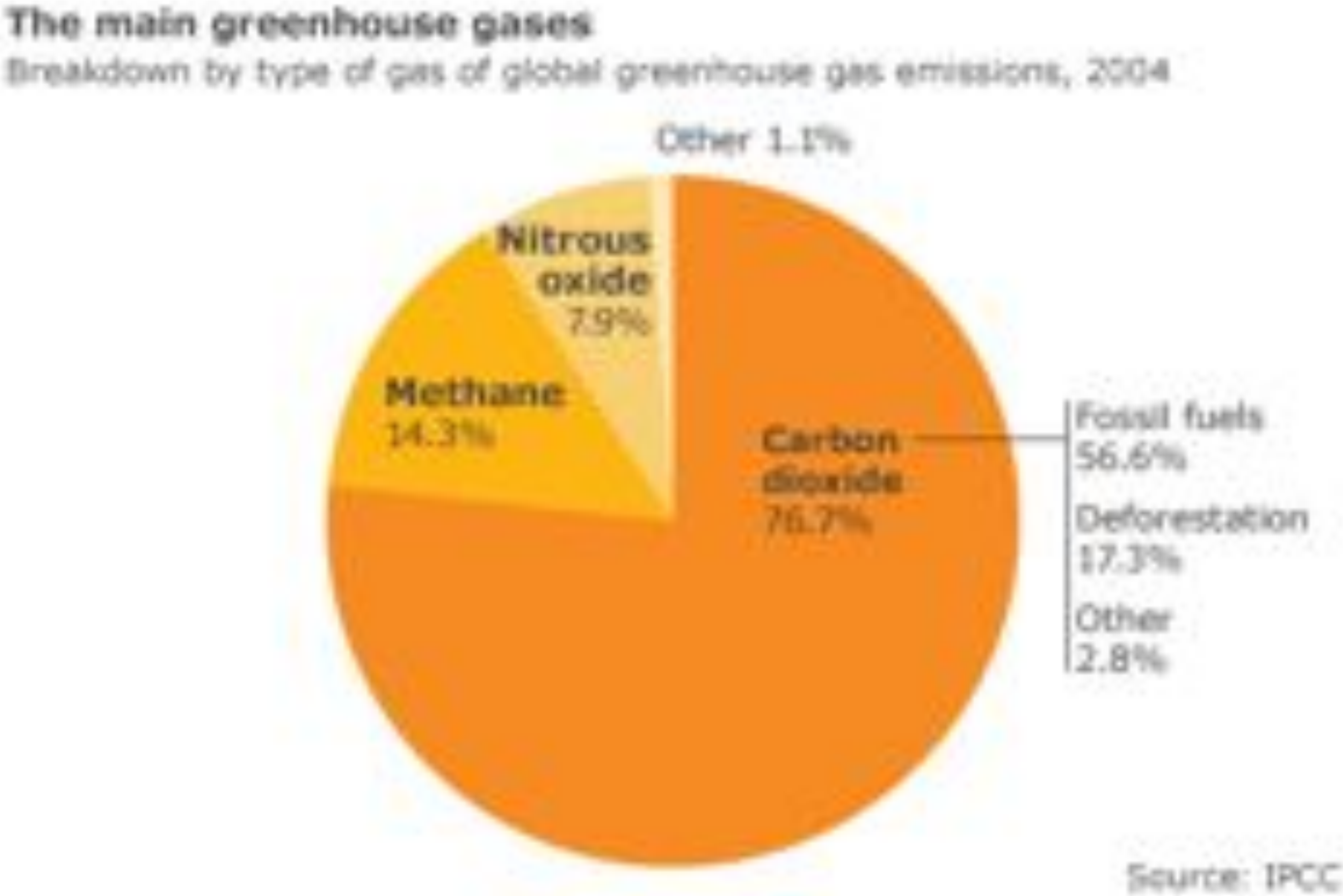
"Global warming" - not a new idea (Arrhenius): he established that there is a temp. increase 30ºC over a greenhouse gas-free earth. Most important "greenhouse gas" - water vapour!

Why is this a problem?

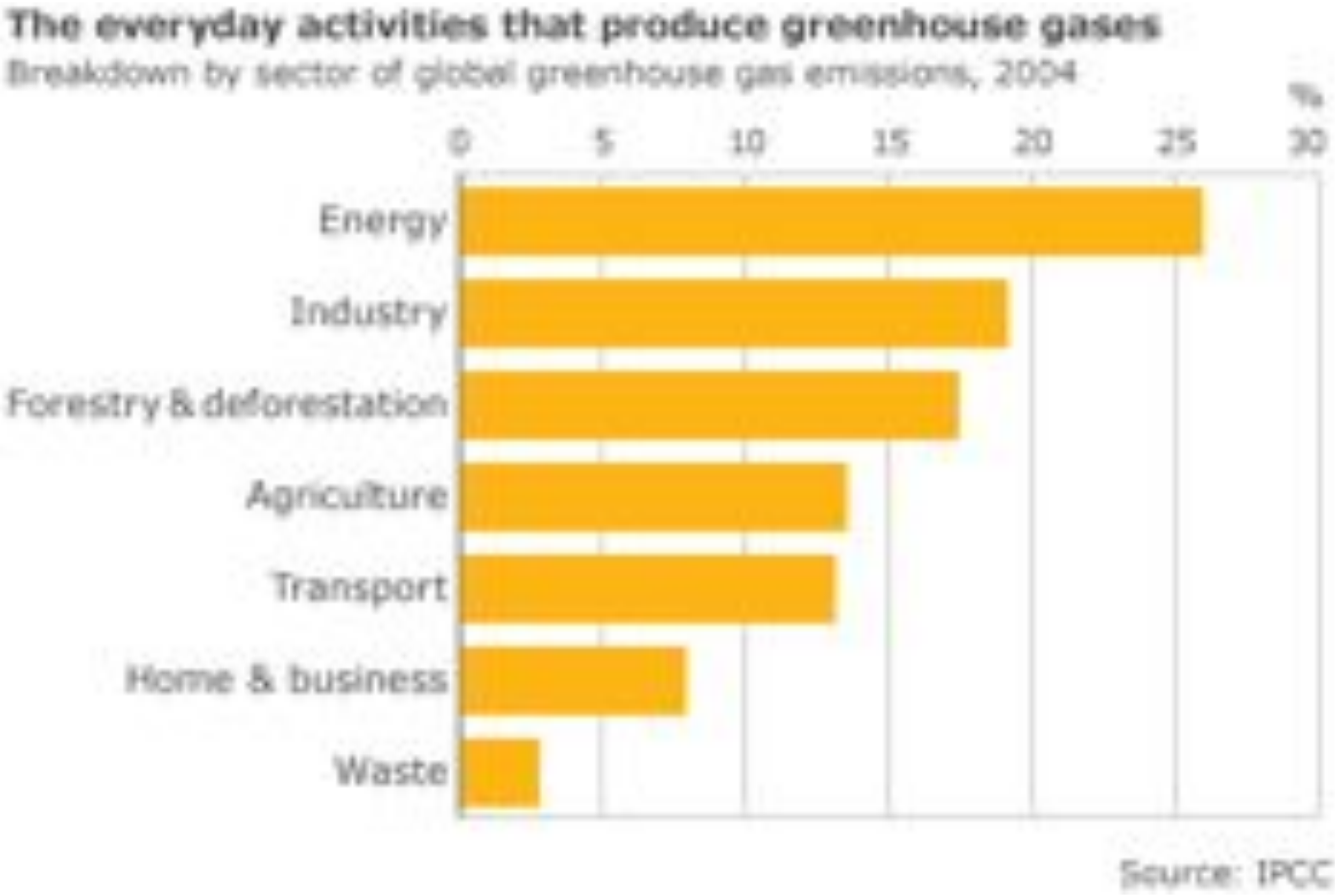
"Climate Change"



