# Energy sources for the 21th century

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# Two challenges for the 21st century

- Provide to the world with the energy it needs

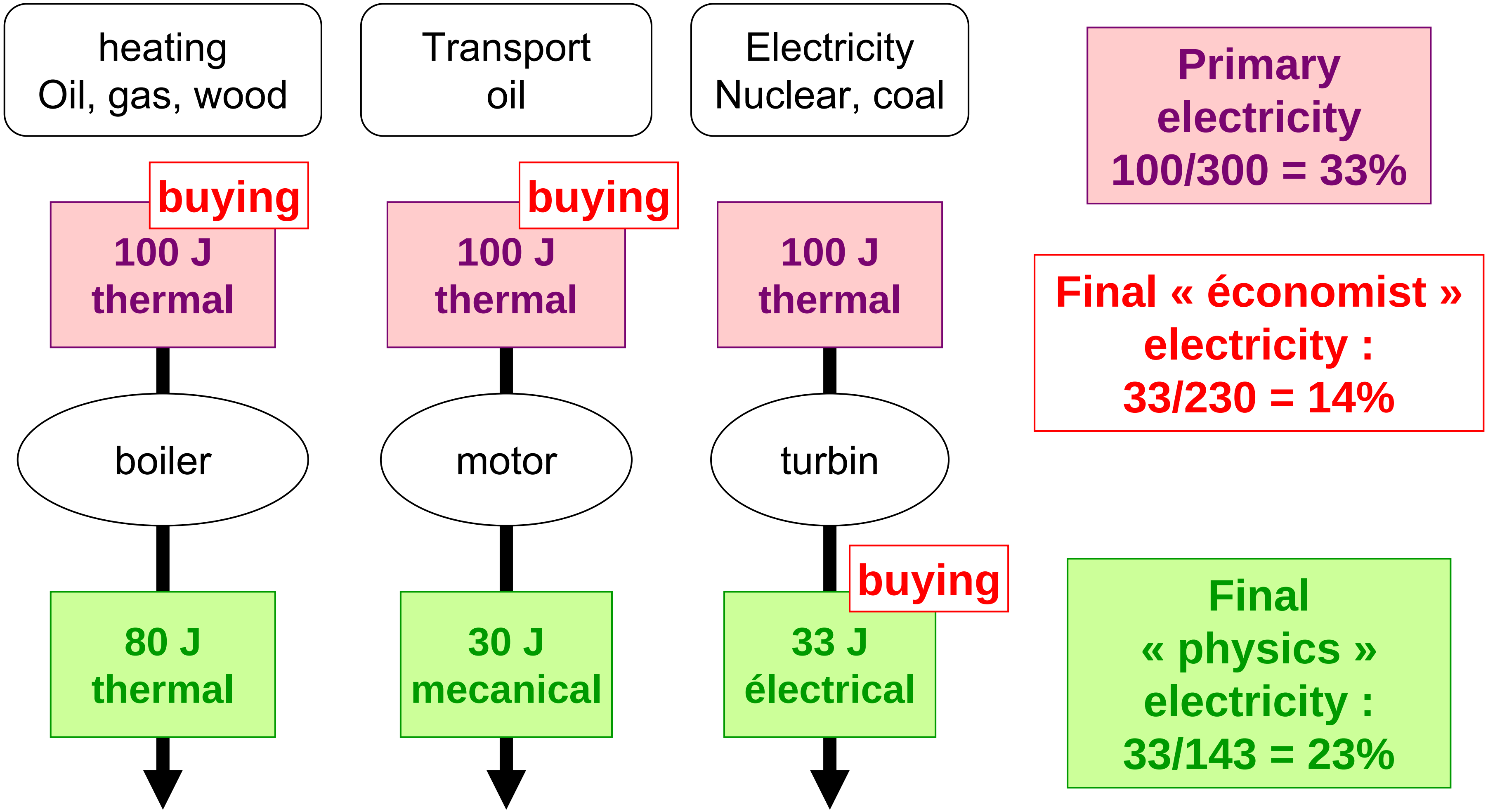
- Limit the emission of green-house gas

# A few words about the different ways to count energy

Different units used

- Physics :
  - [Energy] = Joule (J) ; [Power] = Watt (W) = J/s
  - elementary chemical process eV = $1.6\ 10^{-19}$J
  - elementary nuclear process MeV = 1 million d'eV
- individual
  - Electricity [Energy] = kWh = 1000 * 3600 = 3.6 MJ
  - Transport [Energy] = liter of fuel / 100 km, km / gallon
  - [Power] = Horsepower = 735 W
- Industry
  - Electricity [Energy] = TWh, TWh/an, …
  - Oil [Energy] = « Barrel »
- Food
  - [Energy] = calorie = 4.18 J ou 1 Calorie = 4180 J (!?)
- Economy
  - [Energy] = toe Ton oil equivalent
- Explosive
  - [Energie] = kilos, 1 ton of TNT = $4{,}18\ 10^{9}$ J
- ……………

