ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Renewable Energy

Prof. Sophia Haussener
MER Jan Van herle

Laboratory of Renewable Energy Sciences and Engineering (LRESE)
Group of Energy Materials (GEM)

Administration

- Course:
  - Tuesday: 2h lecture (10:15-12:00), INJ218
  - Responsible: Prof. Haussener, ME D0 2926,
    MER Van herle, ME A2 392

- Exercise:
  - Tuesday, 1h exercises (12:15-13:00), INJ218
  - Responsible part Haussener: S. Tembhurne, ME D0 2726
    Y. Gaudy, ME D0 2919
  - Responsible part Van herle: Philippe Aubin
- Remarks:
  - Expected contributions from your side:
    4 credits ≈ 4x30 hours = 120 hours
    14x3 hours lecture/exercise → 120-42 = 78 hours at home/library
    = 5.5 hours/week at home/library

Administration

- Exam: written at the end of the semester

  closed books, only calculator and 10 A4 pages (single sided, or 5 pages double sided) personal summary can be used

- Course notes and exercises are online before the lecture (moodle.epfl.ch)
  Please print them individually if you need a printout

- References (complementary):
  - David McKay, Sustainable Energy – without the hot air, UIT Cambridge (available on web)
  - Kreith and Goswami, editors, Handbook of energy efficiency and renewable energy, Taylor and Francis Group, 2007.

Course contents

	Lecture Wednesday (10:15-12:00)	Lecturer	Exercise Tuesday (12:15-13:00)
Week 1 (19. 2)	Introduction	JVh	Exercise 1
Week 2 (26.2)	Power cycles, ORC, co-generation	SH	Exercise 2
Week 3 (5.3)	Wind	JVh	Exercise 3
Week 4 (12.3)	Geothermal	SH	Exercise 4
Week 5 (19.3)	Wind	JvH	Exercise 5
Week 6 (26.3)	Ocean, tidal, wave	JvH	Exercise 6
Week 7 (2.4)	Solar thermal	SH	Exercise 7
Week 8 (9.4)	Solar electricity	SH	Exercise 8
Week 9 (16.4)	Electrochemical and thermo-electrical conversion	JvH	Exercise 9
Week 10 (30.4)	Hydrogen	SH	Exercise 10
Week 11 (7.5)	Solar fuels	SH	Exercise 11
Week 12 (14.5)	Storage	SH	Exercise 12
Week 13 (21.5)	Biomass	SH	Exercise 13
Week 14 (28.5)	Biomass	JvH	Exercise 14

What you will learn in this course:

- What is renewable energy?
- What are it's current/future contributions to energy supply?
- For the different renewable energy sources:
  - the potential: theoretical vs. realistic
  - the essential physics and chemistry for conversion and storage
  - approaches to harness them
  - status of the technologies
  - the most useful applications and complementarities
- Renewable power plants you will know:
  B-IGCC, PV, CSP, PEC, EGS, (μ)CHP, ...

Order of magnitude understanding

How much solar energy falls on 1 m^2 in 1 s on a nice sunny day at noon ?

- ○ 1 J
- ○ 10 J
- ○ 100 J
- ○ 1000 J

… and in winter, during any day, at any latitude?

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Order of magnitude understanding

How much power can a water turbine develop from water flowing at 1 m^3/s and falling from 100 m high ?

- ○ 9 kW
- ○ 90 kW
- ○ 0.9 MW
- ○ 9 MW

… and how big a wind turbine must be to develop the same power from a typical wind speed?

… (and what wind speed is 'typical'?)

Order of magnitude understanding

How much power is contained in an ocean wave (per m width), 1 m high, and of wavelength 100 m ?

- ○ 1 kW / m
- ○ 3 kW / m
- ○ 10 kW / m
- ○ 30 kW / m

… and its difference to tidal power?

Order of magnitude understanding

How deep do we have to drill the earth soil to find it hot at 300°C ?

- ○ 300 m
- ○ 1 km
- ○ 3 km
- ○ 10 km

... and then how can we convert this to electrical power ?

Order of magnitude understanding

How much wood does a tree grow in a year, roughly?

- 2 kg
- 5 kg
- 20 kg
- 50 kg

… and on what factors this depends?

Order of magnitude understanding

How much energy can you extract from your own waste (WC, food, garden,…) ?

- ○ not worth bothering
- ○ enough to lit a light bulb a few h a day
- ○ enough to cook all your food with it
- ○ enough to power your house with it

Order of magnitude understanding

What is the size and efficiency of a biomass-fired IGCC plant?

- ○ 400 kW
- ○ 4 MW
- ○ 40 MW
- ○ 400 MW

- ○ 30%
- ○ 40%
- ○ 50%
- ○ 60%

… and furthermore:

- is heat pumping from the soil renewable?
- are bioethanol and biodiesel going to replace petrol?
- what about the biomass-energy competition with food ?
- can we go 100% renewable?
- ‘there is 10’000 times more solar energy around than what all humans consume around the planet, no worries!’
- it’s just of matter of cost?
- But renewable energy is free fuel, isn’t it?
- … or a matter of time, for fossil fuels to run out?
- … or of progress in new technologies?
- … or of political incentive and subsidies?

What you are expected to know at the end

- the real potential of the different renewable sources
- use mass, momentum, and energy balance to estimate orders of magnitude
- be able to easily grasp and switch between kWh, MJ, GW, Mtoe, TWh, …
- the right orders of magnitude (energy and power)
- the technologies to harvest fossil and renewable energies
- explain and calculate the main emission sources of energy conversion processes
- their best service in the energy supply spectrum
- be able to solve the exercises

Common energy units

• 10^6	mega	M	MJ	MW	MWh
• 10^9	giga	G	GJ	GW	GWh
• 10^{12}	tera	T	TJ	TW	TWh
• 10^{15}	peta	P	PJ		
• 10^{18}	exa	E	EJ		

TWh terawatthour = 10^{12} Wh = 1000 GWh = 3.6 PJ (electricity)

GWh gigawatthour = 10^9 Wh = 3600 GJ (electricity)

Mtoe megatonne-oil-equivalent = 10^9 (kg) x 41.9 (MJ/kg) = 41.9 PJ

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Examples of energy and power content

- Energy
  - Daily need of an adult : 6-8 MJ
  - 1 Liter of Oil : 36 MJ
  - 100 km in a small car: 230 MJ (6.4 L)

- Power
  - Computer : 100 -200 W (J/s)
  - Professional cyclist : 450 W
  - Adult : 100 W
  - 100 students : 15 kW
  - Car engine : 75 kW (~100 hp)

From resources to products

- **The energy used is not the energy that is harvested**

- **Energy resources (primary energy)**
  - Non renewable (from a reservoir)
  - Renewable (capturing the sun energy and incorporating into a system)

- **Energy services (final energy)**
  - Temperature in a room
  - Data from internet
  - Mobility

Definitions

- **Primary energy consumption**
  - Energy contained in raw fuels before the start of the conversion chain.

- **Final (distributed) energy consumption**
  - Energy received by consumers and businesses, not including the energy losses in the conversion sector, and from distribution. This indicator evaluates the participation of each type of fuel (solid fuels, oil, gas, renewables)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Let’s enumerate all energy sources we know…

BIOMASS

WIND

WASTES

COAL

GAS

SOLAR – DIRECT

HYDRO

TIDES

NUCLEAR

GEOTHERMAL

OIL

SOLAR – P.V.

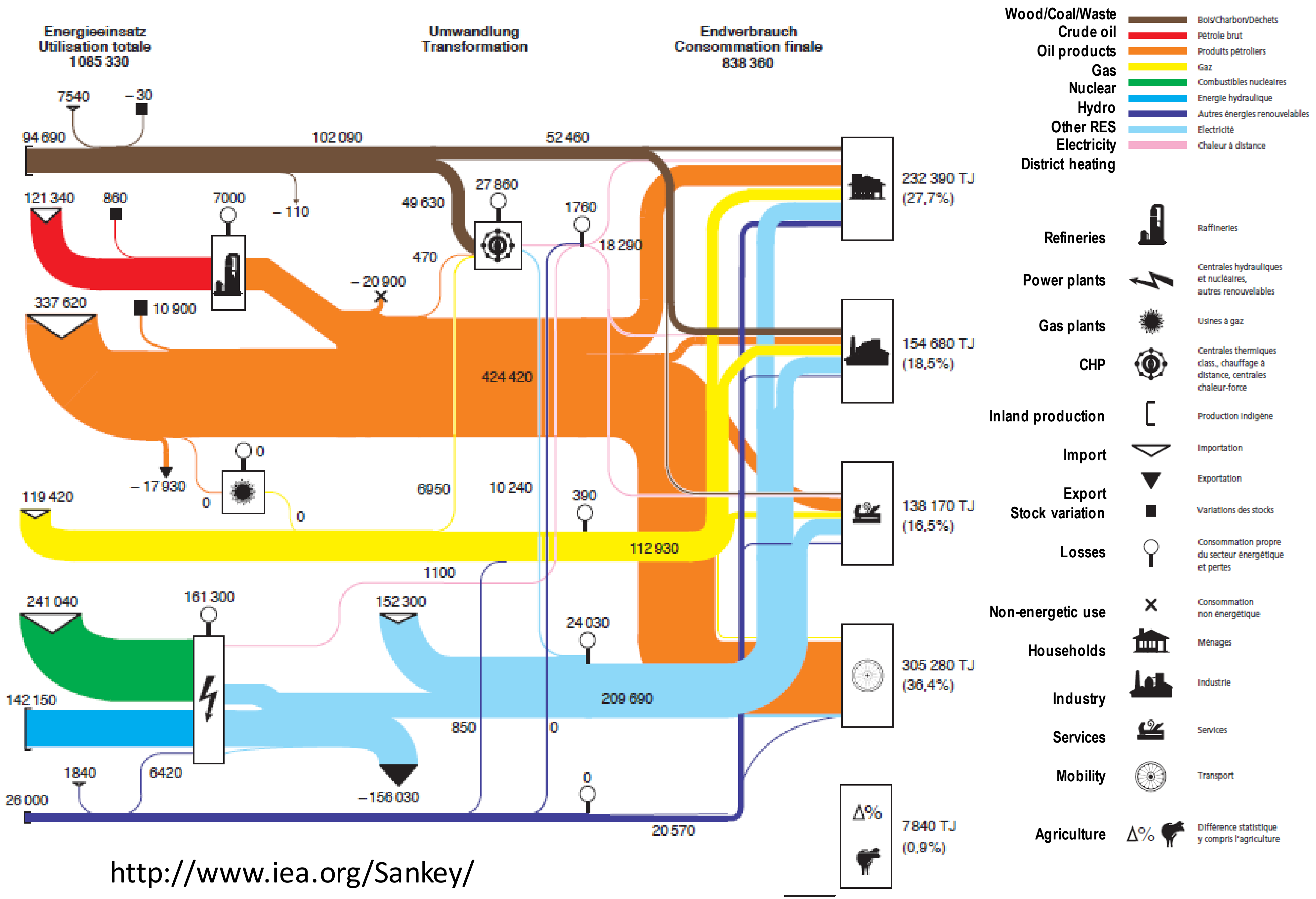
WAVES

SOLAR – THERMAL

…and see how we have been using these

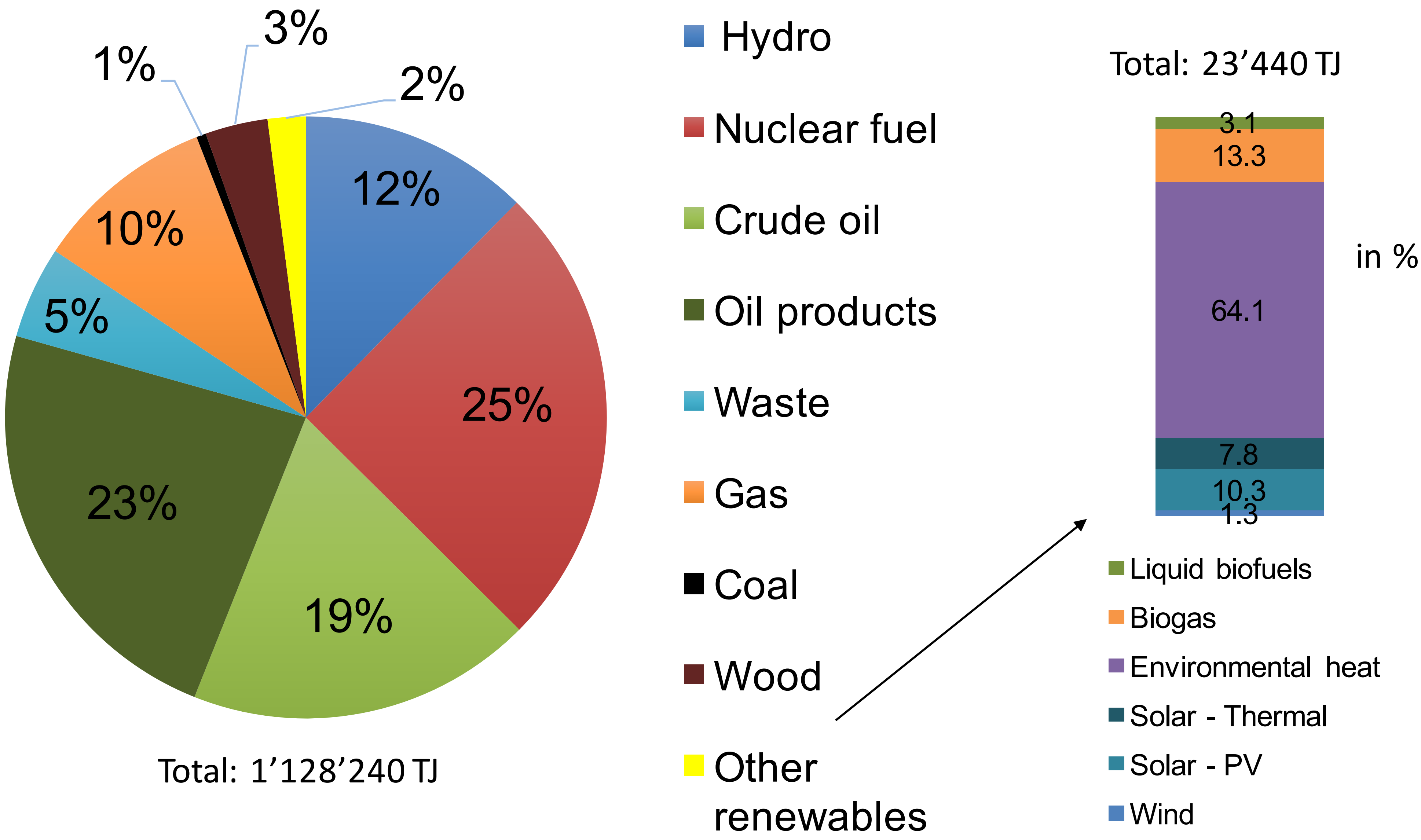
Where do we stand today? Switzerland

Schweizerische Gesamtenergiestatistik 2014/5
Bundesamt für Energie

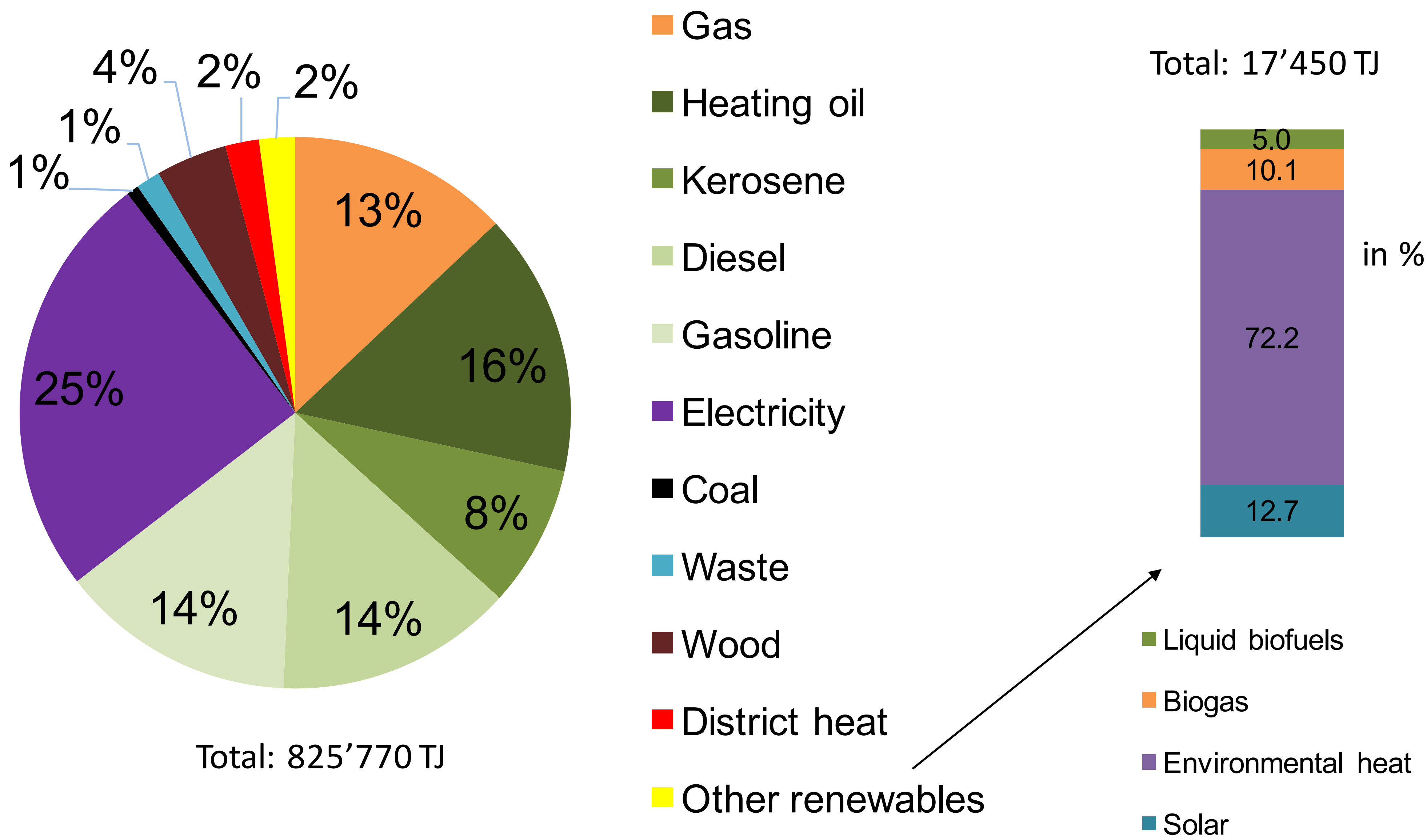


http://www.iea.org/Sankey/

Primary energy – CH 2014

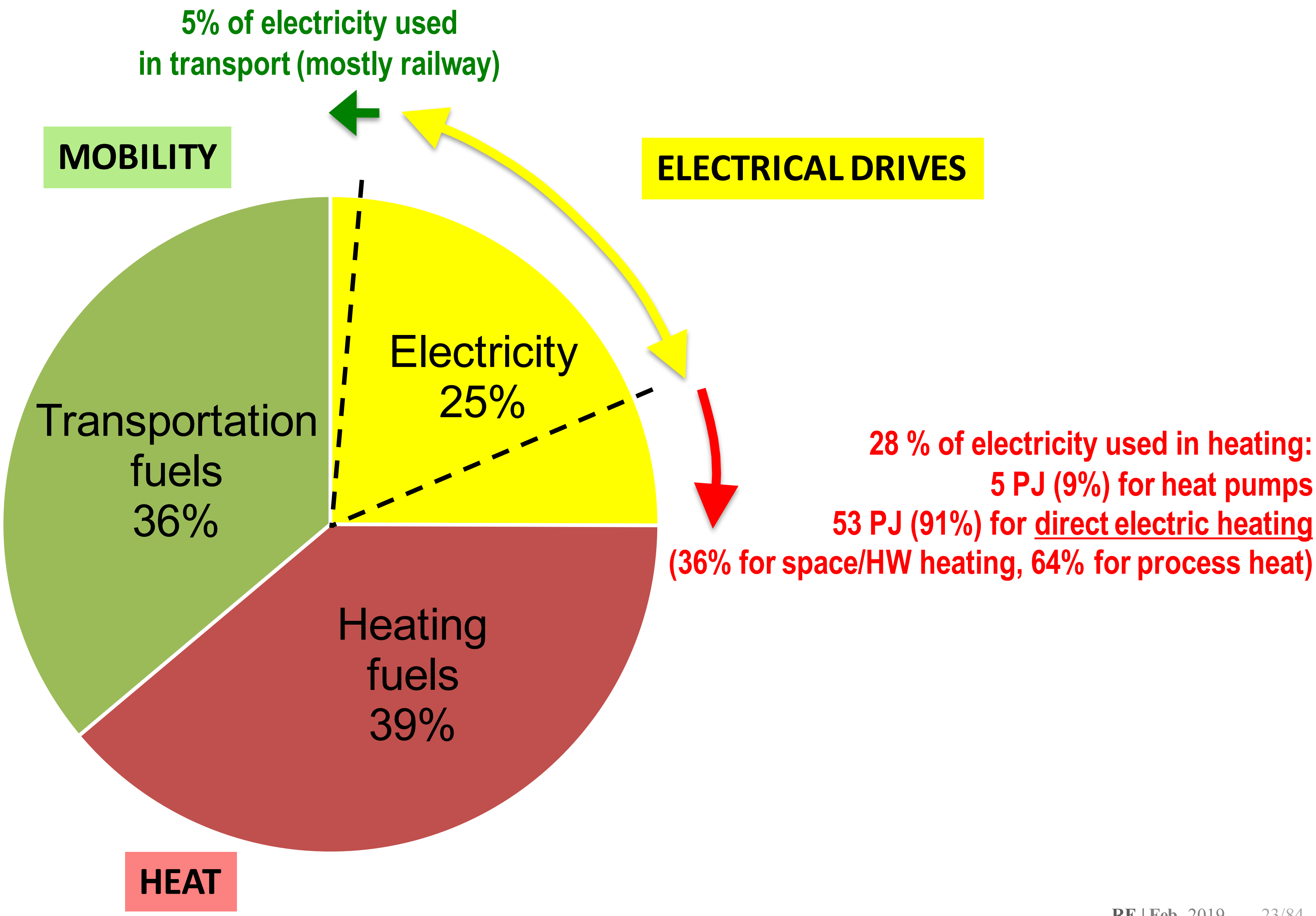


Final energy – CH 2014

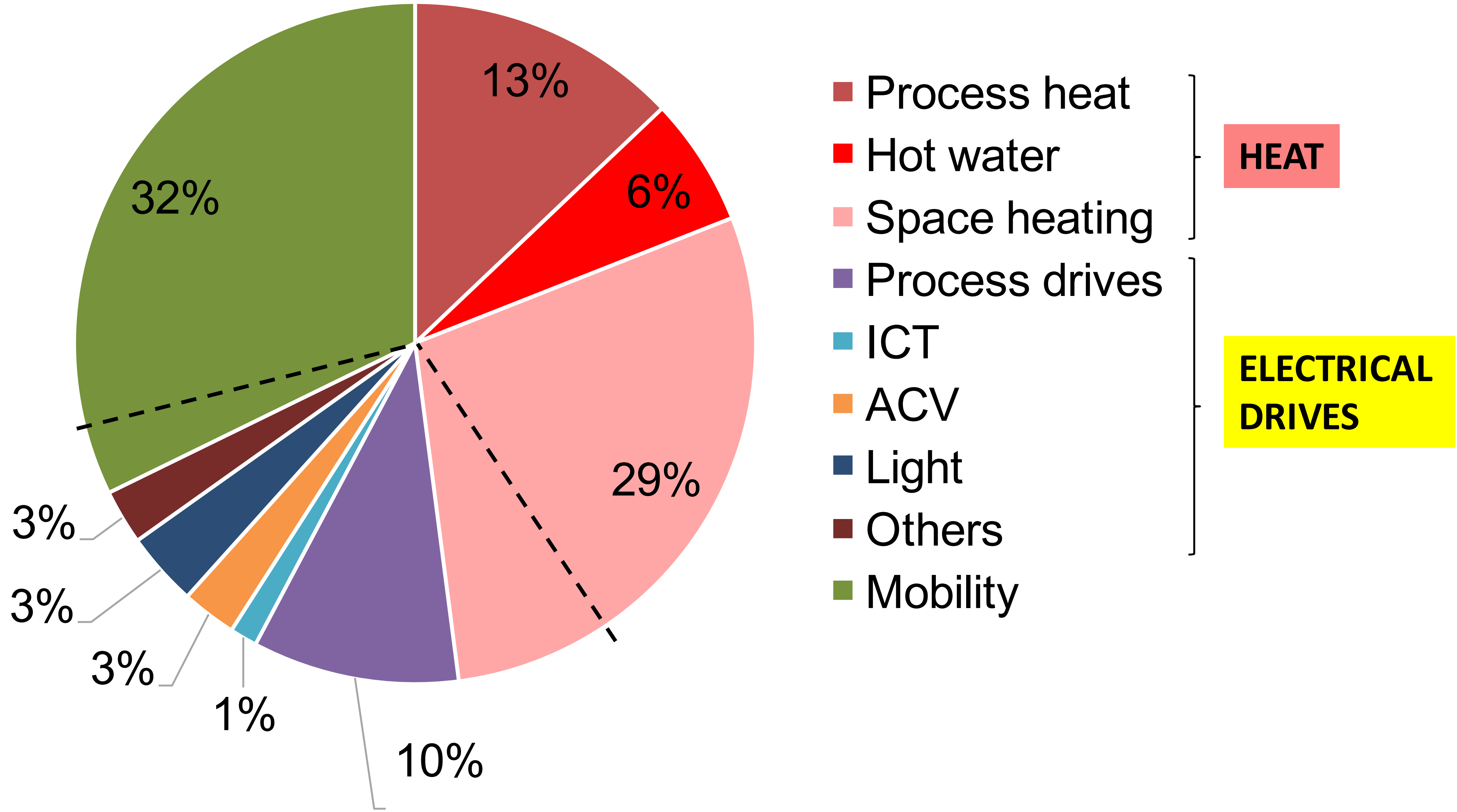


Energy per capita and year: 3.18 kW/cap

End-use shares by application

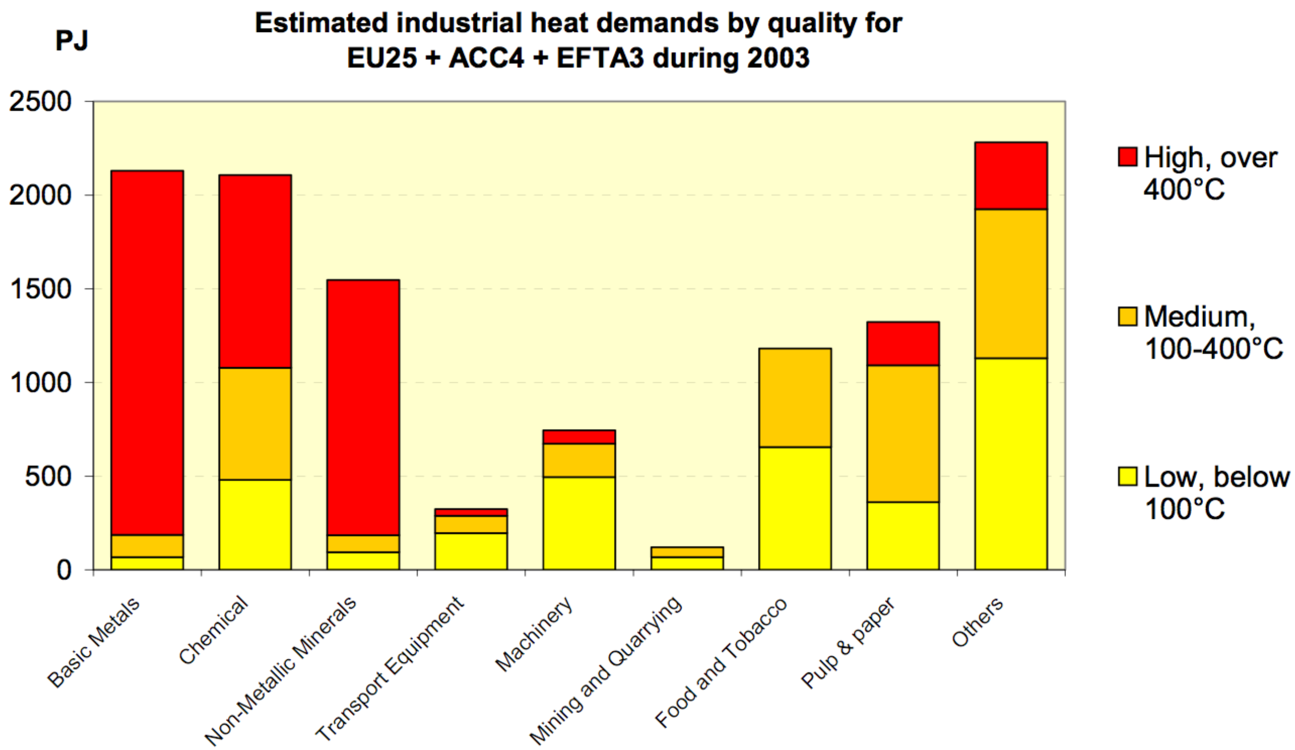


End-use by application: detail



Final energy use …

- There are 5 energy end services:
  - Space heat 20°C
  - Sanitary hot water 40°C
  - Process heat >40°C
  - Electricity
  - Mobility



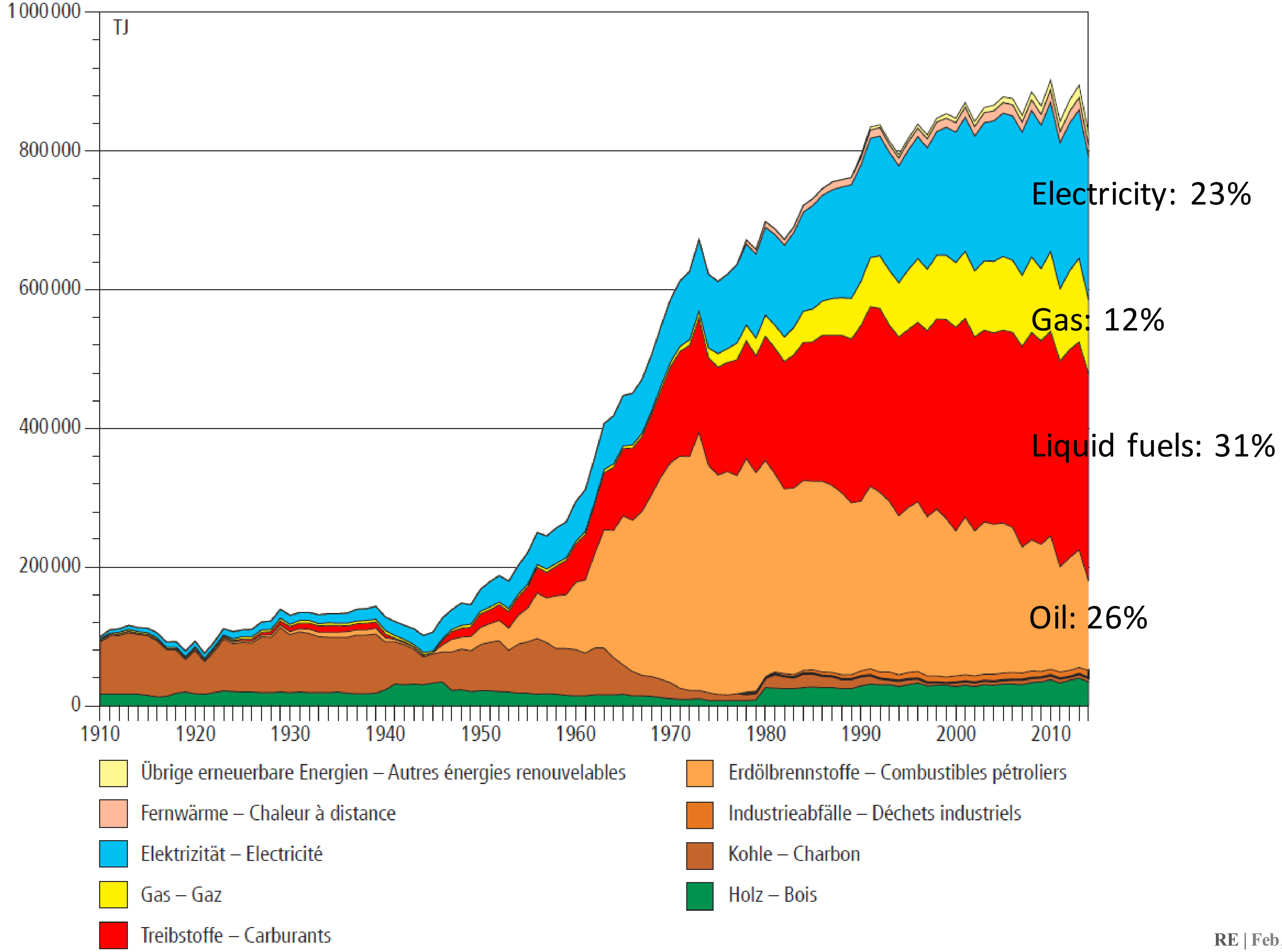
[2]ECOHEATCOOL, *The European Heat Market*, 2006

… and primary energy supply

- Key is to supply these end services in the most meaningful ways, considering:
  - Temperature level
  - Thermodynamics
  - Conversion technology
  - Scale of service / technology
  - **Efficiency**
  - **Savings**
  - Emissions, pollution, impact,…

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

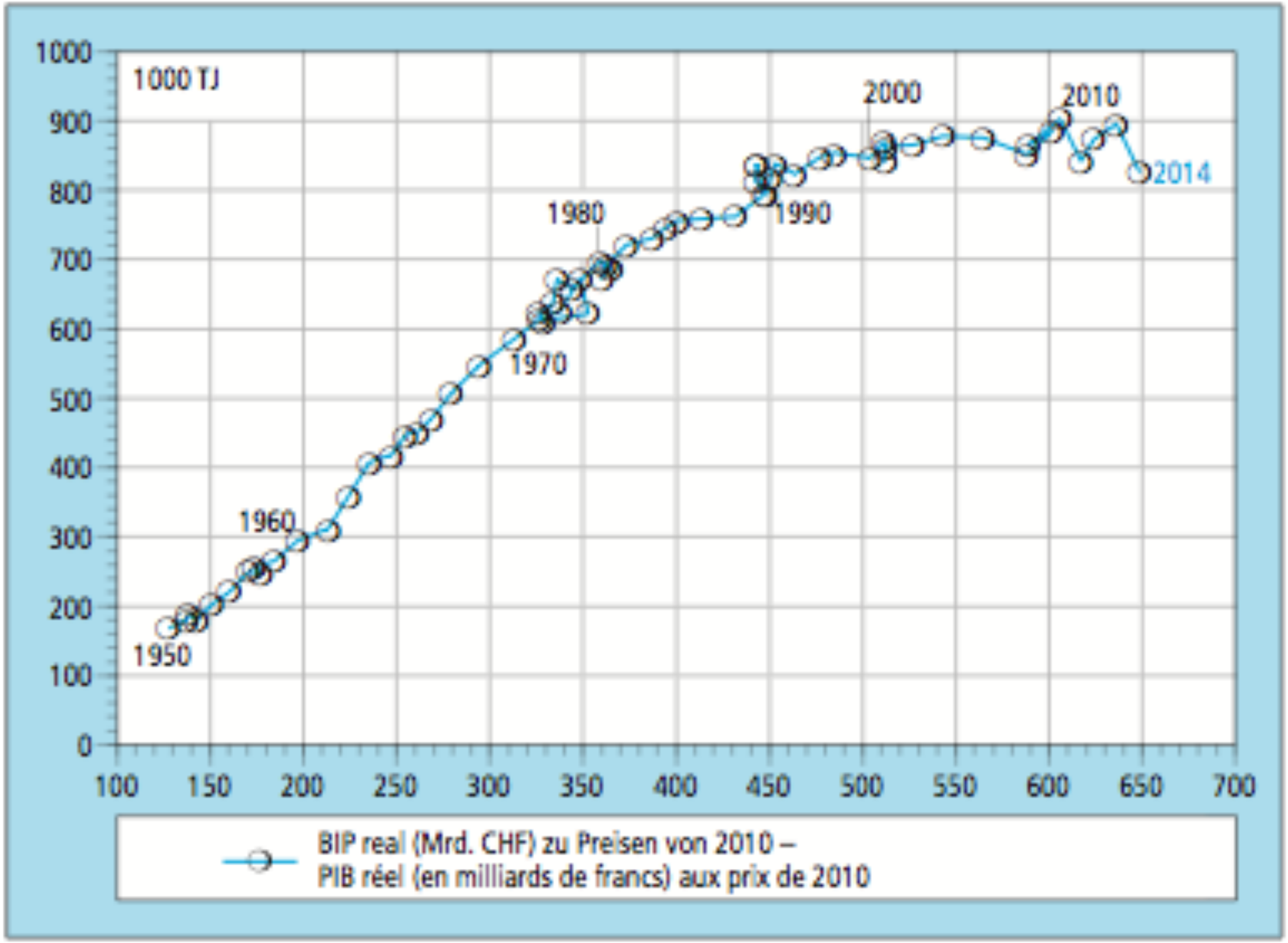
Temporal evolution of final energy use



The link with the PIB

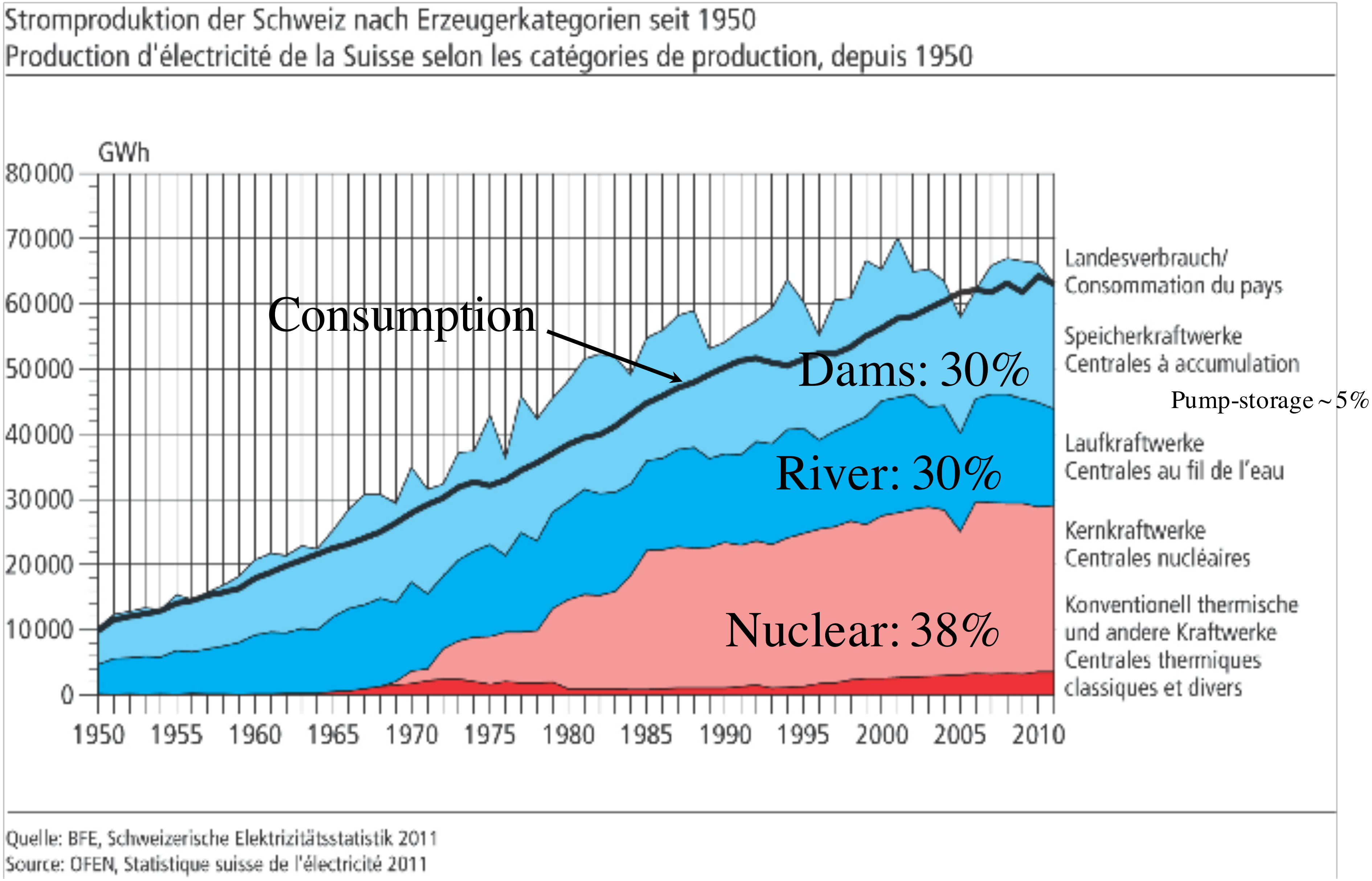
Fig. 15 Zusammenhang zwischen Energieverbrauch und wirtschaftlicher Entwicklung (1950–2014)