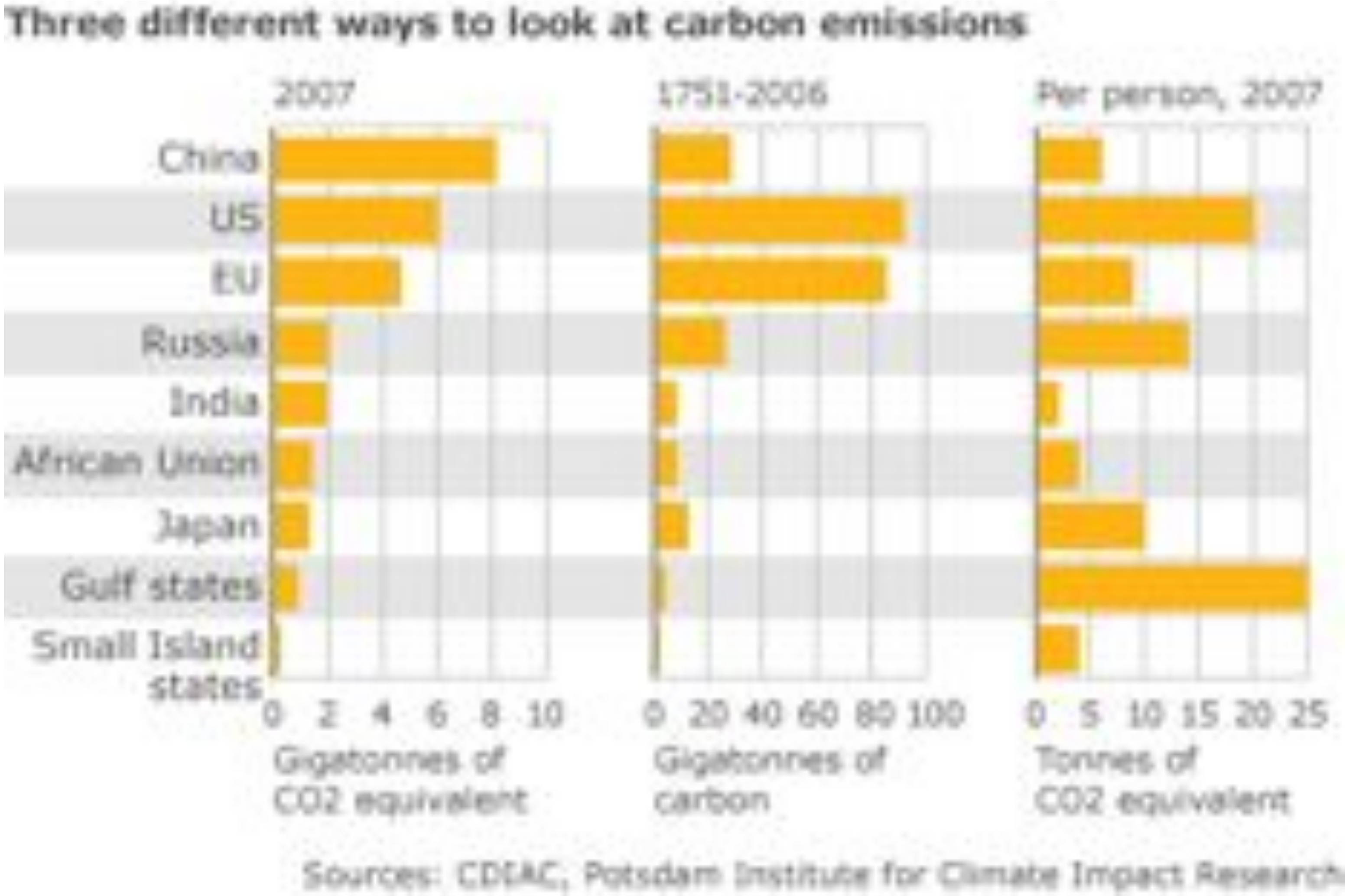
Other “greenhouse gases”



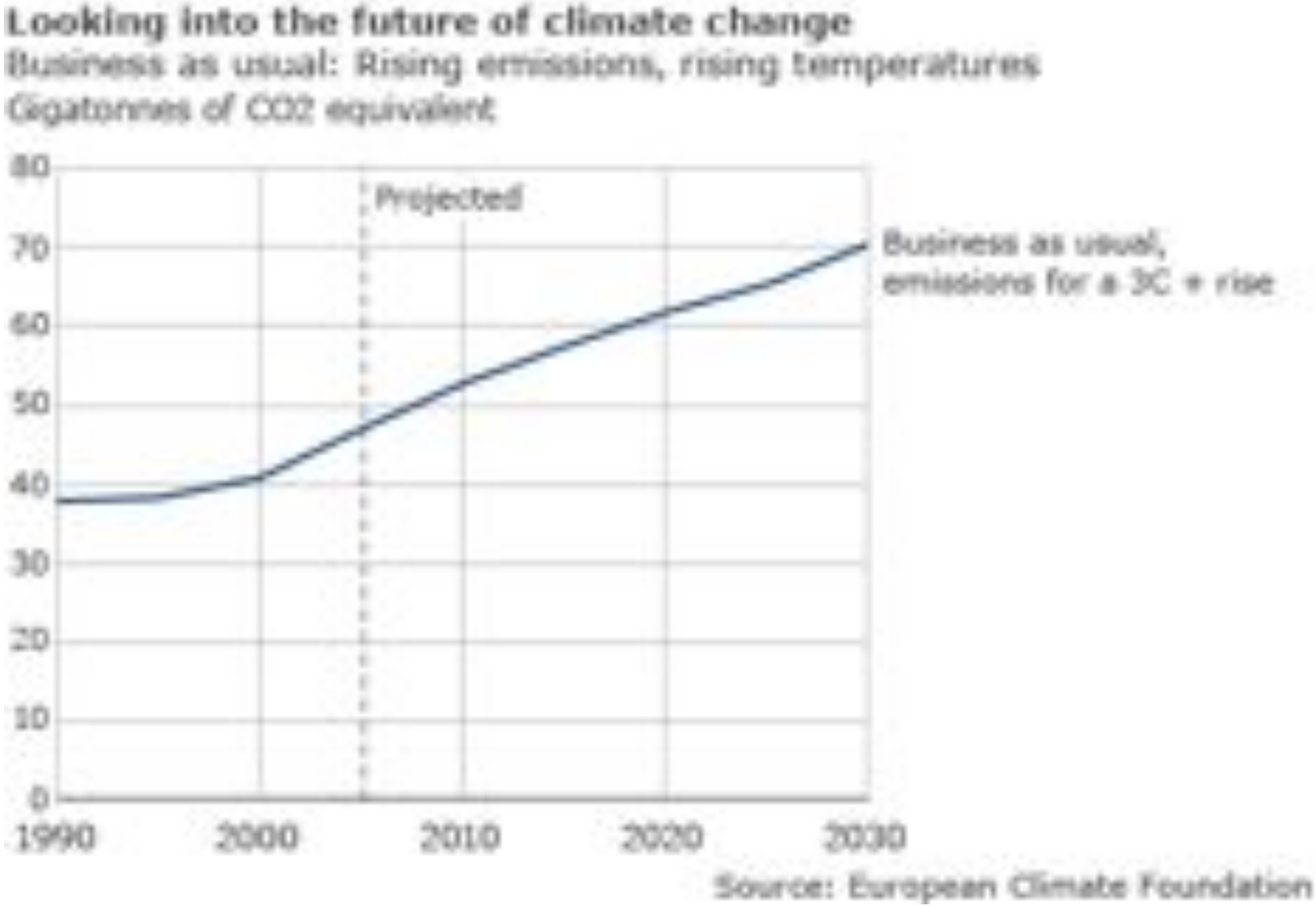
Sources of “greenhouse gases”



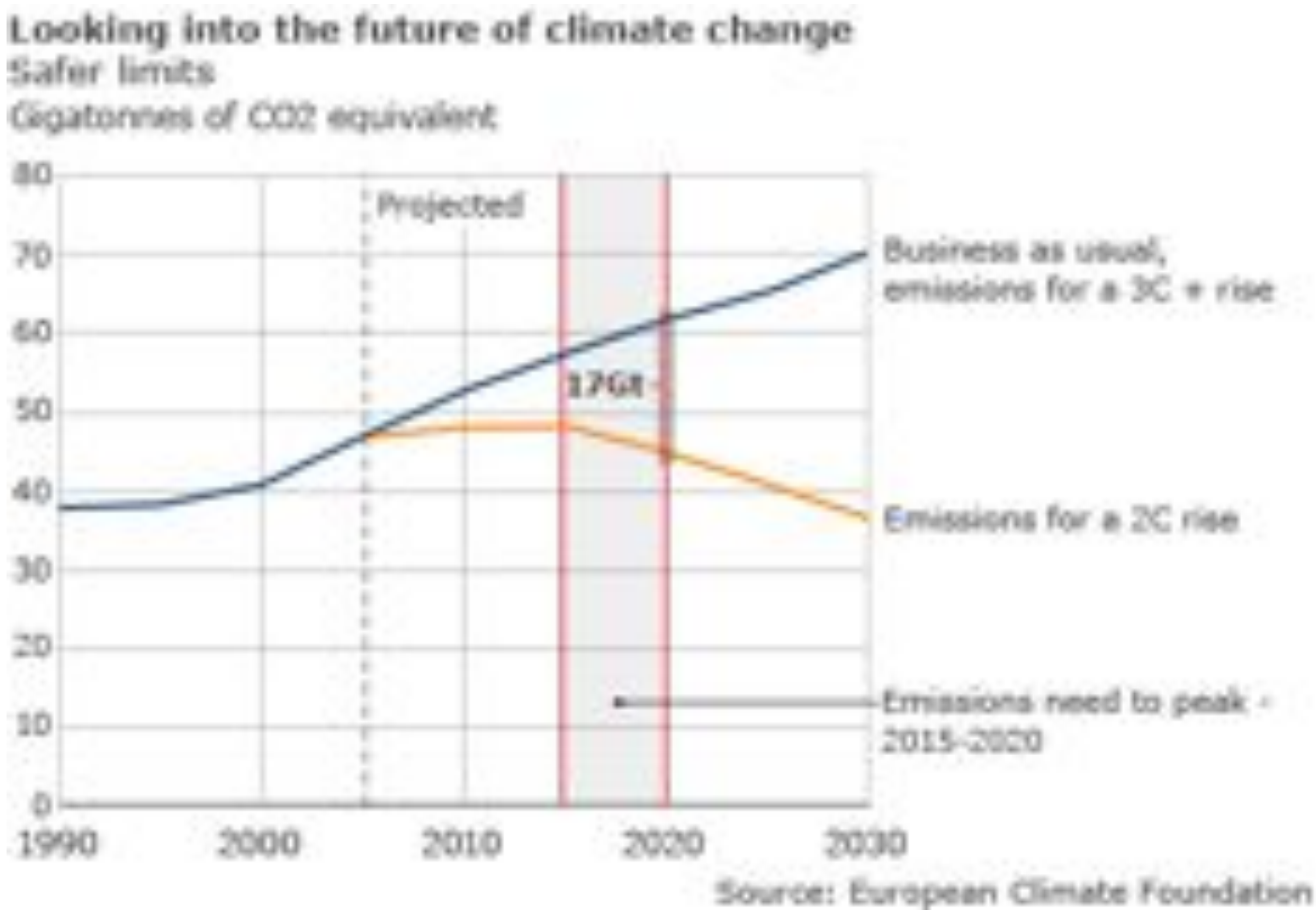
Who's emitting? And when?