# The question of primary energy, final energy, and a new (and absurd) definition of the ton oil equivalent



# Nuclear in France

Final electricity

nuclear : 80 %

Total primary energy

nuclear : 39%

Total final energy « physicist »

nuclear : 26 %

Total final energy « economist »

nuclear : 17%

Just choose the one which confirms what you want to prove…

# The official "ton oil equivalent"

1 toe = 42 GJ

But for electricity…

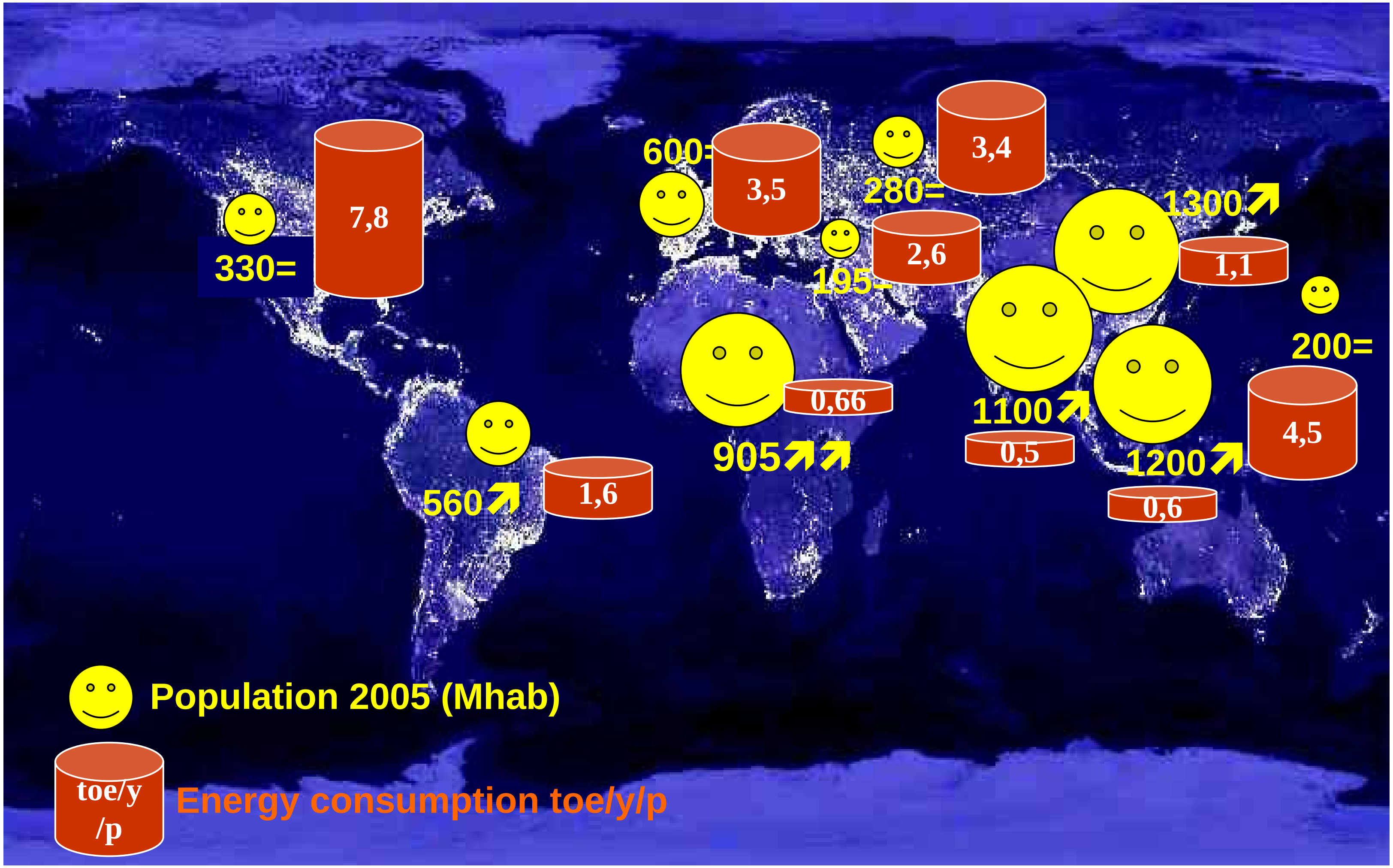
Before 2002 : a logical definition :
the mass of oil one should be use to produce 1 MWh of electricity
Reference efficiency of the oil plant = 38,7%
1 MWh = $3{,}6\ 10^9$ Jelec = $3{,}6\ 10^9$ / 0,387 Jth = $9{,}3\ 10^9$ Jth = 0,22 toe

Since 2002 : an absurd definition
1 MWh of electricity correspond to a certain quantity of primary energy, depending on the source (efficiency), and 1 MWh = Eprimary / 42GJ
This leads to :