Relation entre la consommation finale et l'évolution économique (1950–2014)

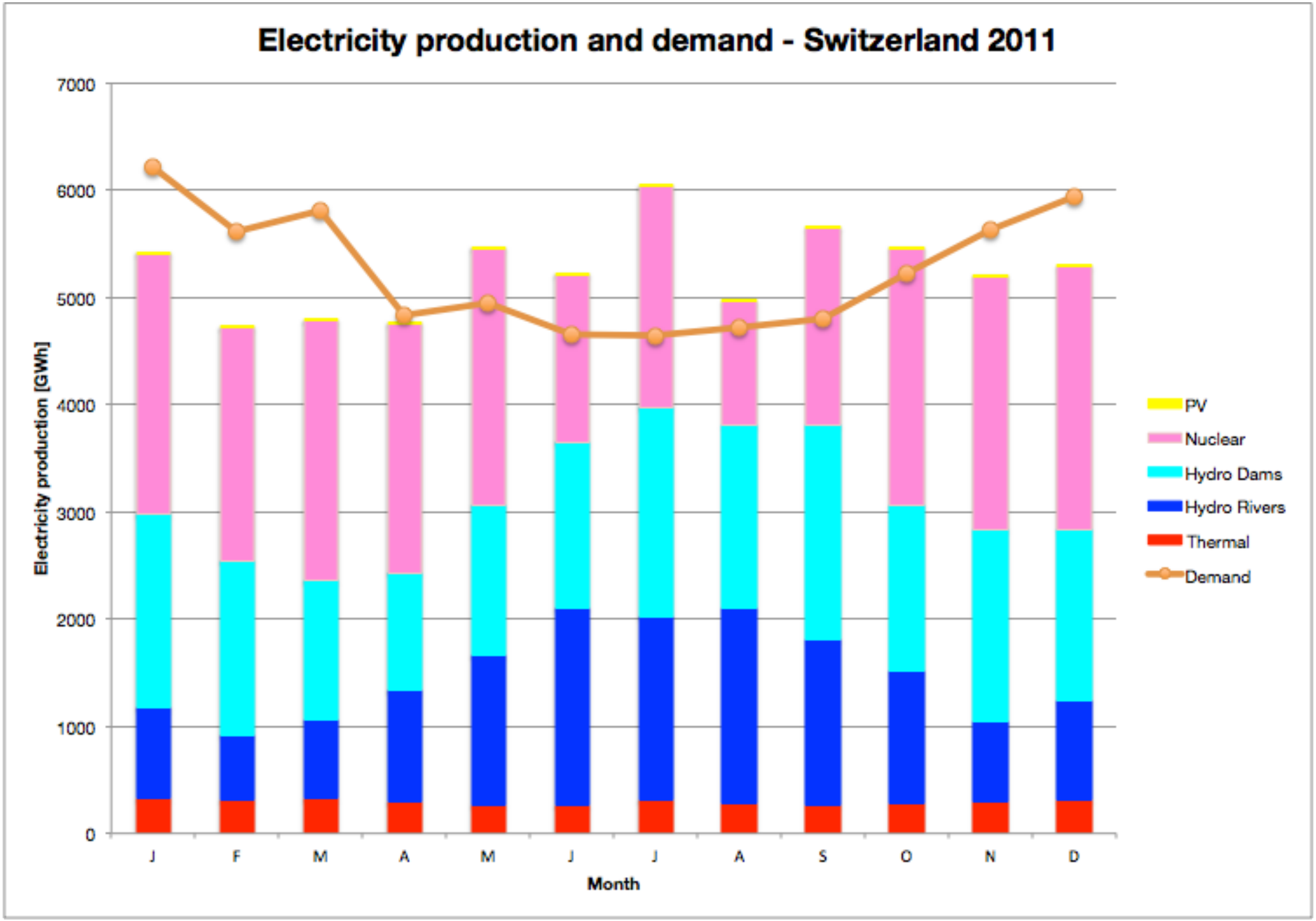


ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Temporal evolution of electricity production

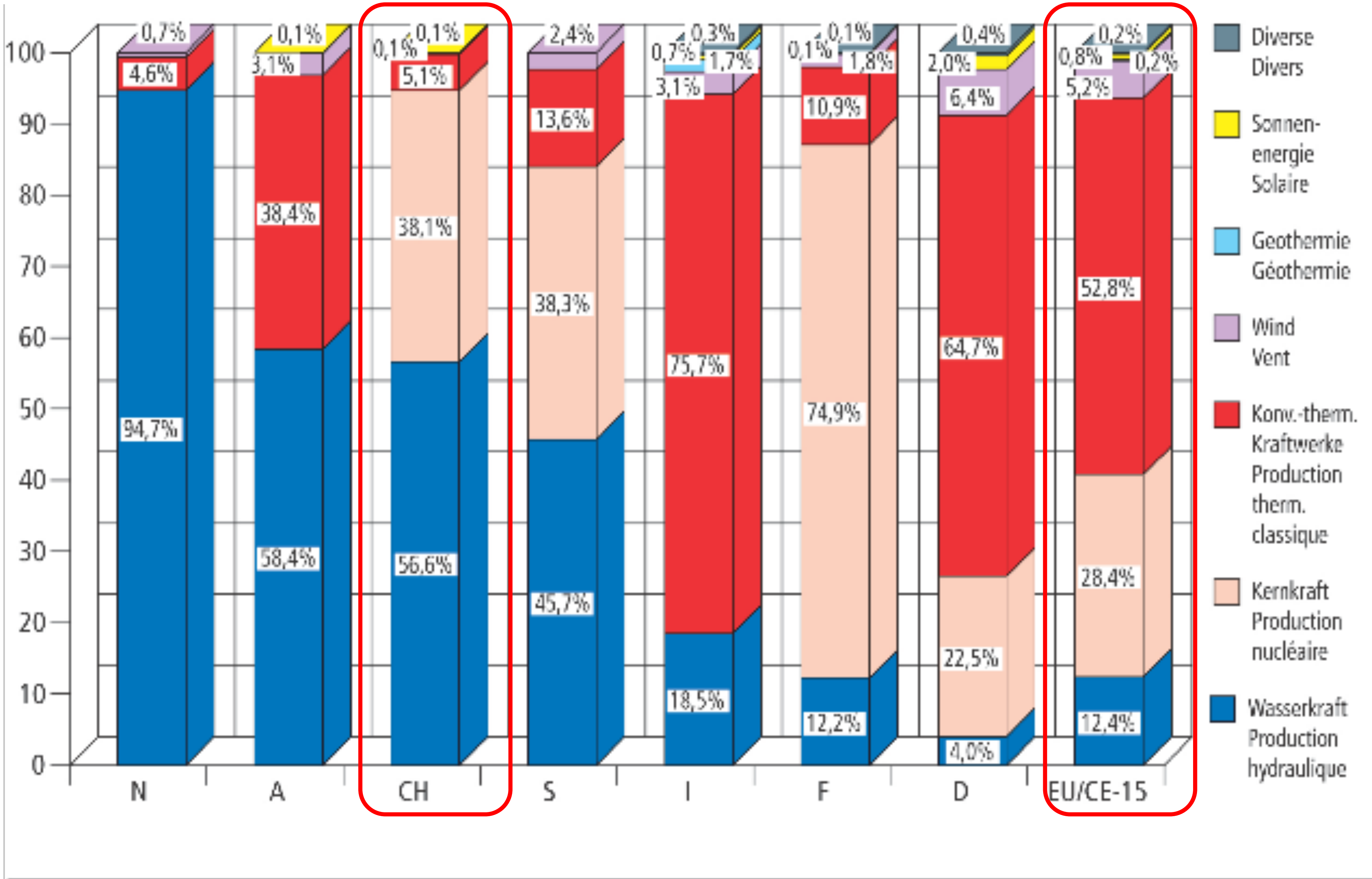


Electricity balance: Production vs Consumption



ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Electricity production in Europe



Quelle: BFE, Schweizerische Elektrizitätsstatistik 2011
Source: OFEN, Statistique suisse de l'électricité 2011

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Energy prices : CH

- **Electricity**
  - Industry : 13 cts/ kWh
  - Households : 19 cts/kWh

- **Heating Oil**
  - 10 cts/kWh

- **Natural Gas**
  - 9.6 cts/kWh

- **Fuels**
  - 1.51 CHF/l => 15 cts/kWh

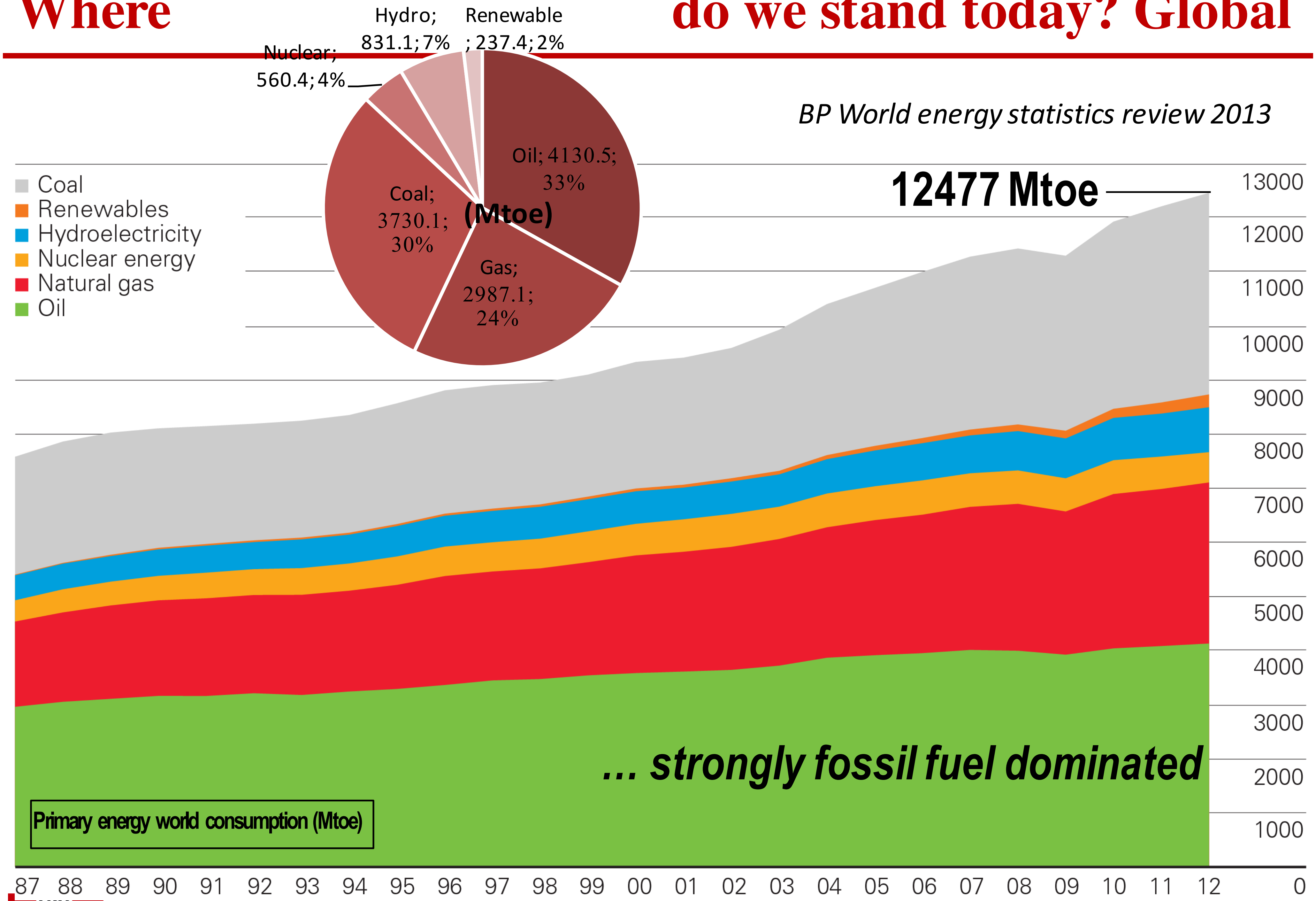
Energy in Switzerland

The Swiss Energy …

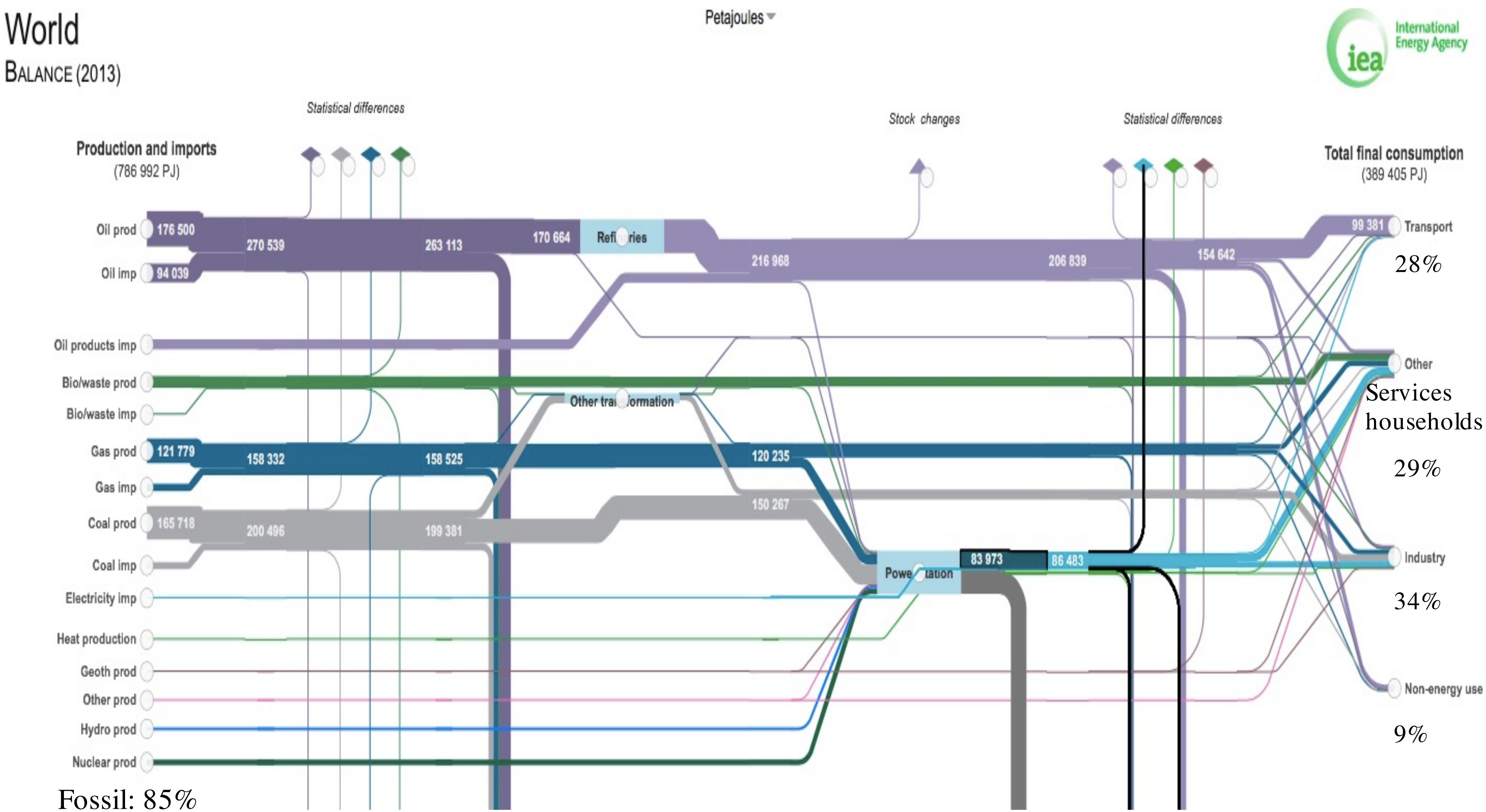
www.bfe.admin.ch

Where do we stand today? Global

BP World energy statistics review 2013



The World Energy Balance



Fossil: 85%
Renewable: 10%
Nuclear: 5%

75% of electricity is fossil based
50% losses in electricity generation

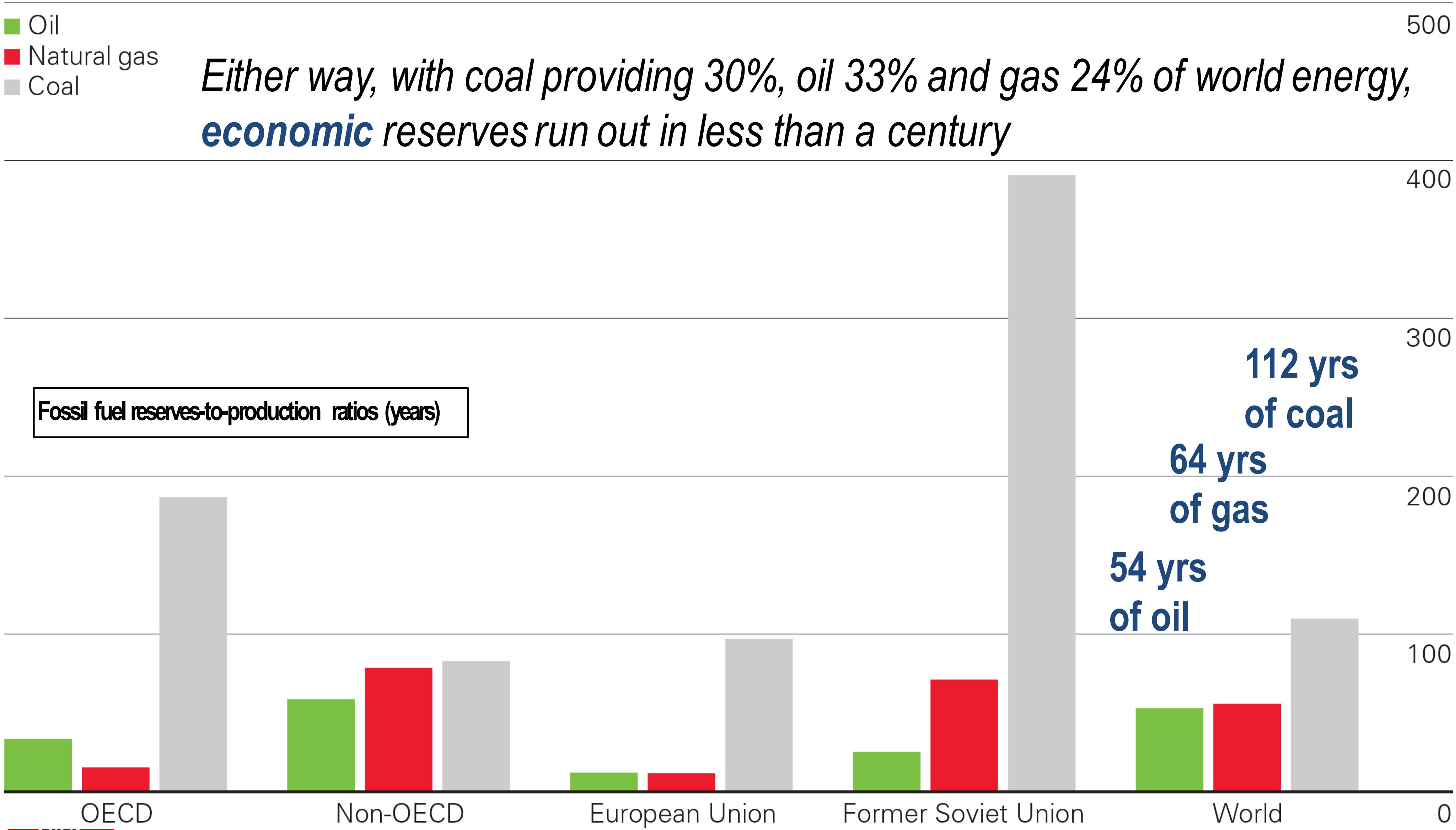
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

http://www.iea.org/Sankey/

For how much longer like this?

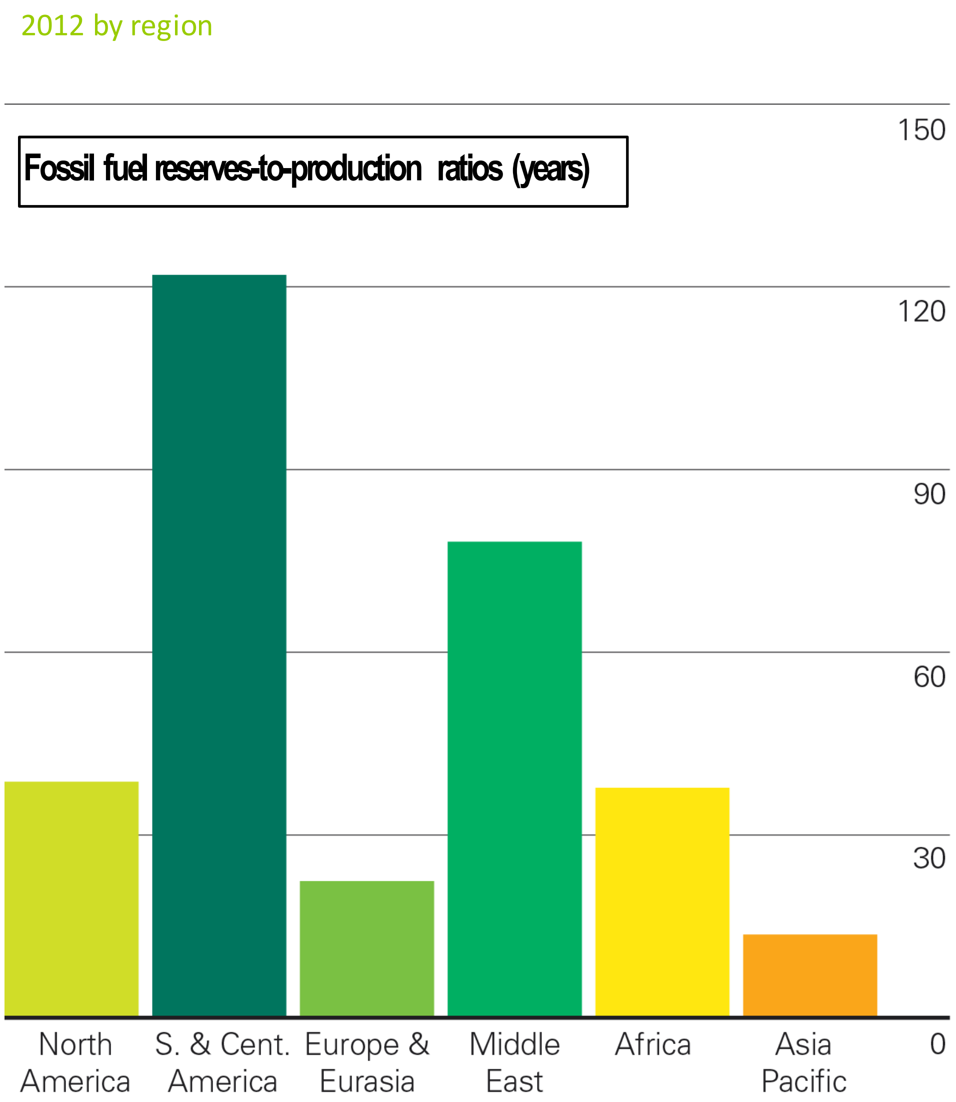
BP World energy statistics review 2013

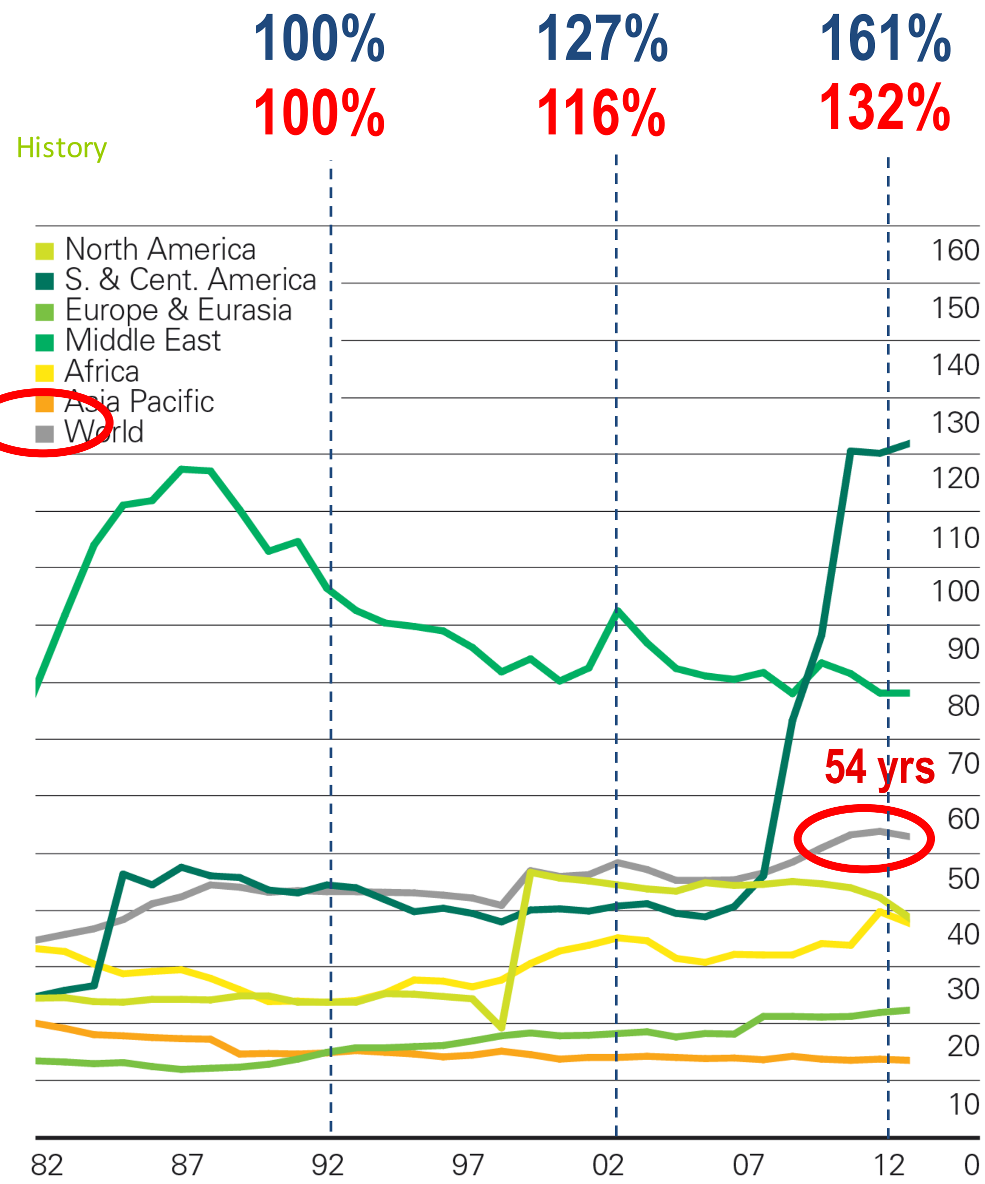
Either way, with coal providing 30%, oil 33% and gas 24% of world energy, ***economic*** *reserves run out in less than a century*