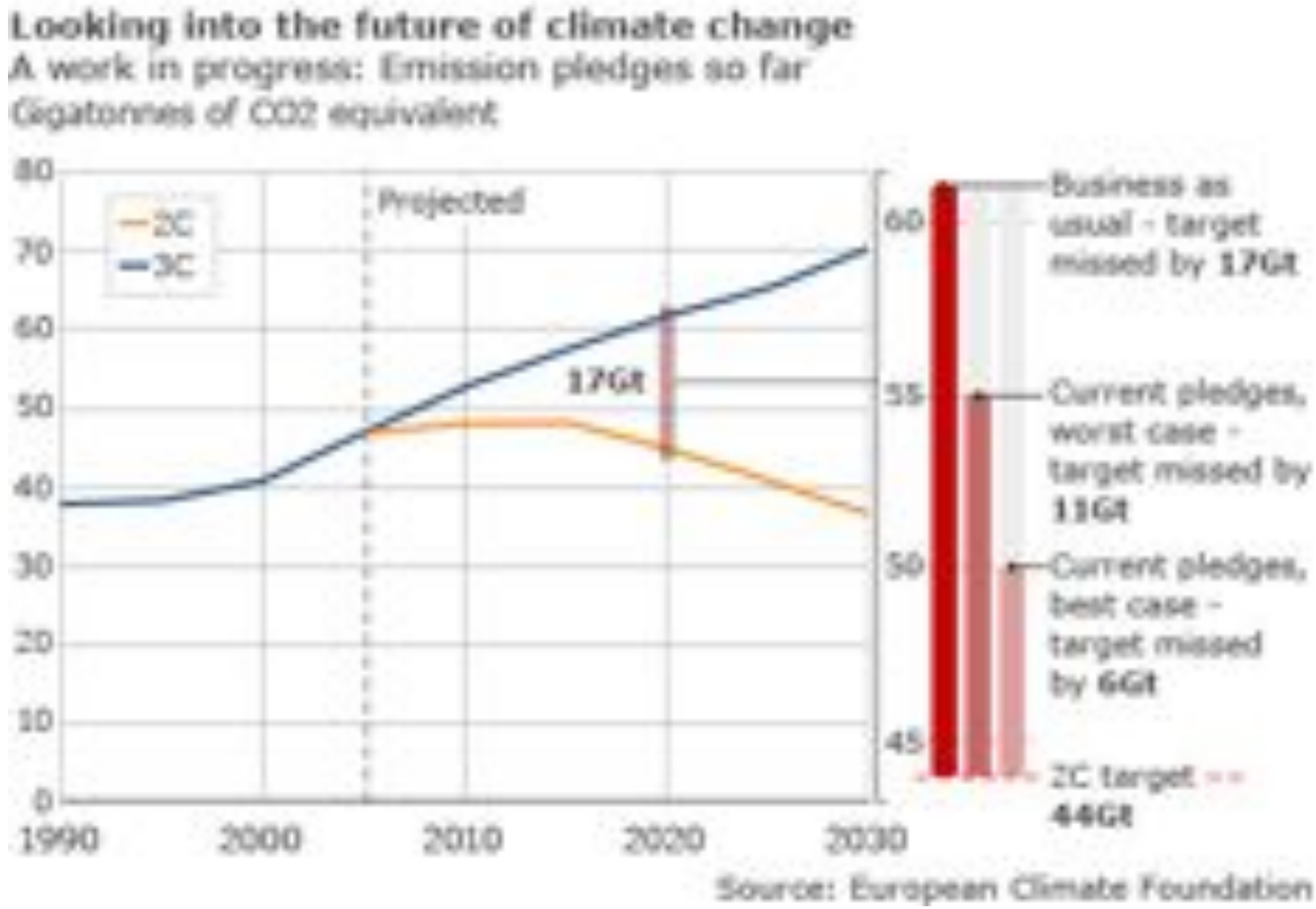
The future? - temperature/emissions



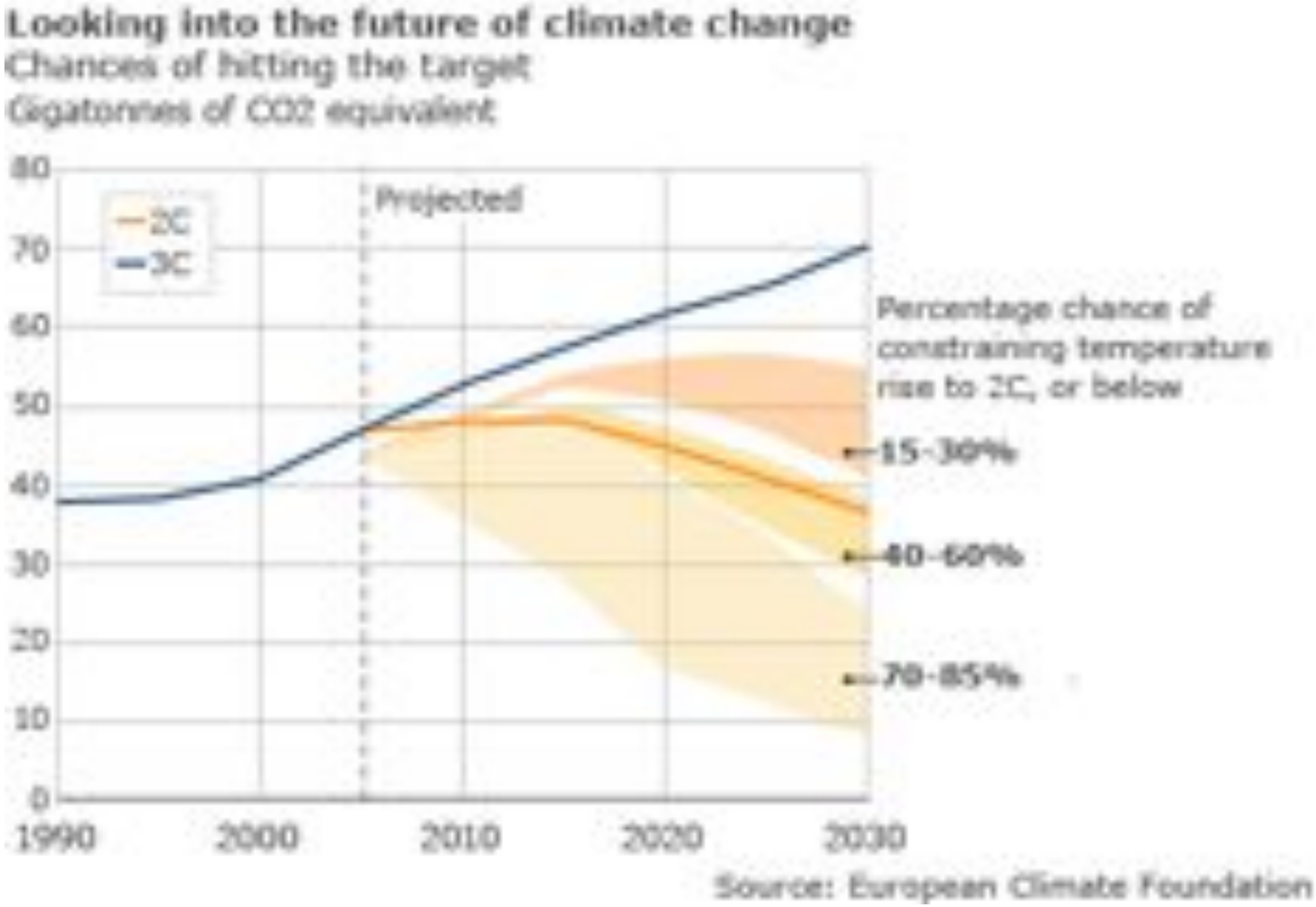
Emissions reduction?



What we are asked to do!!



Predictions - “prophets of doom”



Two sides to the “energy problem:

1. SOURCES. Medieval - “the dark ages” before Edison - all energy was environmental - human effort, draft animals, biomass.

   Industrial society was built on, and remains almost exclusively dependent on, “fossil fuels” - coal, oil, gas.

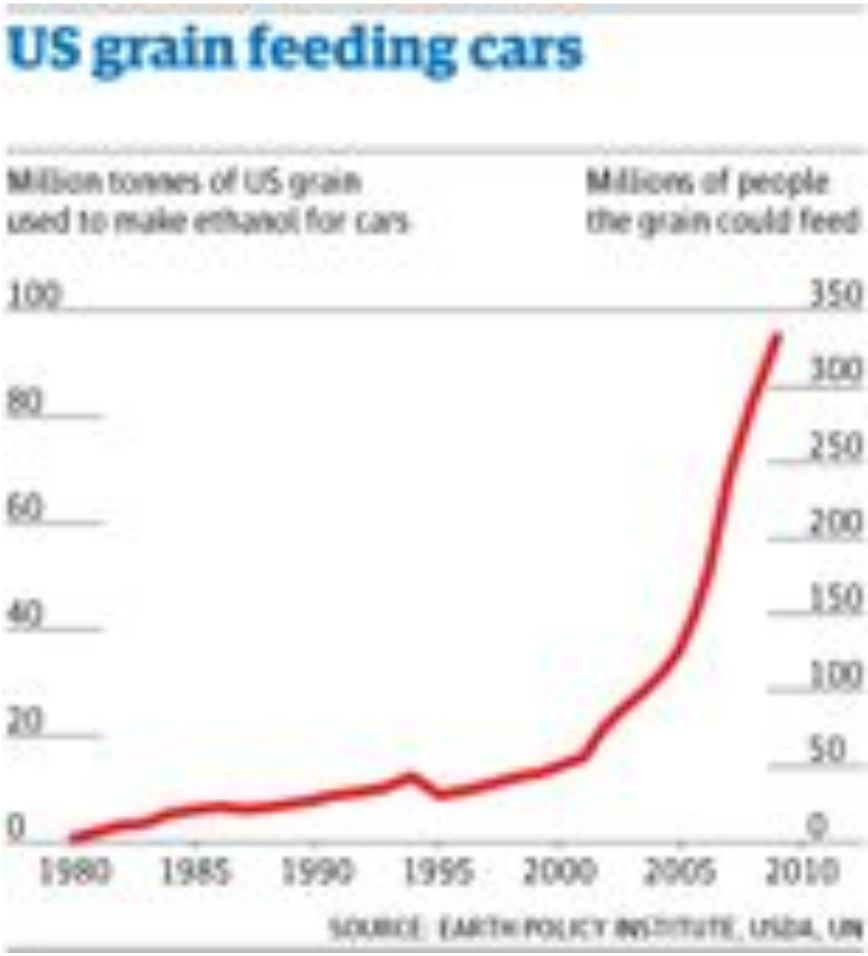
2. SINKS. The medieval society was almost totally renewable - all waste products were returned to the environment.