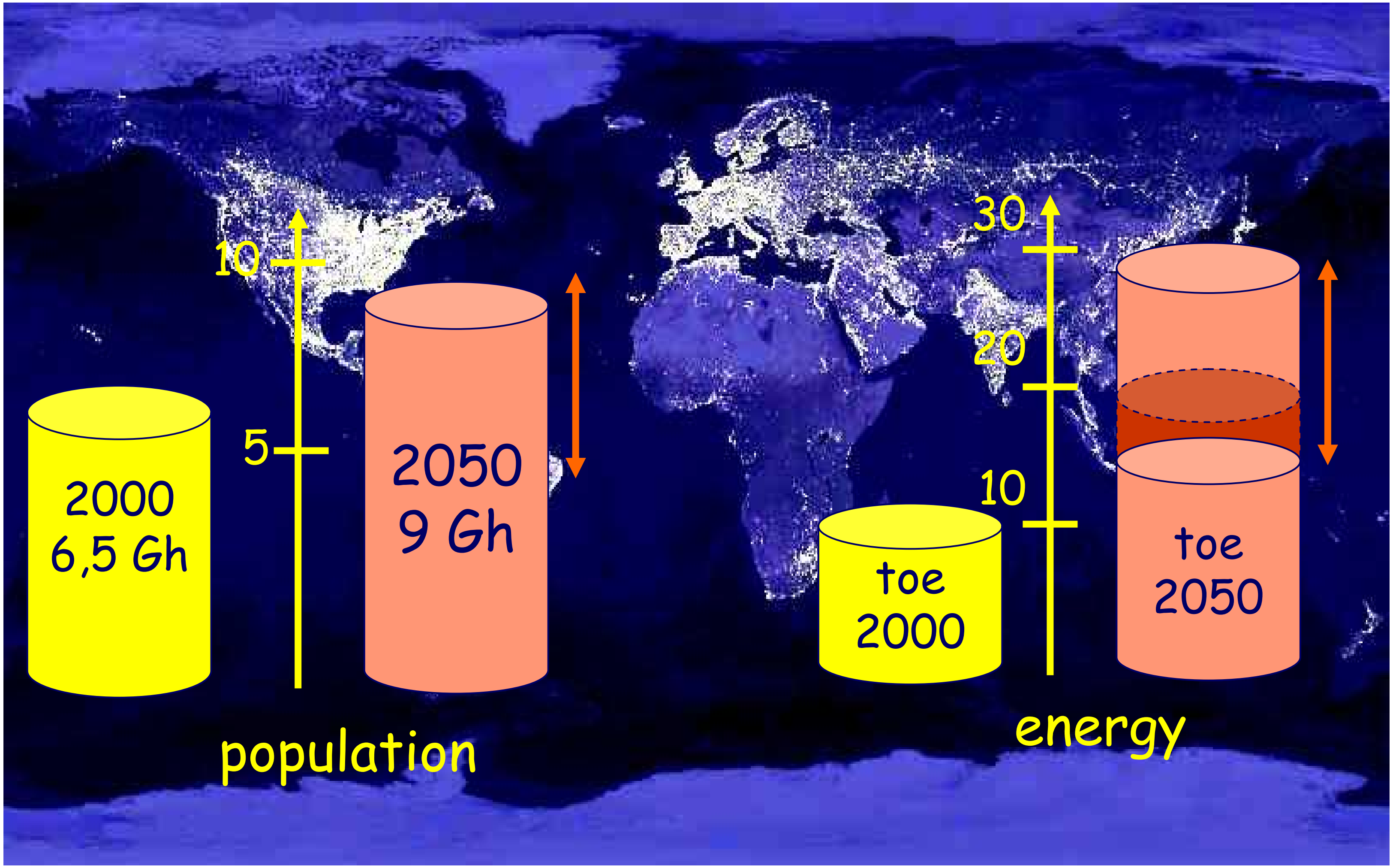
| | |
|---|---|
| Gas, coal | 1 MWh = 0,17 – 0,29 toe |
| Nuclear | 1 MWh = 0,26 toe |
| Solar, wind | 1 MWh = 0,086 toe |
| Geothermal | 1 MWh = 0,86 toe |

The same quantity of electricity does not correspond anymore to the same quantity of oil, this is not a "ton oil equivalent"