OIL: *despite increased consumption, world reserves go up…!*

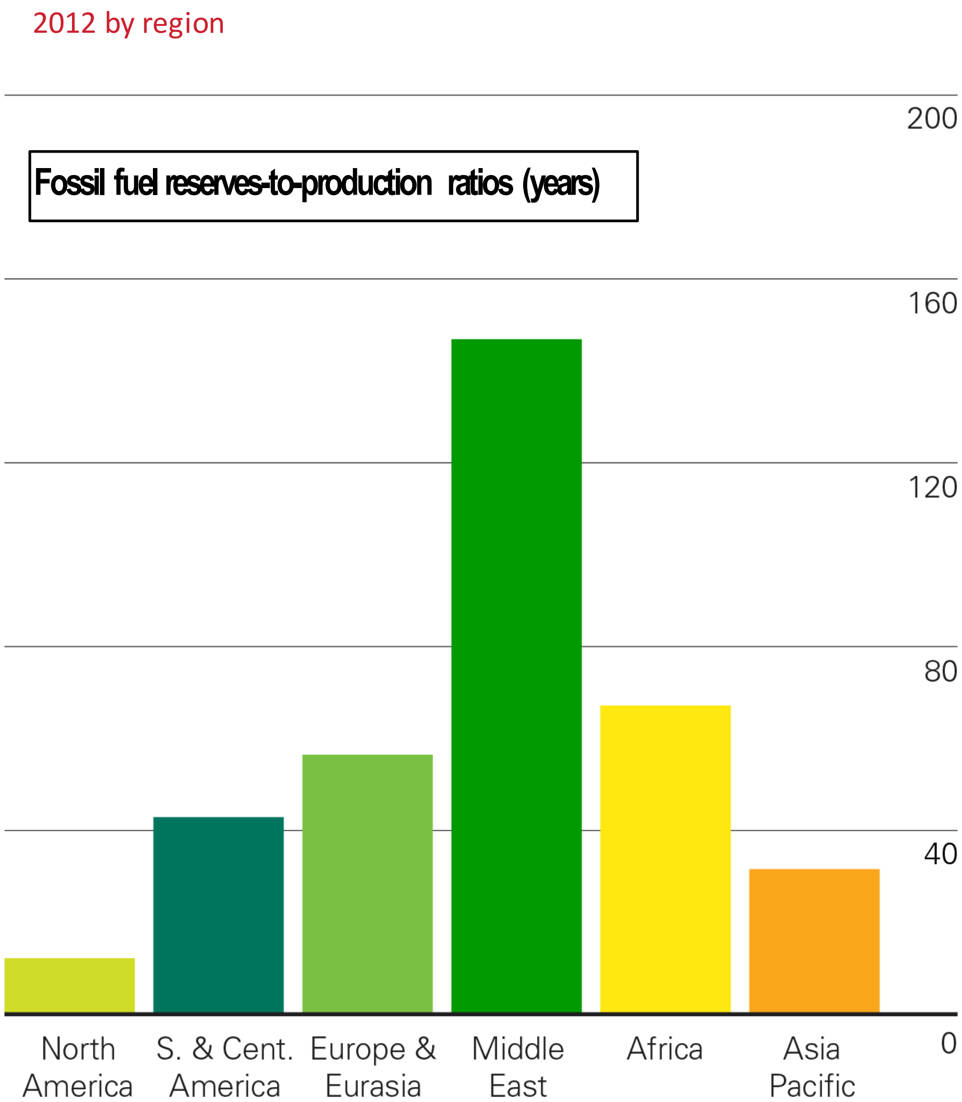
BP World energy statistics review 2013

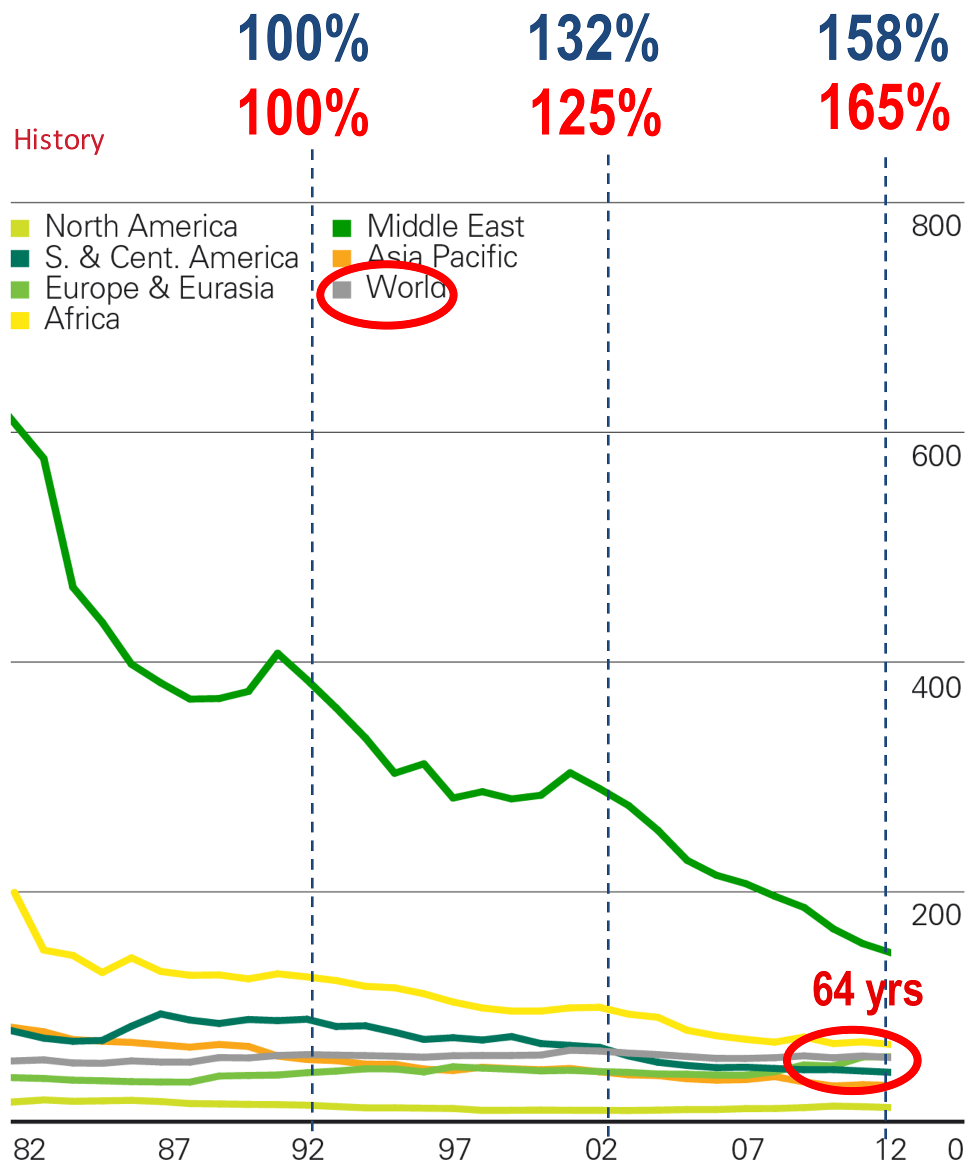




GAS: *despite increased consumption, world reserves go up…!*

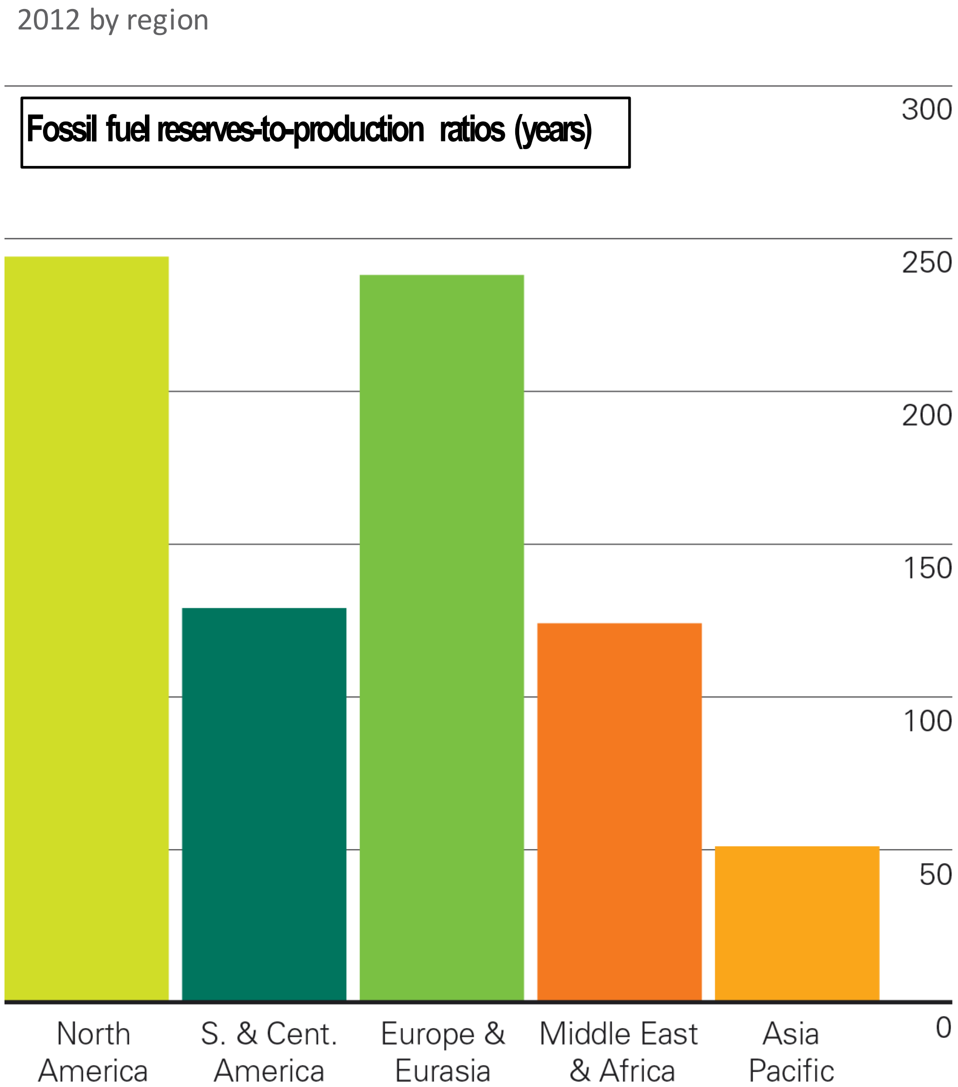
BP World energy statistics review 2013

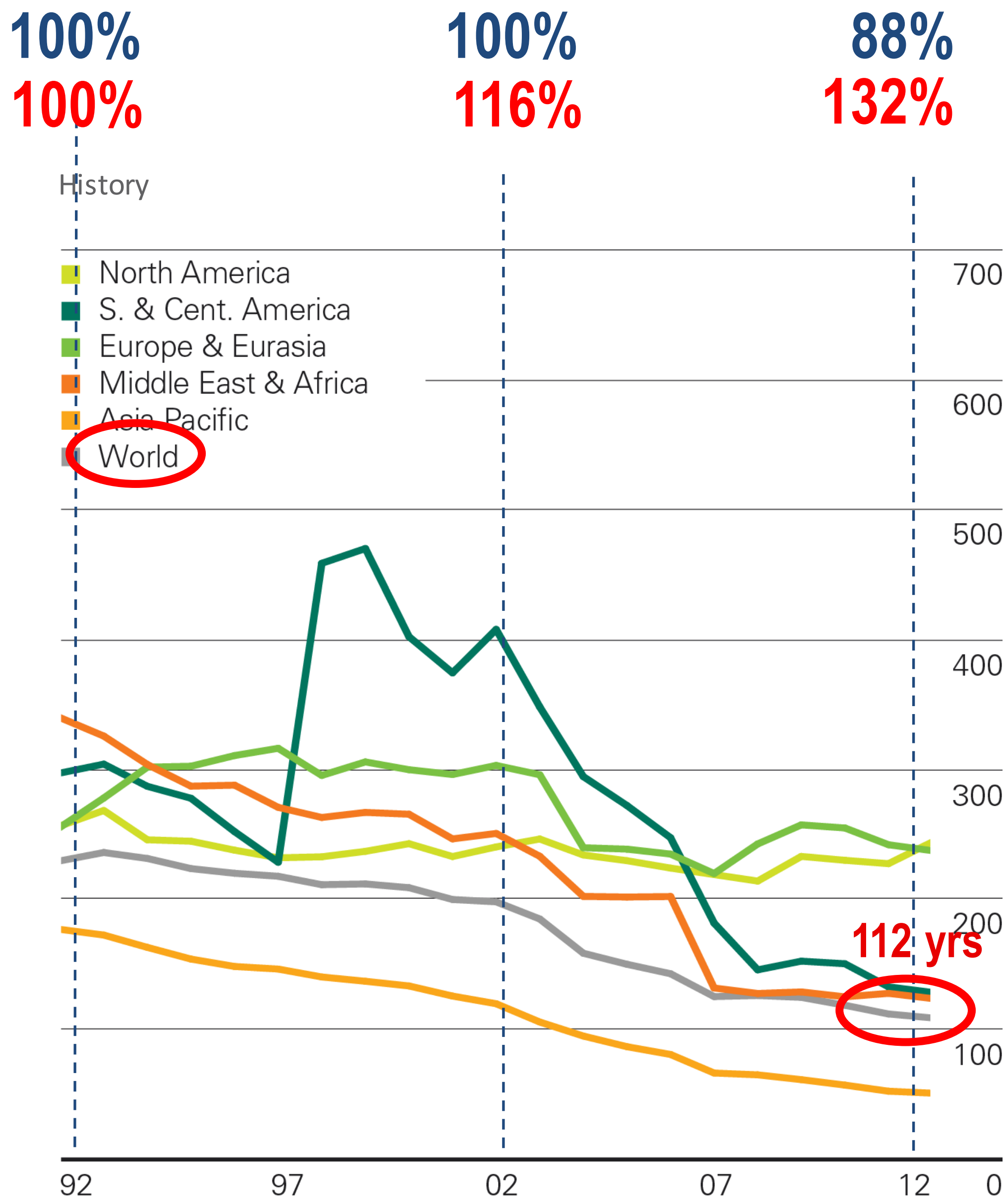




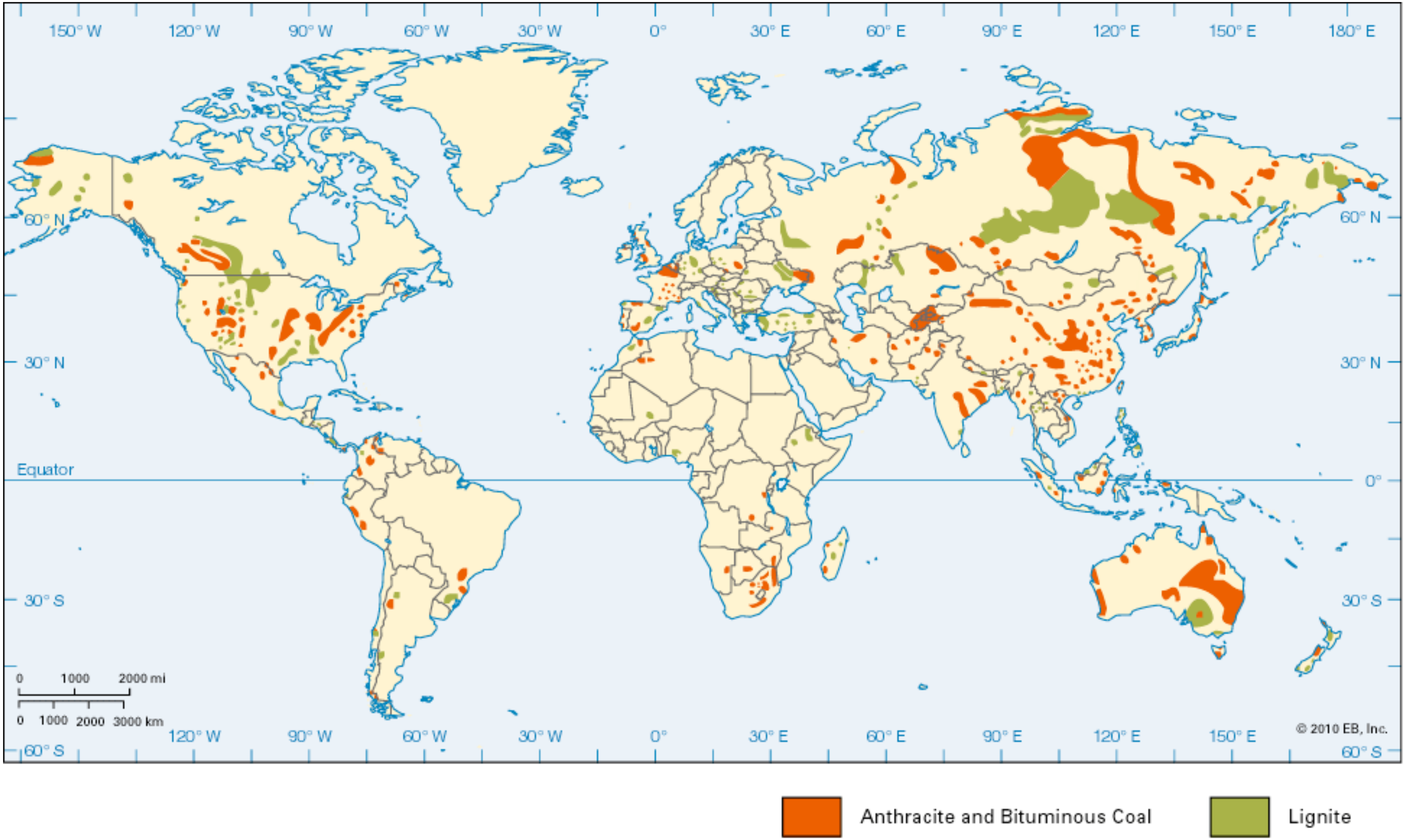
COAL: *increased consumption + huge reserves, but they start to decline…!*

BP World energy statistics review 2013

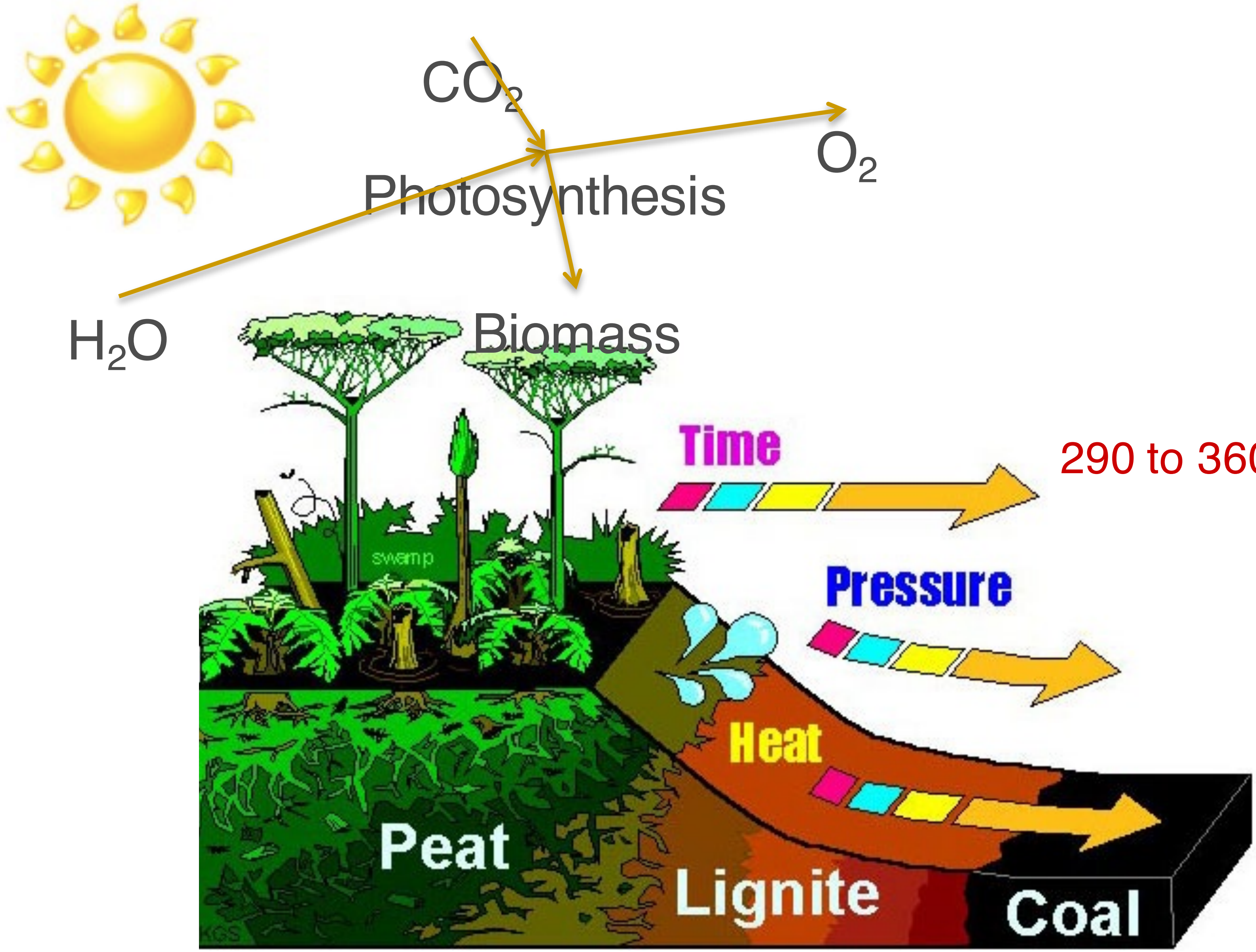




Coal mines in the world



Coal



290 to 360 mio. years

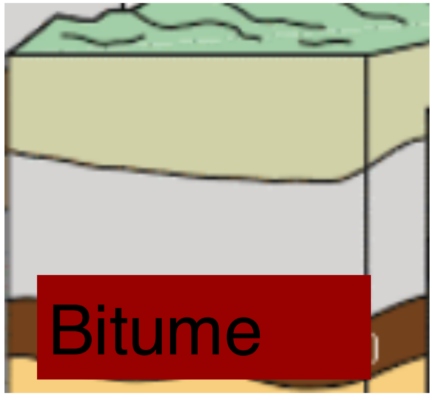
Coal

water	25%
volatiles	50%
C	20%
ash	5%

200-400m

water	35%
volatiles	30%
C	25%
ash	10%

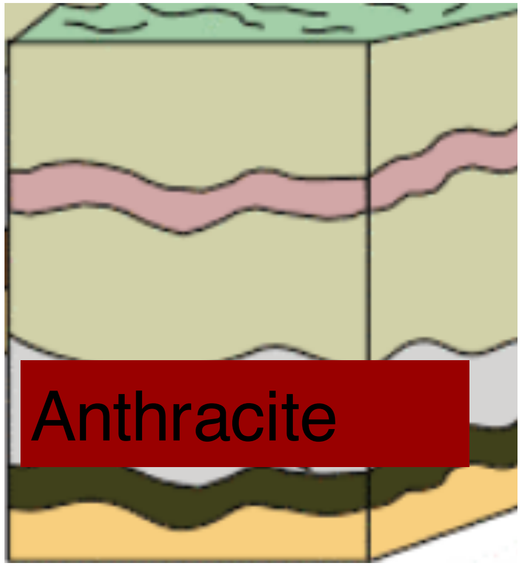
1-2 km



water	5%
volatiles	20%
C	70%
ash	5%

3-4 km

water	2%
volatiles	3%
C	90%
ash	5%

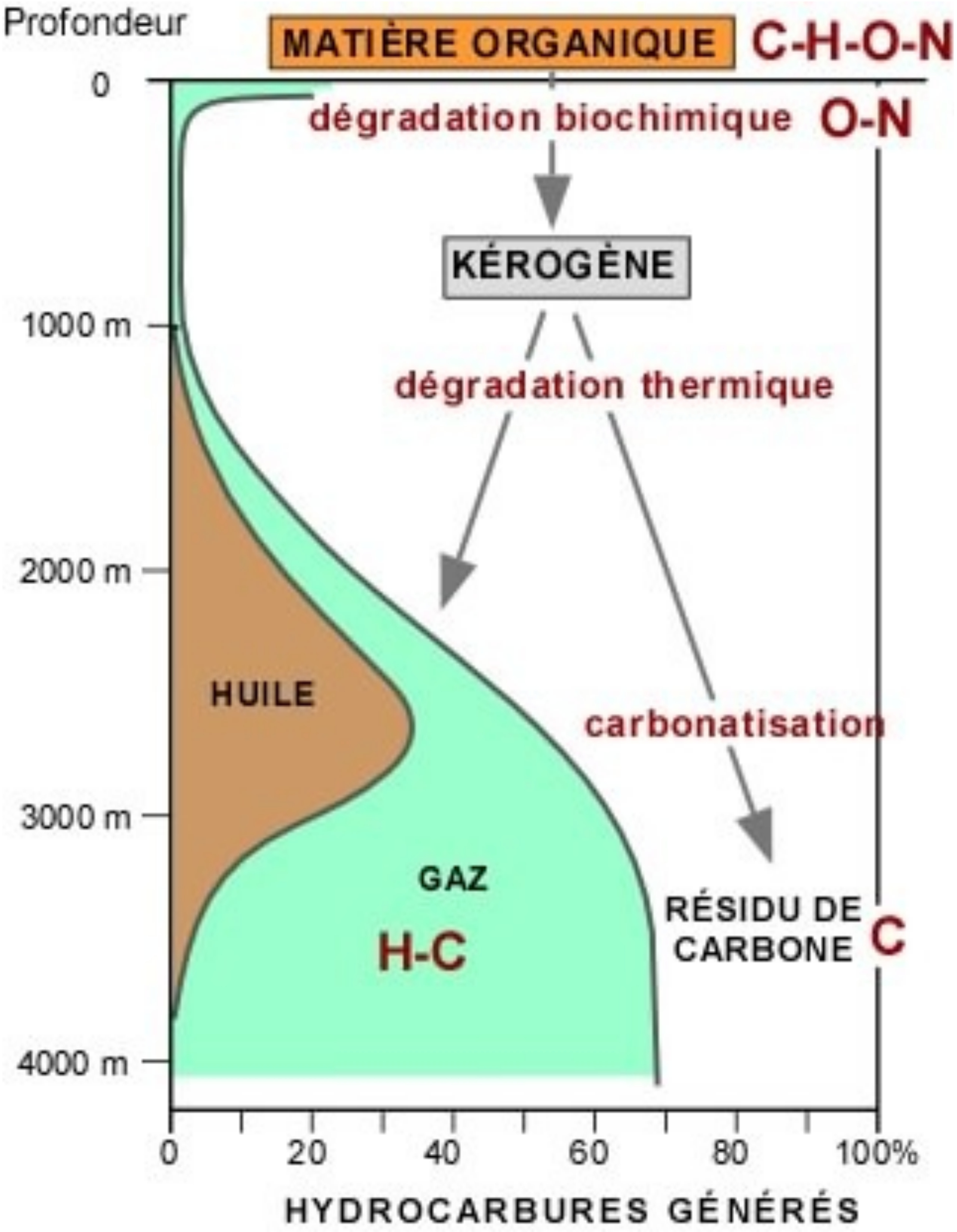


Energy →

14GJ/tonne 19GJ/tonne 24-30GJ/tonne 30-32GJ/tonne

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Liquid and gas fuels



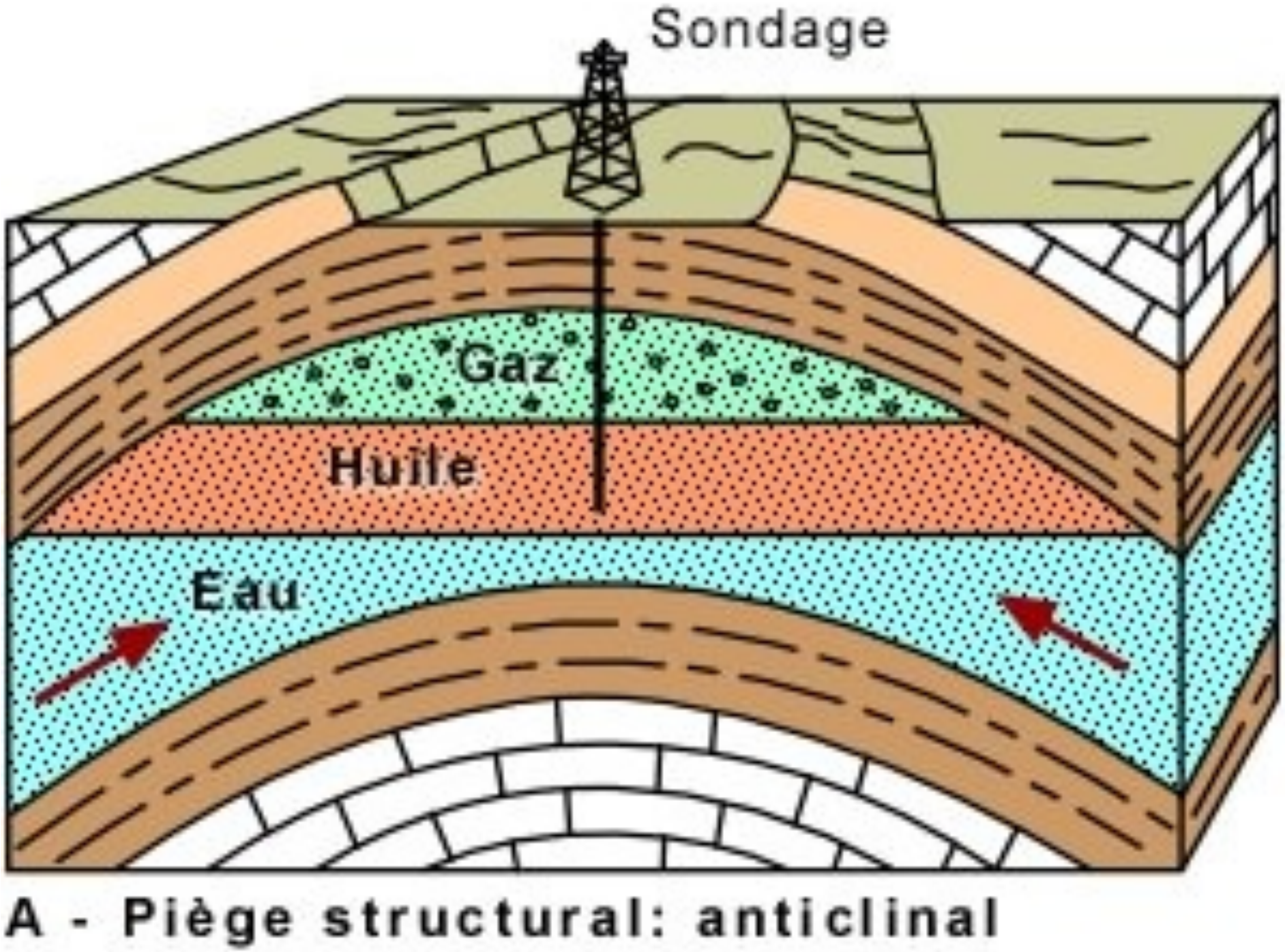
In the first 1 km, bacteria convert organic matter into kerogen (embryonic oil).

> 1 km, burying leads to a gradual transformation of the sediment rock and thermal degradation (~100°C) of kerogen.

Between 2 and 3 km, this is where the kerogen produces a lot of oil.

At 3.5 km, less to no oil is produced but a lot of gas.

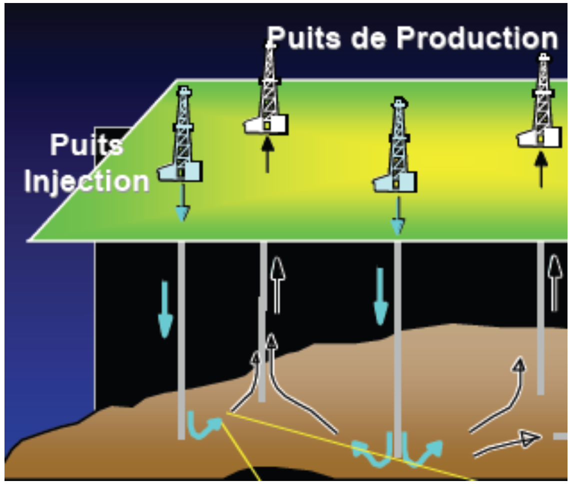
A geological cap captures the oil/gas



Drilling and extraction

Spontaneous extraction from the pressure of the well

Mechanical extraction

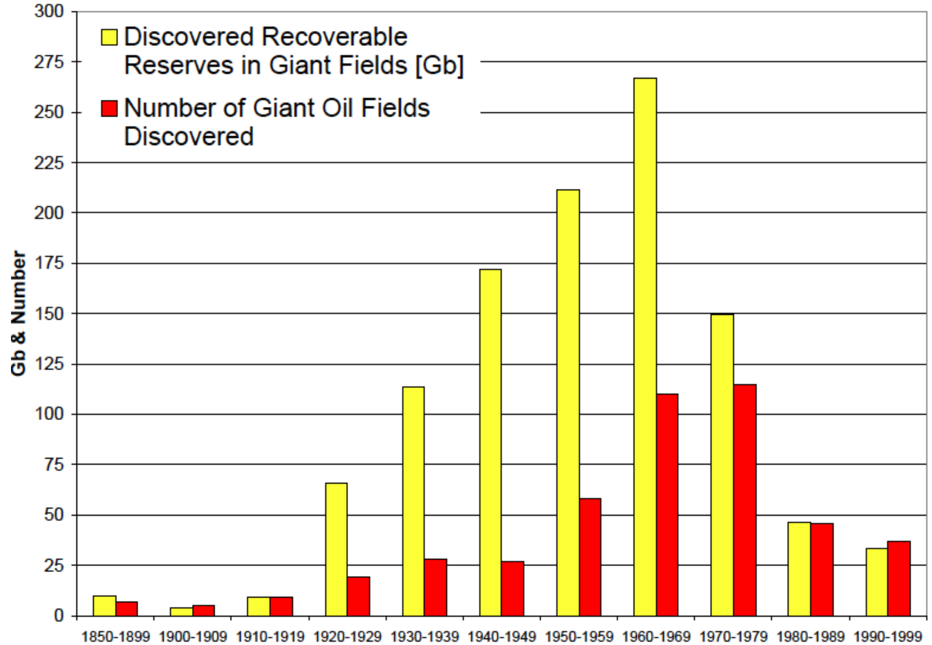


Enhanced oil and gas recovery by water/CO_2 injection
→ CO_2 sequestration

The biggest fields

Field Name	Country	Discovery year	Range of URR [GB]
Ghawar	Saudi Arabia	1948	66-100
Burgan Greater	Kuwait	1938	32-60
Safaniya	Saudi Arabia	1951	21-36
Bolivar Coastal	Venezuela	1917	14-36
Berri	Saudi Arabia	1964	10-25
Rumalia N&S	Iraq	1953	22
Zakum	Abu Dhabi	1964	17-21
Cantarell Complex	Mexico	1976	11-20
Manifa	Saudi Arabia	1957	17
Kirkuk	Iraq	1927	16
Gashsaran	Iran	1928	12-15
Abqaiq	Saudi Arabia	1941	10-15
Ahwaz	Iran	1958	13-15
Marun	Iran	1963	12-14
Samotlor	Russia	1961	6-14
Agha Jari	Iran	1937	6-14
Zuluf	Saudi Arabia	1965	12-14
Prudhoe Bay	Alaska	1969	13

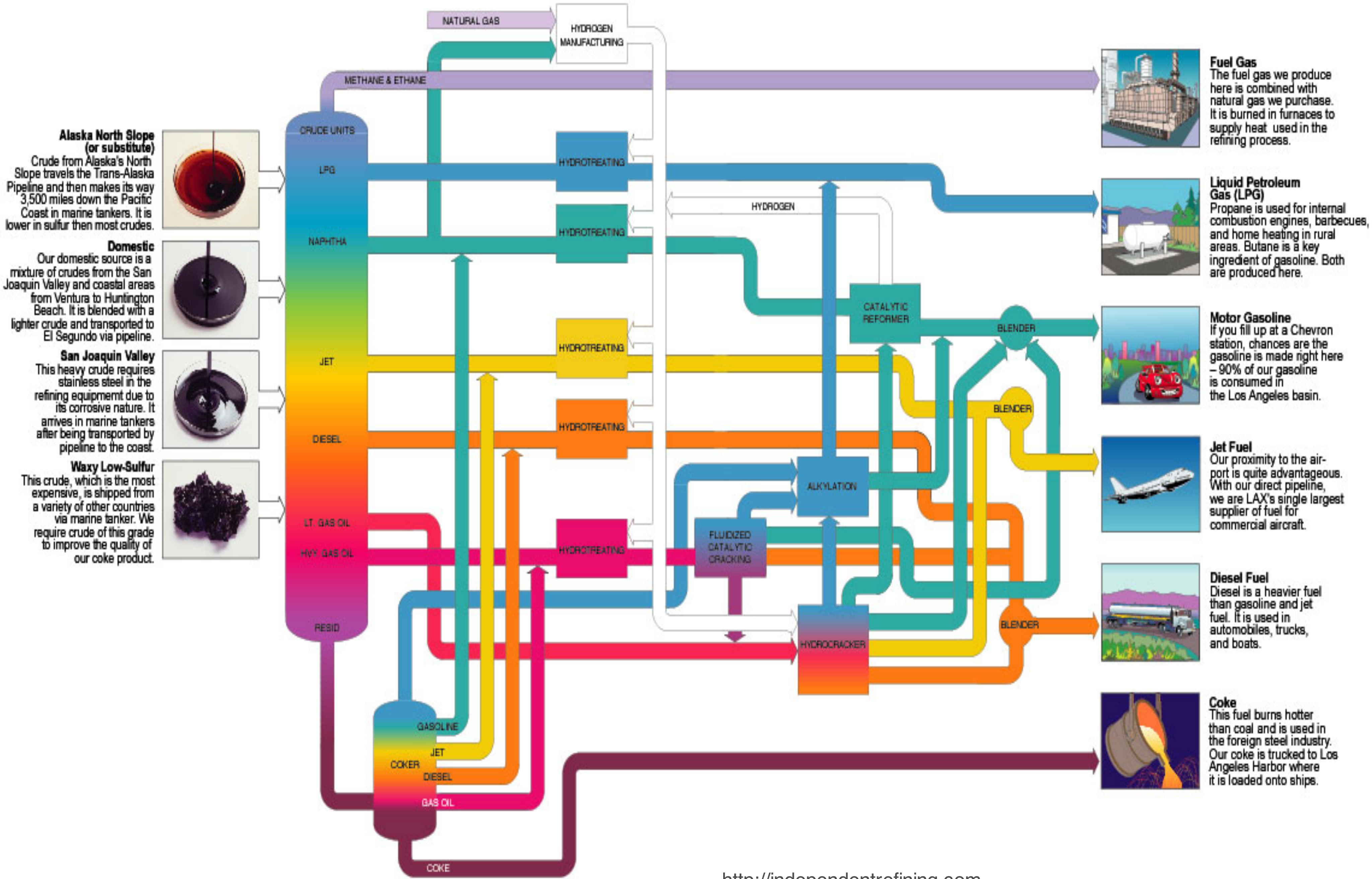
Field	Country	Discovery Year	Ultimate Recoverable Reserves [Gb]
Kashagan	Kazakhstan	2000	7-9
Azadegan	Iran	1999	6-9
Roncador	Brazil	1996	2.9
Cusiana/Cupiagua	Colombia	1991	1.6
Sihil	Mexico	1999	1.4
Ourhoud	Algeria	1994	1.2
Thunder Horse	US GoM	1999	1-1.5



Source: AAPG, UHDSG

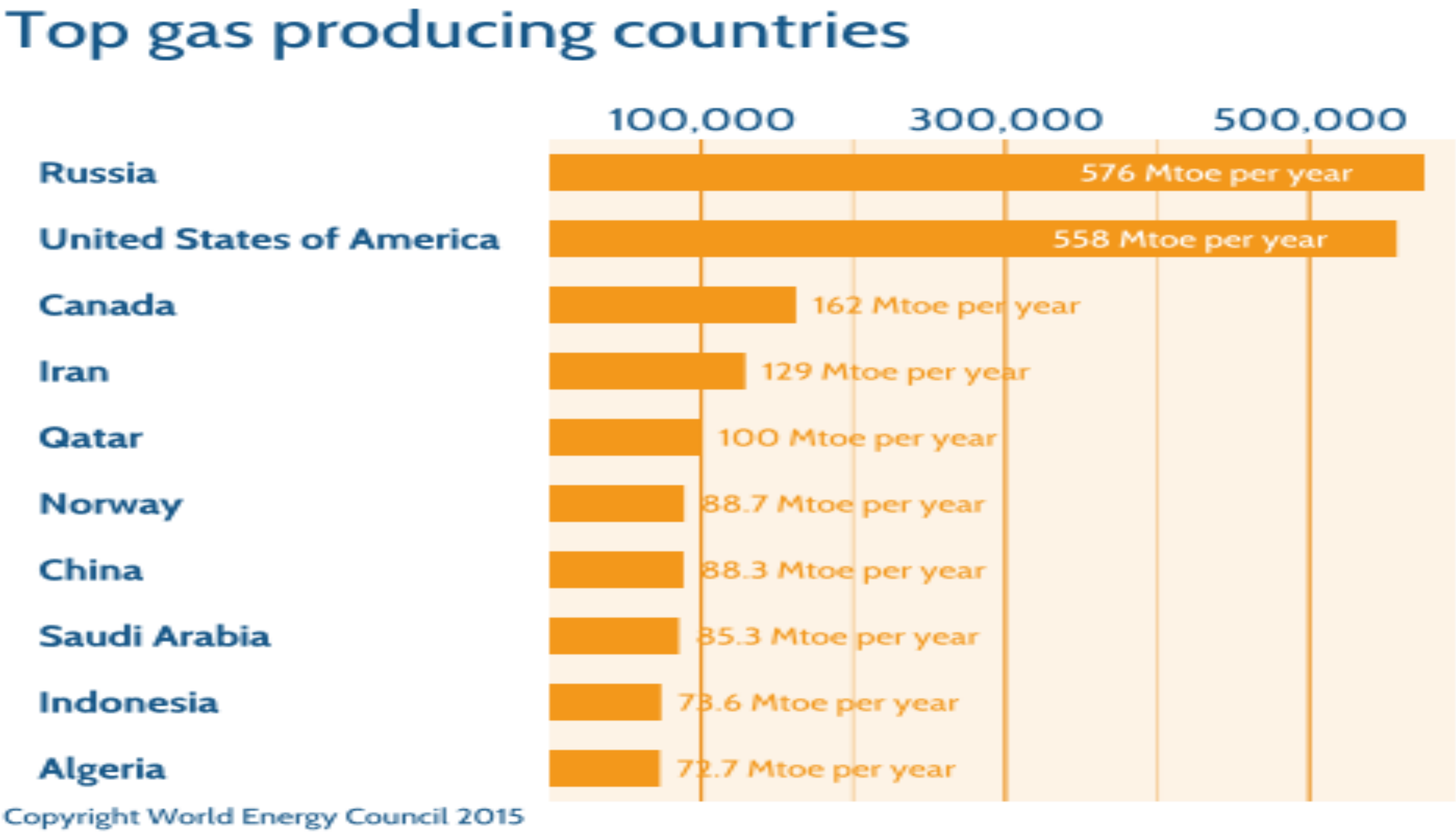
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Oil refinery



http://independentrefining.com

Natural gas


Top gas producing countries
100,000
300,000
500,000
Russia
576 Mtoe per year
United States of America
558 Mtoe per year
Canada
162 Mtoe per year
Iran
129 Mtoe per year
Qatar
100 Mtoe per year
Norway
88.7 Mtoe per year
China
88.3 Mtoe per year
Saudi Arabia
85.3 Mtoe per year
Indonesia
73.6 Mtoe per year
Algeria
72.7 Mtoe per year
Copyright World Energy Council 2015

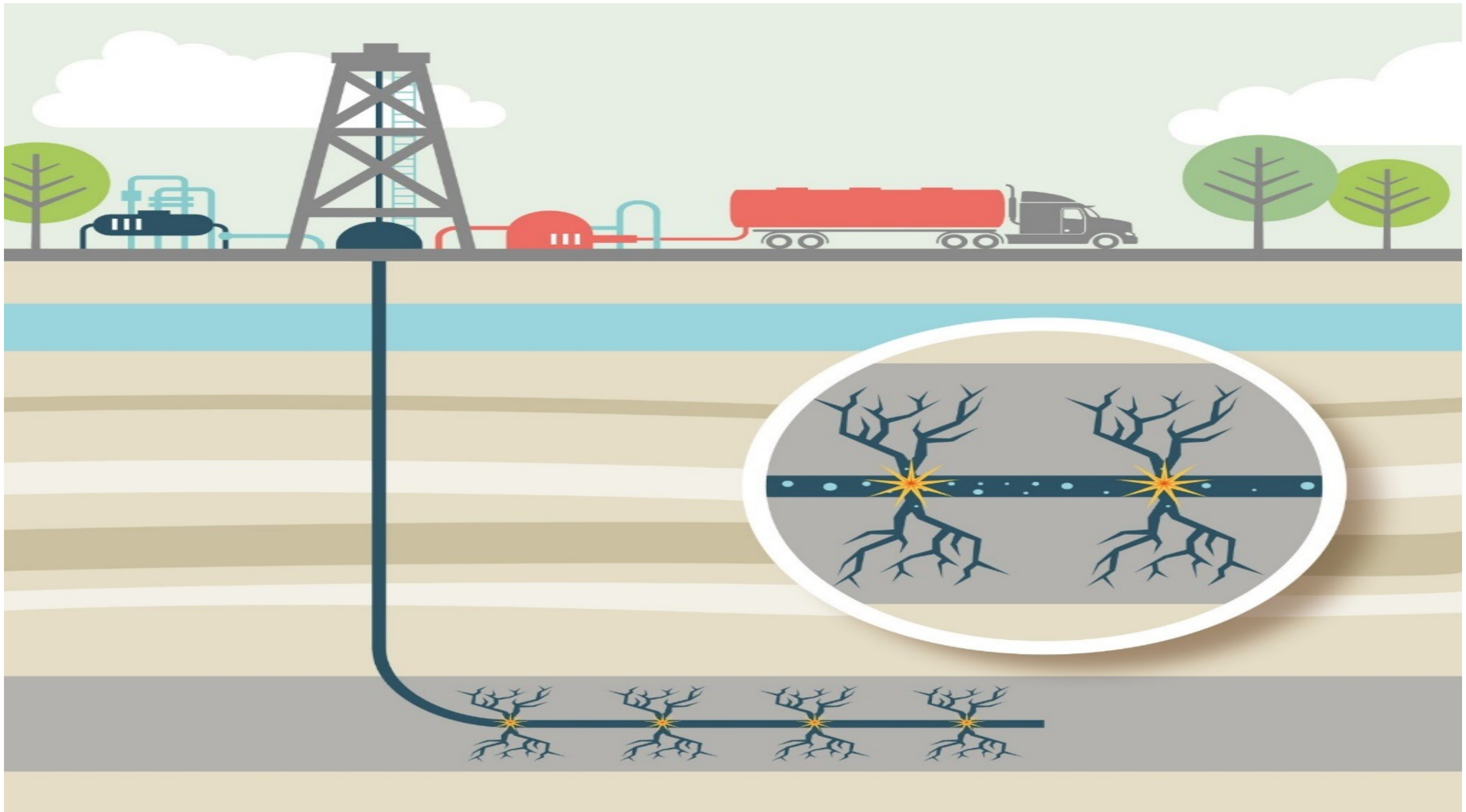
Non conventional gas and oil

Hydraulic fracking: Oil and Gas

High pressure (500 bar) water

Tensio-active and biocide compounds to ease the extraction

Water is extracted and has to be treated

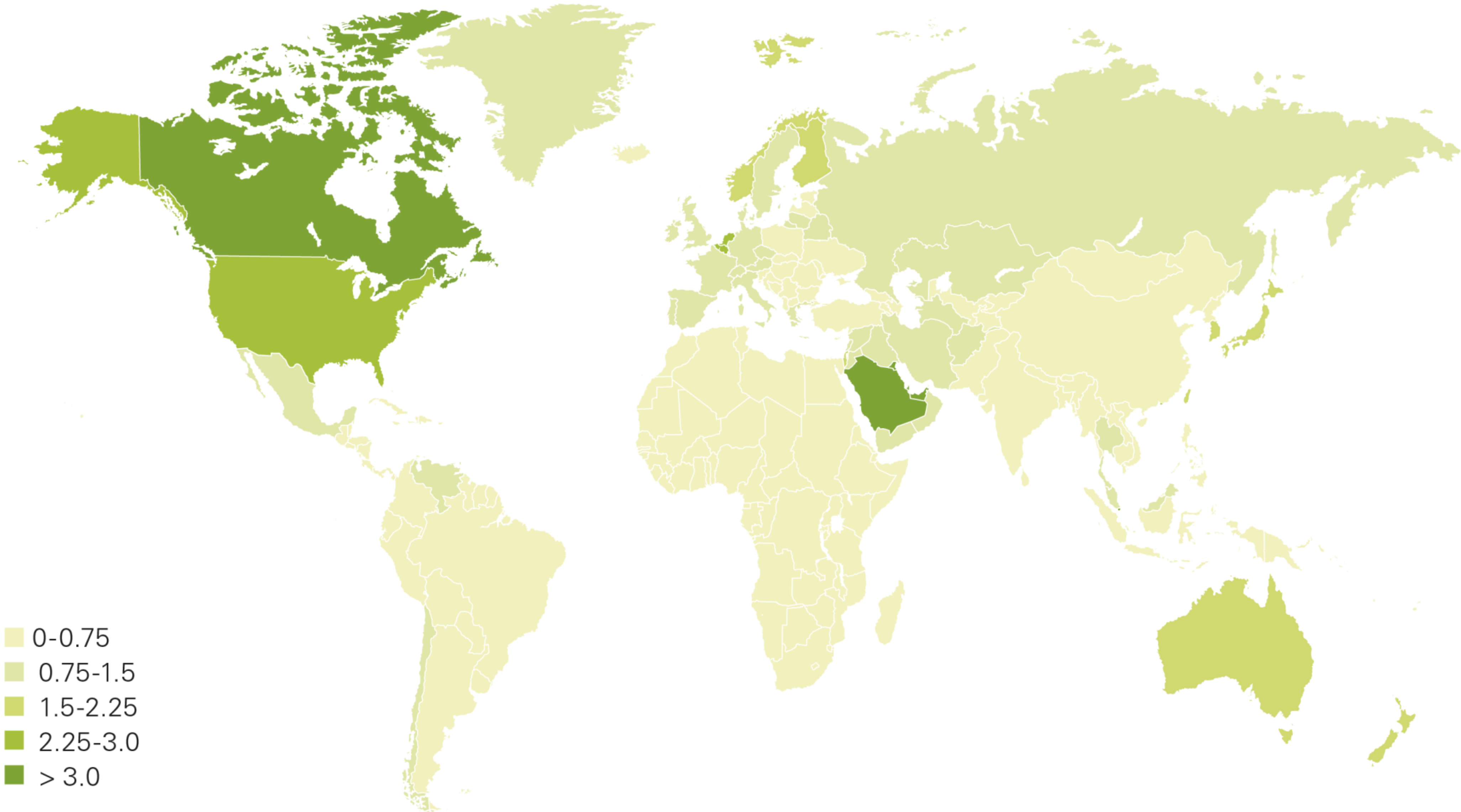


ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Who consumes the oil?