   In industrial society we continued that habit, presuming the environment - earth, air, ocean - could indefinitely continue to absorb waste.

   As a result of the climate change scenario and other pollution problems, we know now that it can’t.

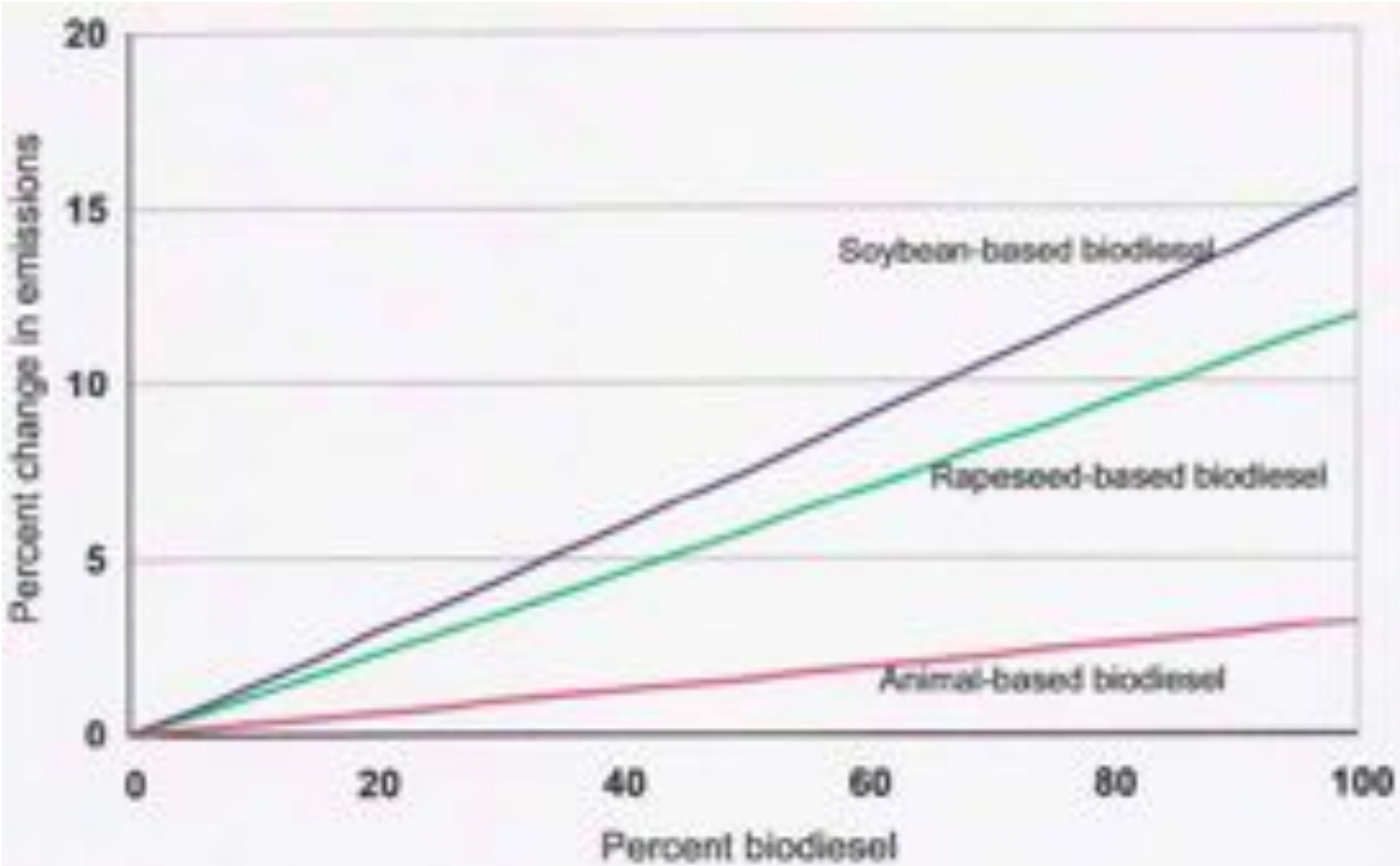
Can we reconcile modern living standards with environmental imperatives?

Is this ethical? Do we want this?



Similar considerations apply to biofuels from food crops - sugar, palm oil etc. Renewable? - but unethical?

Present-day biofuels may not help much anyway!



Possibilities - some answers to the "prophets of doom"

New energies from the earth:

Geothermal - we have seen this month just what this resource can do!

New fuels: alternative petroleum sources - oil shale, tar sands.(Emissions?)

Natural gas - based energy economy - CH_4 is already half way to a "hydrogen economy". Marine methane deposits - possibly renewable - could represent a significant future component in our energy resources.

Nuclear - fission and fusion:

New disposal methods for fission products.

New reactor concepts - thorium, sub-critical reactors, fuel recycling.

Fusion - always +40 years? ITER - better luck this time!

A very important resource:

Sensible energy economy, e.g.efficient lighting, home insulation, materials replacement, industrial technology - greenhouse or not, it's worthwhile!
Example - no electricity from natural gas or coal for aluminium production

False dawns?

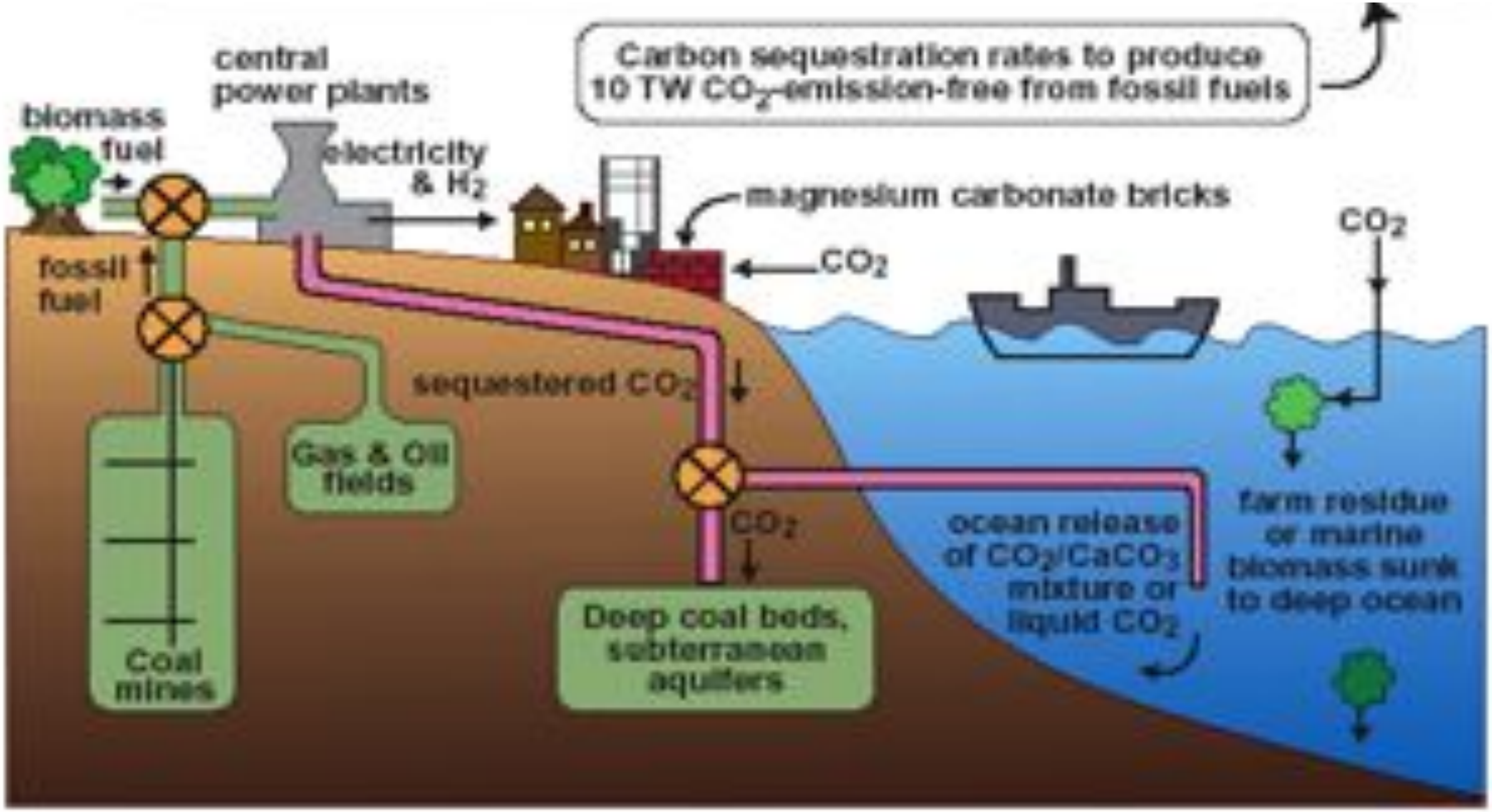
The "**hydrogen economy**" - depends of the energy source for hydrogen production. "Renewable hydrogen" depends on the availability and cost of "renewable energy" - PV, concentrated solar, bioprocesses etc.