# Contexte énergétique mondial



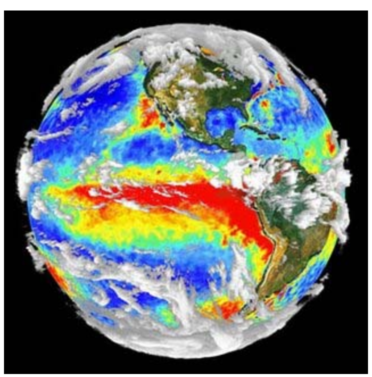
# Contexte énergétique mondial



# Energy, environment and human health, an old story

-5000 y — caverna — Biomass

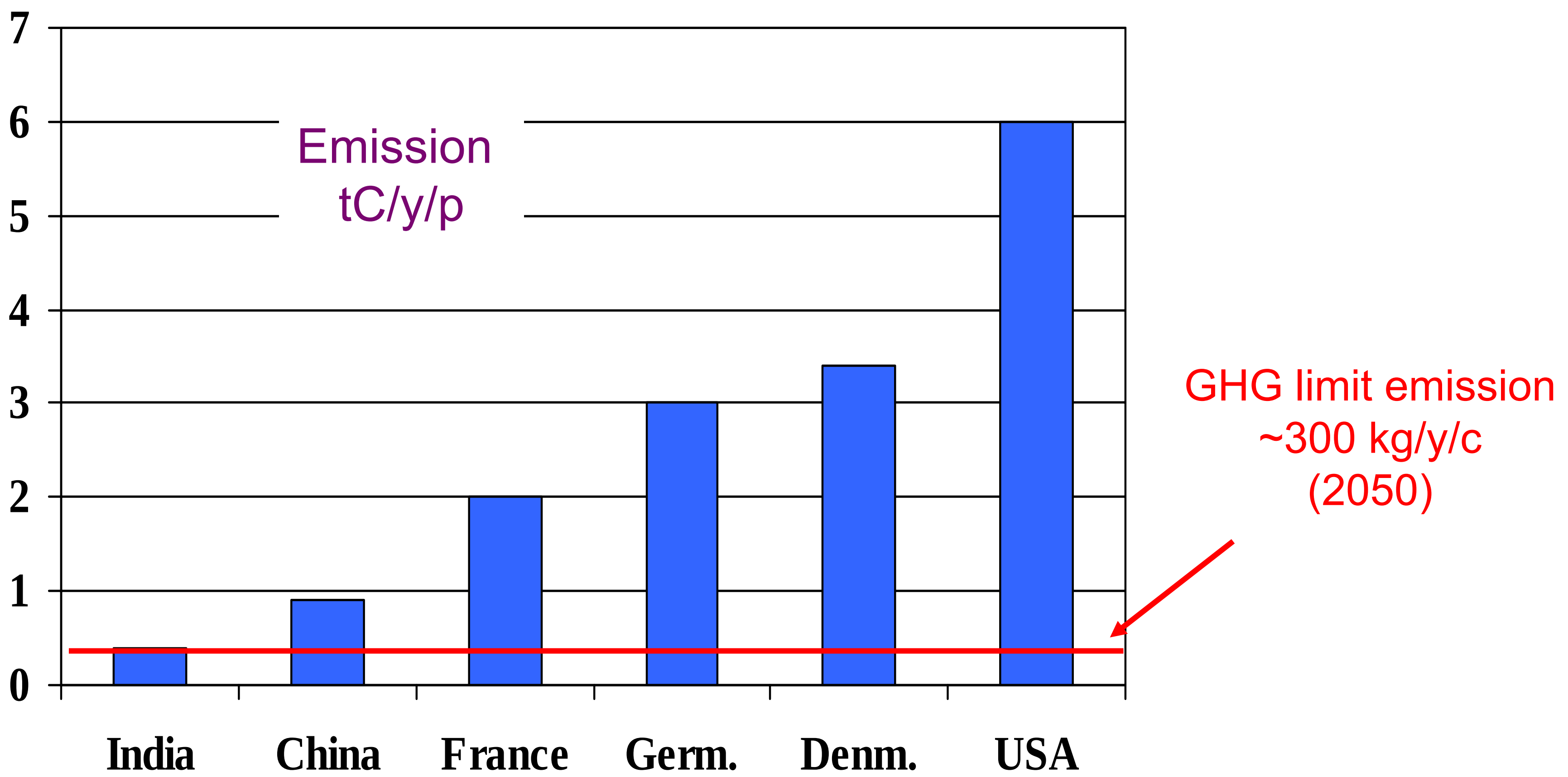