BP World energy statistics review 2013

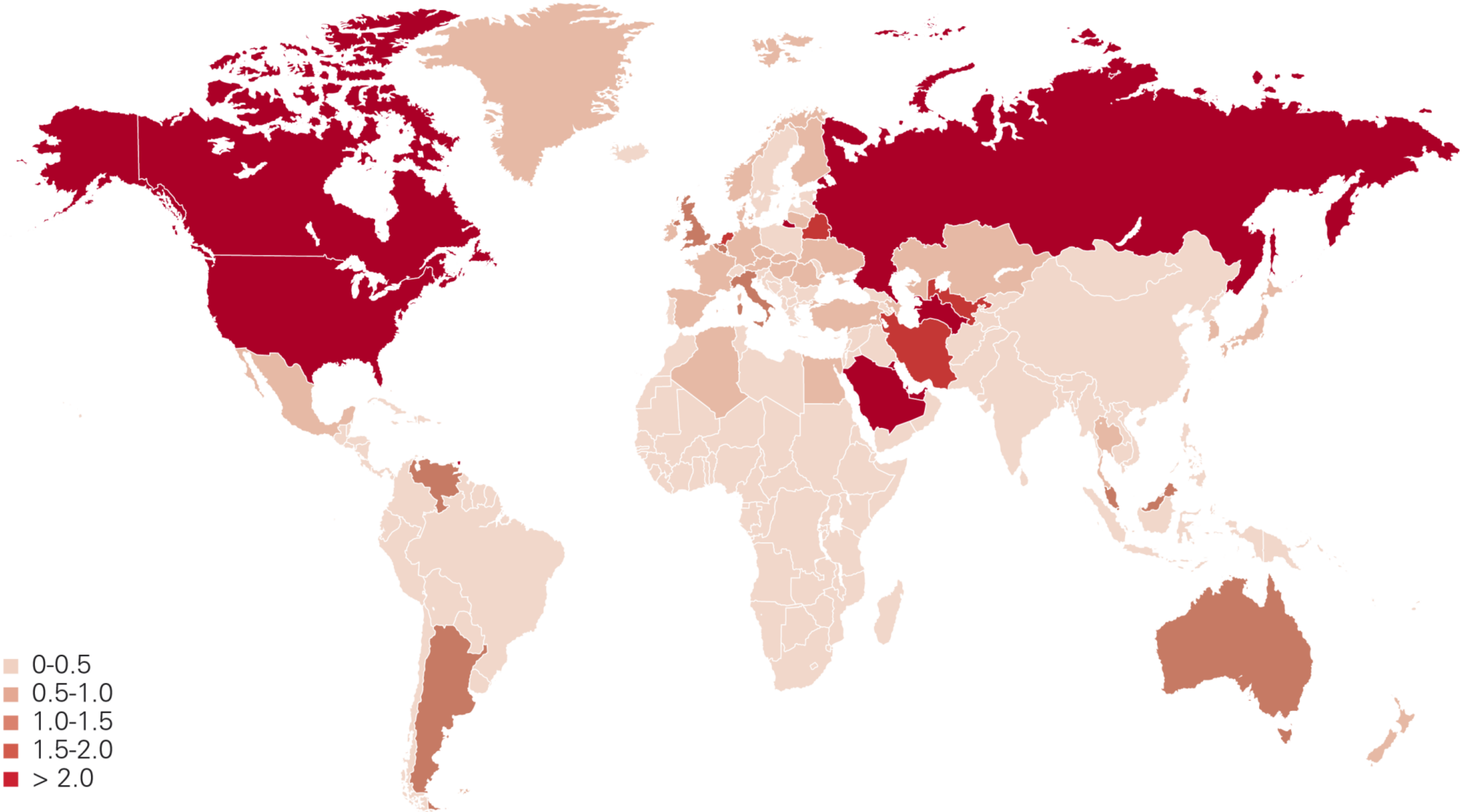
Oil consumption per capita 2012 (Toe)



Who consumes the gas?

BP World energy statistics review 2013

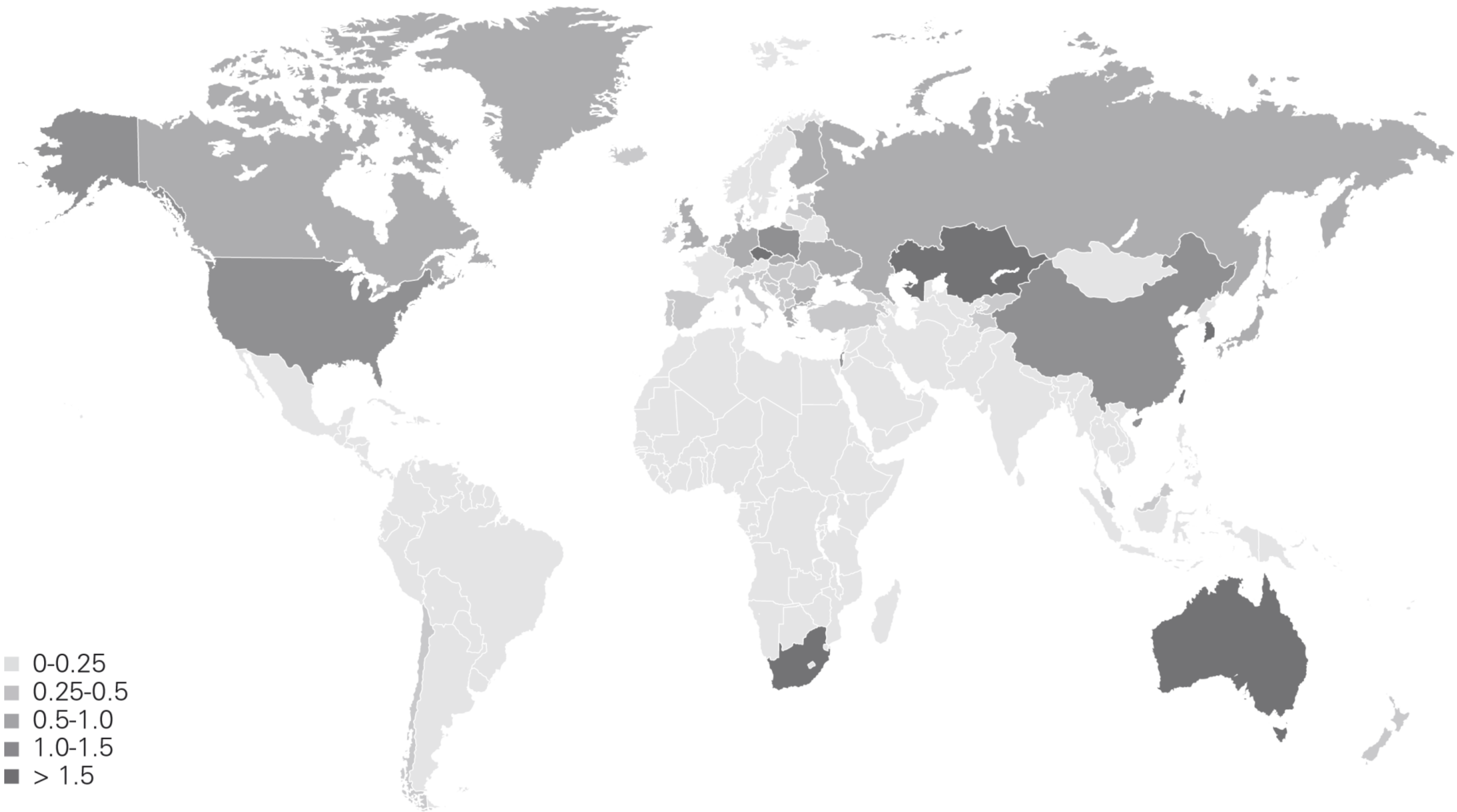
Gas consumption per capita 2012 (Toe)



Who consumes the coal?

BP World energy statistics review 2013

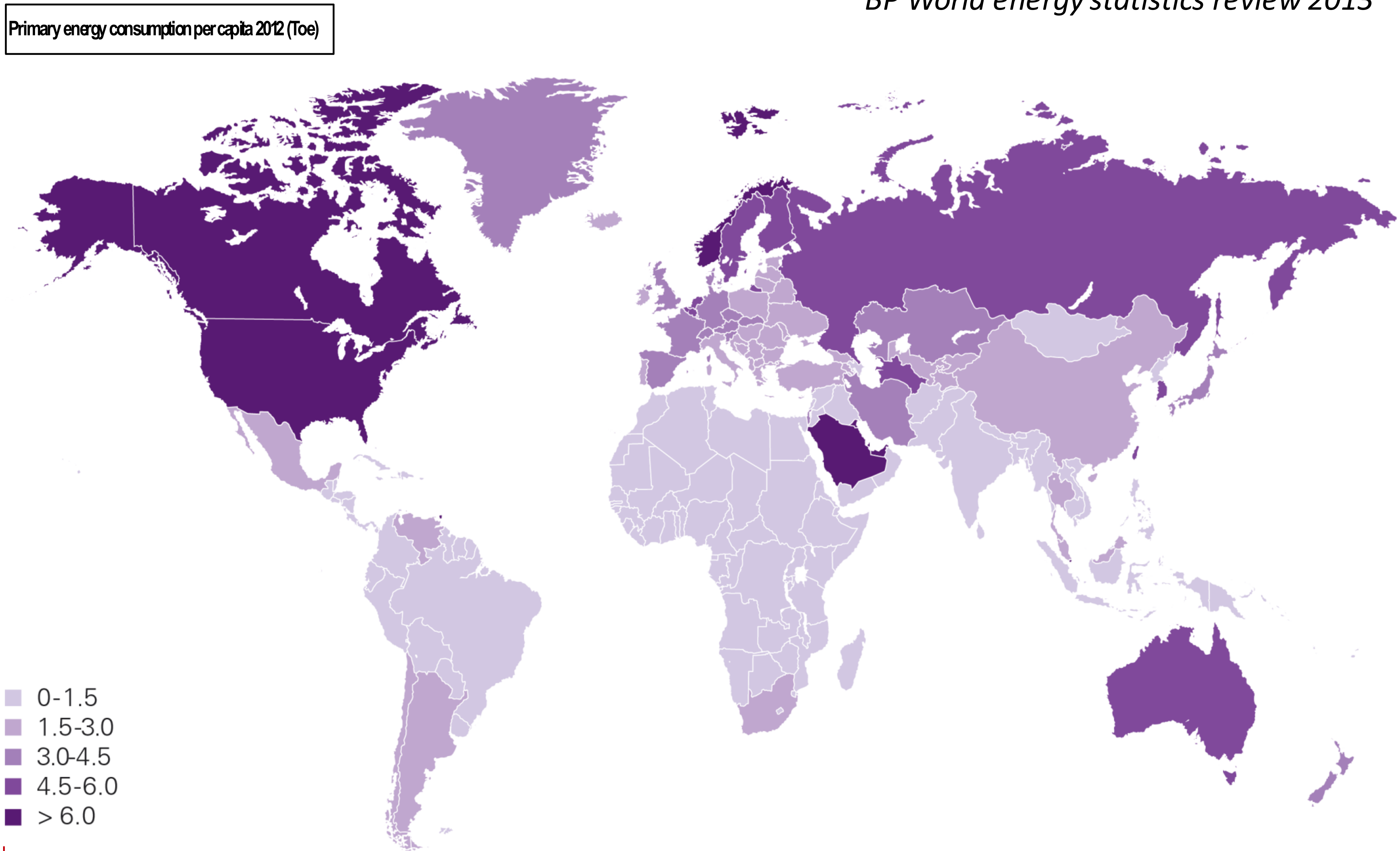
Coal consumption per capita 2012 (Toe)



ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Where is the overall primary energy consumption?

BP World energy statistics review 2013

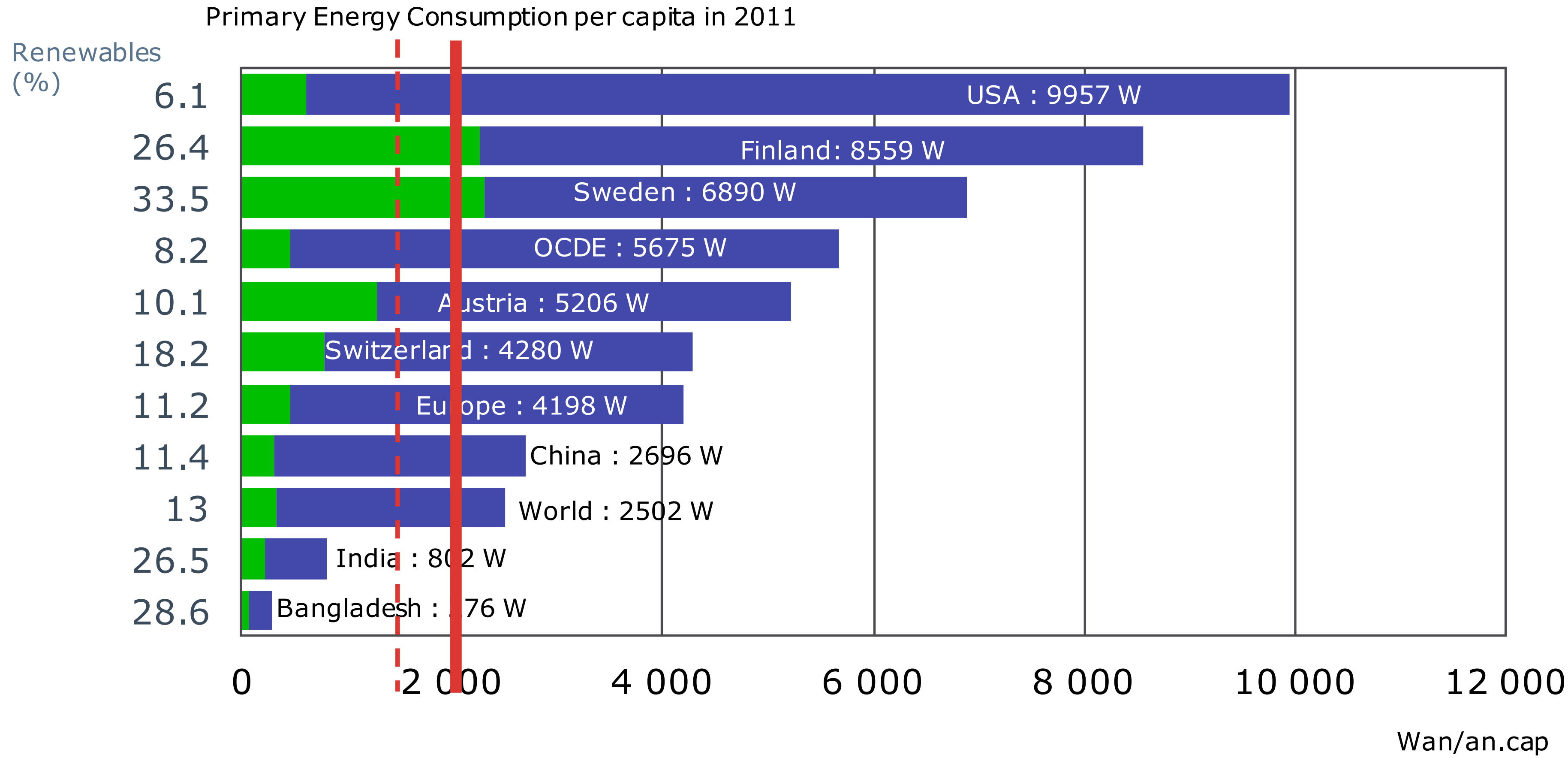


ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

‘Reserves’ and ‘fuel cost’

- The given reserves are proven and valid for current production rates, at present economics
- Ultimate reserves (physical) could be 10x larger for coal and 4-5x larger for oil and gas, recoverable at higher cost, and extending the use to several centuries
- Isn’t renewable energy, by contrast, ‘free’ fuel?
- No! What matters is the cost of harnessing any fuel, anywhere (localization, extraction, storage, transport, conversion,…)
- In this way, only direct solar energy that warms your body could be considered free; else, when not considering the cost of harnessing, also gas, oil and coal are free fuels, made by nature!

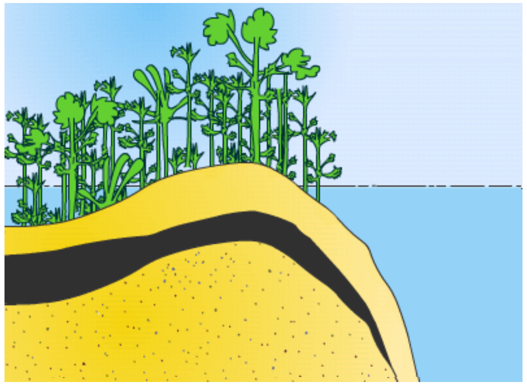
2000 W society concept / 75% renewable



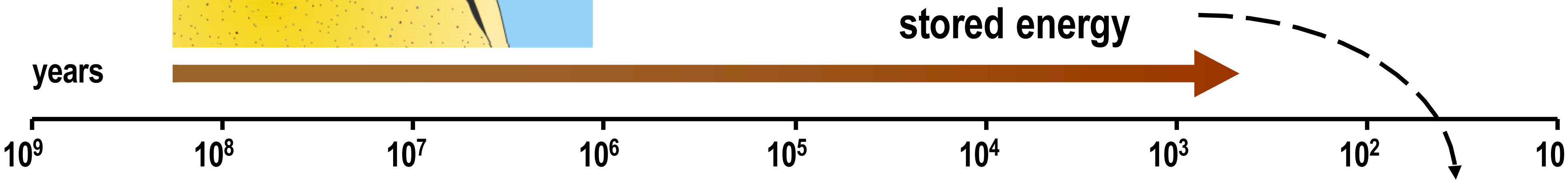
Source: Key World Energy Statistics, IEA, edition 2013,
Renewables Information IEA, edition 2012

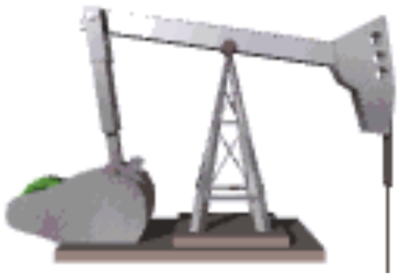
2000 W / cap / year
1 t CO_2 / cap / year → 75% renewable

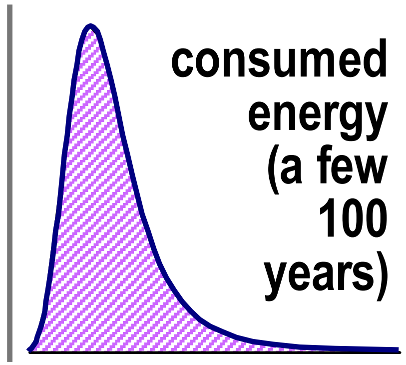
Time scale for fuel generation and consumption



Generation time : 100 - 400 10^6 years





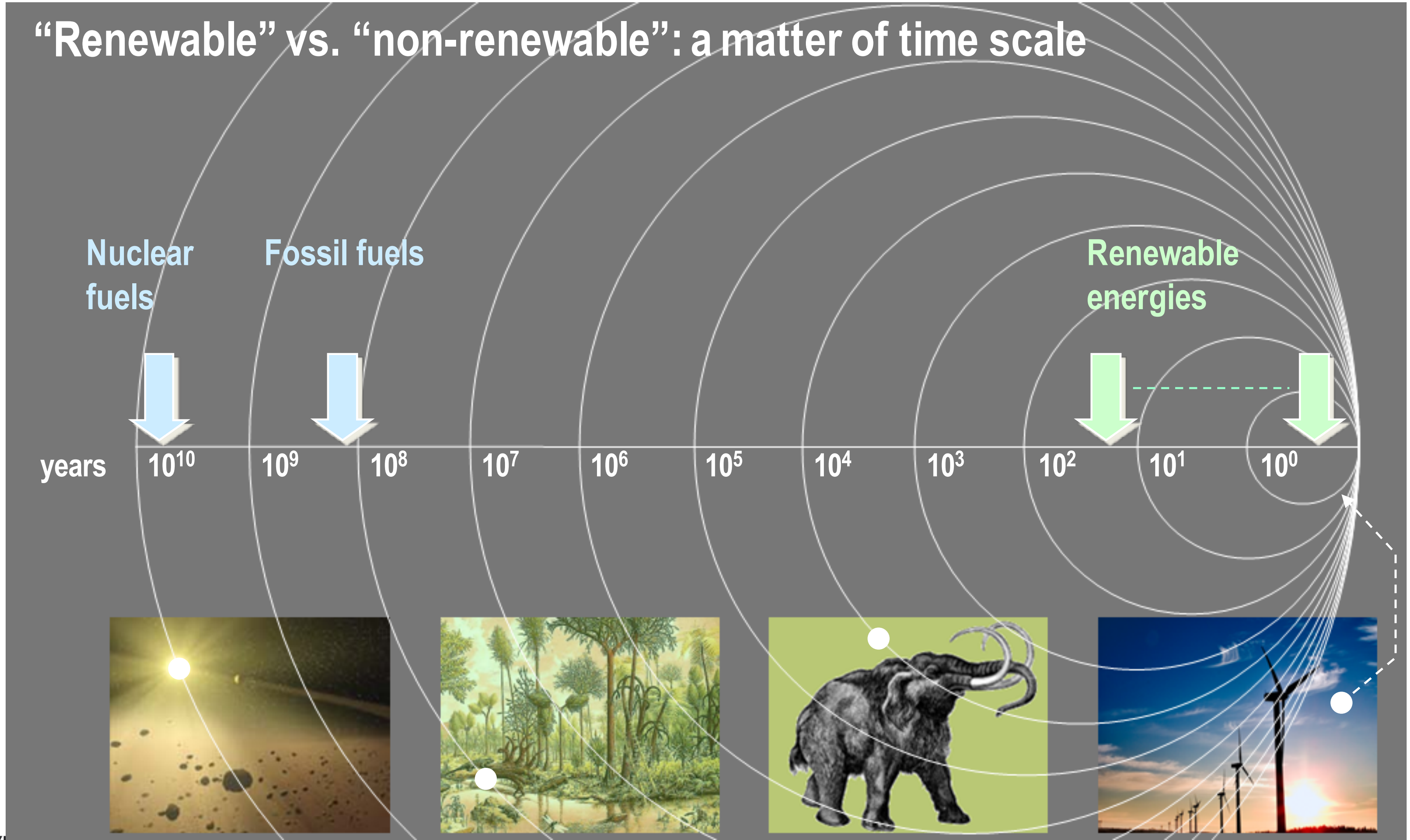


consumption time
<< generation time

⇒ non-renewable

Renewable = sustainable

Fuel generation time ≤ fuel consumption time

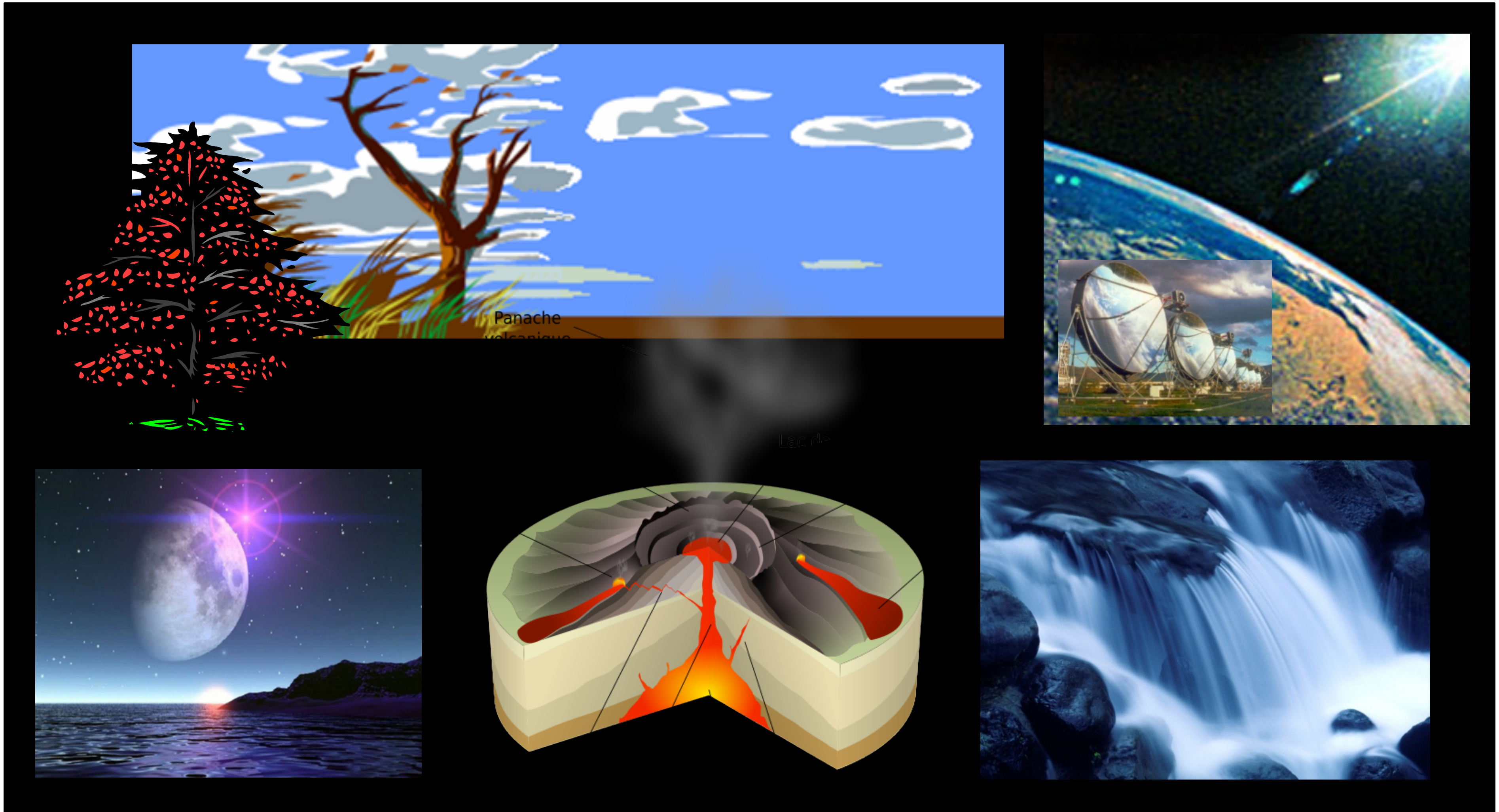


Non renewable = stored energy

Fossil (and nuclear) fuels are like energy **capital**, in the 'bank' for present use. Once used, it's no longer replenished on the life scale of mankind.

Renewable ≈ energy fluxes (mostly unstored)

Unlike ‘burning energy capital’, we have to harvest these fluxes on a ‘daily’ basis for our energy ‘income’.



Classification w.r.t. timescale

Instantaneous use (seconds, minutes)	Short term storage (days, weeks)	Medium term storage (months, years)	V. long term storage (millions of years)
SOLAR – DIRECT	WIND	BIOMASS	OIL
SOLAR – THERMAL	HYDRO	WASTES	GAS
SOLAR – P.V.	WAVES	GEOTHERMAL	COAL
WIND	TIDES		NUCLEAR
HYDRO			GEOTHERMAL

Classification w.r.t. origin

$E = mc^2$

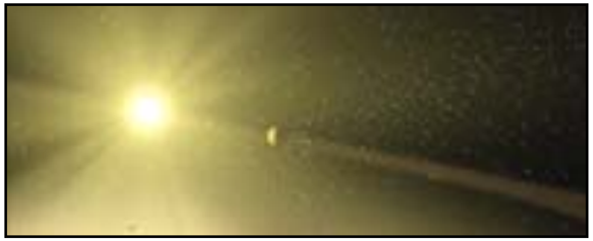
MATTER

FUSION

STARS

(dead) stars

the sun



other

(dead) stars

- uranium
- thorium

- hydrogen (deuterium, tritium)

the sun — Immediate use or short-term storage

- solar
- hydro
- wind
- biomass
- ocean heat
- ocean waves

the sun — Long-term geological storage

- coal
- oil
- natural gas

other

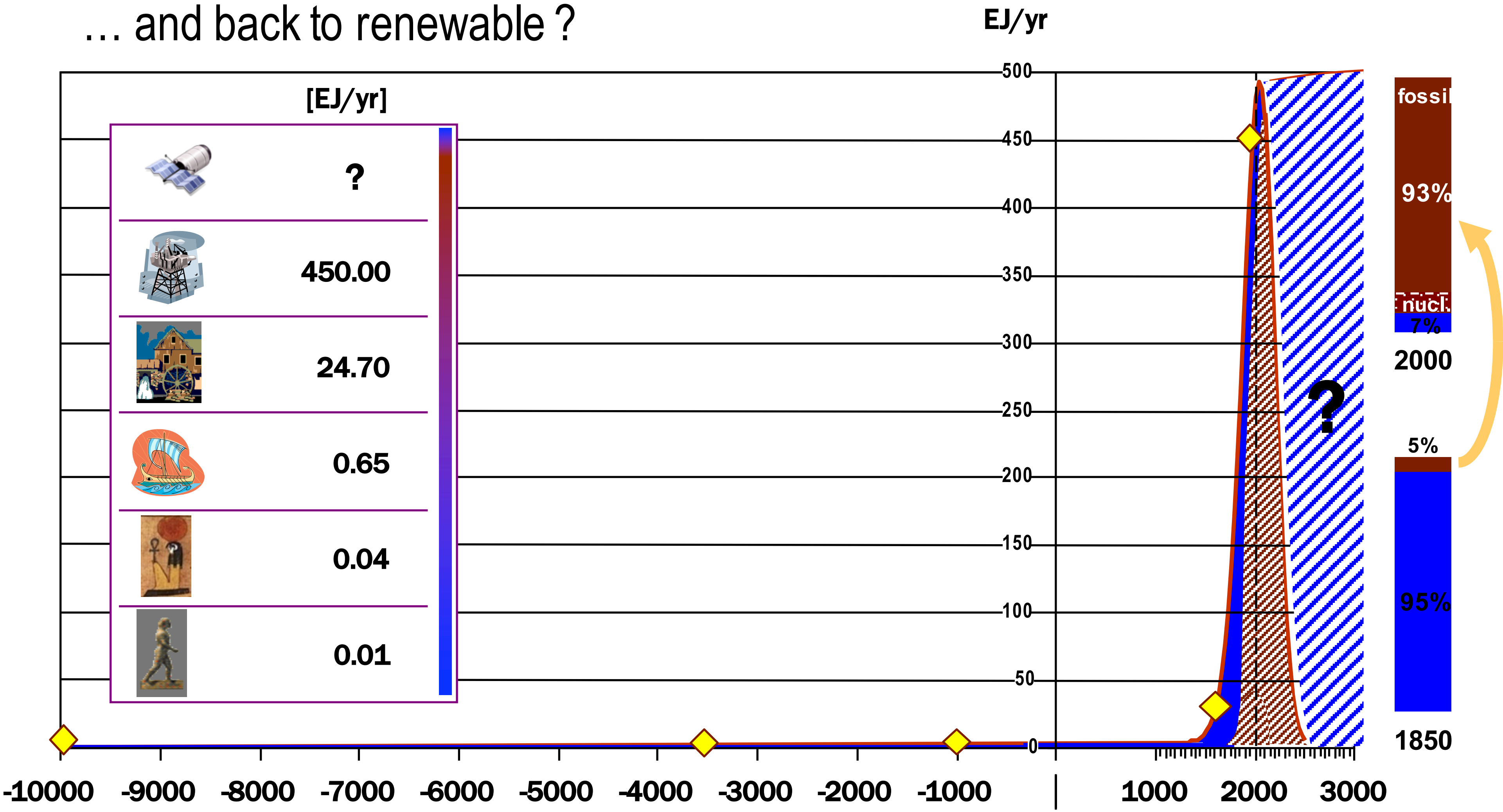
- tidal

- geothermal

Humankind and energy: ever on the rise

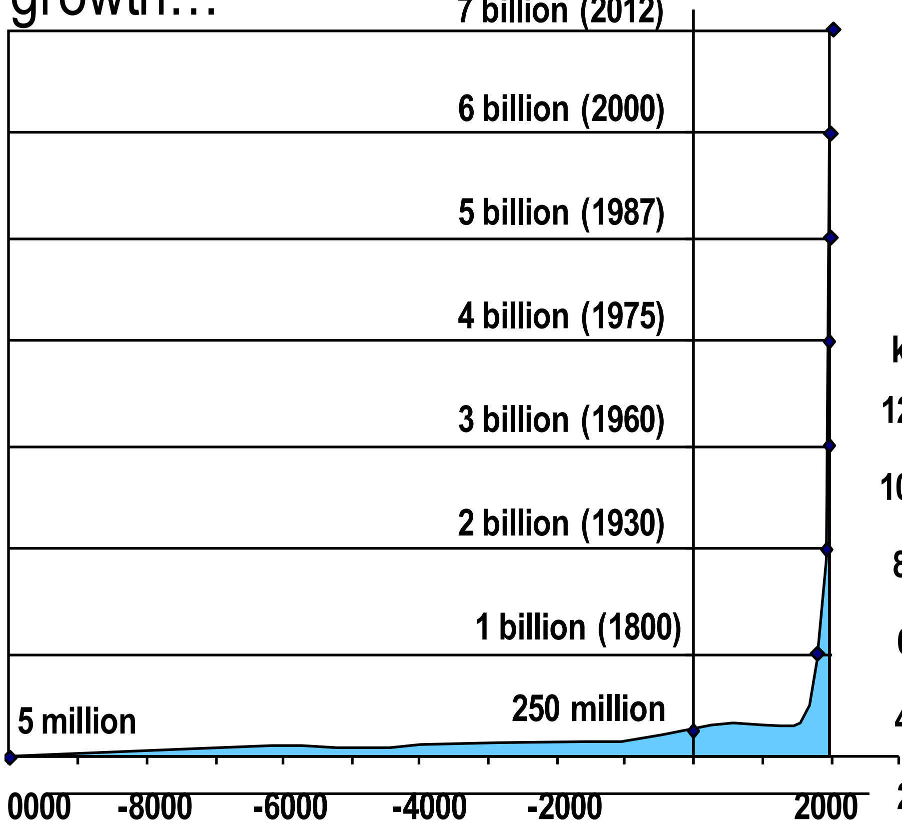
From renewable to fossil energies

… and back to renewable ?