"**Carbon capture and storage**" - very high infrastructure and investment costs for capture of a fraction of emissions in industrialised countries. "Sequestration" = dumping. Any USE for carbon dioxide?

"**Enhanced biomass**" - nature does it best! Cellulose, lignins - genetic engineering of processing organisms?

Fusion? - worth an effort, even for the development of associated technologies and materials:"day after tomorrow"

Carbon sequestration - or just another form of dumping? Is this scenario credible?



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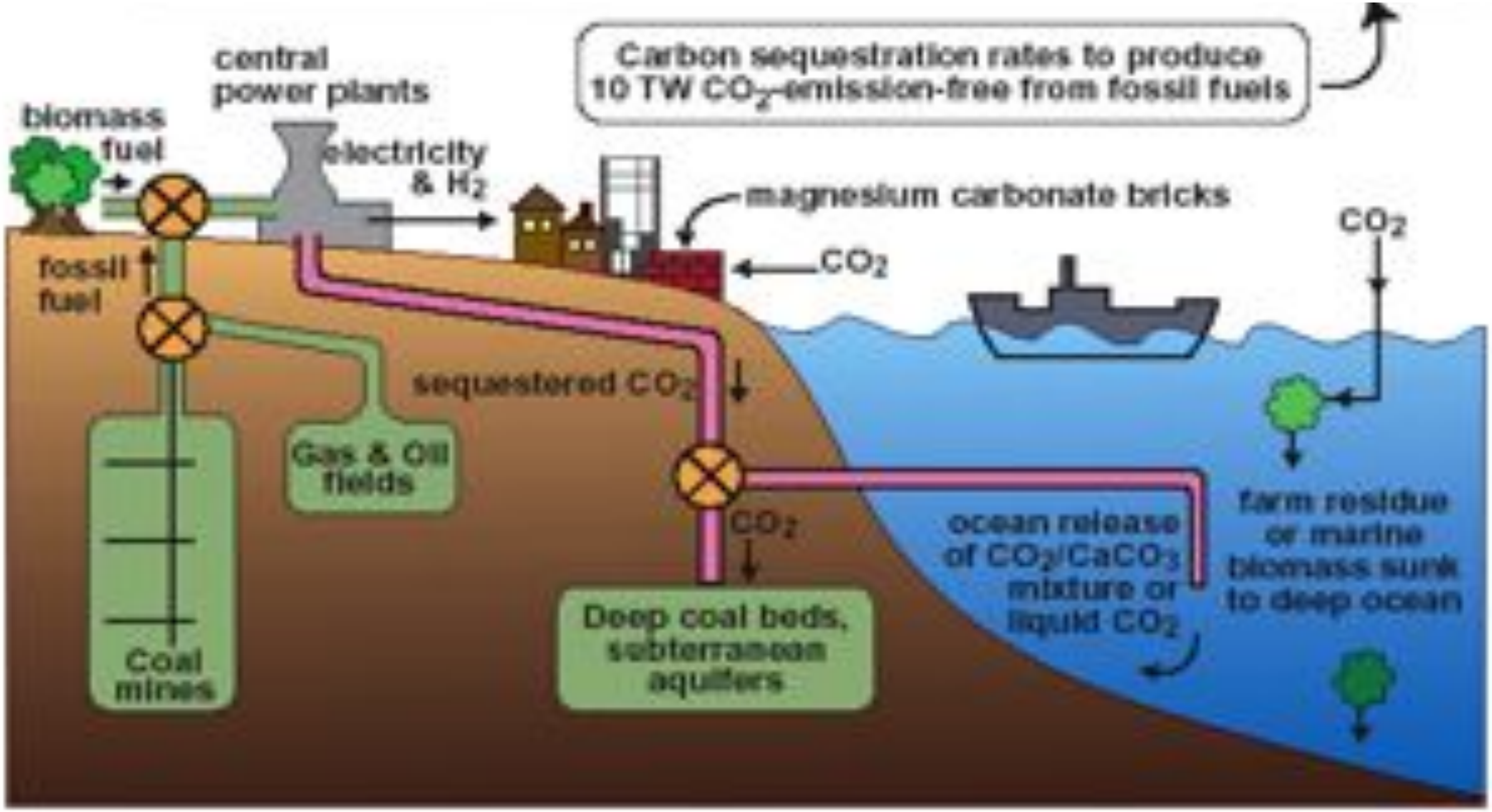


Let’s look at ”renewable/sustainable” energy sources - answer the “prophets of doom”

1. Hydroelectric Energy Potential

Globally

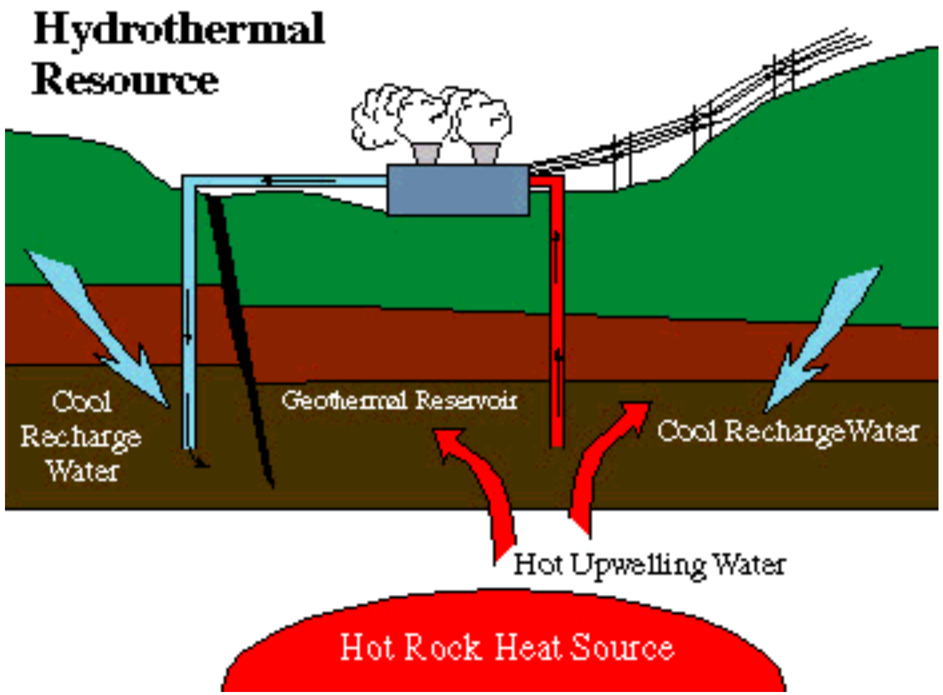
- Gross theoretical potential 4.6 TW
- Technically feasible potential 1.5 TW
- Economically feasible potential 0.9 TW
- Installed capacity in 1997 0.6 TW
- Production in 1997 0.3 TW

(can get to 80% capacity in some cases)

Source: WEA 2000

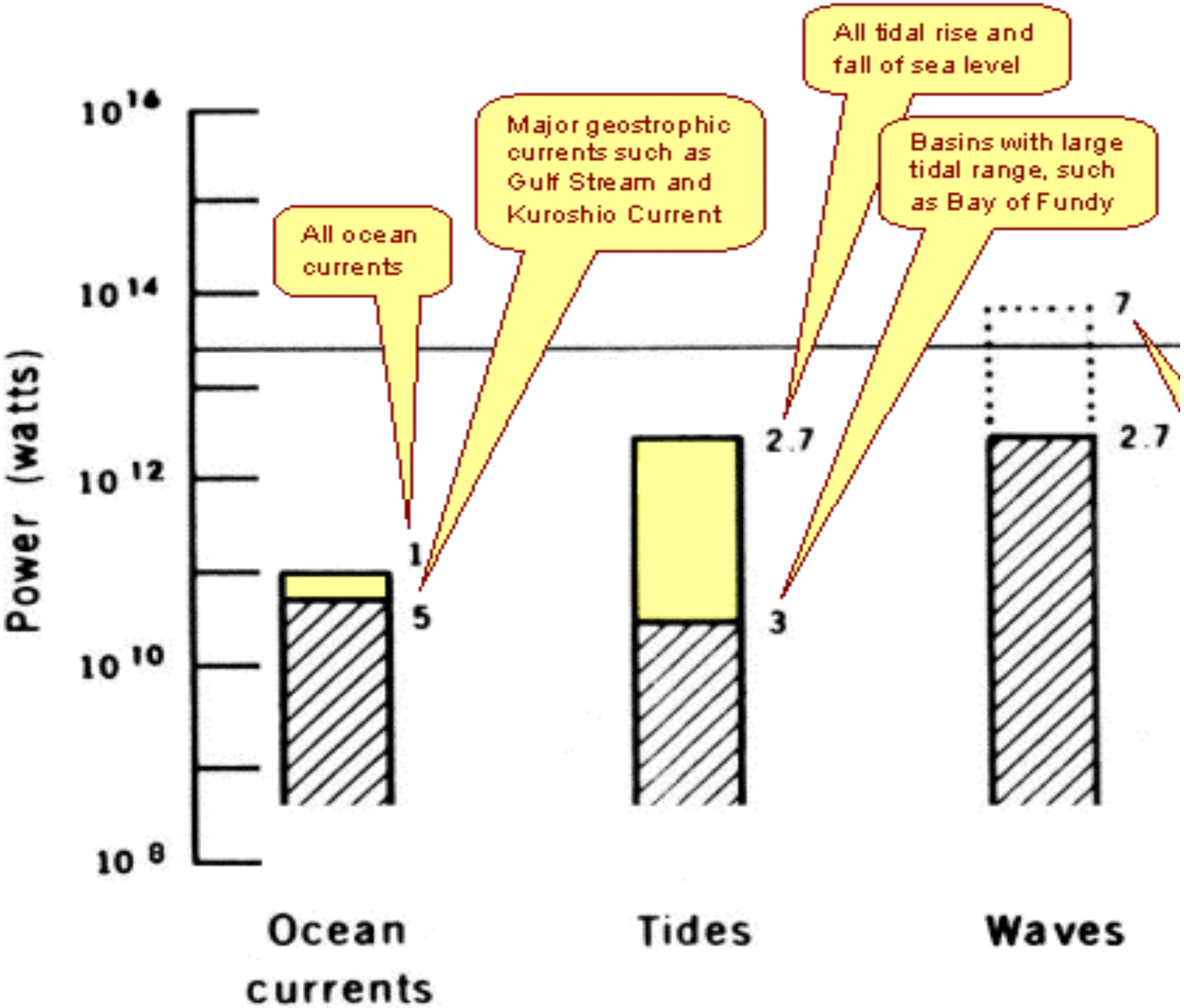
2. Geothermal - pity we can't tame volcanoes!