-50 y — Big cities (London big smog 1952) — Coal



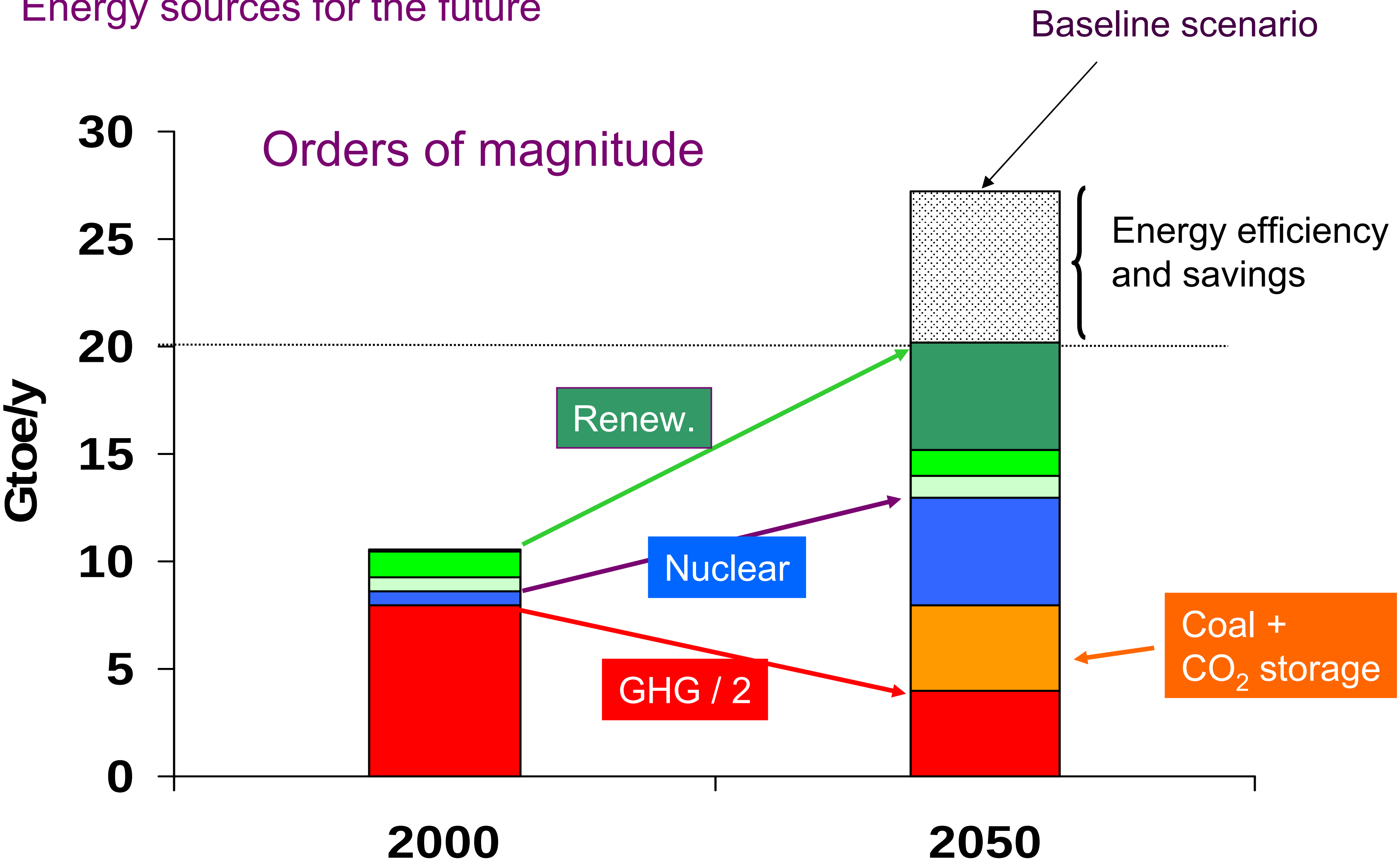
today — planet — Coal, Oil, Gas

# GreenHouse Gas Emission

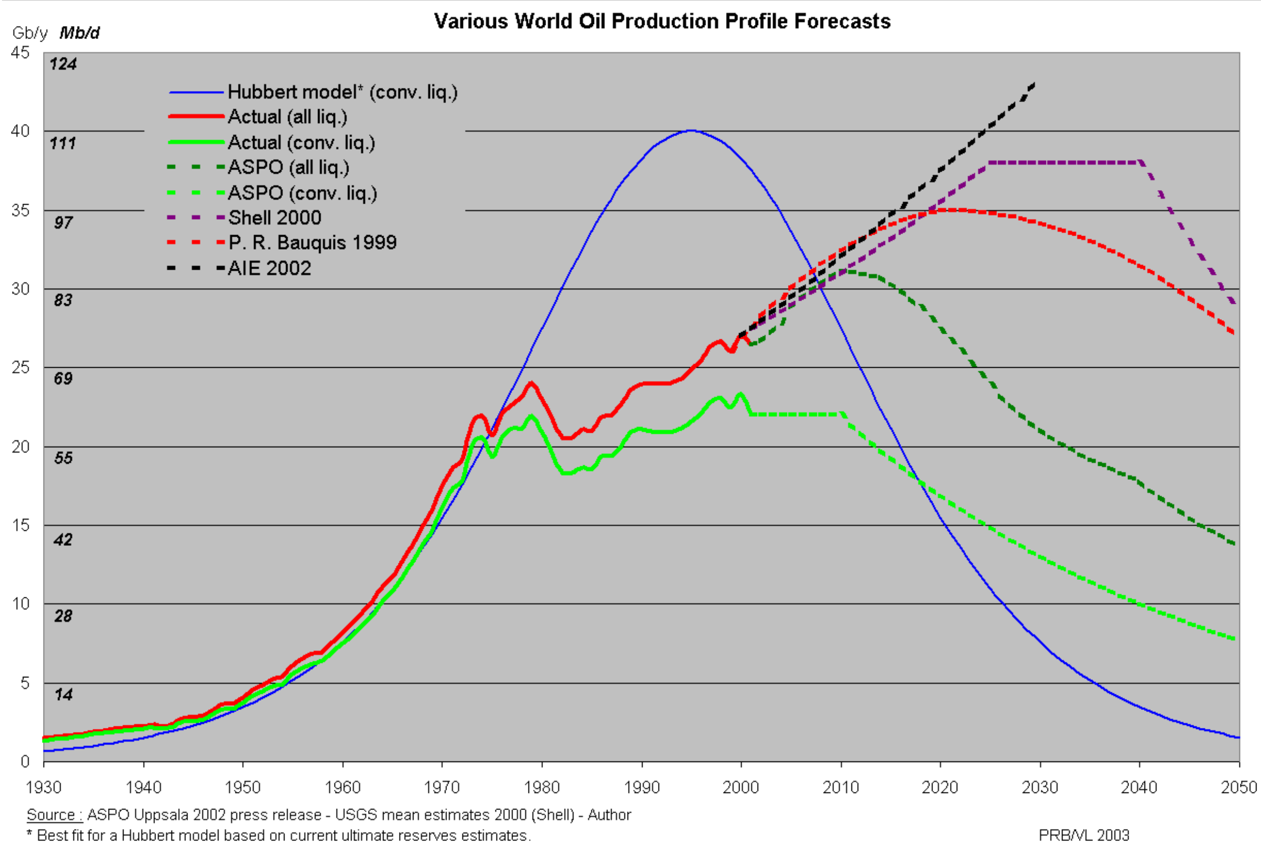
Reduce the GHG emission from 6,5C/y to 3GtC/y in 40 years