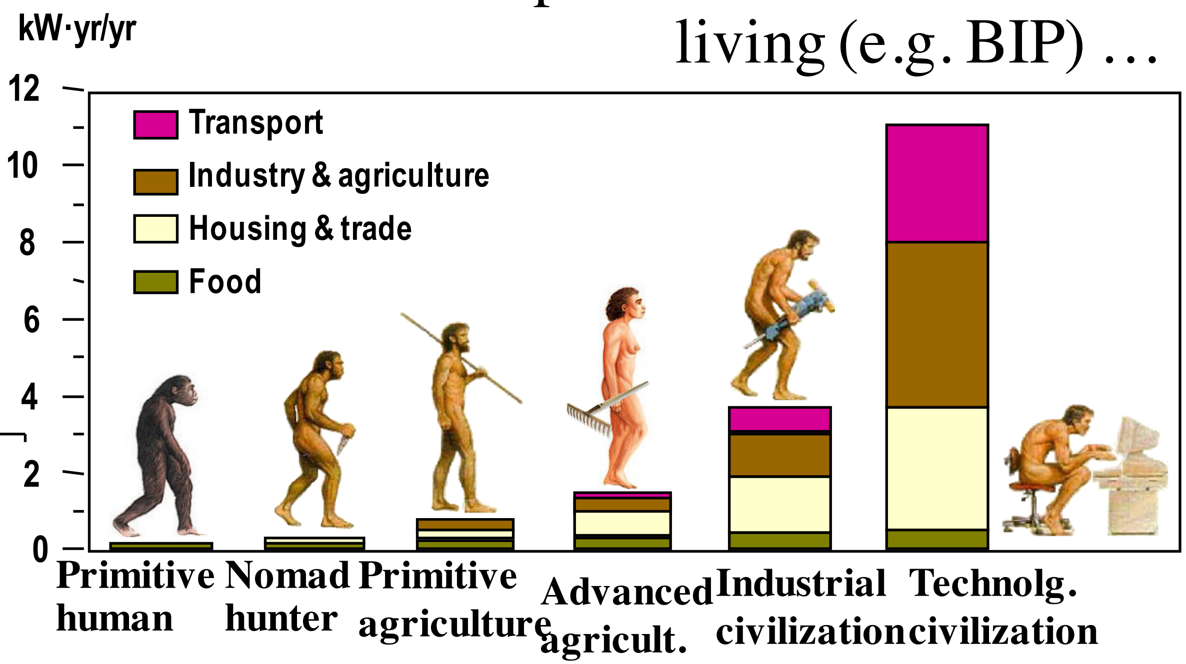
Main drivers for rise in energy demand

Demographic growth…

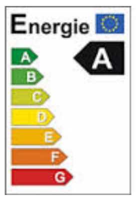


..x..

…improvement of standard of living (e.g. BIP) …



..x..



.. Energy intensity of energy service

Sustainability

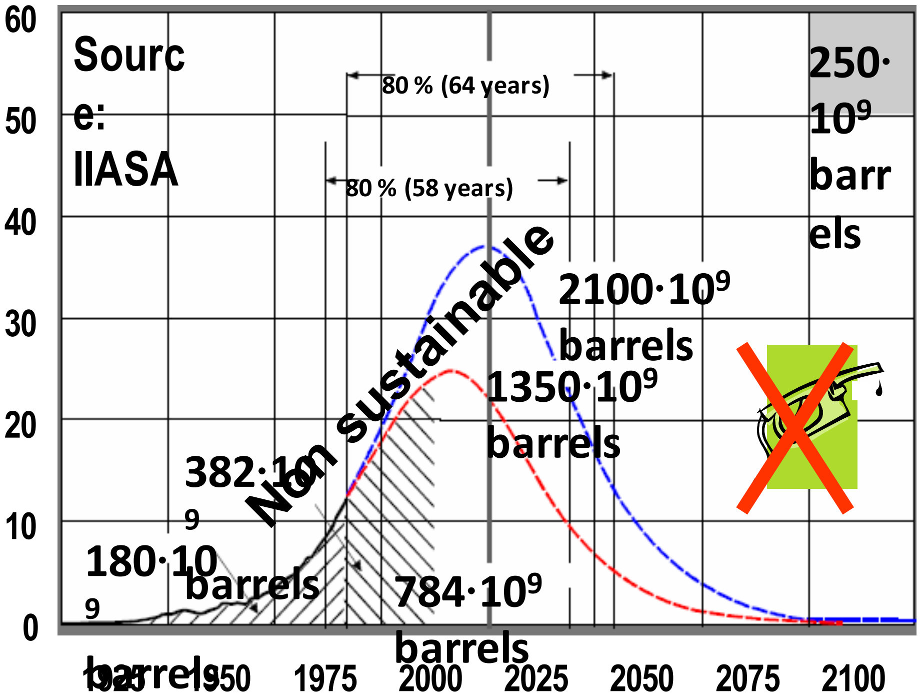
Not only a ‘source’ issue, but now even more a ‘sink’ issue !

consumption rate >>> generation rate

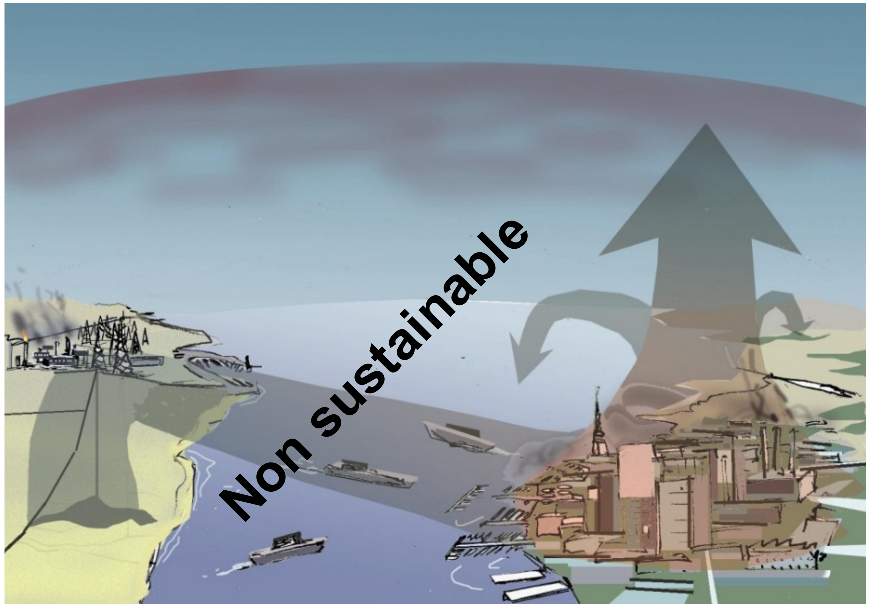
emissions rate > ‘recovery’ rate

Burning of energy capital

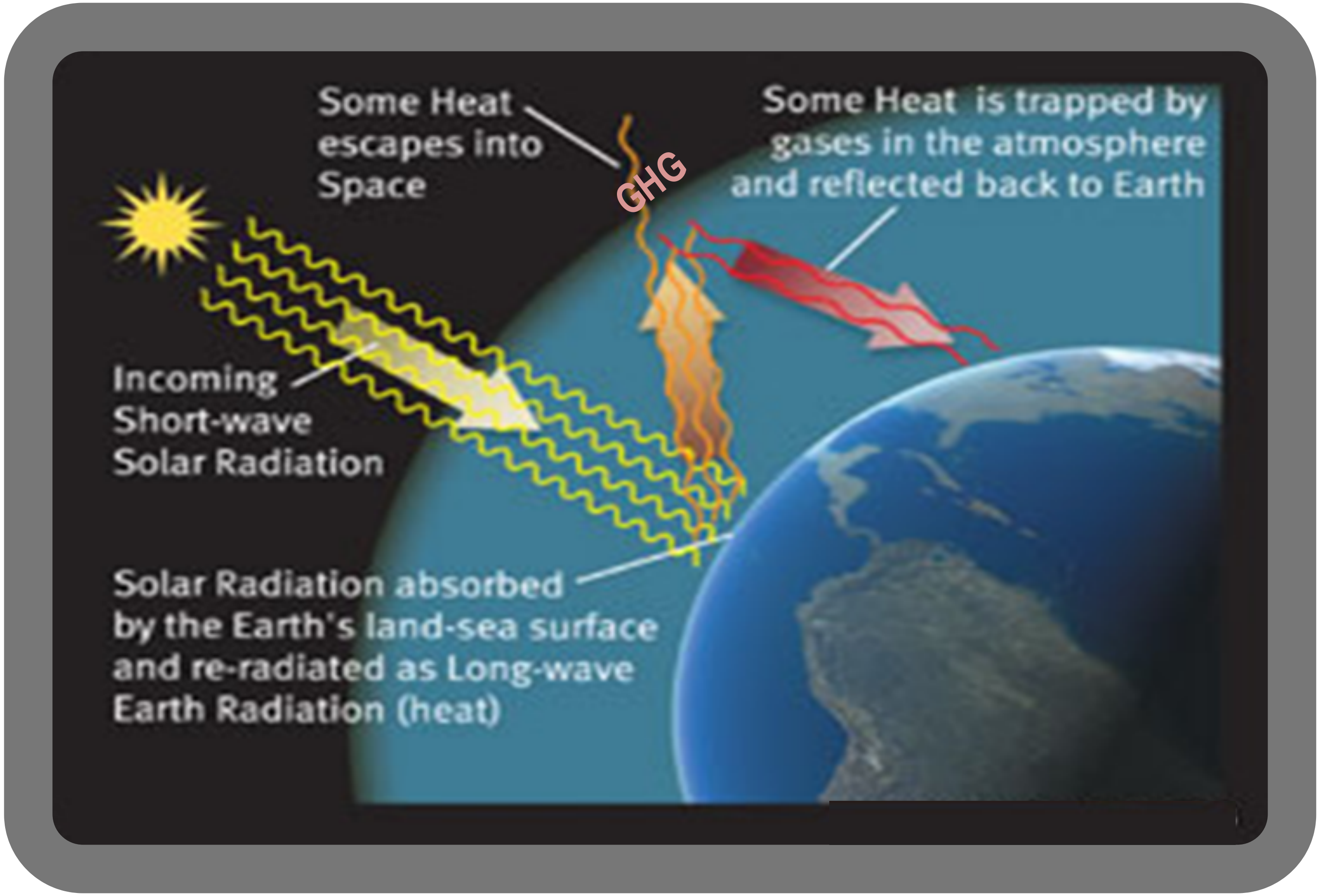
Production [10^9 barrels/yr]



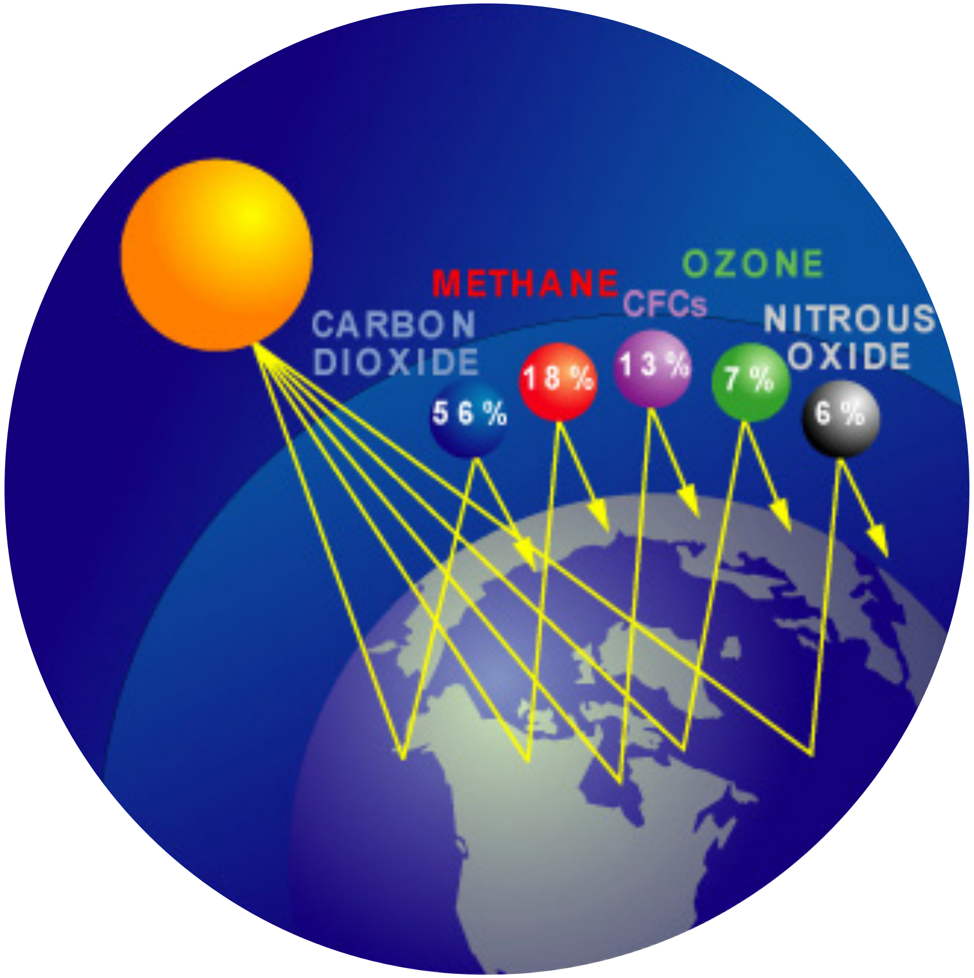
Irreversible damageable impacts on the environment

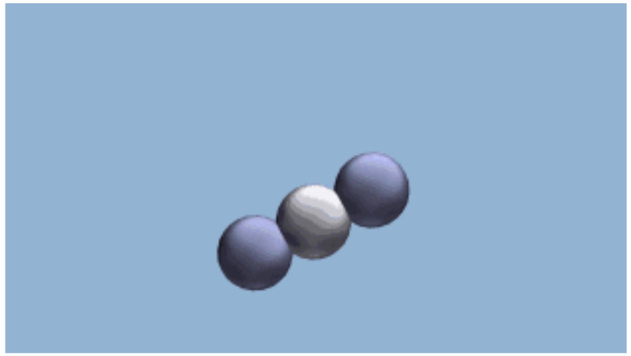


The sink: anthropogenic climate change



The green house effect

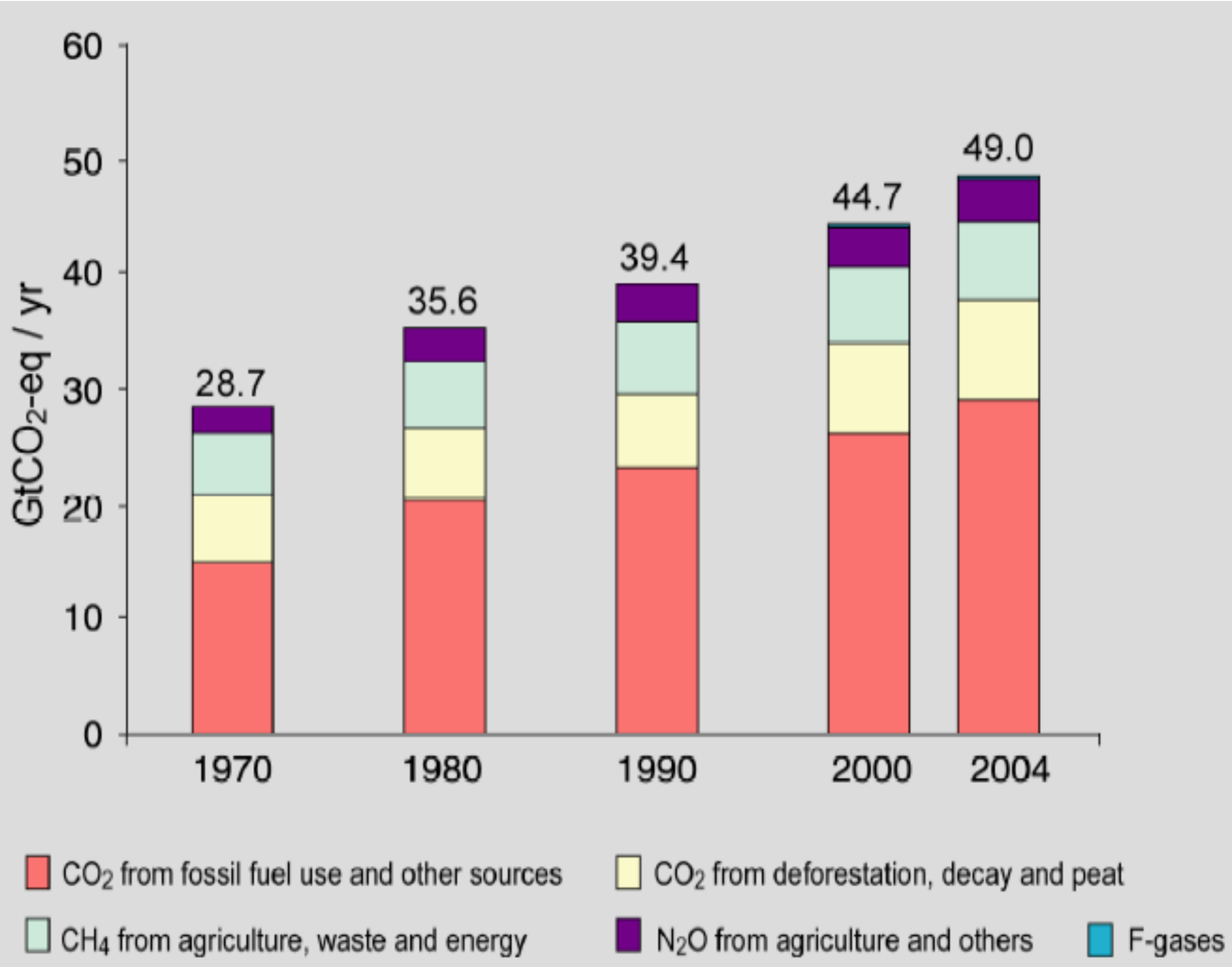


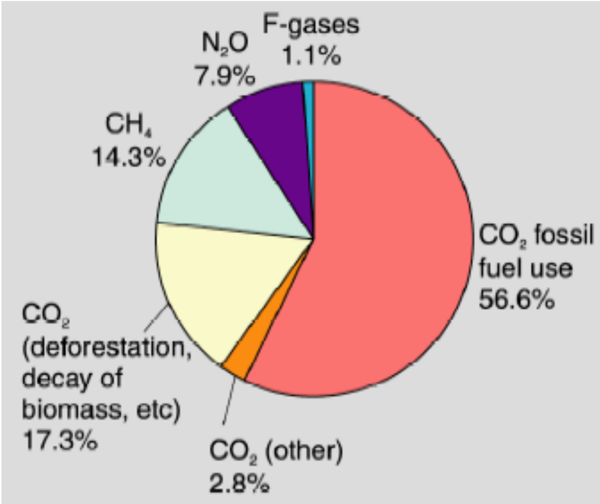


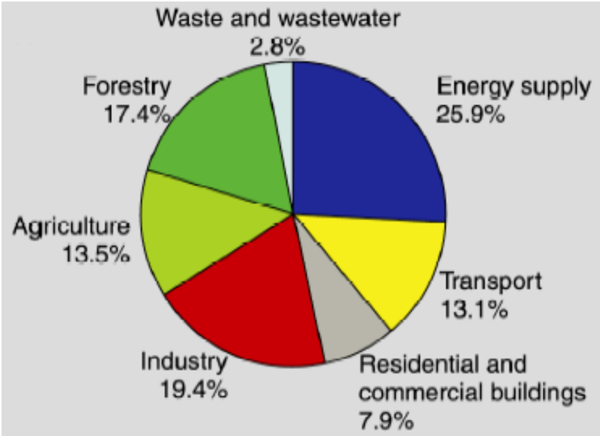
CO_2 absorbs IR radiation in its vibration states. The vibrating molecule re-emits the radiation which is absorbed by another GHG molecule. This absorption - emission - absorption cycle keeps the heat near the surface, effectively insulating the Earth from cold Space.

relative importance of anthropogenic greenhouse gases

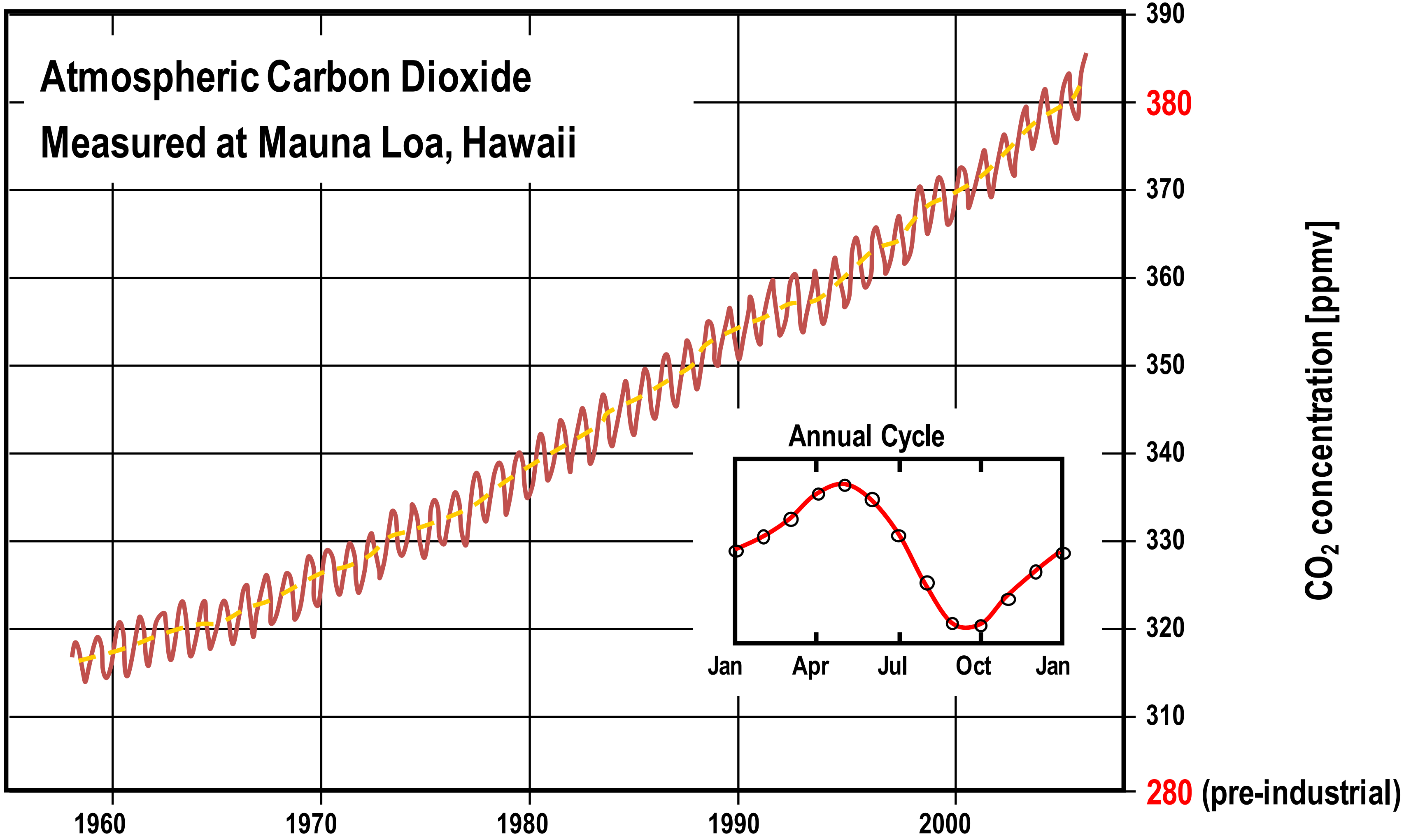
Global warming is for at least half due to energy use



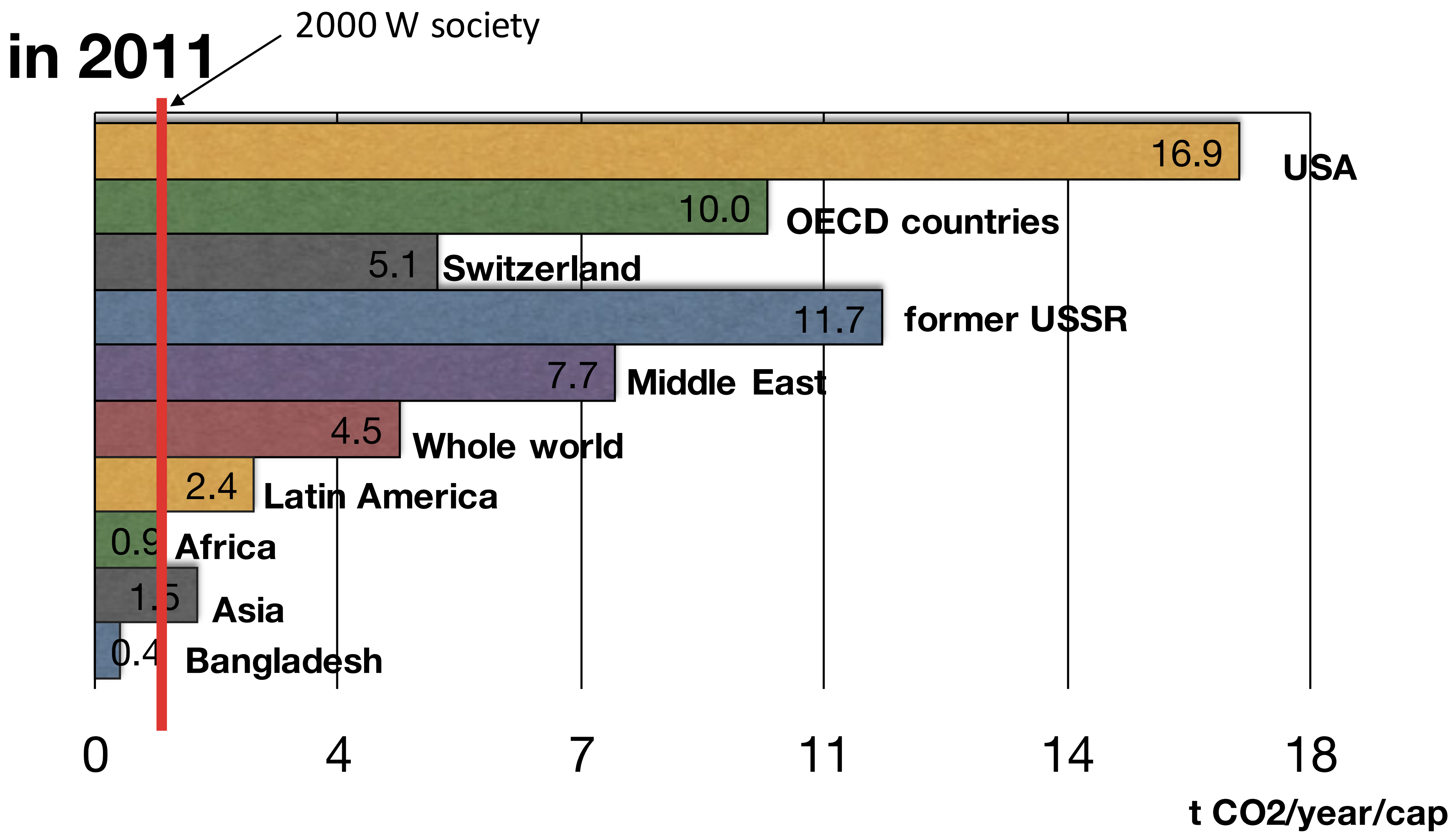




Measured data

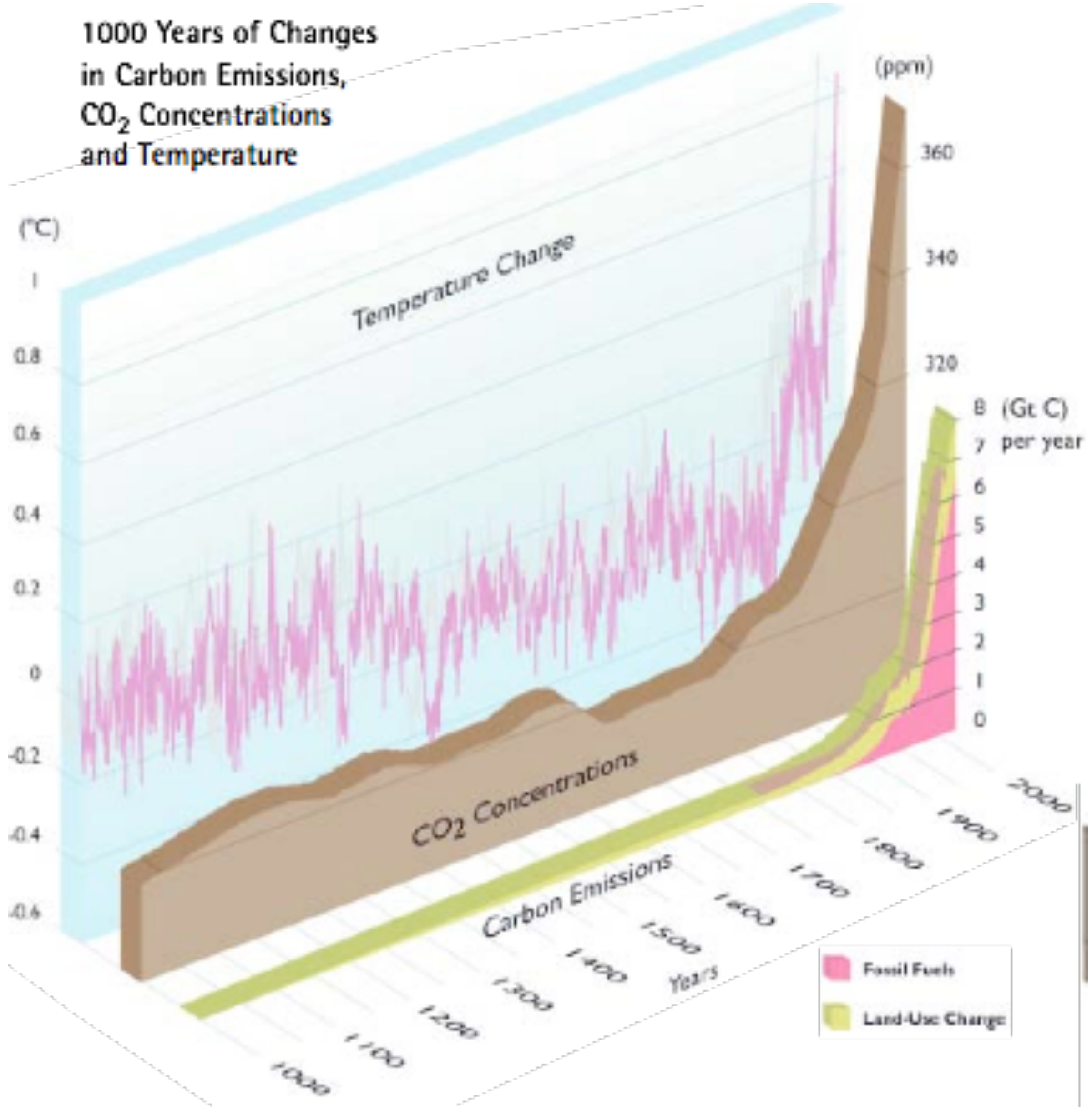


CO2 emissions per capita



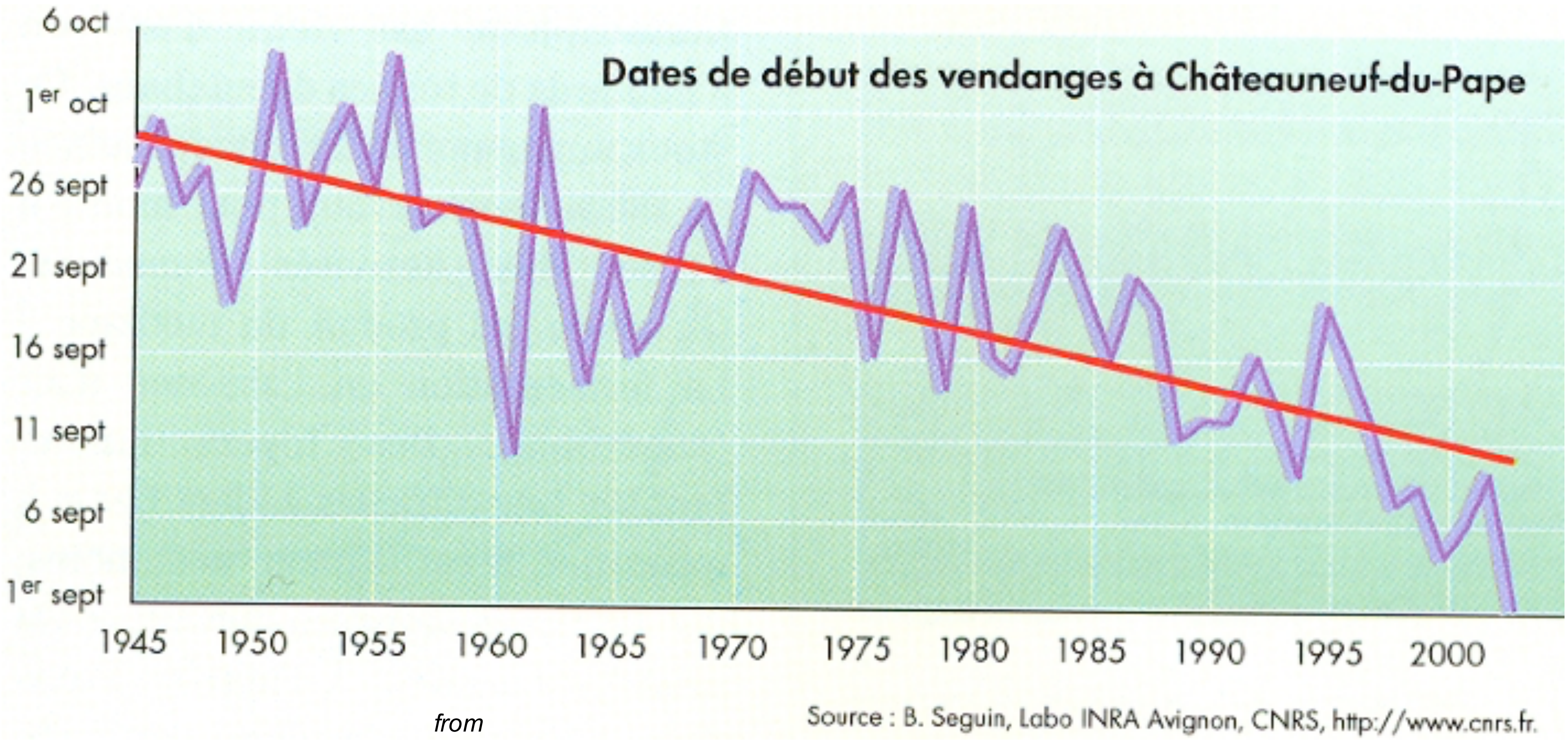
Source: Key World Energy Statistics, IEA, edition 2013

Carbon emissions, CO_2 conc. and temperatures variation



Hassol, 2004

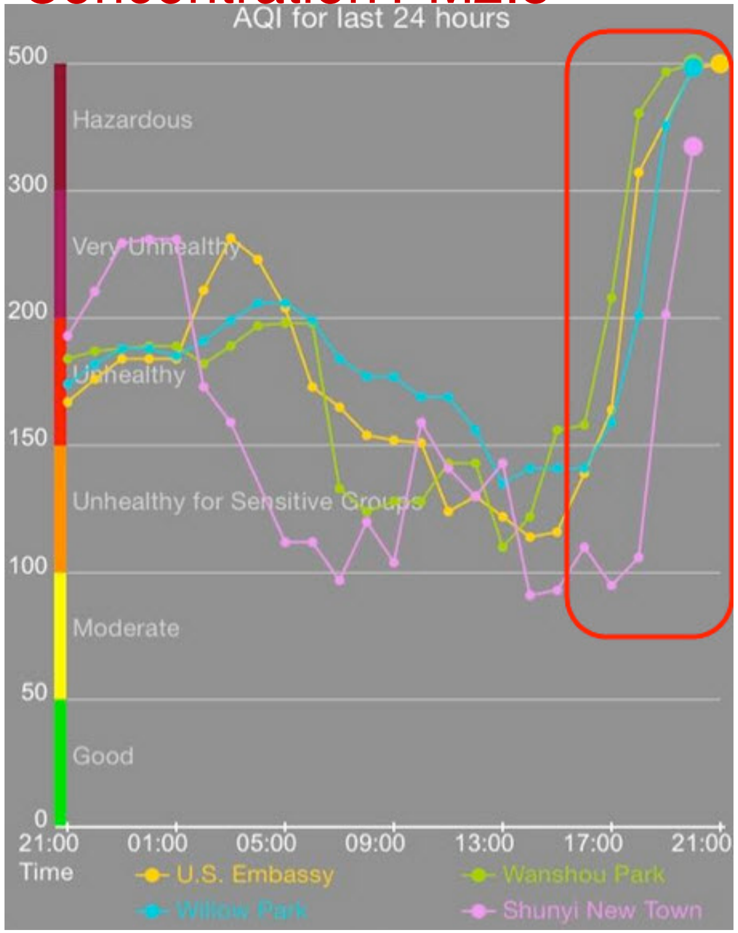
Earlier grape collection!