Hydrothermal systems
Hot dry rock (igneous systems)
Normal geothermal heat
(200º C at 10 km depth)



Already applied in Italy, New Zealand, Iceland, Kenya, El Salvador, USA
Worldwide (2007) installed capacity 10 GW, 0.3% of electricity demand.

3. Ocean energy potential



4. Wind

- **Very rapid adoption** - Germany, Denmark, USA etc.

- **<u>Top-down</u>**:
  Downward kinetic energy flux: 2 W/m^2
  Total land area: 1.5×10^{14} m^2
  Hence total available energy = 300 TW
  Extract <10%, 30% of land, 30% generation efficiency:
  2-4 TW electrical generation potential

- **<u>Bottom-Up</u>**:
  Theoretical: 27% of earth's land surface is class 3 (250-300 W/m^2 at 50 m) or greater
  If use entire area, electricity generation potential of 50 TW
  Practical: 2 TW electrical generation potential (4% utilization of ≥class 3 land area, IPCC 2001)

  Off-shore potential is larger but must be close to grid to be interesting, < 20 km offshore now

5. Biomass

- Land with Crop Production Potential, 1990: $2.45x10^{13}$ m^2
- Cultivated Land, 1990: 0.897 $x10^{13}$ m^2
- Additional Land needed to support 9 billion people in 2050: $0.416x10^{13}$ m^2
- Remaining land available for biomass energy: $1.28x10^{13}$ m^2
- At 8.5-15 oven dry tonnes/hectare/year and 20 GJ higher heating value per dry tonne, energy potential is 7-12 TW
- Perhaps 5-7 TW by 2050 through biomass (recall: $1.5-4/GJ)
- Possible/likely that this is water resource limited
- 14% of U.S. corn provides 2% of transportation fuel
- Challenges for chemists: cellulose to ethanol, lignin, straws etc.

6. Last - and most "resourceful of all" - solar

- **Theoretical: $1.2x10^5$ TW solar energy potential**

  (1.76 $x10^5$ TW striking Earth; 0.30 Global mean albedo
- **Energy in 1 hr of sunlight ↔ 14 TW for a year**
- **Practical: ≈ 600 TW solar energy potential**

  (50 TW - 1500 TW depending on land fraction)

  Onshore electricity generation potential of ≈60 TW, η = 10%
- **Midday solar irradiation (AM1) = 1kW/m^2; PV electric yield 100 W/m^2**
- **Energy (N. Europe) 800kWh/kW$_{pk}$; 80 kWh/m^2, or 2 kg. $H_{2/}$year**
- **But 0.13% of earth's surface covered with PV panels of 10% efficiency =**

  present world total energy demand!
- **It's a matter of scale and economics!**
- **Solar energy is very powerful, but very dilute!**
- **And don't forget solar thermal!**

Solar Land Area Requirements

6 Boxes at 3.3 TW Each

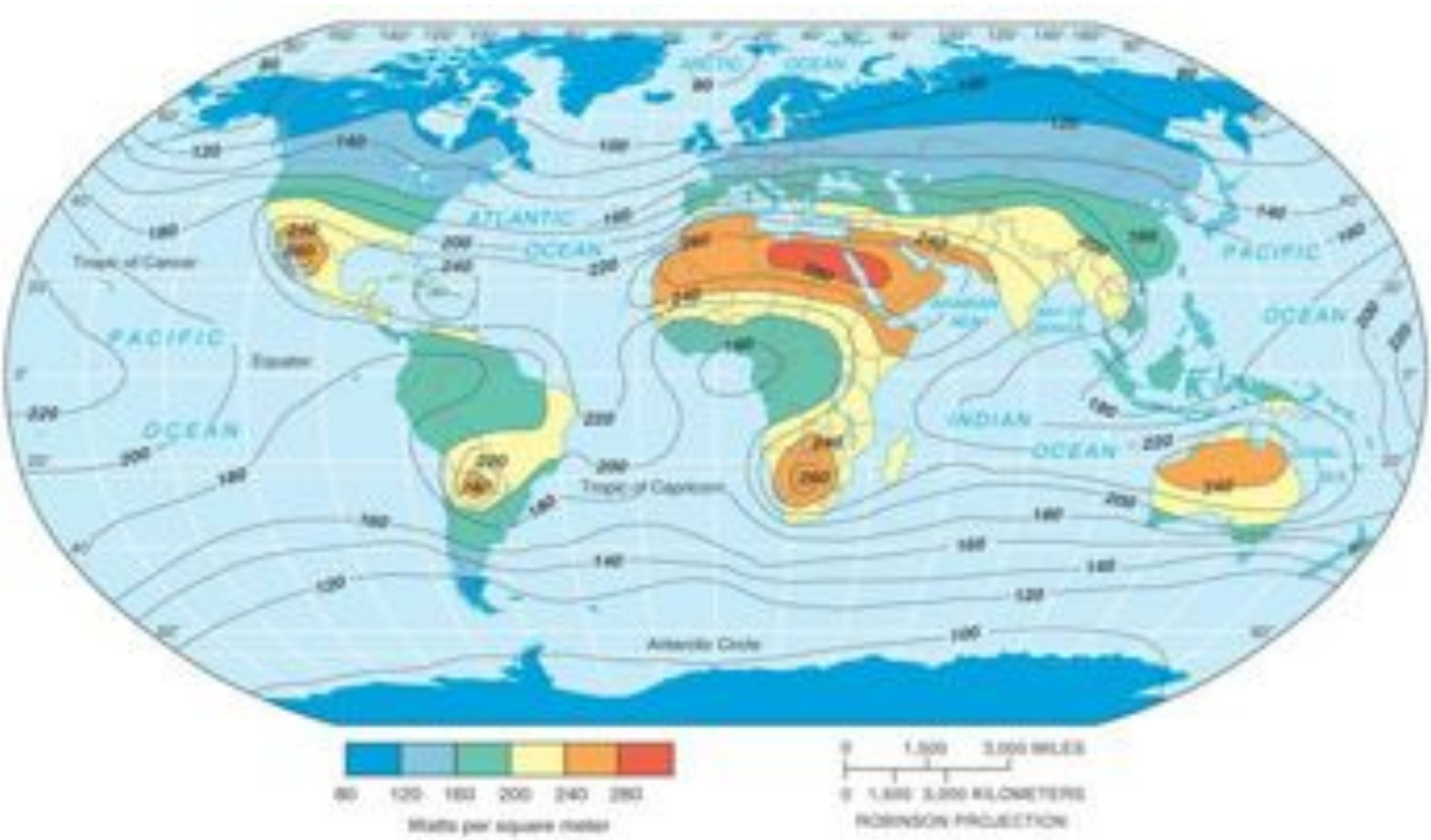

So sources are not lacking!

Earth at night - global distribution of population and demand

DMSP & NASA(http://visibleearth.nasa.gov/)

Fundamental problem - energy storage & distribution.

Global distribution of the solar resource does not match population and demand.



Waste and inefficiency - resources lost

Europe,
Middle East
& Africa

Oil industry and gas flaring visible from space.

Example: flaring natural gas

How much? - about 150 billion cubic meters/year (2009), equivalent to about 25 percent of the United States' yearly gas consumption or 30 percent of the European Union's gas consumption. The annual 35 bcm of gas flared in Sub-Saharan Africa alone could generate half of that continent's power consumption. Gas flaring also has a global impact on climate change by adding some 400 million tons of CO_2 annually.

Source: World Bank.

Good news - but not enough! - gas flaring has declined by a total of 22 billion cubic meters over the past three years, despite a 5% rise in crude oil production, according to the latest satellite study commissioned by the Bank Group-led GGFR partnership.

Where? - According to these satellite estimates, the ranking of top 10 flaring countries are Russia,Nigeria, Iran, Iraq, Algeria, Kazakhstan, Libya, Saudi Arabia, Angola and Qatar. Most of the gas flaring reduction is coming from Russia and Nigeria.

Example - Nigeria

”Gas flares pump 400 million tons of CO_2 annually into the atmosphere. 13% of the gas flared in the world comes from Nigeria alone and stands at about 23 billion cubic meters per year. This quantity is enough to meet Nigeria’s energy needs and leave a healthy balance for export. Through this obnoxious procedure the country has lost about $72 billion in revenues for the period 1970-2006 or about $2.5 billion annually. All these go up in smoke yearly, leaving death and destruction in their path ". N. Bassey.