## Energy sources for the future



## Uncertainties concerning oil and gas reserves in the coming decades




Réf: PR Bauquis – Total Prof. Associés

Peak before 2050 for oil and gas, more reserves for coal

# Fossile fuels and greean-house gas emission

| fuel | $M_{CO_2}$ (kg/toe) |
|---|---|
| coal | ~4 400 |
| oil | 2 900 |
| gas | 2 290 |

Combustion : gas produces twice less $CO_2$ than coal, for the same energy production

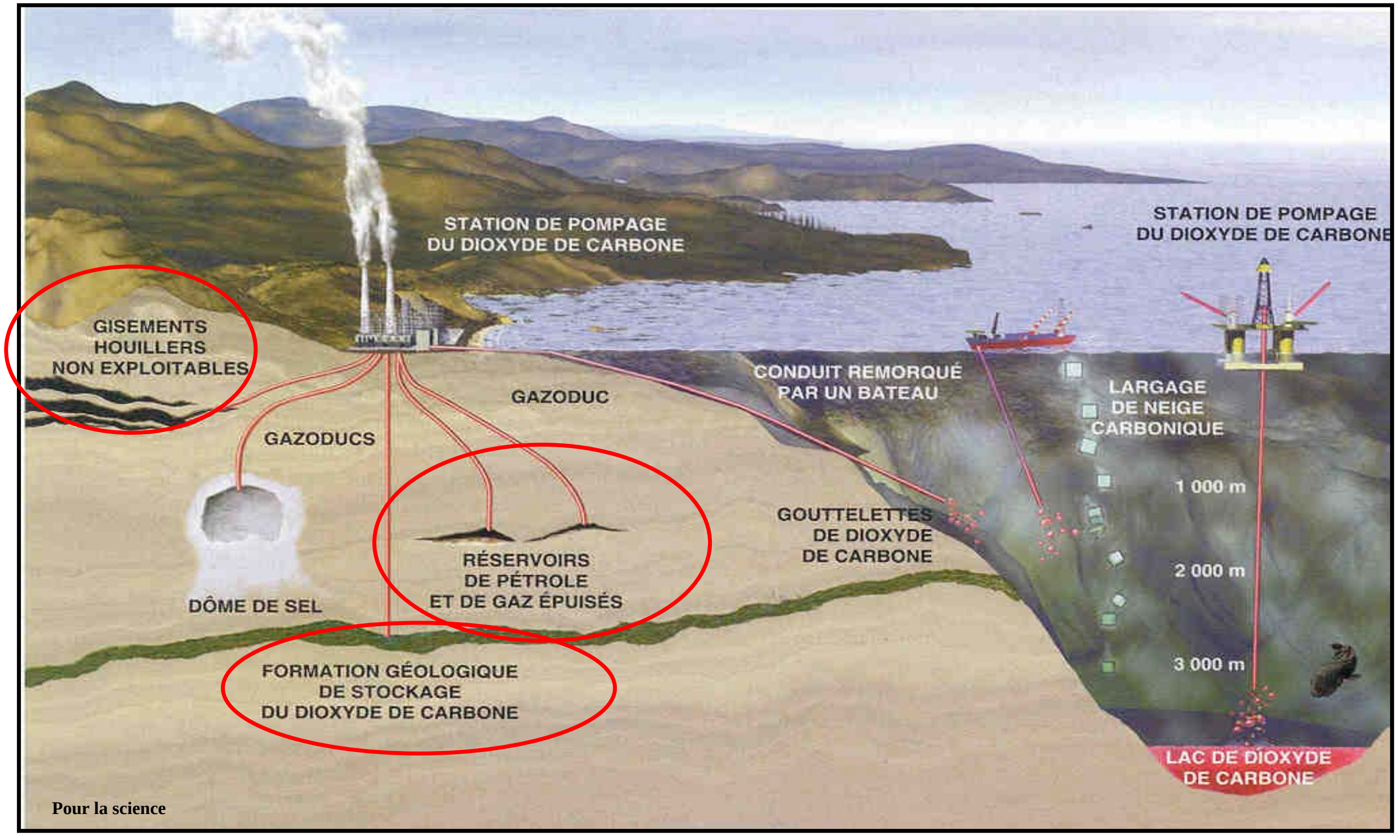
But

global warming potential 1 $CH_4$ = 25 $CO_2$

4% of $CH_4$ leakage during extraction is sufficient to double the GHG emission of natural gas in "$CO_2$ equivalent"

Emission of gas and coal are equivalent ~4000 kg.eq. $CO_2$ / toe

## $CO_2$ storage : centralised use (electricity, heat?)




Large R&D needs, cost, acceptability

Order of magnitude to reach : 15 Gt $CO_2$ / year !!