from Denhez,2005

Coal combustion and its impact (Pekin, winter, 2014)

Concentration PM2.5



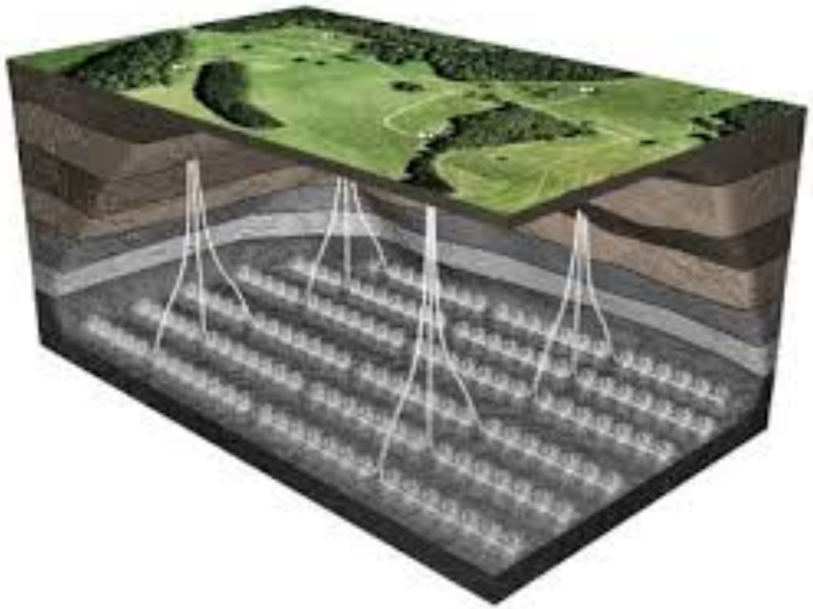
theguardian.com, Tuesday 25 February 2014 - *Chinese scientists have warned that the country's toxic air pollution is now so bad that it resembles a nuclear winter, slowing photosynthesis in plants – and potentially wreaking havoc on the country's food supply.*

Environmental impact

Marcellus field (US)

Leakage in the aquifer

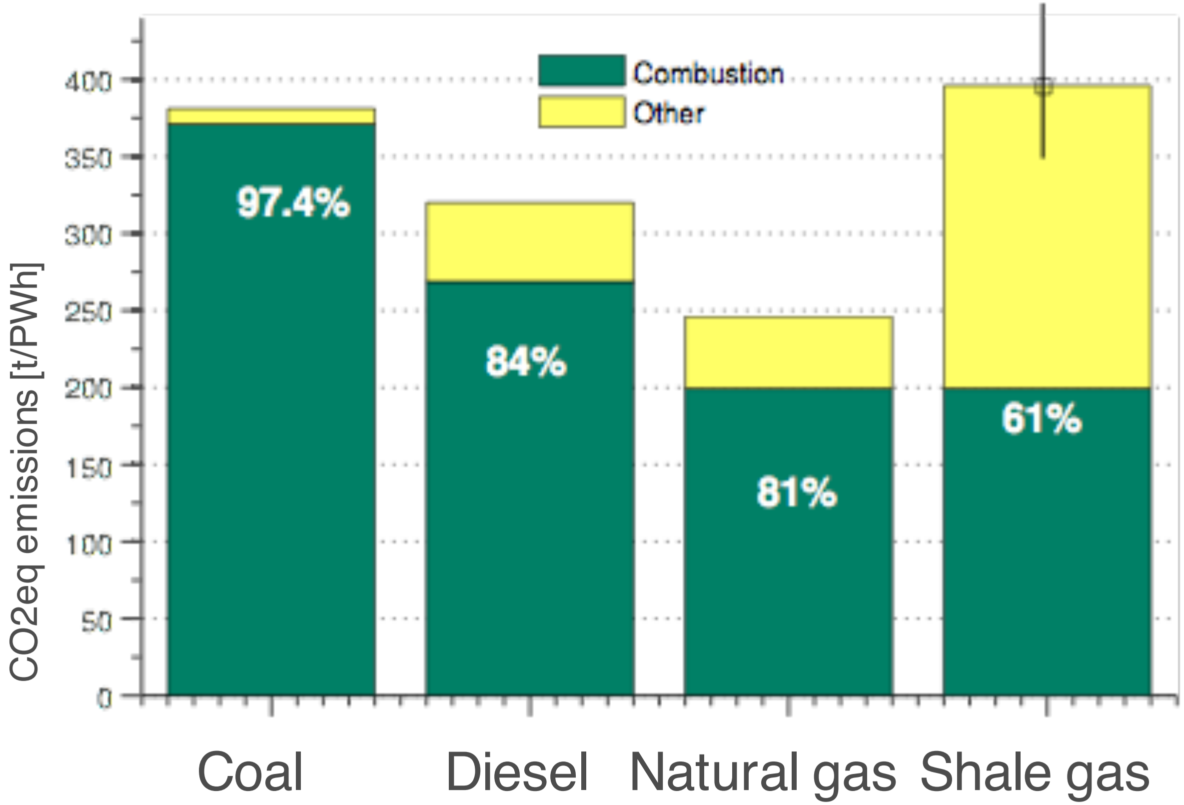
Eau de Fracking



Under ground ? -> Earthquake

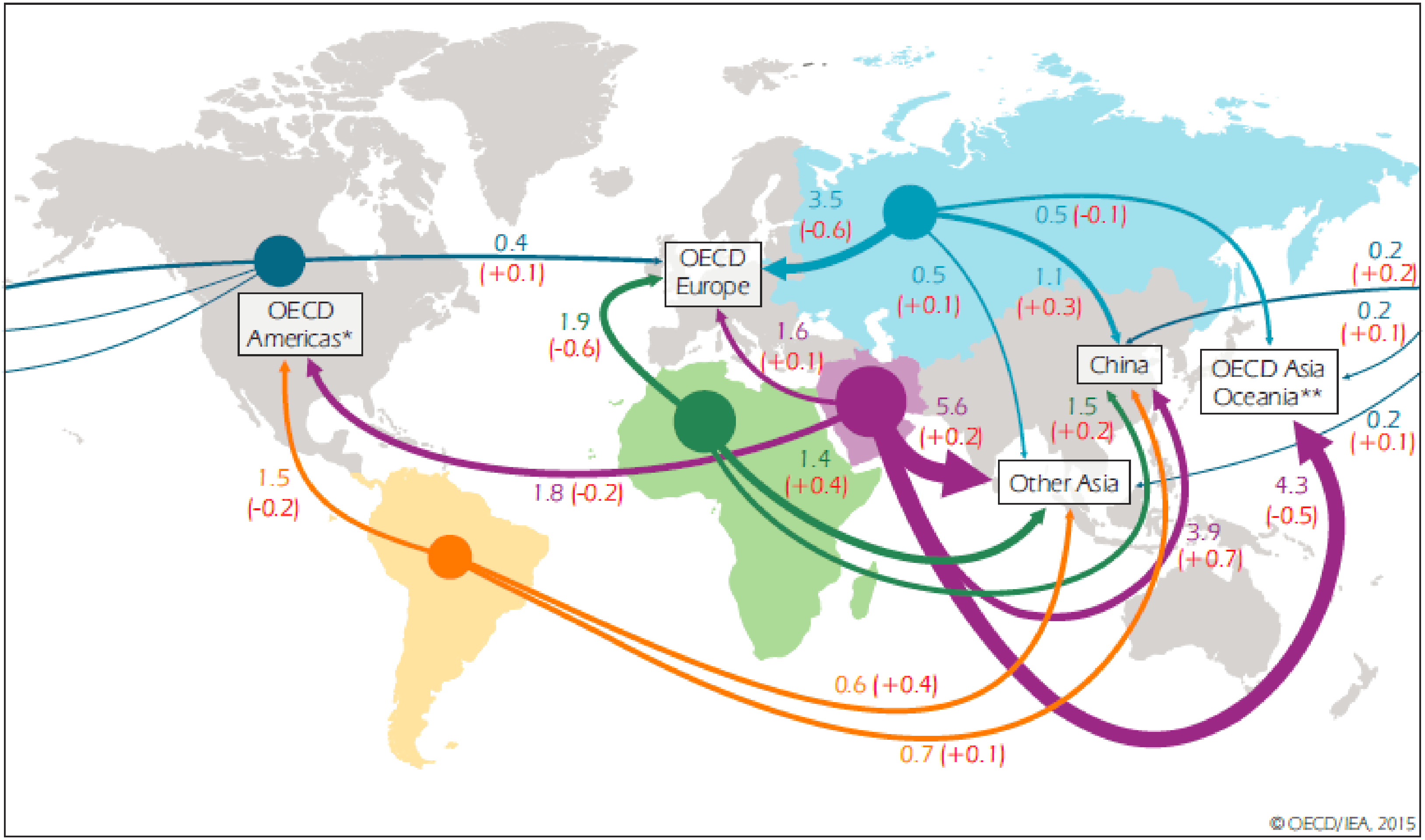
Environmental impact

- Importance of life cycle
  - Extraction
  - Treatment
  - Transport
  - Raffinery
  - Distribution
  - Combustion



Geopolitical impacts (flows)

- **Map 3.1** Crude exports in 2020 and growth in 2014-20 for key trade routes



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Note: Excludes intra-regional trade.

* Includes Chile.

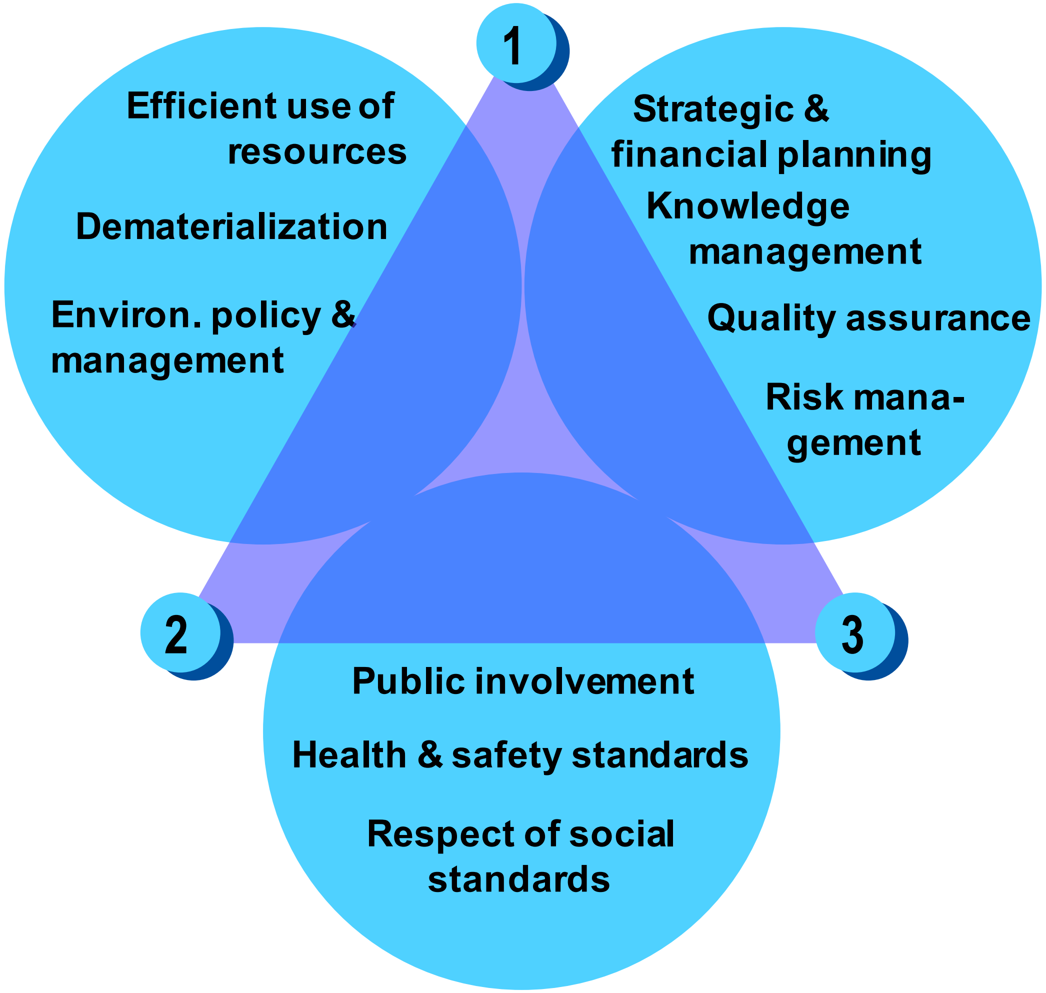
** Includes Israel. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD and/or the IEA is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

https://www.iea.org/publications/freepublications/publication/MTOMR_2015_Final.pdf

How to mitigate emissions and climate, while keeping the services

Sustainable development: meets needs of present without compromising ability of future generation

Sustainability



1. Economy
2. Environment
3. Society

→ ***Need for efficient, economical, renewable, and environmentally friendly energy technologies***

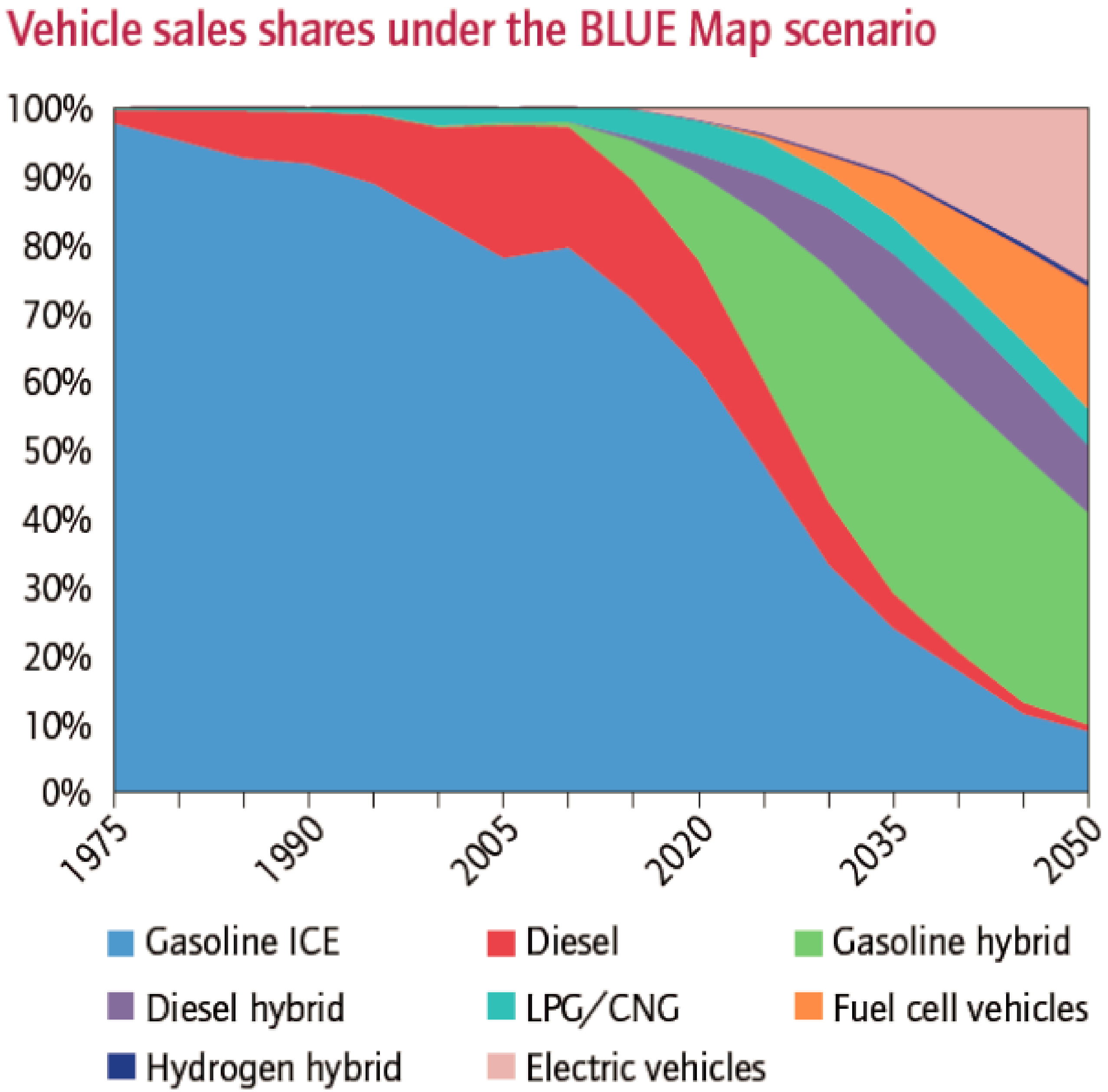
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Principal measures

1. Efficiency remains the first and foremost key
   - **ALL** technologies
   - Process integration and optimization
2. Fossil replacement by renewables
3. Address the storage issue (seasonal; esp. for renewables)
4. Grids (development, management)
5. Consumer awareness; incentives

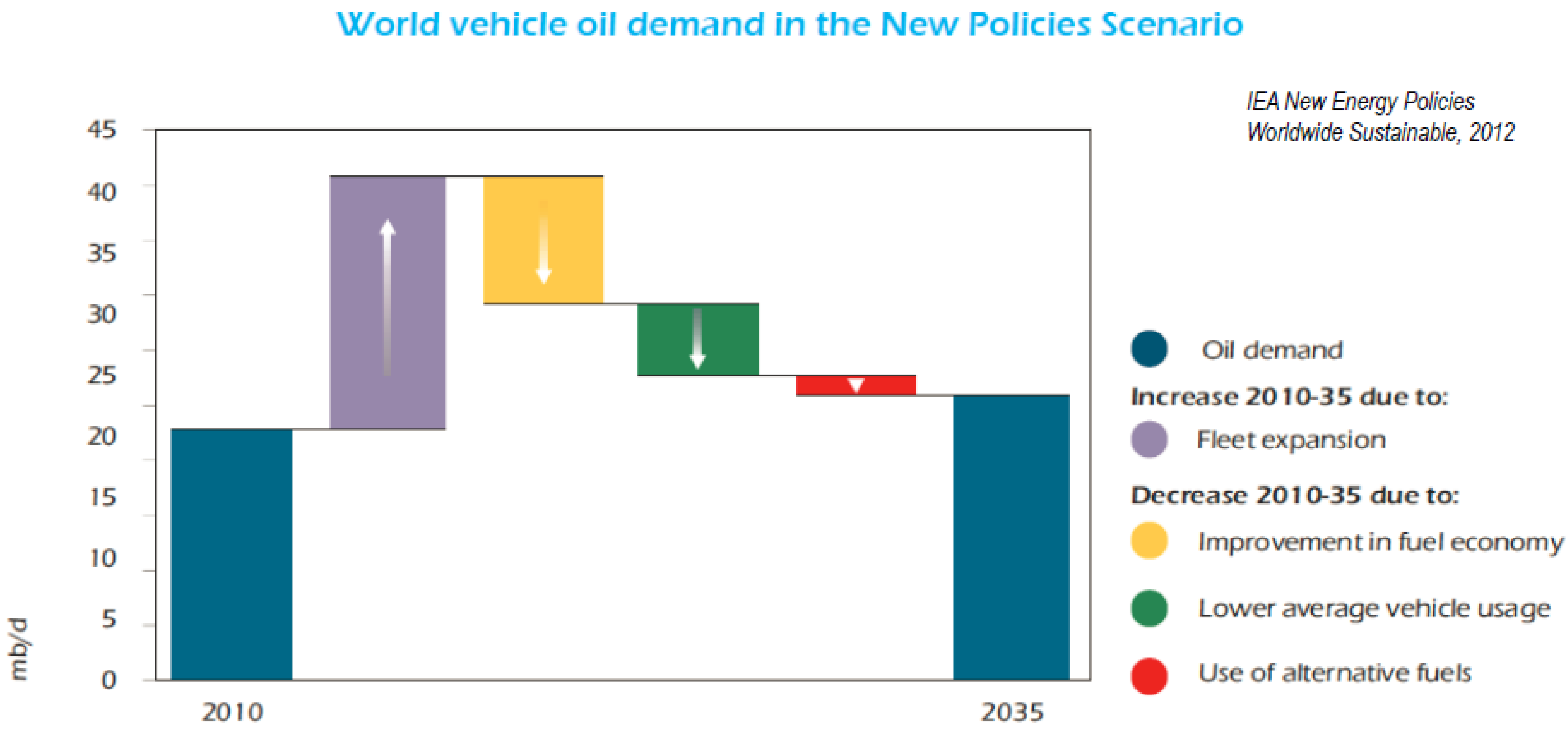
All are interconnected!

Efficiency and renewables in transport



Source: IEA 2010.

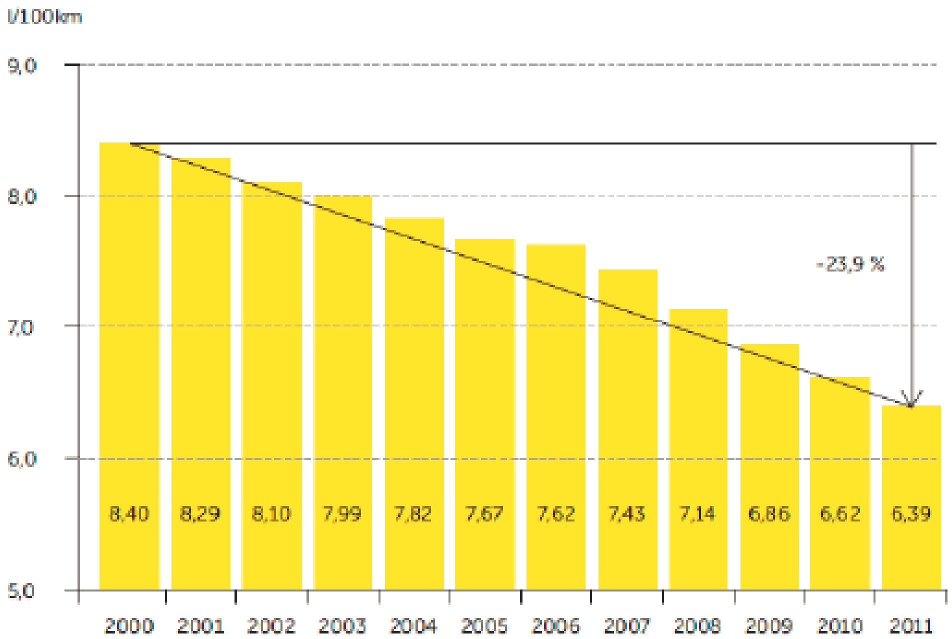
But overall oil consumption still rises

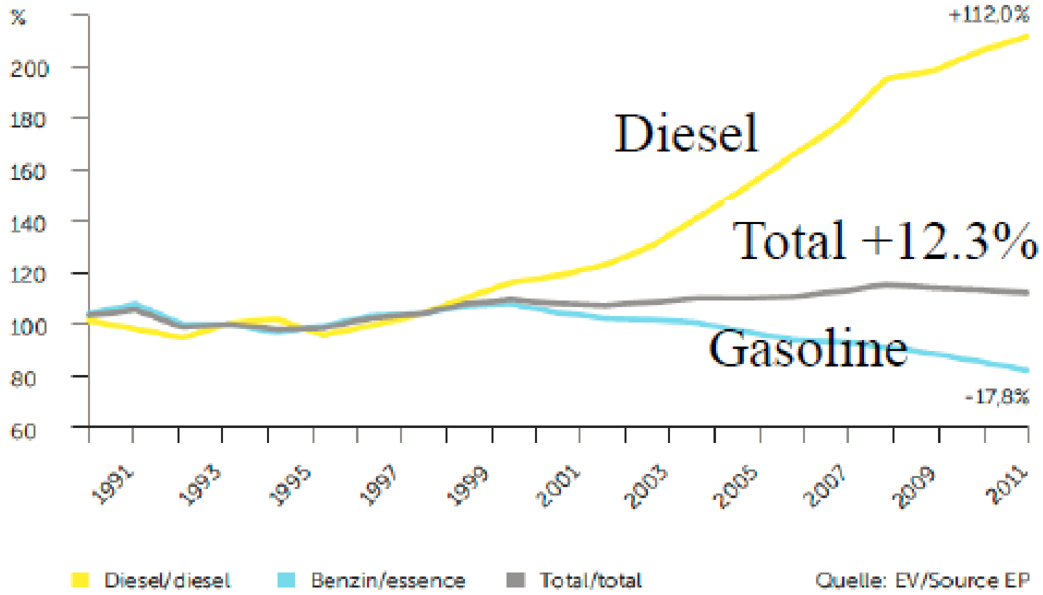


IEA New Energy Policies Worldwide Sustainable, 2012

Oil use by cars expands by only 15% between 2010 & 2035, with more efficient vehicles, less usage and switching to non-oil fuels offsetting most of the impact of a doubling of the fleet

Example Switzerland



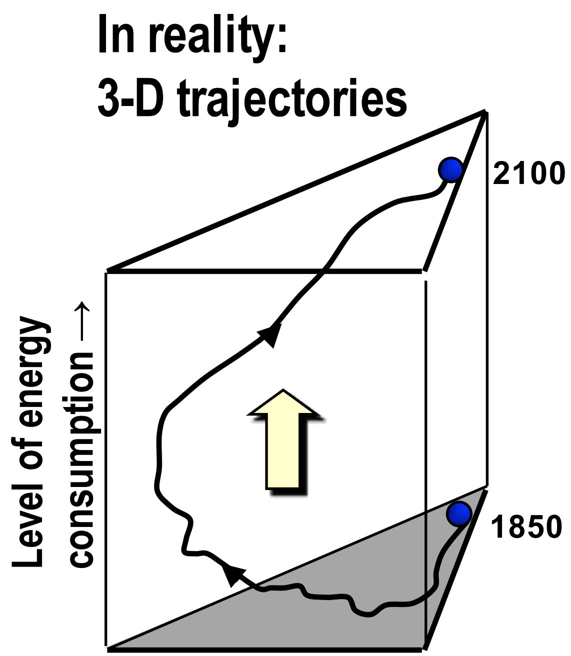


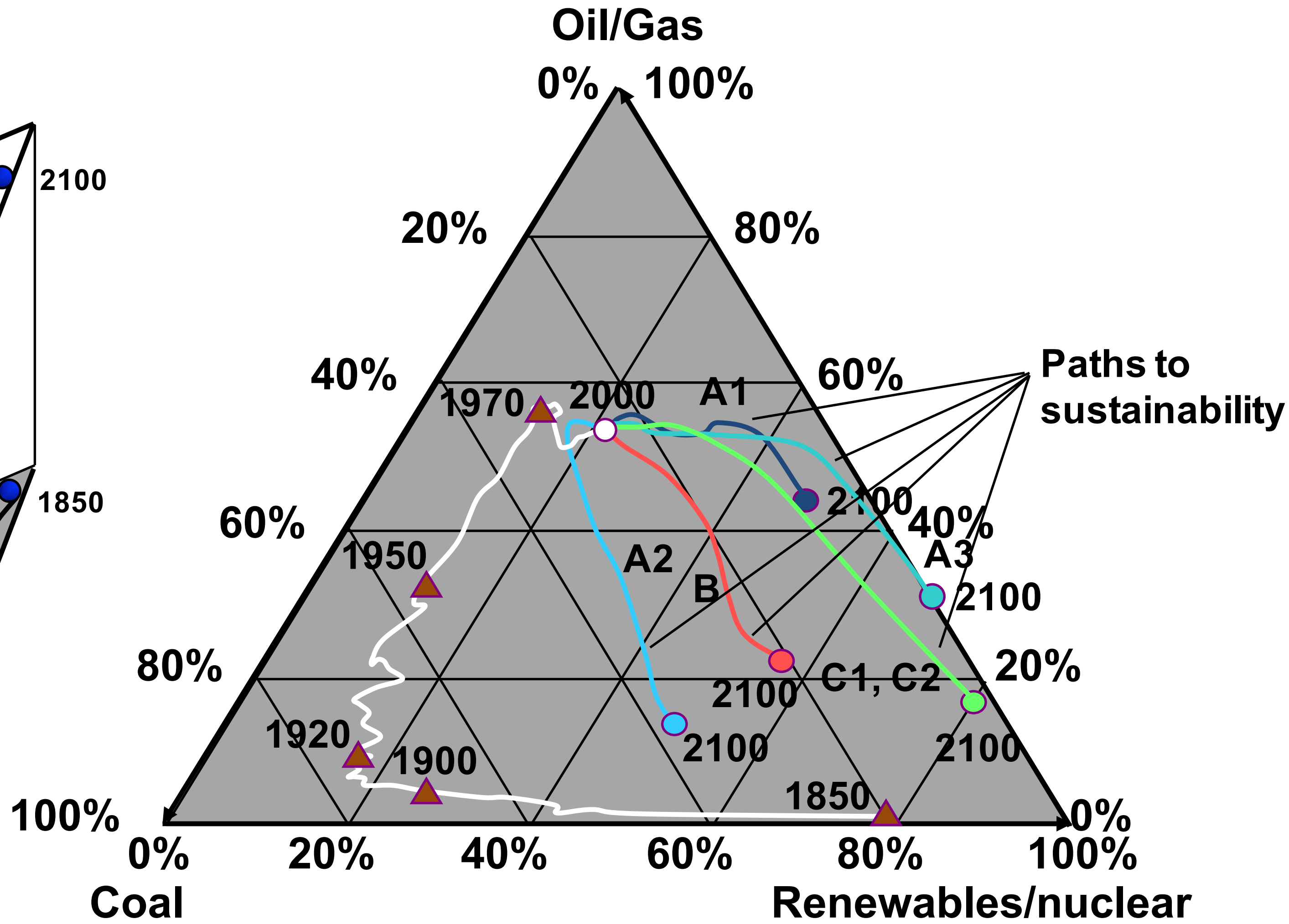
D. Favrat, Presentation AE, Dec 2012

Efficiency improvement but overall increase in consumption
Due to increased fleet

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

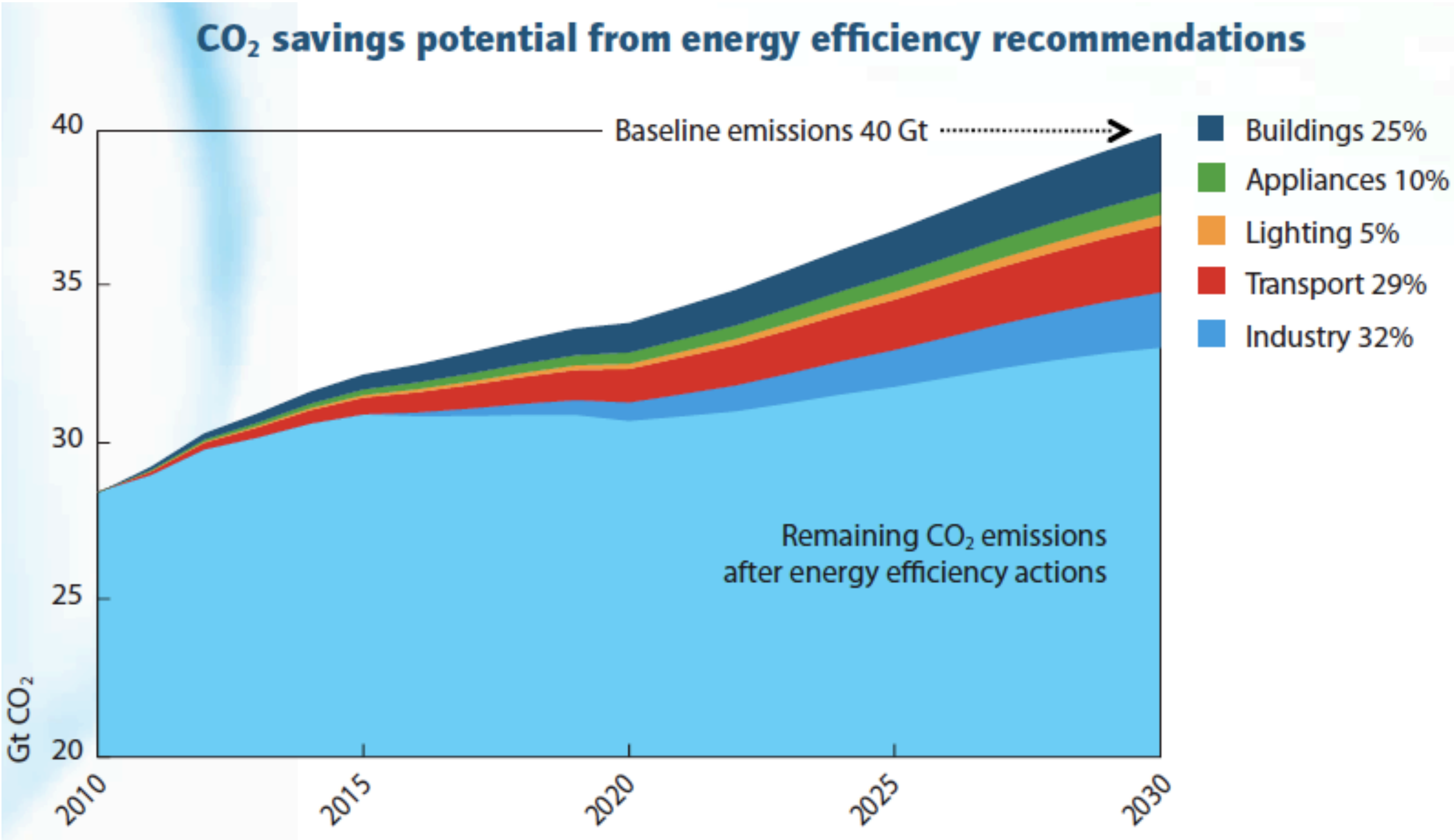
Pathways


In reality:
3-D trajectories
2100
1850
Level of energy consumption →


Oil/Gas
0%
100%
20%
80%
40%
60%
60%
40%
80%
20%
100%
0%
0%
20%
40%
60%
80%
100%
Coal
Renewables/nuclear
1970
2000
A1
1950
1920
1900
1850
A2
B
A3
C1, C2
2100
2100
2100
2100
2100
2100
Paths to sustainability

Efficiency remains key

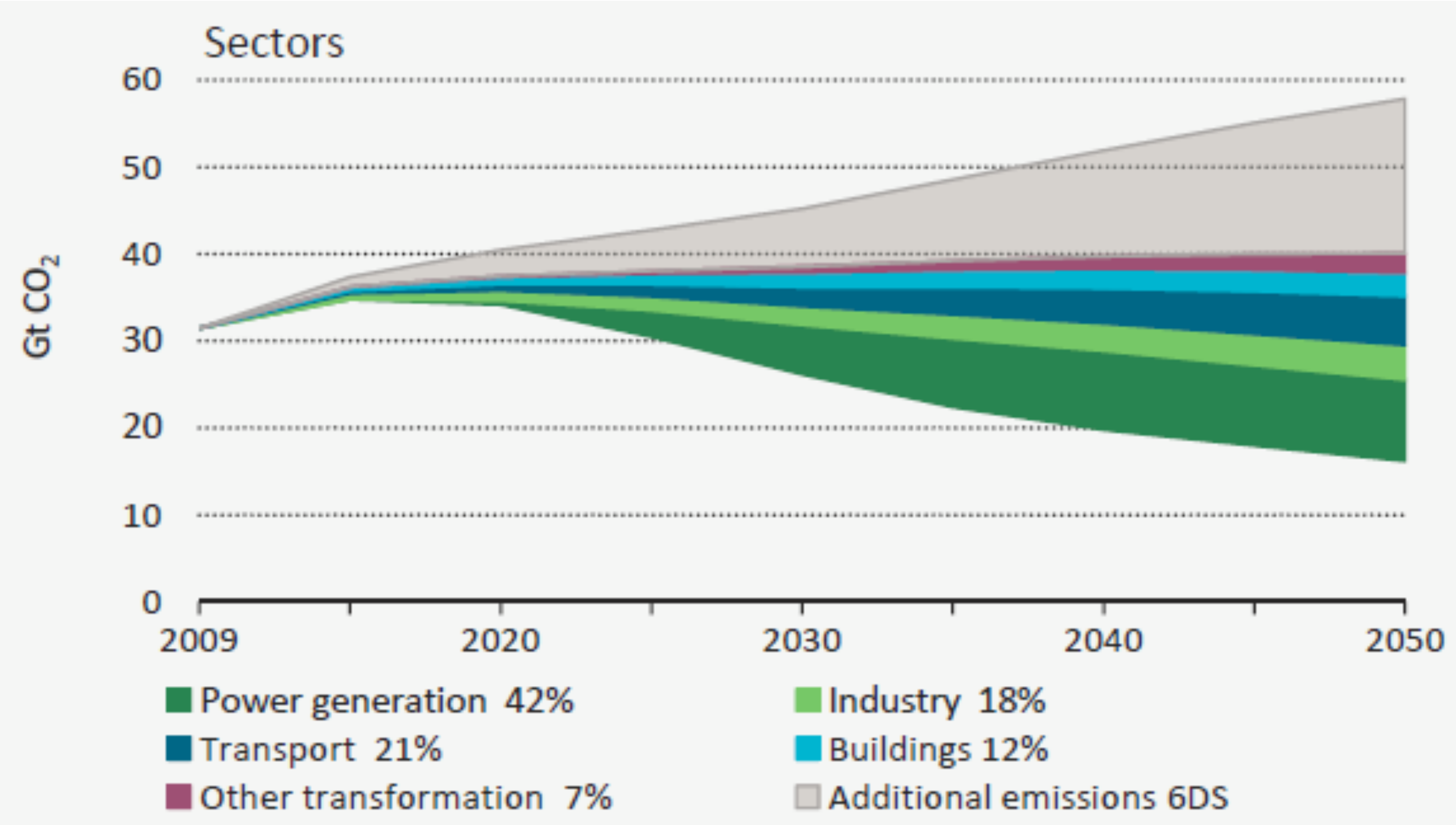
IEA_efficiency_recommendations, 2011



Energy efficiency is the hidden fuel that increases energy security and mitigates climate change.