Natural gas for 500 years? - Methane hydrate

(Or why BP has a problem in capping that oil spill in the Gulf of Mexico).

The ice which burns forms spontaneously at high pressure and at temps close to 0ºC

The size of the global gas hydrate resource is staggering, holding more ultimate energy potential than all fossil fuels combined, according to the U.S. Geological Survey (USGS).

Is it safe?

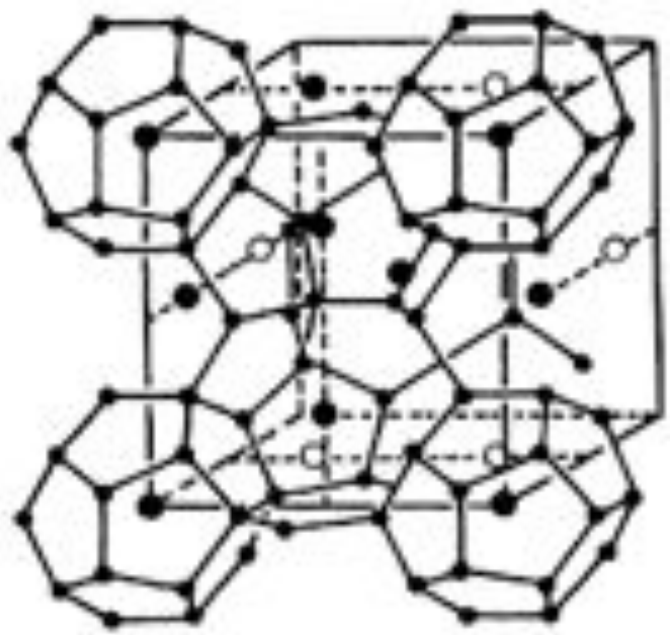
Every technology has its risks!

Loss of methane to the atmosphere - greenhouse gas

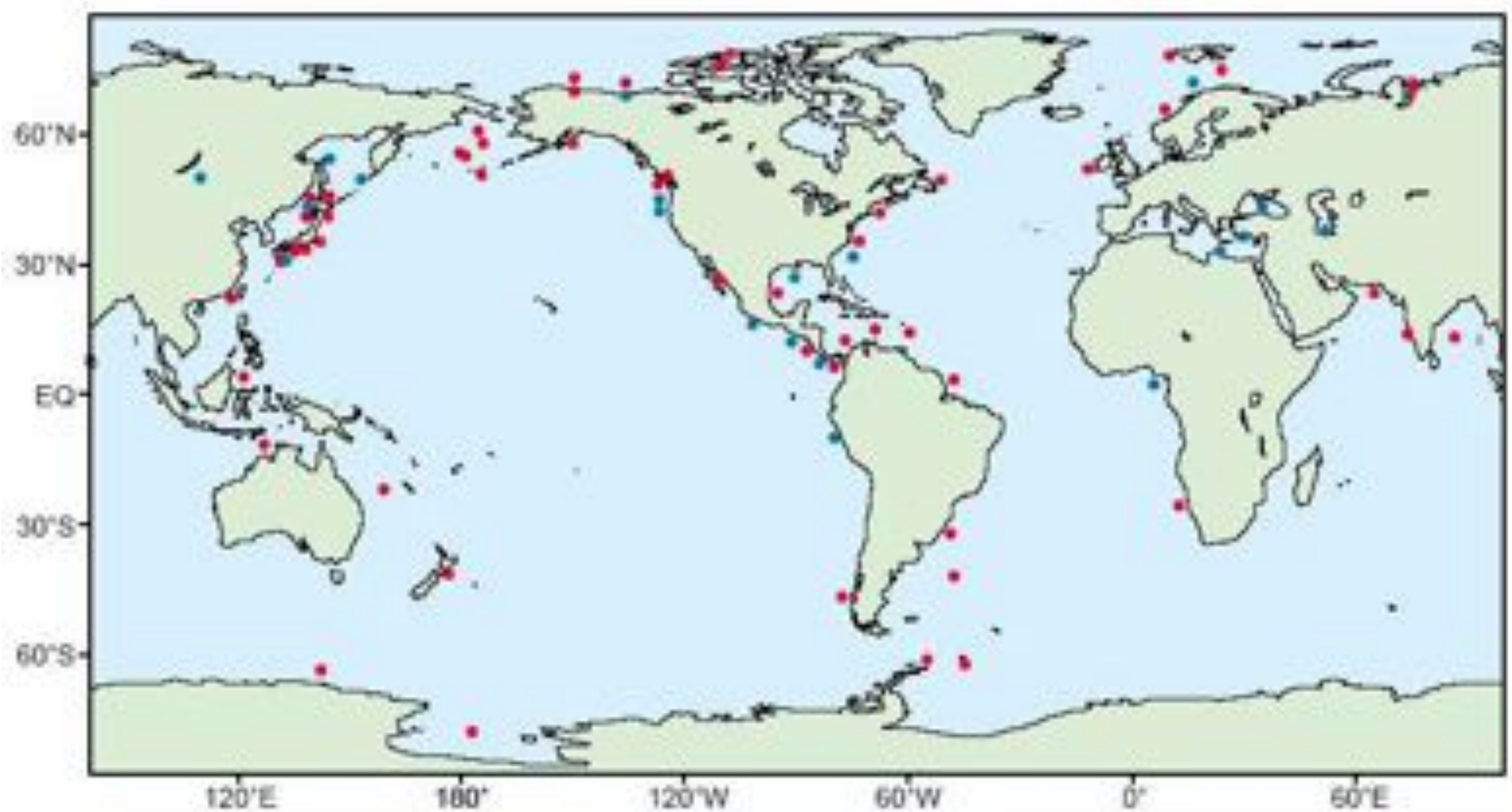
Depressurisation of hydrate deposit - uncontrolled release - geological/hydrological stability?

Methane hydrate (clathrate) crystal structure

The clathrate is a well-defined crystal composed of methane and water, the caged methane molecule aggregating into a cubic unit cell. The methane to water ratio is 1 to 5.75

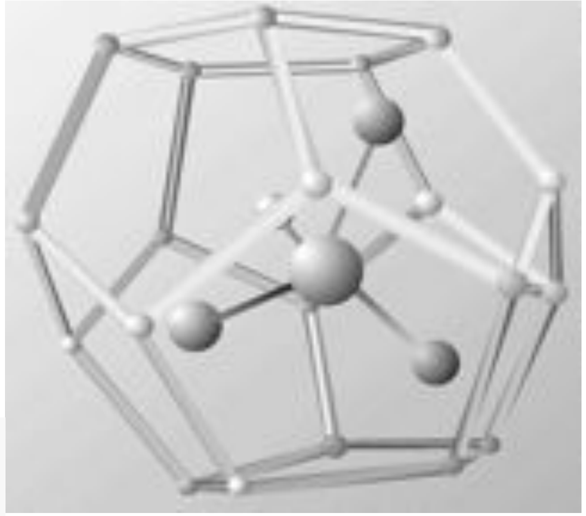


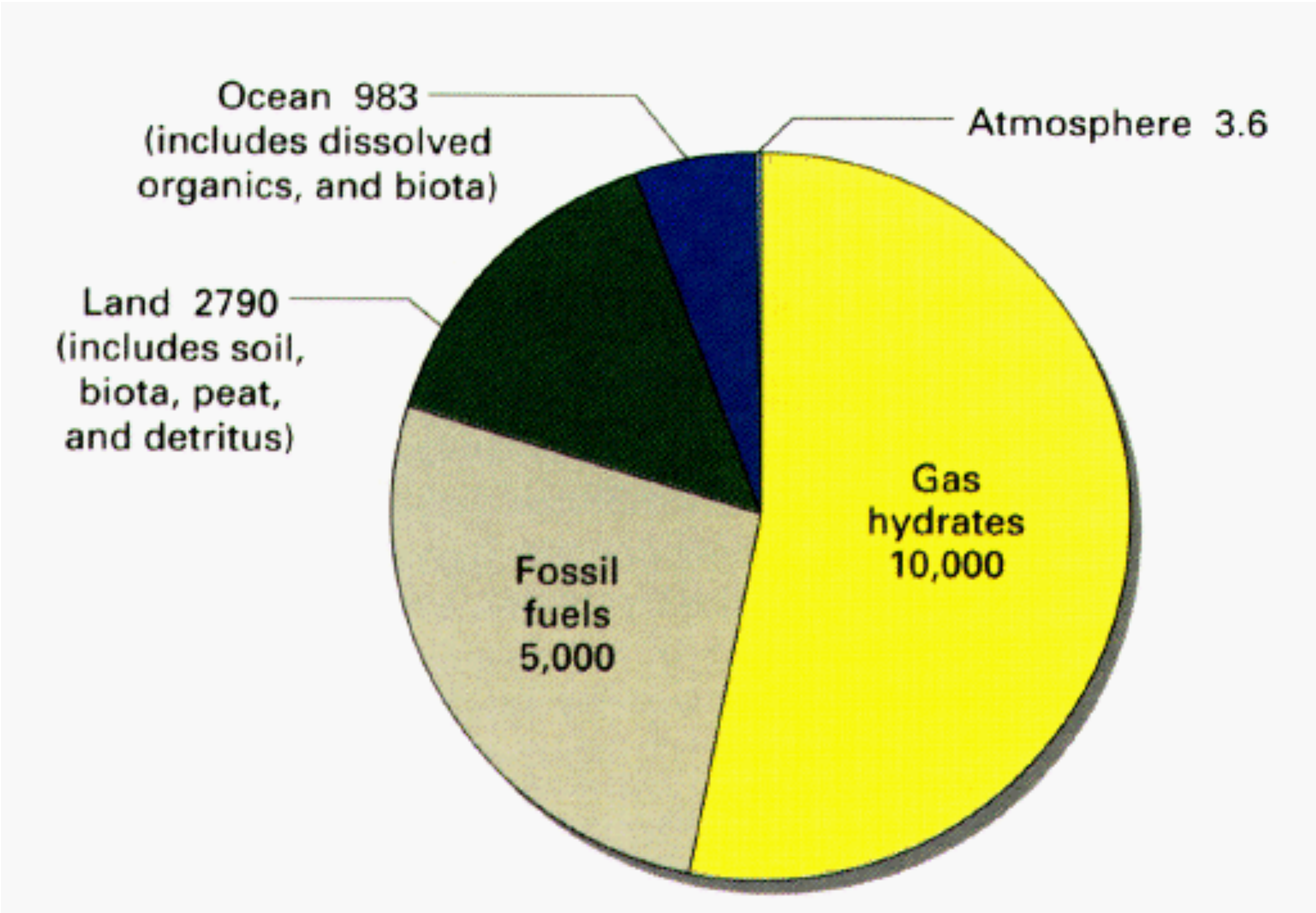
Estimated global distribution of methane hydrate