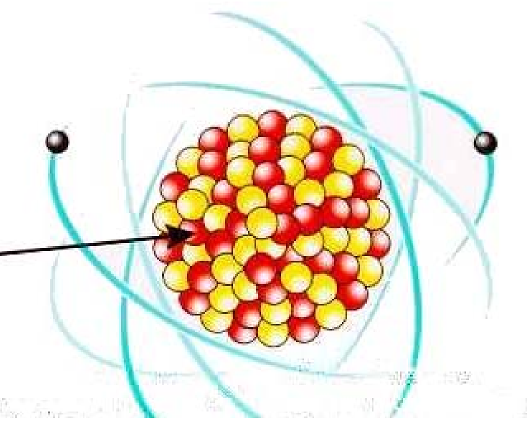
A way to make us accept the present coal revival ?

# Other primary sources



Sun

Energy produced by fusion p+p



Nuclear binding energy

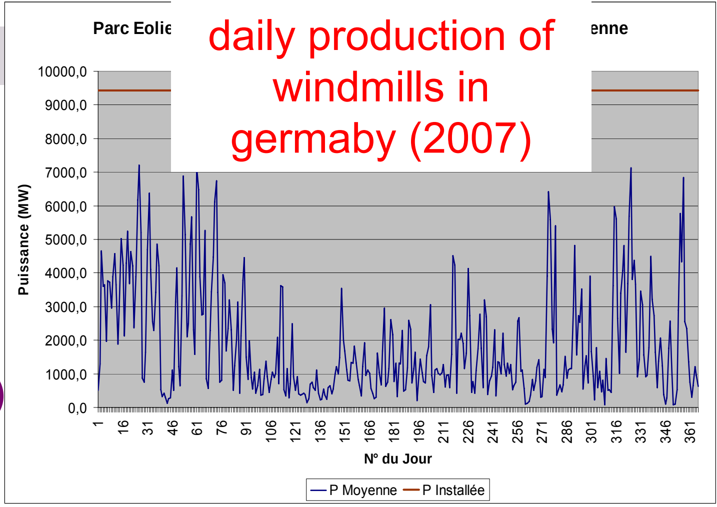
| | |
|---|---|
| Primary light on earth | 250 W/m² |
| Photovoltaïc | 25 W/m² |
| Heating pannels | 50 W/m² |
| Wind | 10 W/m² |
| Biomass | 1 W/m² |
| Hydropower | 5-25 W/m² |

intermittent (Primary light, Photovoltaïc, Heating pannels, Wind)

Diluted = large surface needed

Biomass : very low efficiency, but stored energy !
Hydropower and PV ~ same surface needed, but costs are ≠, PV intermittent
Wind : intermittent, large surface needed, but small surface « on ground »

# Wind and Photovoltaic :
# how to manage intermittence ?




- New network : small and intermittent production units
- Coupled with flexible unit : gas&coal (non satisfactory)
- hydropower (limited)

- Really efficient if large electricity storage capacities are available
  - Chemical storage : limited (100 Wh/kg) but efficient for transport
    - Car consumption 10-20 kWh/100km, 200 kg battery, auton. 250 km
  - Double hydroelectric plants : very effective
  - Hydrogen $H_2O \rightarrow H_2 + ½\, O_2$ + 120 MJ storage (hydrolyse, HT cracking)
    - re-use of energy : $H_2 + ½\, O_2 \rightarrow H_2O$
    - But : efficiency of the complete chain very low
    - But : economic way to use $H_2$ : Coal-to-Liquid process !

| Solar wind | electricity | $H_2$ | Conditionning transport | Fuel cell or combustion | electricity | motor |
|---|---|---|---|---|---|---|
| 100 | 15 | 8 | 6 | | 3 | 2,5 |

**2,5% to be compared to 10% for electric car, or 0,2% for biofuels**

# Fission nuclear energy

16% of the world electricity production

If nuclear power must play a role in the future

- ≈ 50% of electricity
- ≈ 3000 reactors in the world
- Major challenge : change scale
    - Uranium reserve
    - Optimize the waste management
    - World safety culture
    - others application : heat, $H_2$

# Uranium reserves

Generation 2&3 reactors use essentially $^{235}U$ as fissile material

$^{235}U$ = 0,7% of uranium ore only

If nuclear power increases significantly (≈x10), the uranium peak could be reach in 50 years

Generation 4 systems

Use 100% of uranium ore : $^{238}U$ non fissile

Breed their own fissile material : $^{238}U + n \rightarrow {}^{239}Pu$ ; $^{232}Th + n \rightarrow {}^{233}U$

Reserves for 50000 years at least !

Minimisation of long-term waste (transmutation)

But

New technologies, more complex, expensive (fast neutrons)

Sodium technology → is safety compatible with 3000 reactors ?

# geothermal

- Heat from radioactivity of $^{238}U$, $^{232}Th$, $^{40}K$

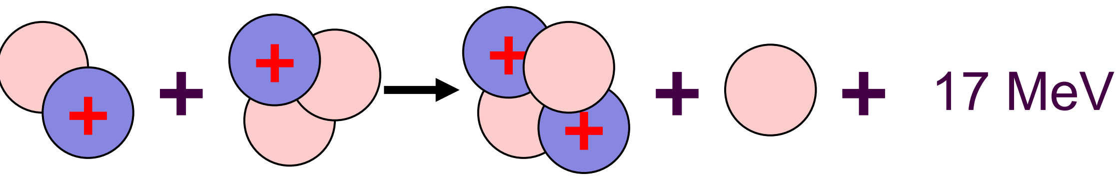
- Total geothermal power = 22 TW
Same order of magnitude of the world energy consumption
Geothermal flux = 0.06 W/m$^2$ (<< solar)