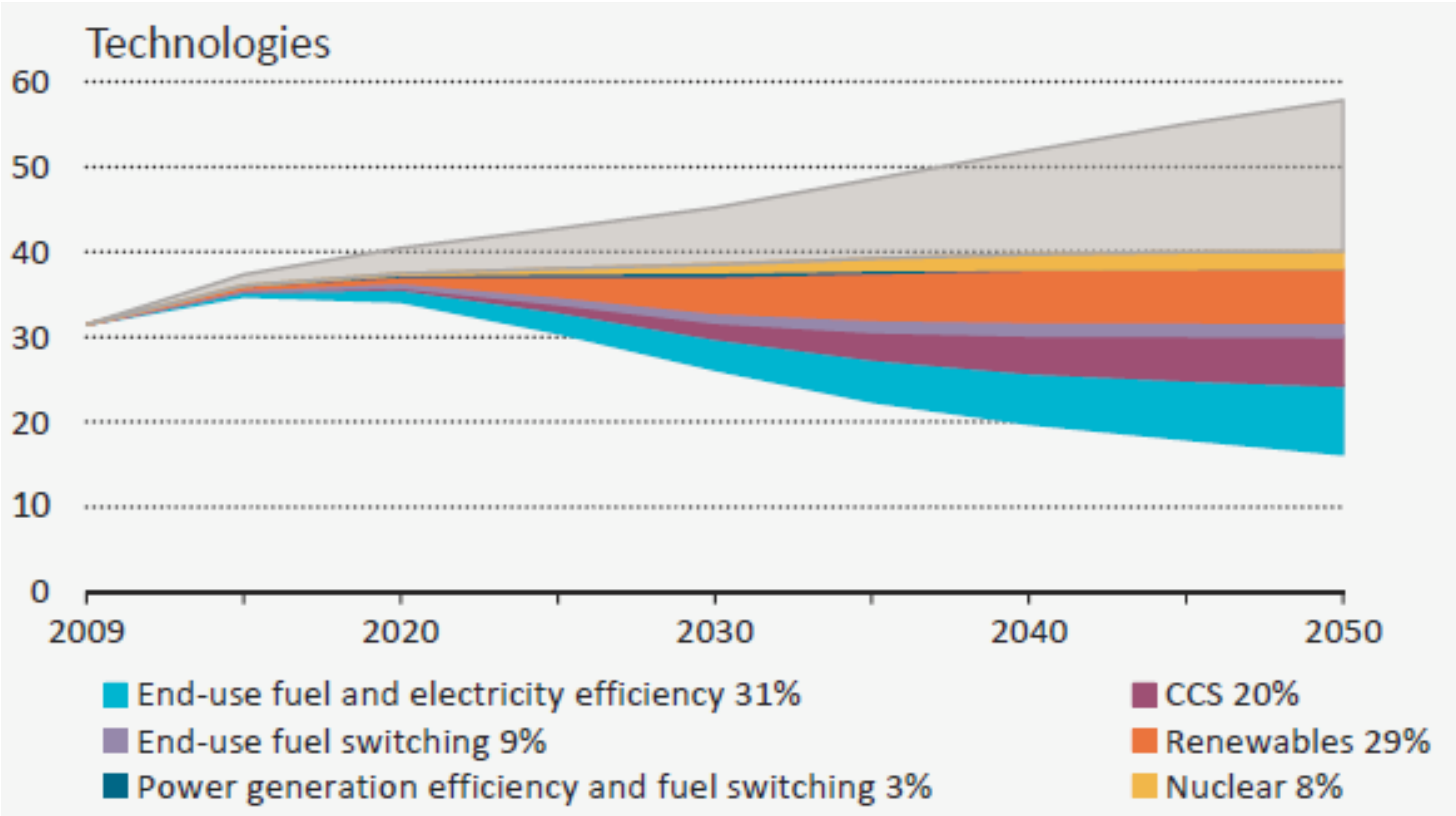
All sectors most contribute

IEA 2012, Energy Technology Perspectives



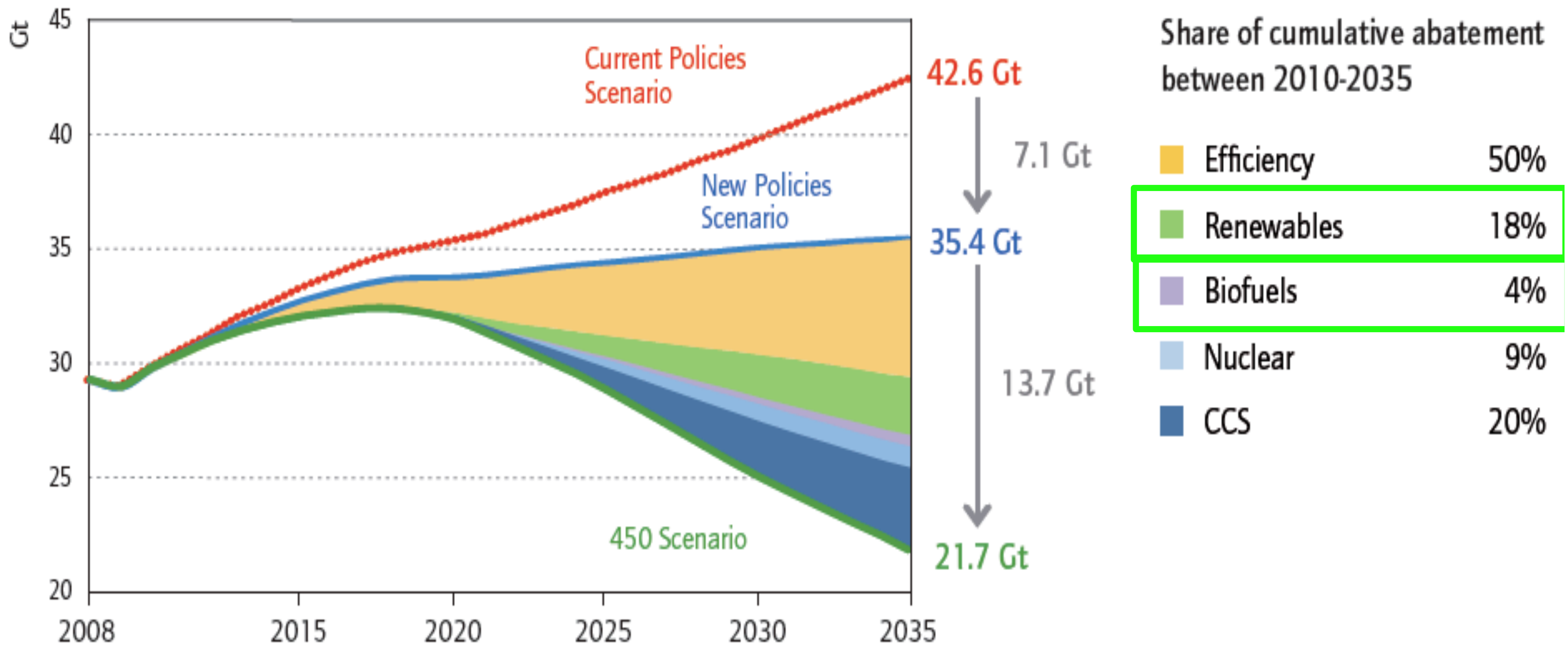
A portfolio of technologies is needed

IEA 2012, Energy Technology Perspectives

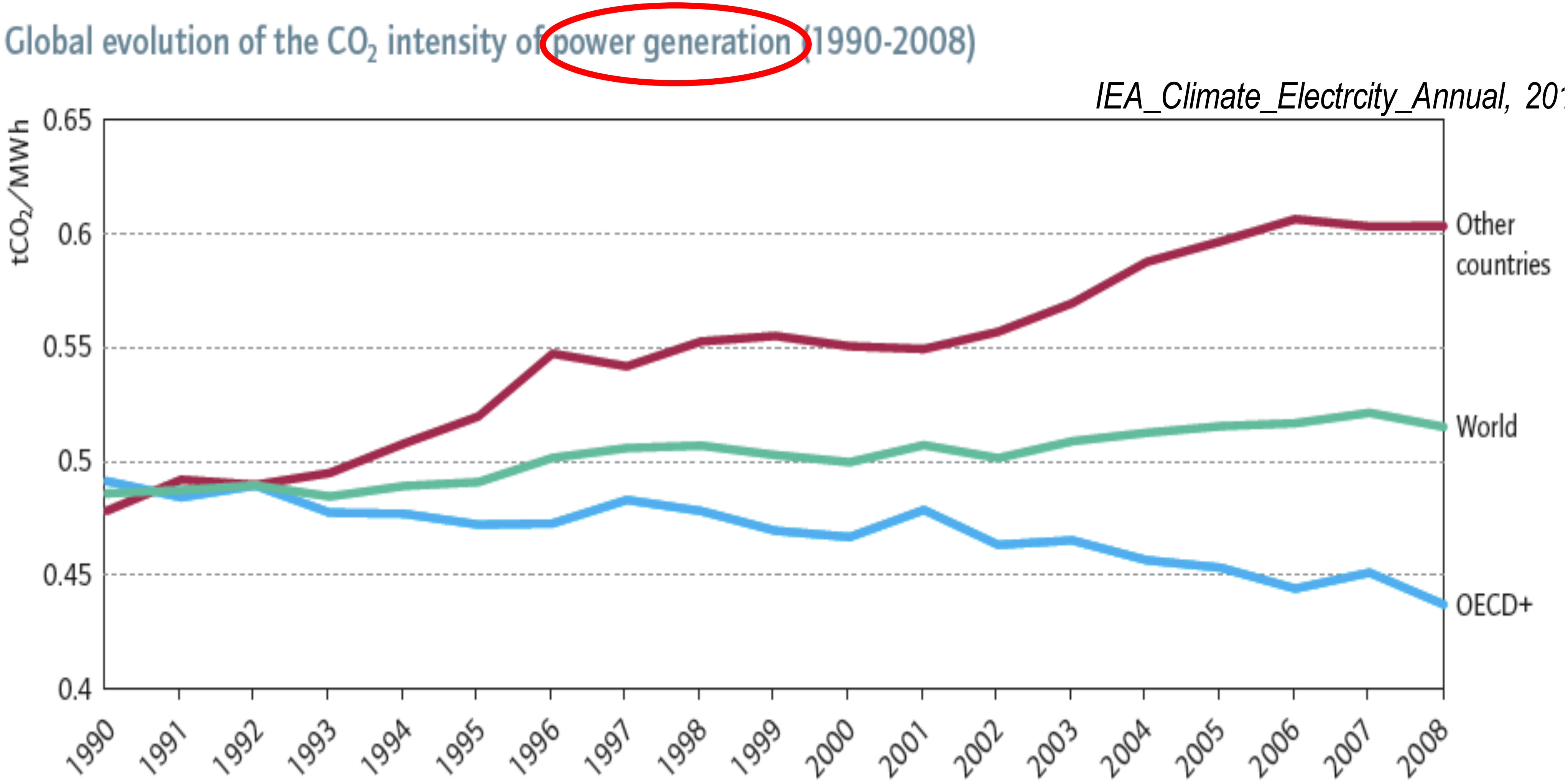


Renewables as second major measure

IEA_Climate_Electricity Annual, 2011



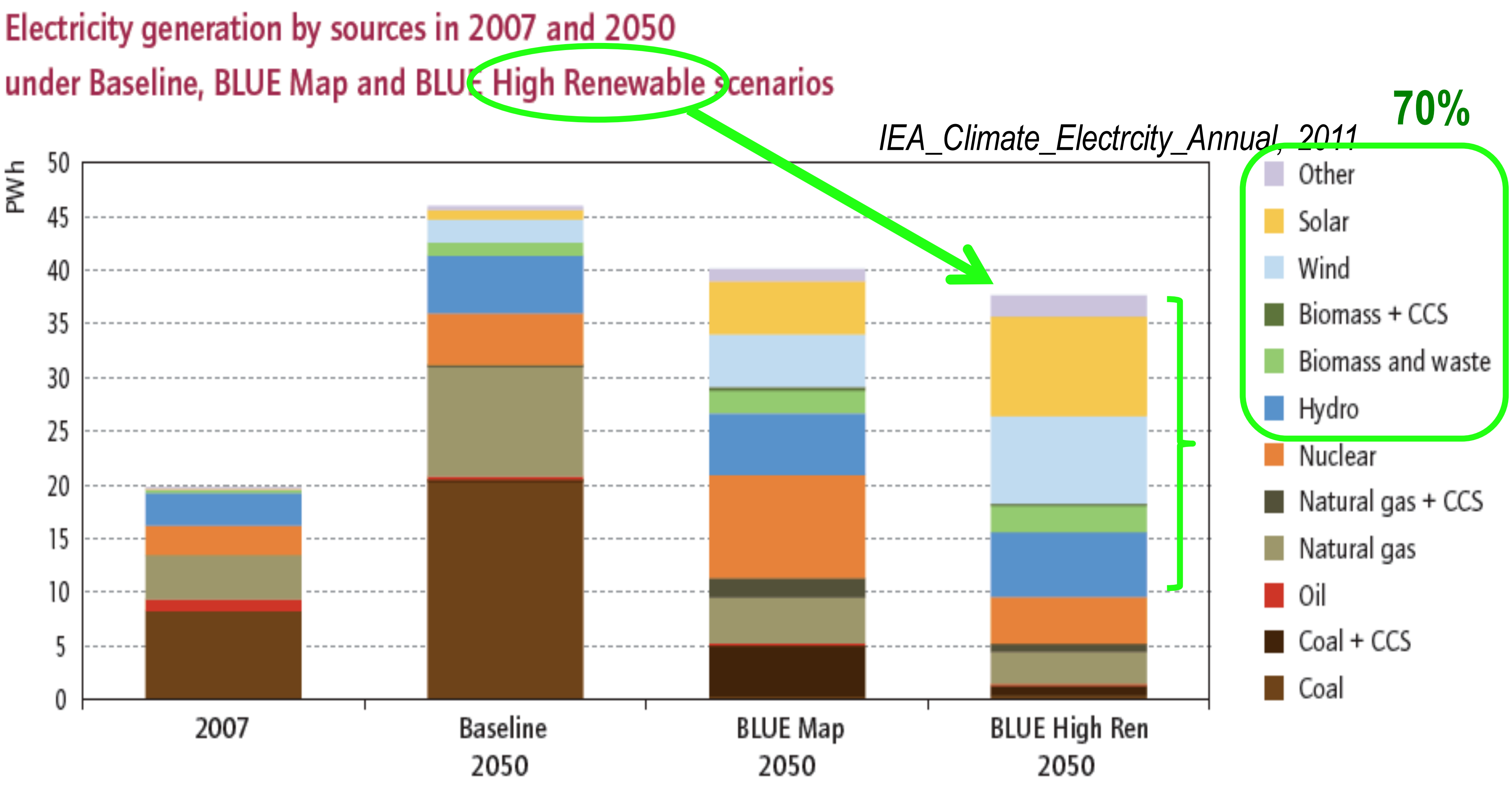
Efficiency should be global



→ ***Renewables could especially contribute to decarbonising power generation***

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

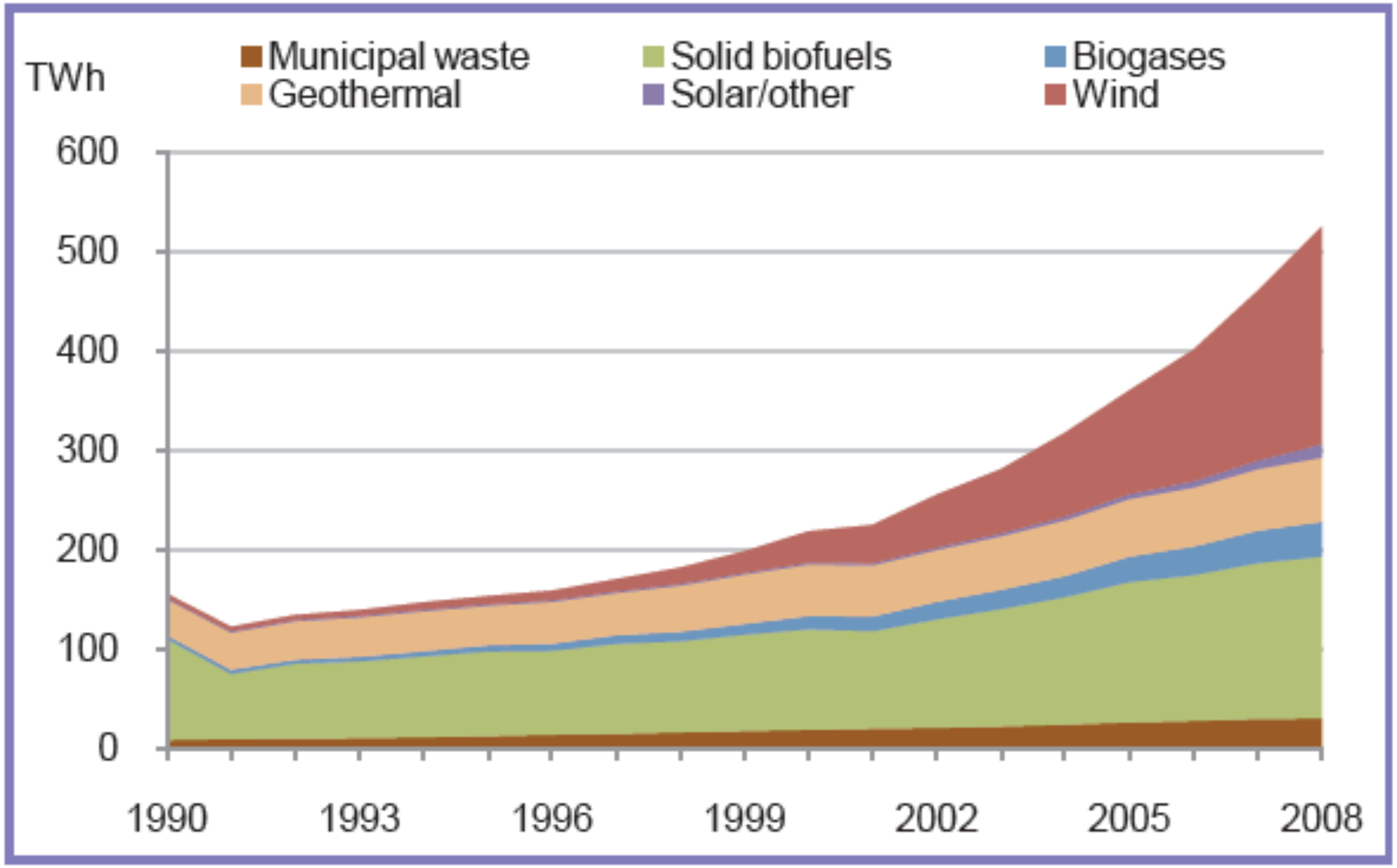
Renewables for power generation



ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

The trends are right...

Electricity from renewables (excluding hydro)



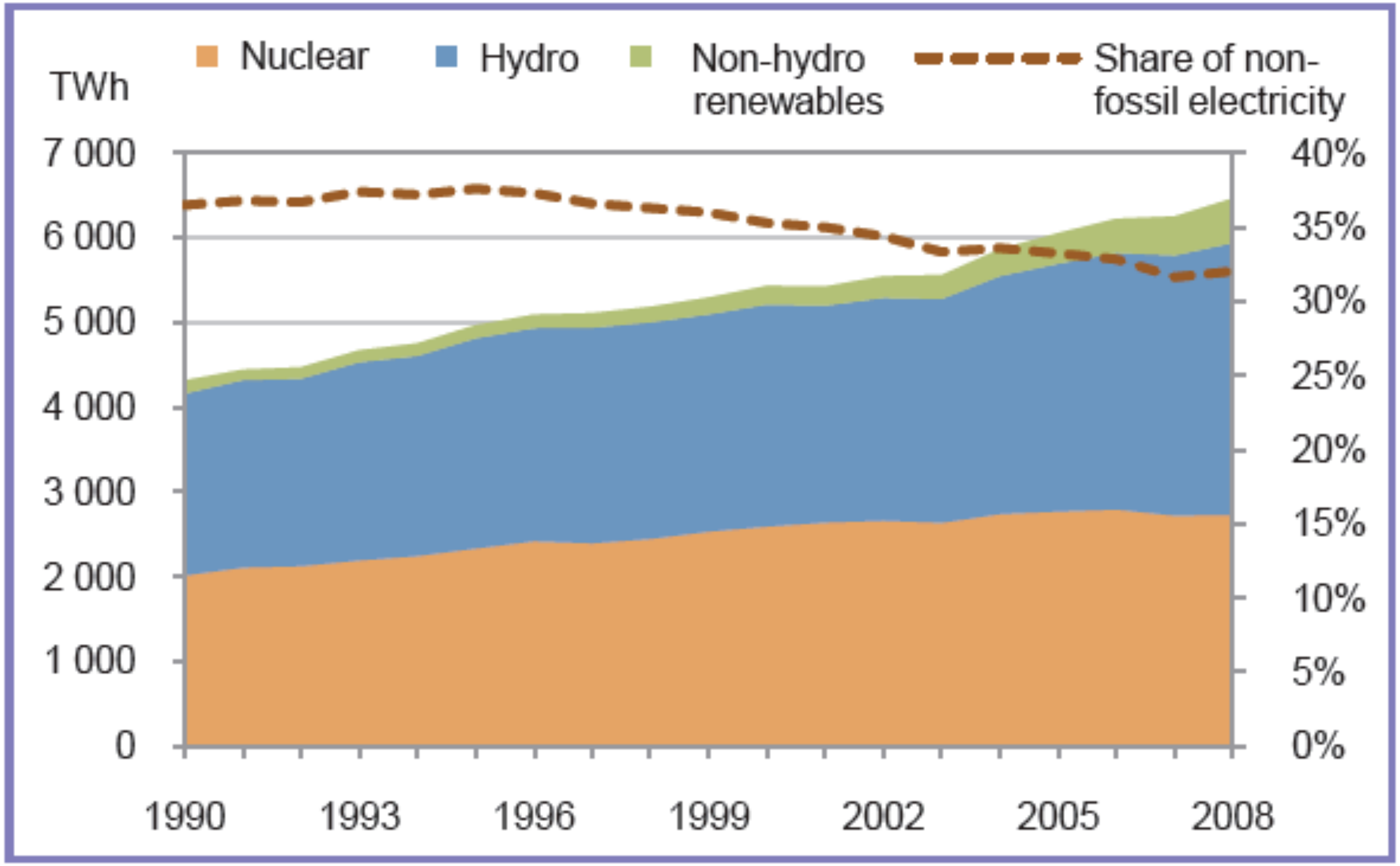
Source: IEA, 2010.

Notes: Biogases includes small quantities of liquid biofuels. Municipal waste only includes the renewable portion of waste.

… but not yet good enough

The total demand for electricity is such that renewable electricity, despite a steady increase in absolute numbers, in fact decreases as share of the total.

Electricity generation by non-fossil fuels

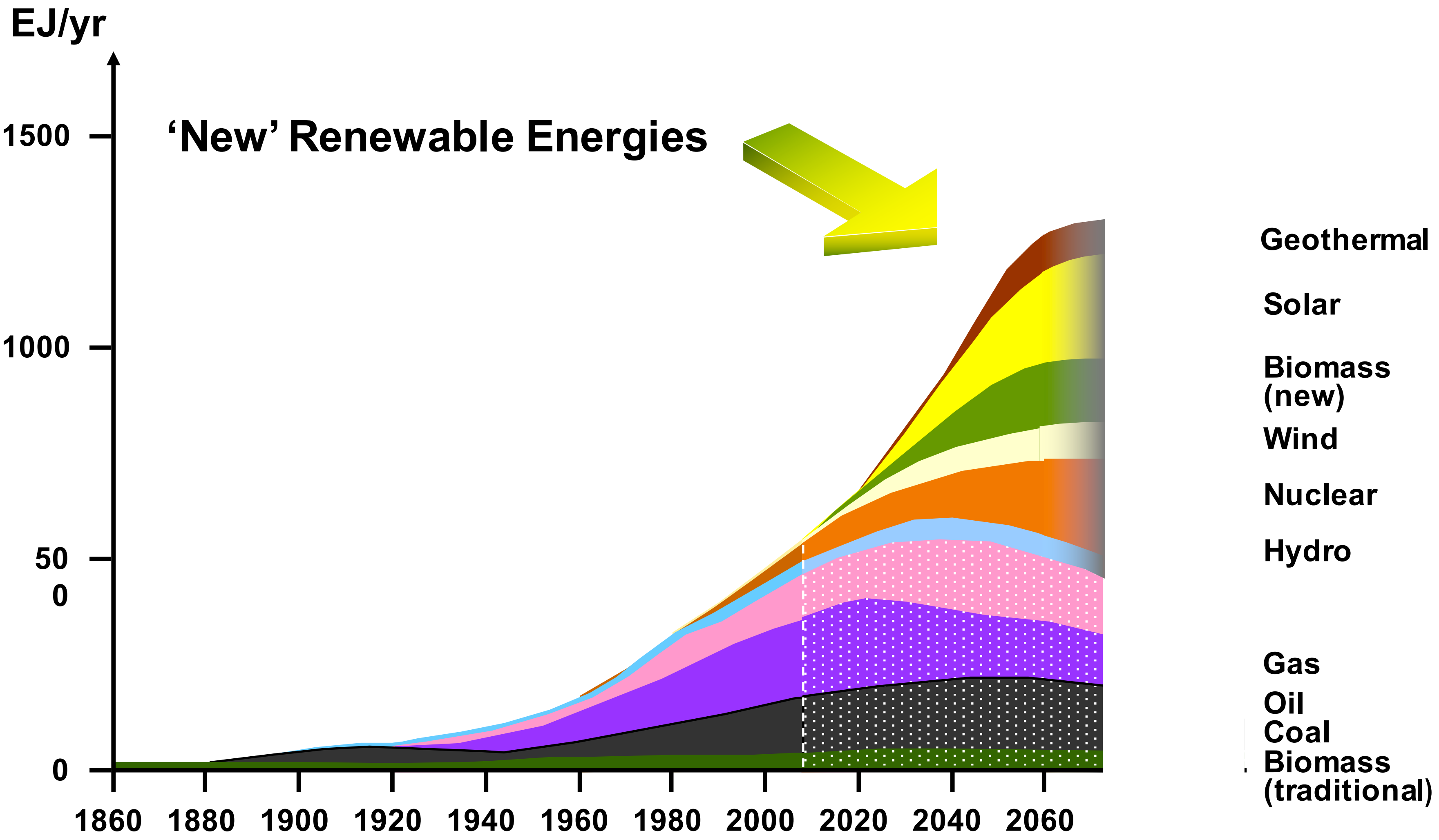


Source: IEA, 2010.

Note: Non-hydro renewables includes geothermal, solar, wind, biofuels and renewable municipal waste.

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Massive deployment is necessary

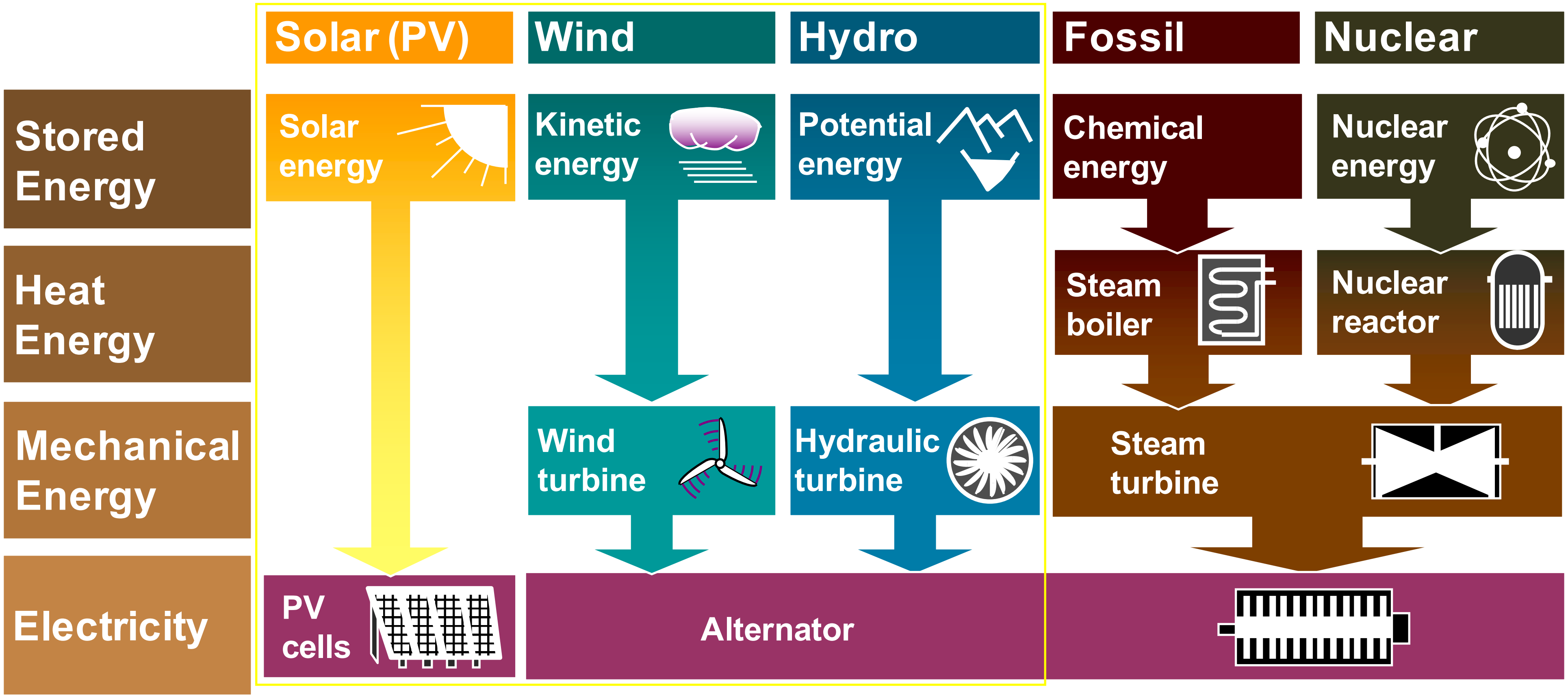


The scientist's / engineer's role (duty)

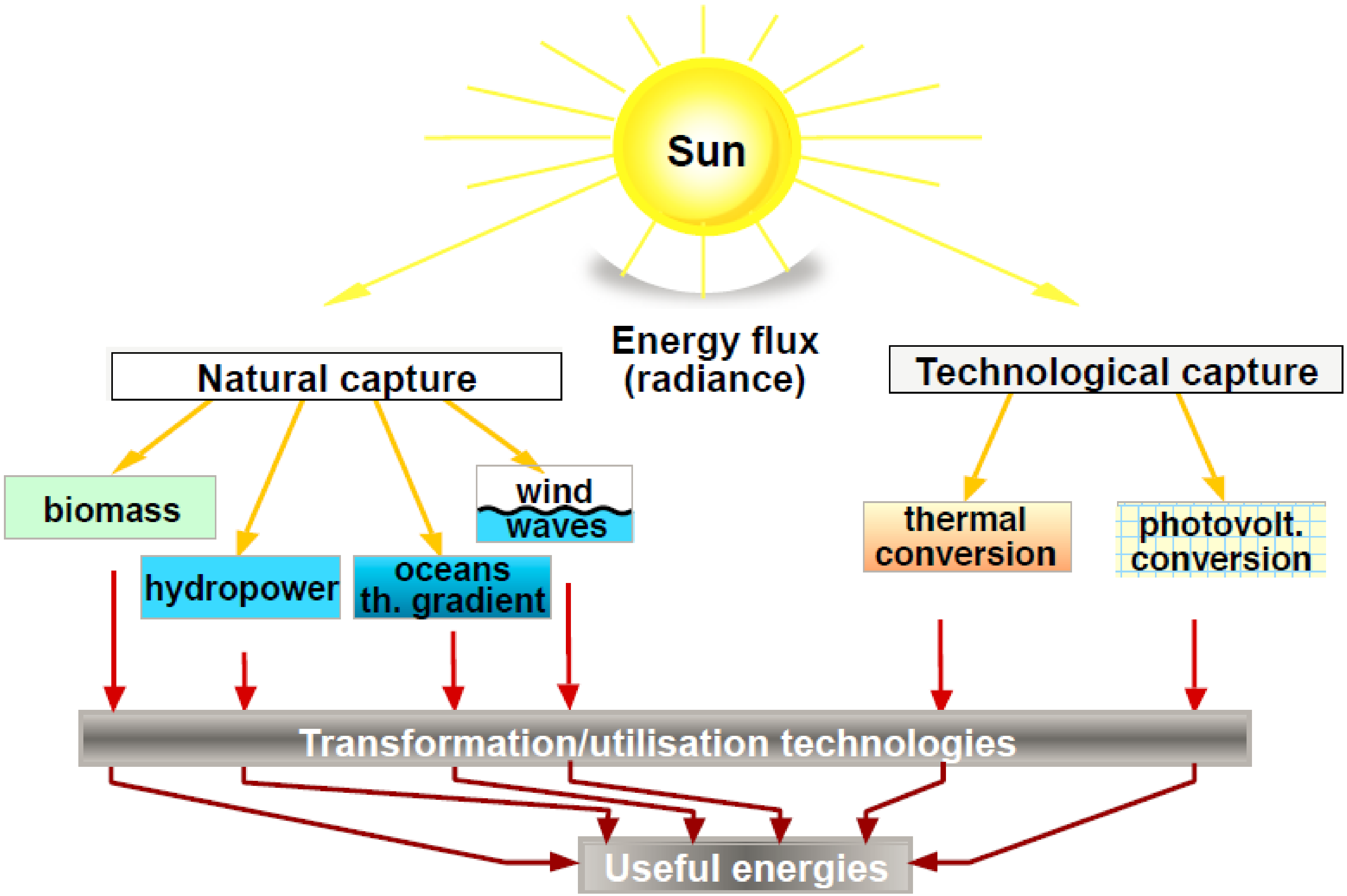
- Investigate all options
- Set the facts (and numbers) right!