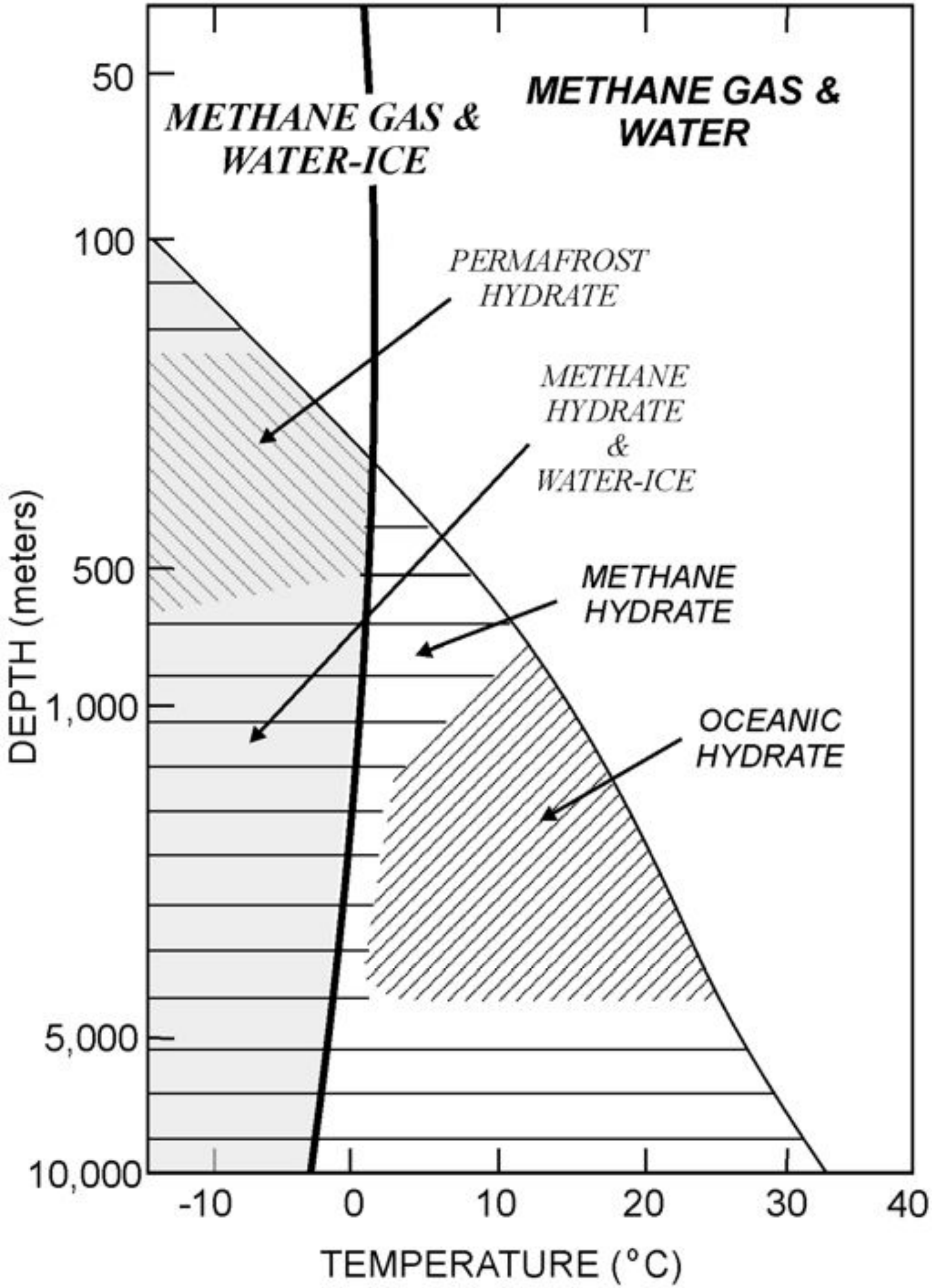


Global distribution of confirmed (blue) or inferred (red) methane hydrate sites. This information represents the presently very limited knowledge. Gas hydrate is probably present in essentially all continental margins.

How much? - estimated world organic carbon x 10^{12} kg (gigatons!)







Physical equilibria - methane hydrate

Is it "renewable"? - it's certainly "sustainable"
What is the formation process?

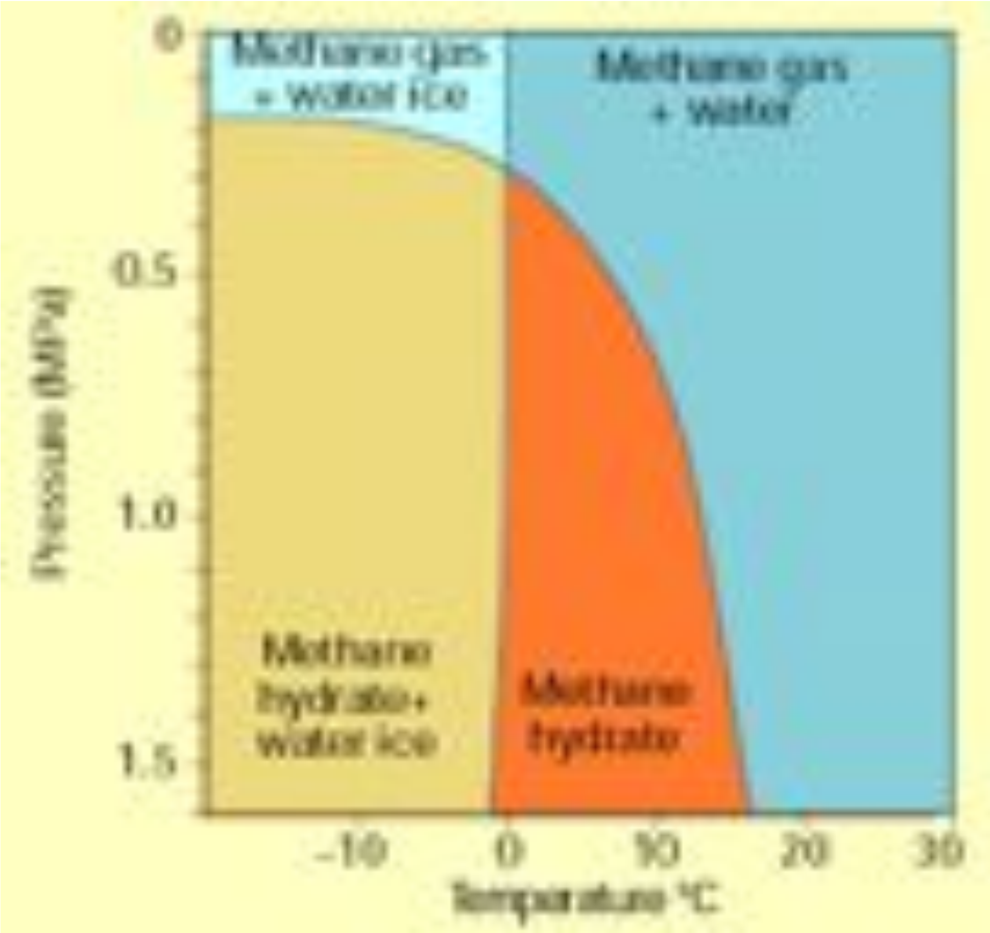
•Decomposition of organic detritus by anaerobic bacteria under seafloor sediments

•Methane gas evolves and dissolves in ocean water

•High pressure and low temp. allow hydrate formation

•Kinetics/equilibrium?

•Or is there a geological source - deep earth? (Green)



Other unconventional options.

Methane clathrates have been presented in detail as an example of an energy source which does not enter into most scenarios.

Are there others?

1. Nuclear. It is asserted that the reserves of uranium are only sufficient for 100 years. But U^{238} - not fissile but fertile - is presently wasted in tank shells! With breeder reactors the uranium resource is multiplied by 50. And using a thorium cycle (India) the Resources can supply nuclear power for the next millenium.

2. Solar. The established technology is the “physicist’s solar cell” using semiconductor junctions. As we have seen, it is effective and reliable, but not economically competitive. There is intensive development of the “chemist’s solar cell” - dye sensitisation (DSC) or organic devices, involving nanotechnolgy or thin films.

Energy from sea & sky

Methane Hydrate (Clathrate) - “the ice that burns”

Methane clathrate hydrate could provide an significant energy supply for the future. There is an estimate that there is more fuel in these icy deposits than in all the oil reserves on the planet! The problem is that methane is 30 times as bad a green house gas as carbon dioxide but at least it is safely frozen on the bottom of the ocean! However clathrate in permafrost is another question!

Vitrification of nuclear waste

Energy for Light in our lives

That’s why we are here! - it is a challenge for us all

Thank you for your
attention & participation!