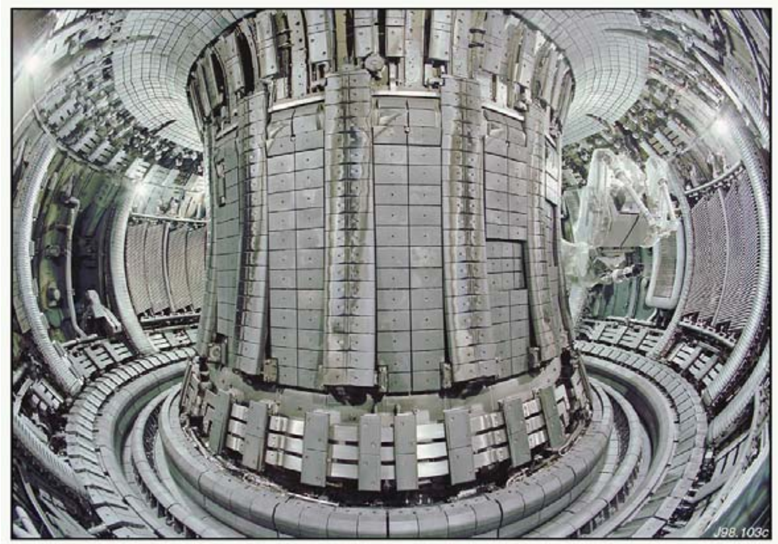
-But : heated rocks = thermal energy stored
Not renewable, but significant capacities possible in some region

Europe : 10% of heating possible

*Specific case : Iceland*
*Surface 103 000 km²*
*Population 320 000*
*Density 3 / km²*
*(France ~120)*

## Fusion nuclear energy



Tritium does not exist in nature :

$^{6}Li + n \rightarrow t + {}^{4}He$

Fuel : deuterium and lithium : reserves for thousands of years

Long-term reserach

Reserves of deuterium and lithium for 50000 years too

But, will we be ready for 2050?

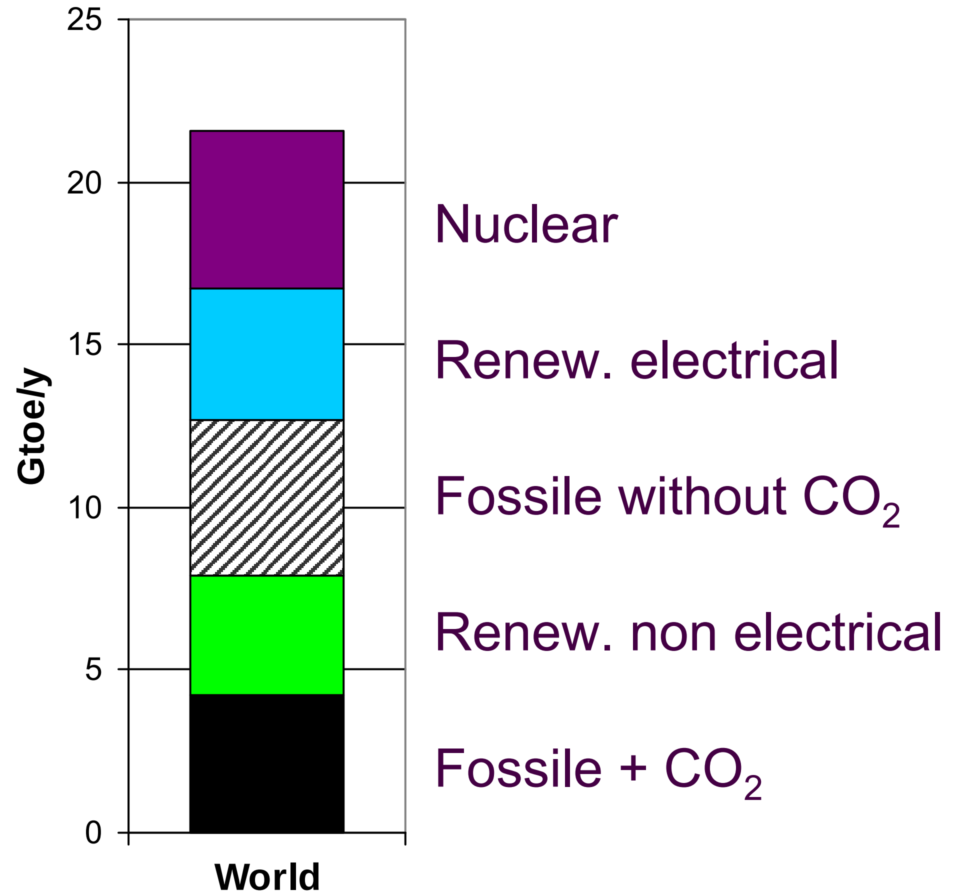
2 constraints for 2050

20 Gtoe/y

GHG emission reduced by a factor 2

Energy mix based on optimistic evaluation of renewable sources, nuclear and $CO_2$ storage capacities

A large use of electricity for heating is needed (this leads to a energy production greater than 20 Gtep)



# As a conclusion