"Everyone is entitled to his own opinion, but not to his own facts"

Energy transformation chains



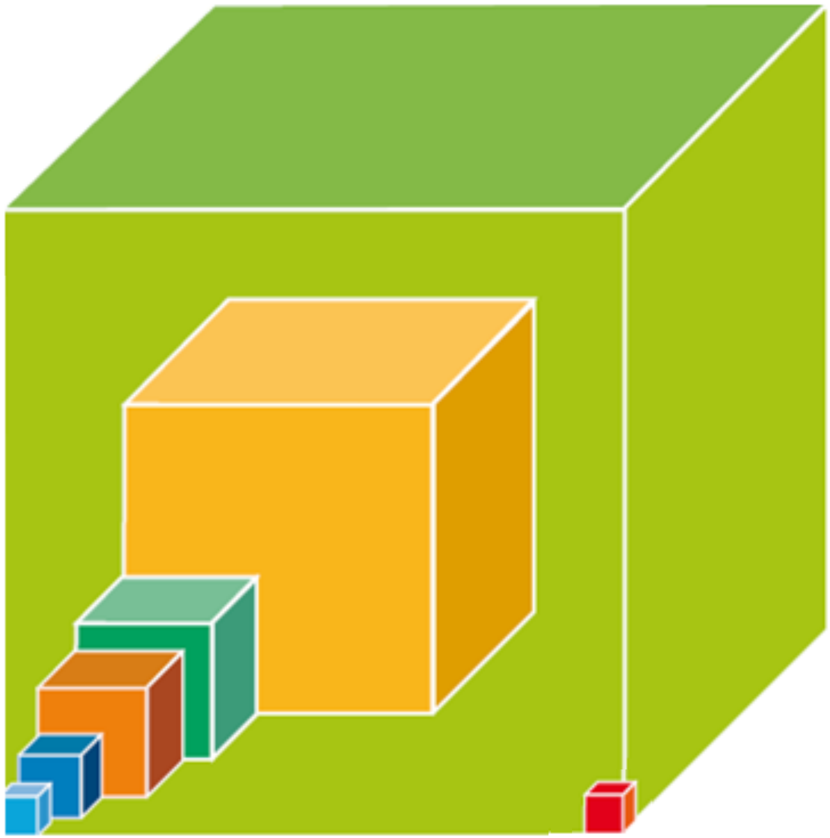
Renewable energy capture porcesses



Short summary of the ‘issues’ with renewables

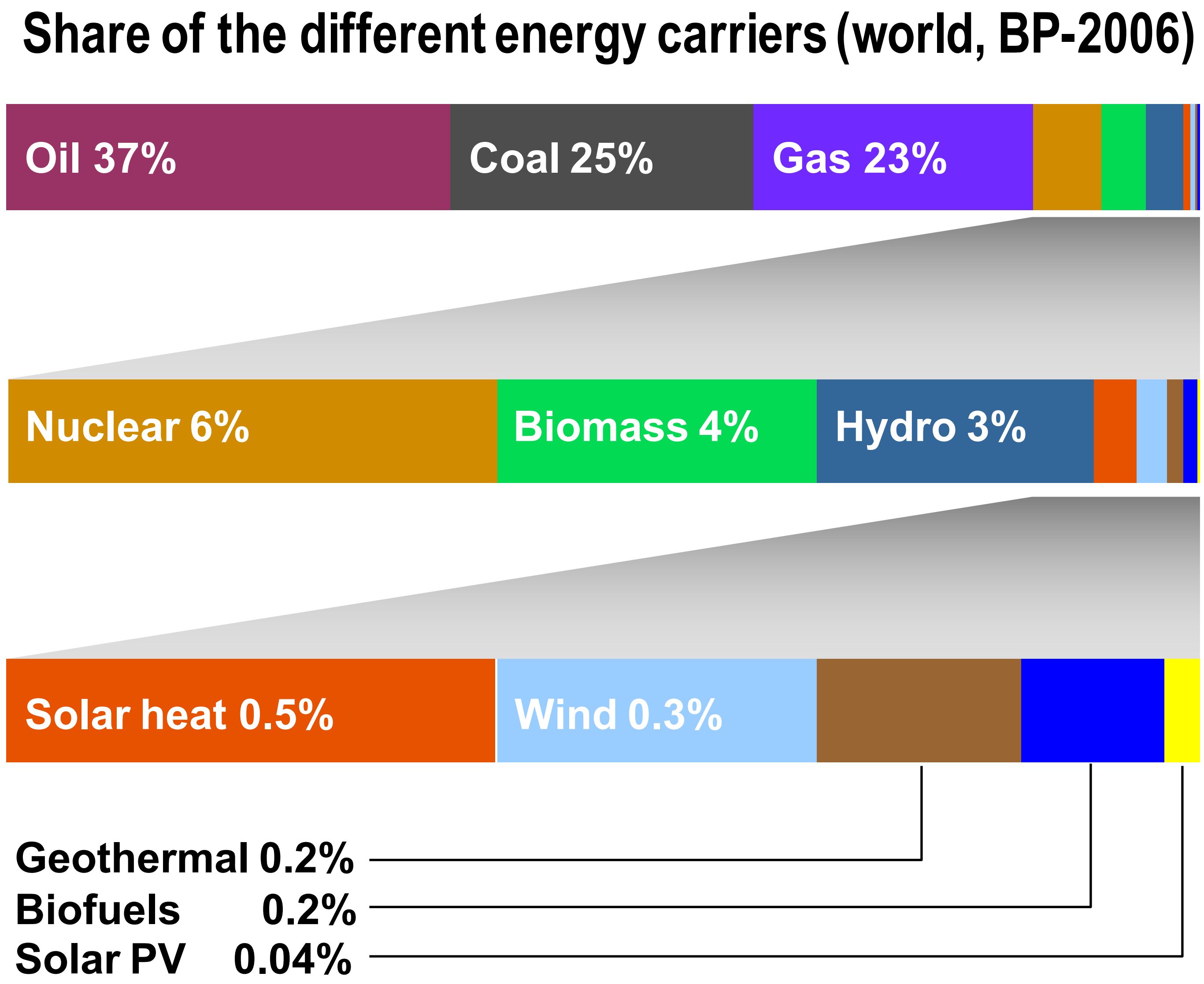
1. Energy potential (theoretical vs. reality)
2. Availability (intermittence)
3. Cost
4. Grid integration

1. Renewable energy theoretical potentials



- Continental solar radiation (1800 x)
- Wind energy (200 x)
- Biomass energy (20 x)
- Geothermal energy (10 x)
- Tidal energy and thermal energy of the seas (2 x)
- Hydroelectric energy (1 x)
- Present world consumption of primary energy (~ 540 EJ/yr)

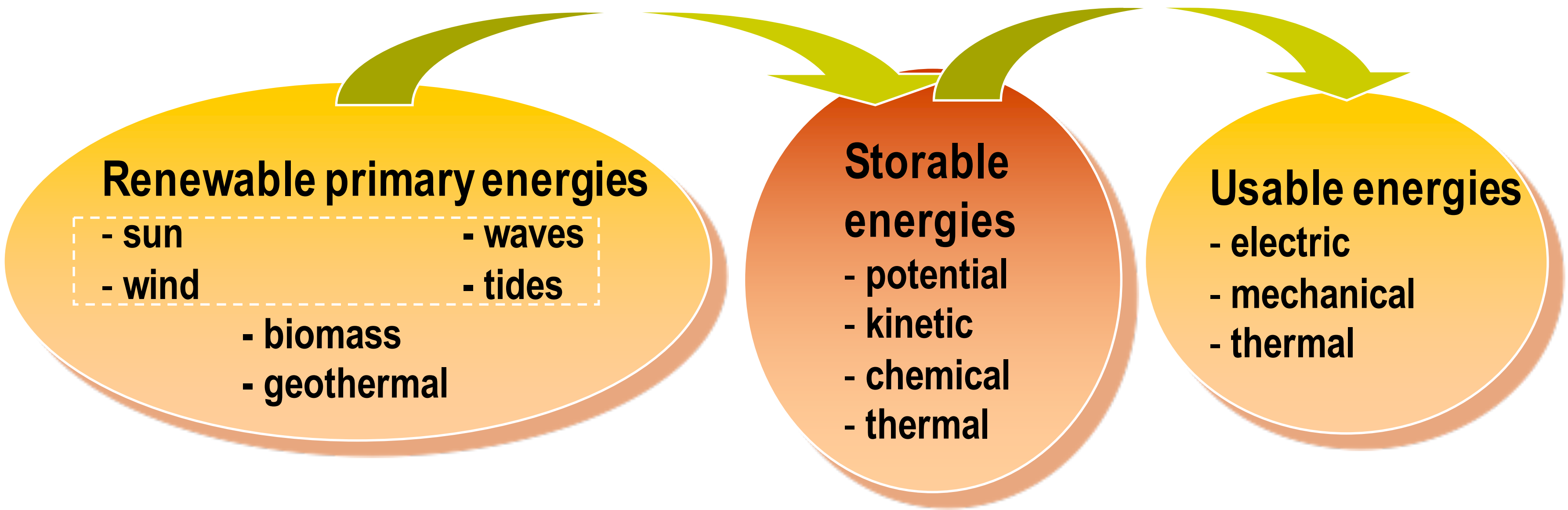
Reality far behind such potentials



2. Availability issue / storage

A characteristic feature of many renewable energies:
→ uncertain and variable availability

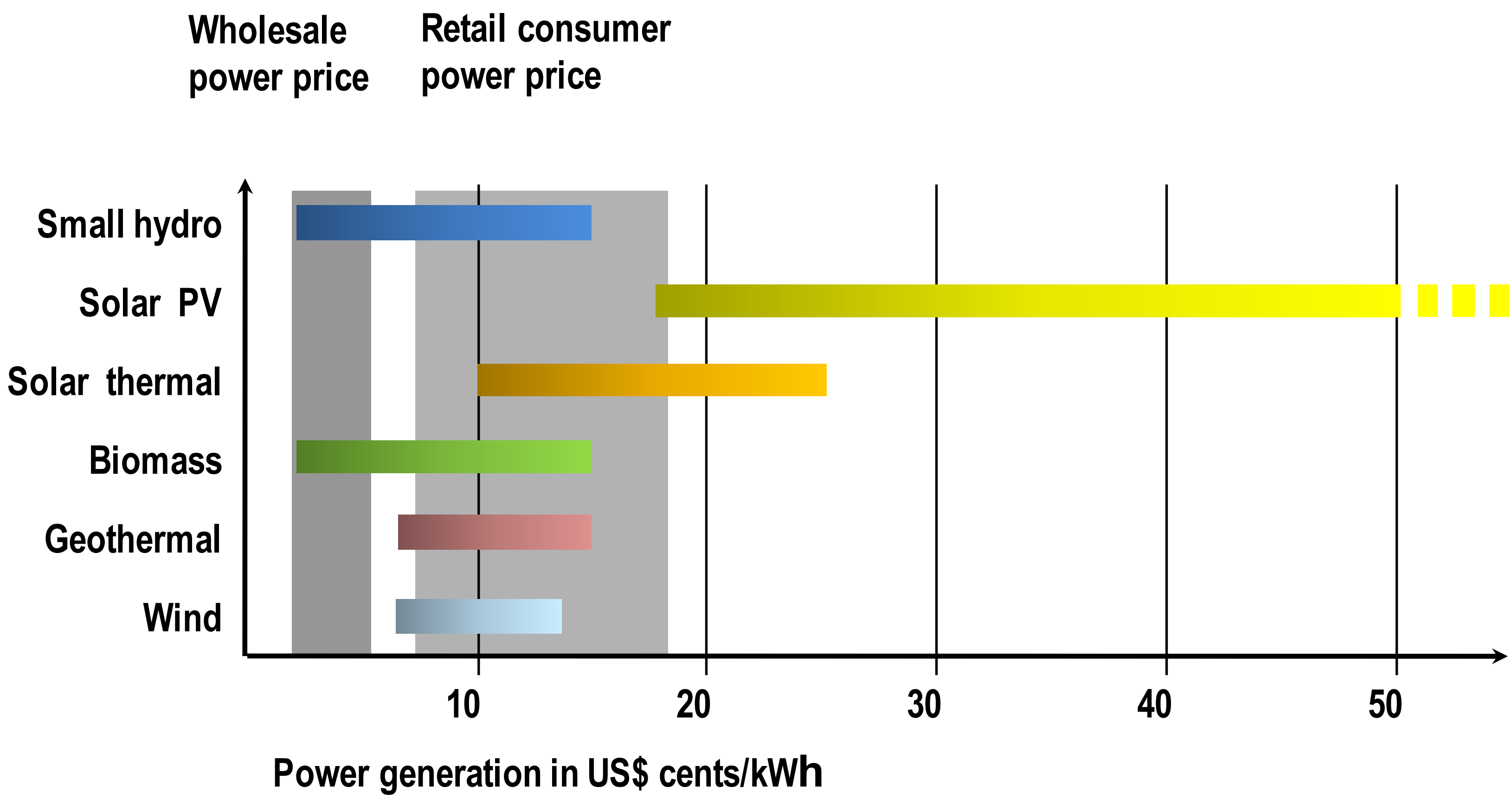
→ some form of energy storage required



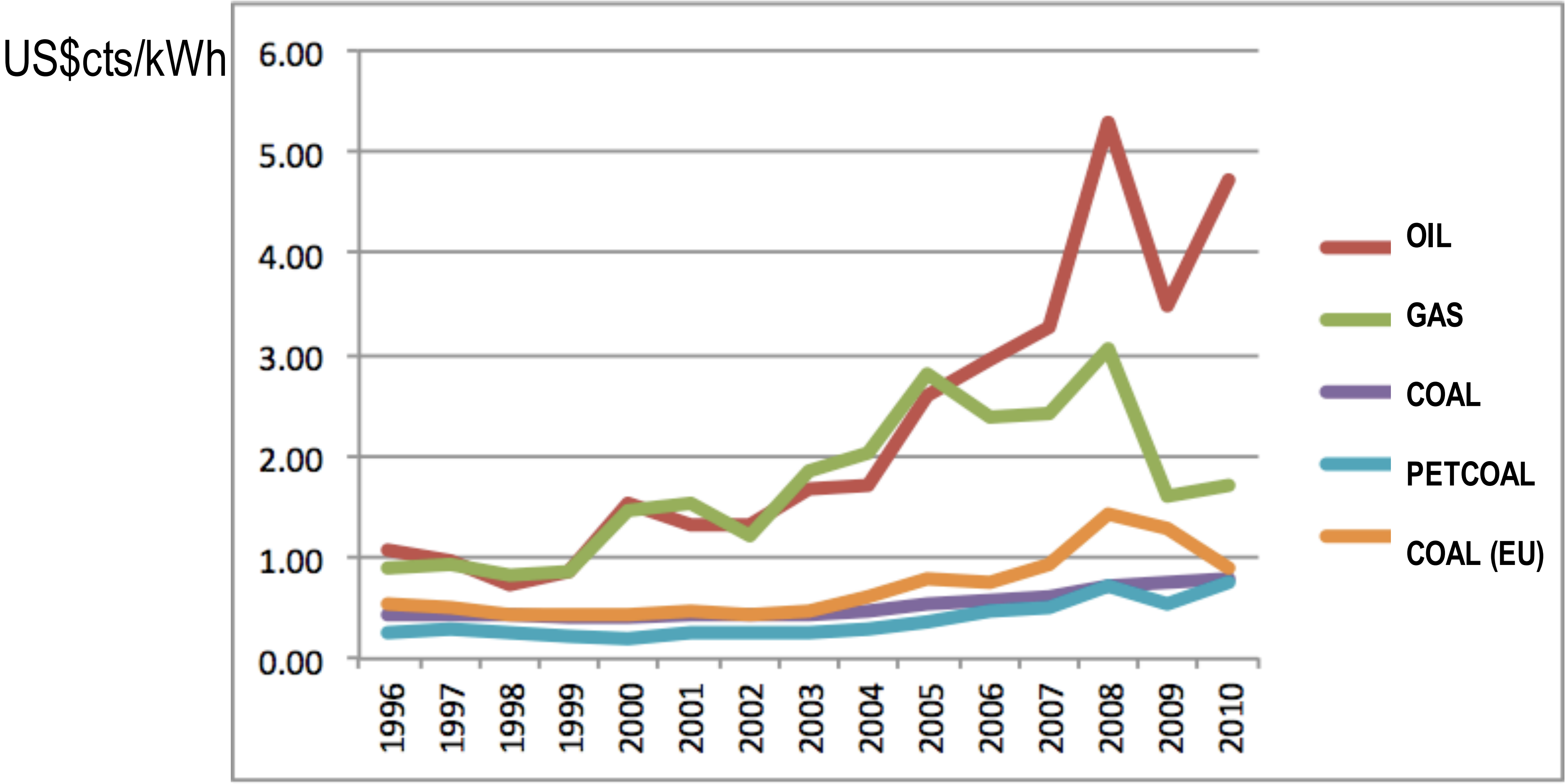
3. Cost issue

Cost-competitiveness of some renewable power technologies

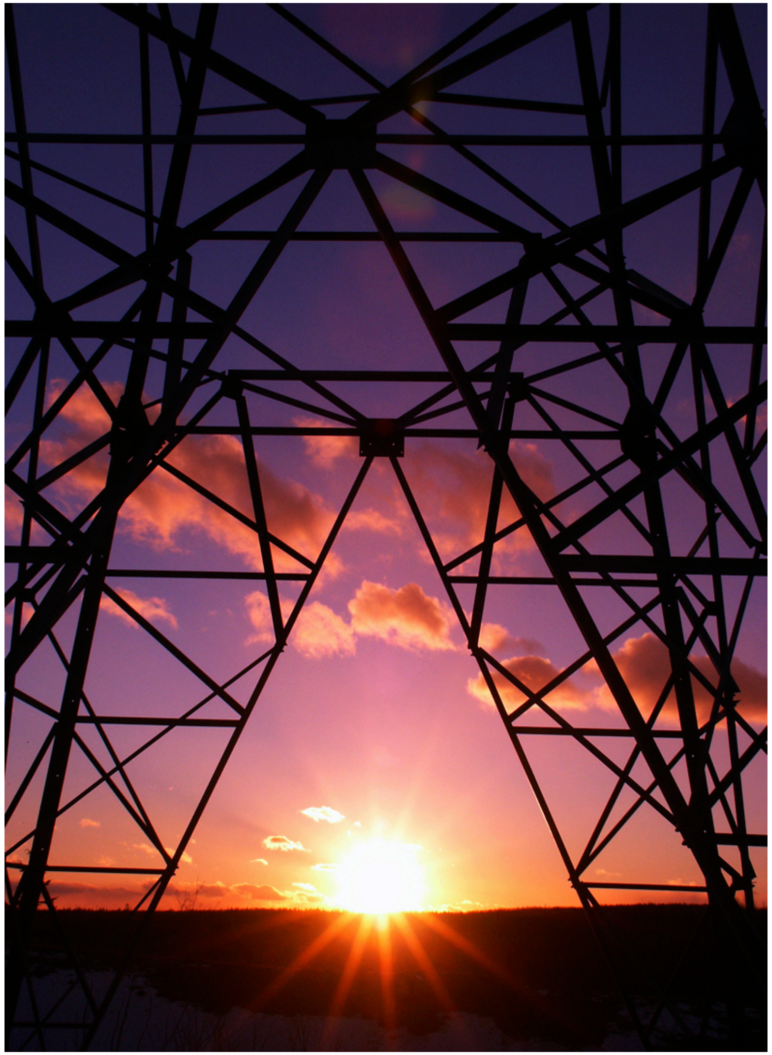
Source: Renewable Energy, RD&D Priorities, OECD/IEA 2006



Fossil fuel price is still extremely low !!!



4. Grid integration of renewable energies



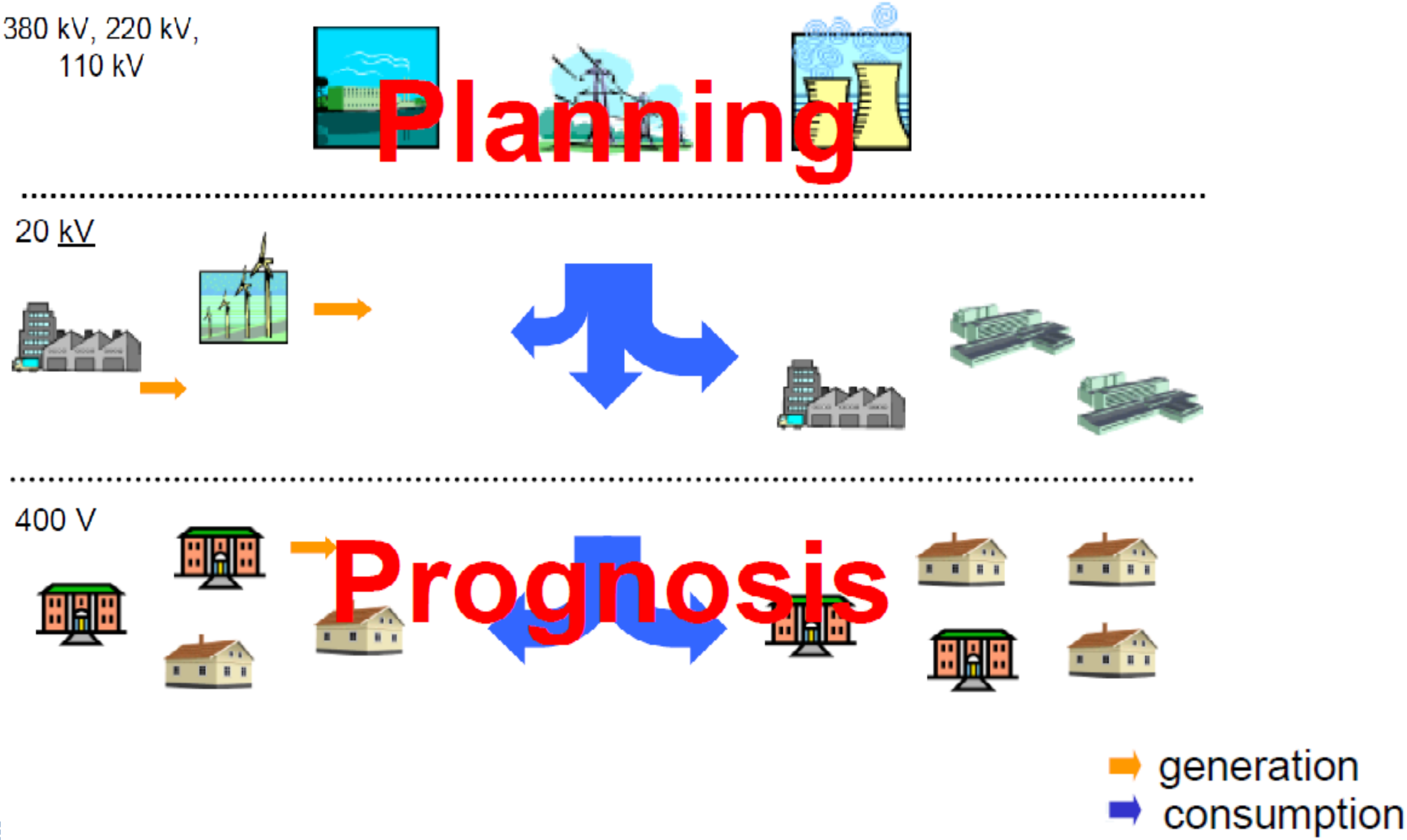
Two levels of integration:

- network integration as precondition for market access (e.g. wind turbines) - pull
- ‘direct’ market access (e.g. PV) - push

Integration requirements:

- technical aspects (e.g. non-dispatchable)
- economics
- legal framework

Present: largely centralized power

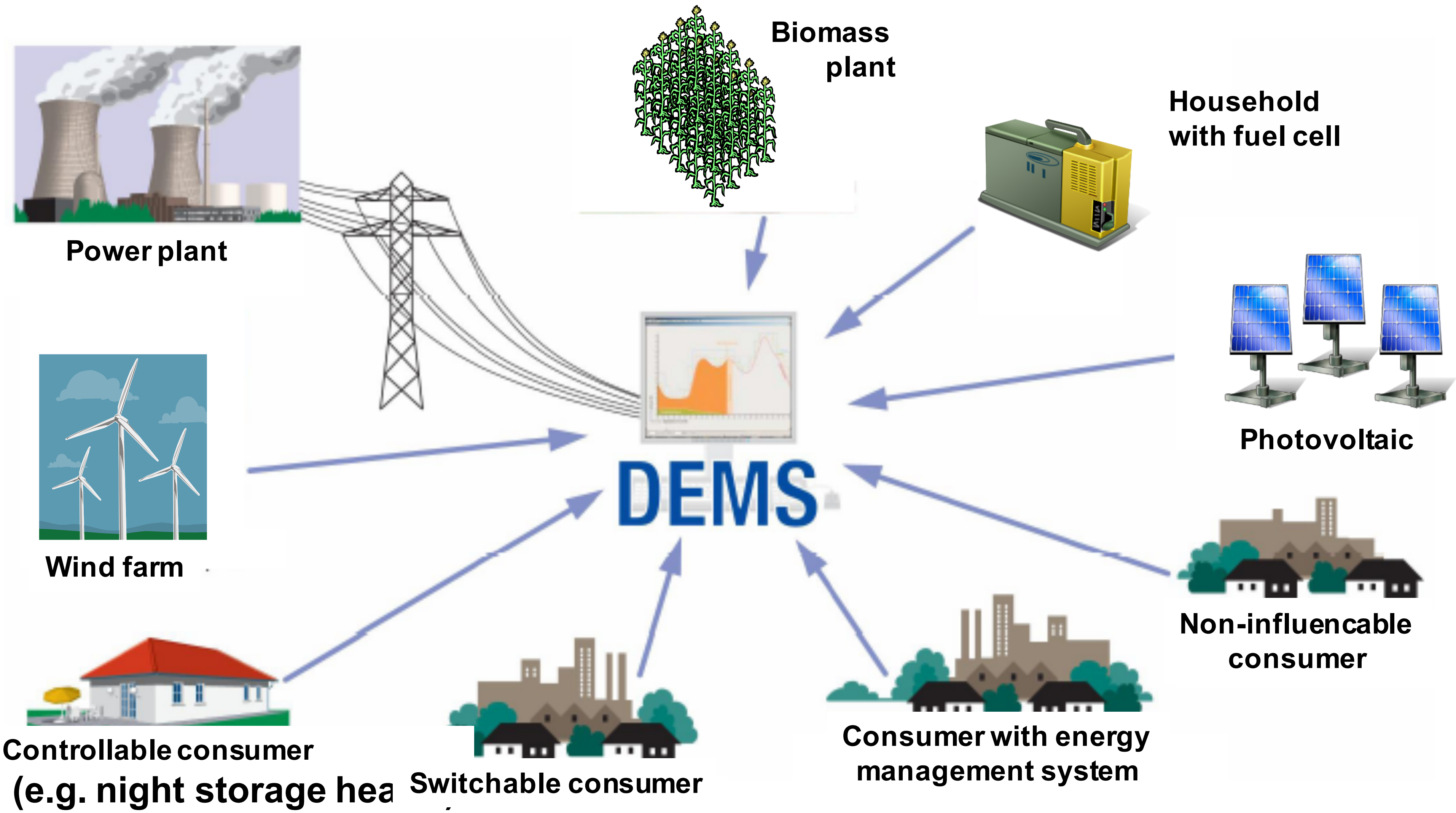


Source: EWE

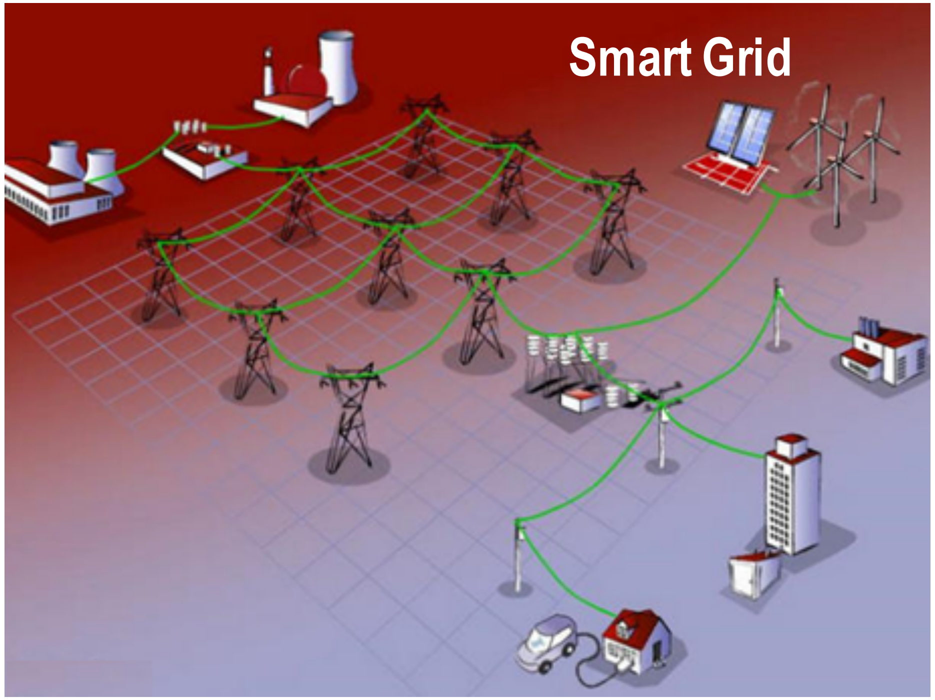
Future: highly decentralized fraction?

Source: EWE

Decentralized energy management system (DEMS)



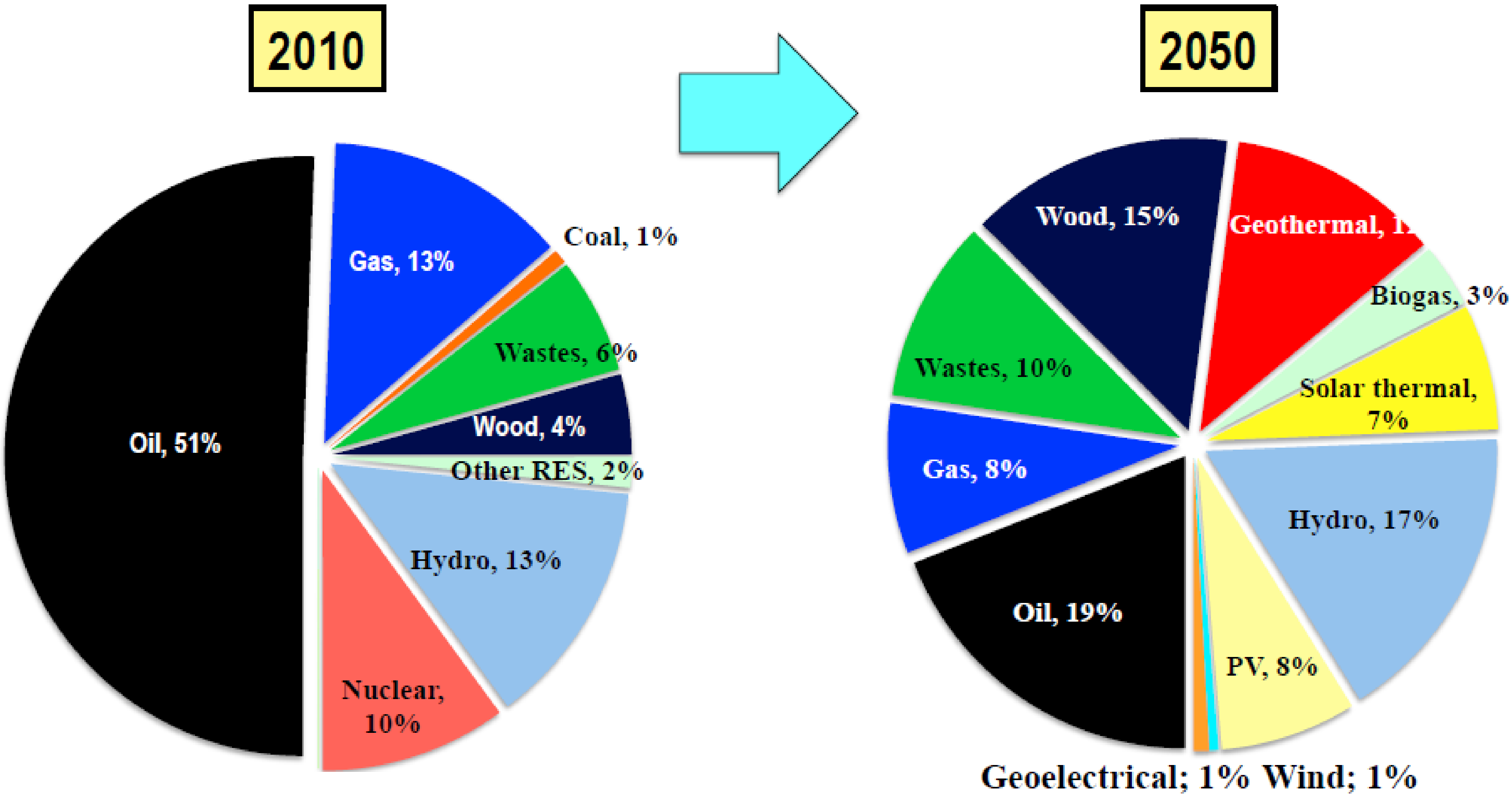
Smart grids



A *smart grid* is an electrical power distribution network that, in addition to transmitting electricity, includes two-way, digital communications between producers and consumers to save energy, reduce cost and increase reliability and transparency

A smart grid includes an intelligent monitoring system that keeps track of all electricity flowing in the system

Future energy scenario for Switzerland?

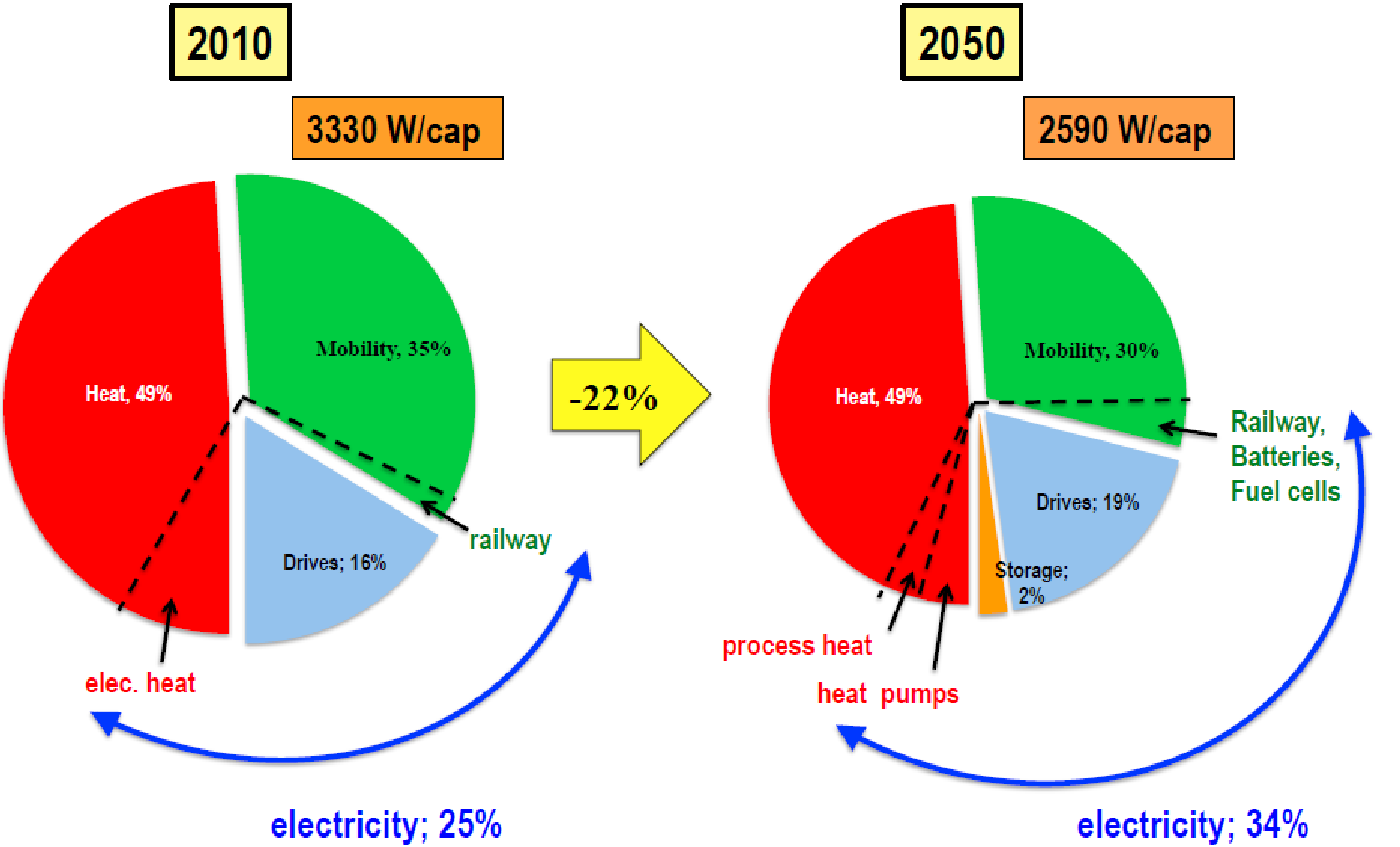


FOSSIL: 68% → FOSSIL: 32%

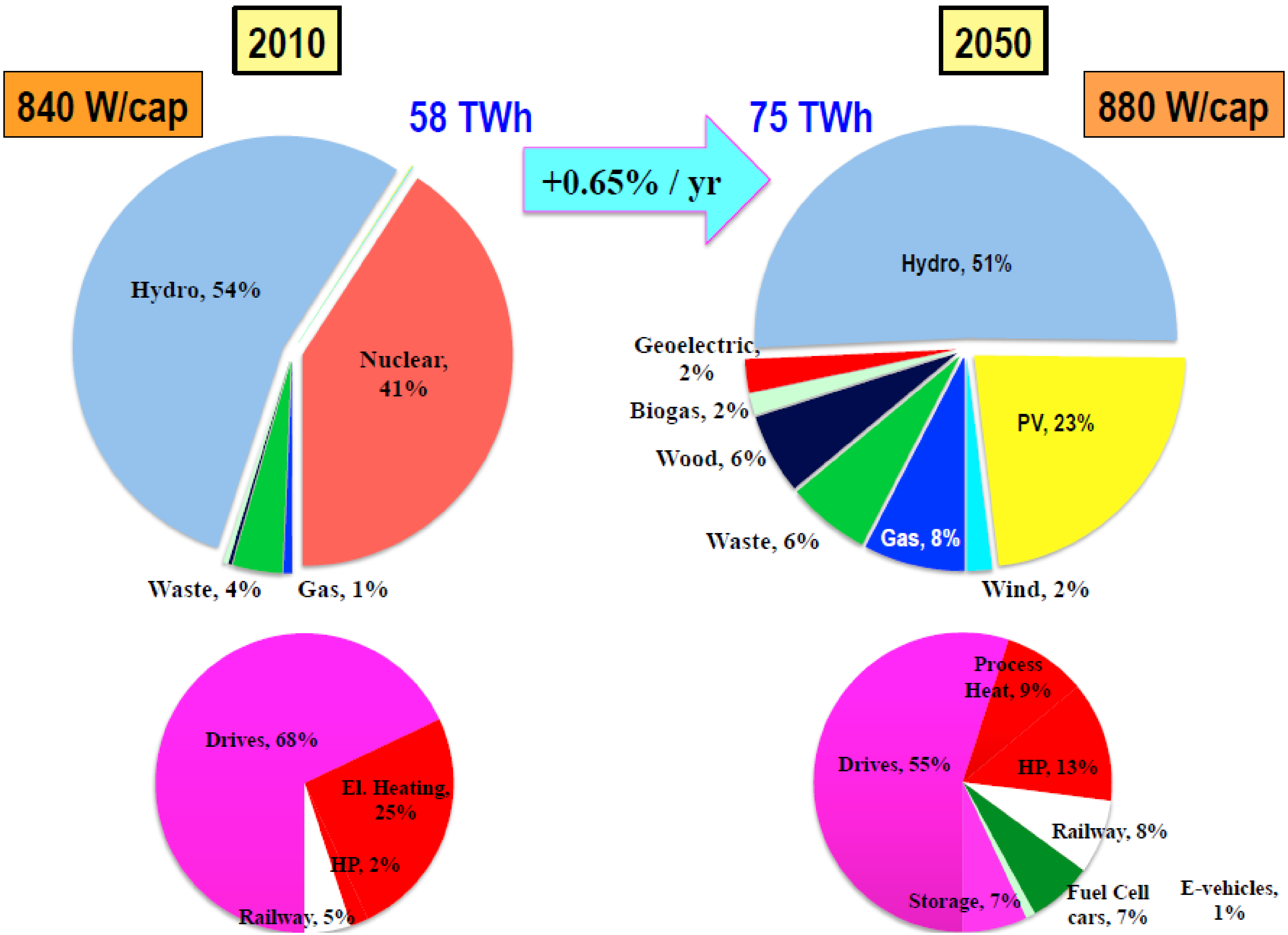
RENEWABLES: 22% → RENEWABLES: 68%

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Inland energy end-use per application



Electricity



ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Summary

1. Energy supply is still strongly fossil fuel based
2. Economic fossil reserves suffice for ca. 100 yrs, but the climate issue is more urgent
3. EFFICIENCY remains the key objective in any technology
4. After the efficiency measures, RENEWABLES can deliver an important contribution (>20% of CO_2 reduction), when massively developed and deployed
5. The issues with renewables are:

   realistic potential, dilute renewable energy streams storage, cost and (grid) integration