CZ-AT WINTER-SUMMER SCHOOL

INTRODUCTION TO "ENERGY SYSTEMS"

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CONTENT:

1. *Motivation: Energy problems*
2. *Basic principle: Providing energy services – not consumption of energy !*
3. *What is an energy system?*
4. *“Currencies”: Units & conversion factors*
5. *Dynamics: Why history is important*
6. *Indicators and Drivers of energy consumption*

1. MOTIVATION:

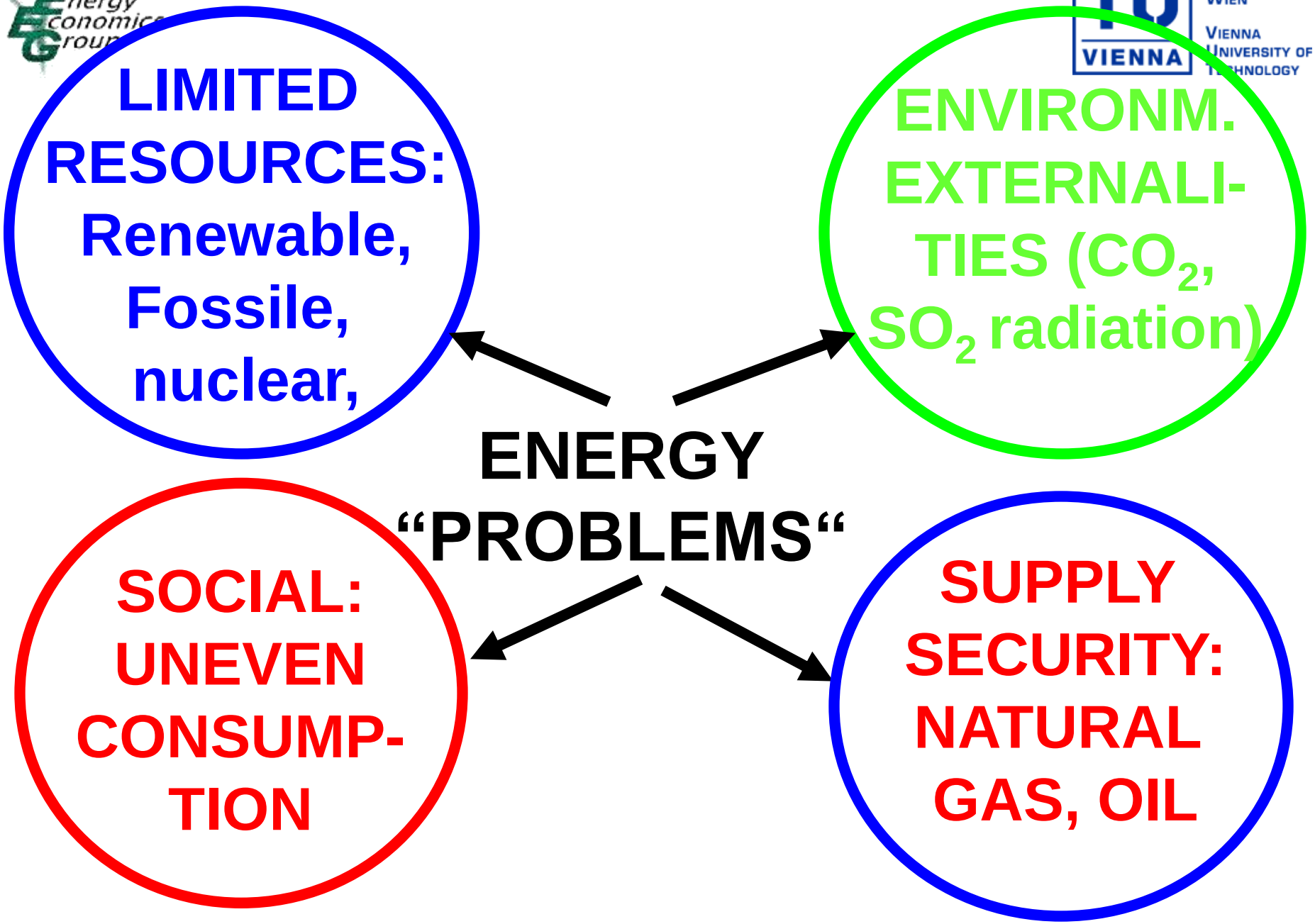
Why are we here today?

- Energy is the fundament of our standard of life today
- Every second of our life – even in deep sleep – we „consume“ energy

- Dramatic increase in energy consumption in recent years!
- Dramatic increase in **electricity** consumption in the next decades expected!

Mobile Phones Charging

Source: Modi, 2011


LIMITED RESOURCES: Renewable, Fossile, nuclear,
ENVIRONM. EXTERNALI-TIES (CO_2, SO_2 radiation)
ENERGY "PROBLEMS"
SOCIAL: UNEVEN CONSUMP-TION
SUPPLY SECURITY: NATURAL GAS, OIL

The Key Energy Challenges

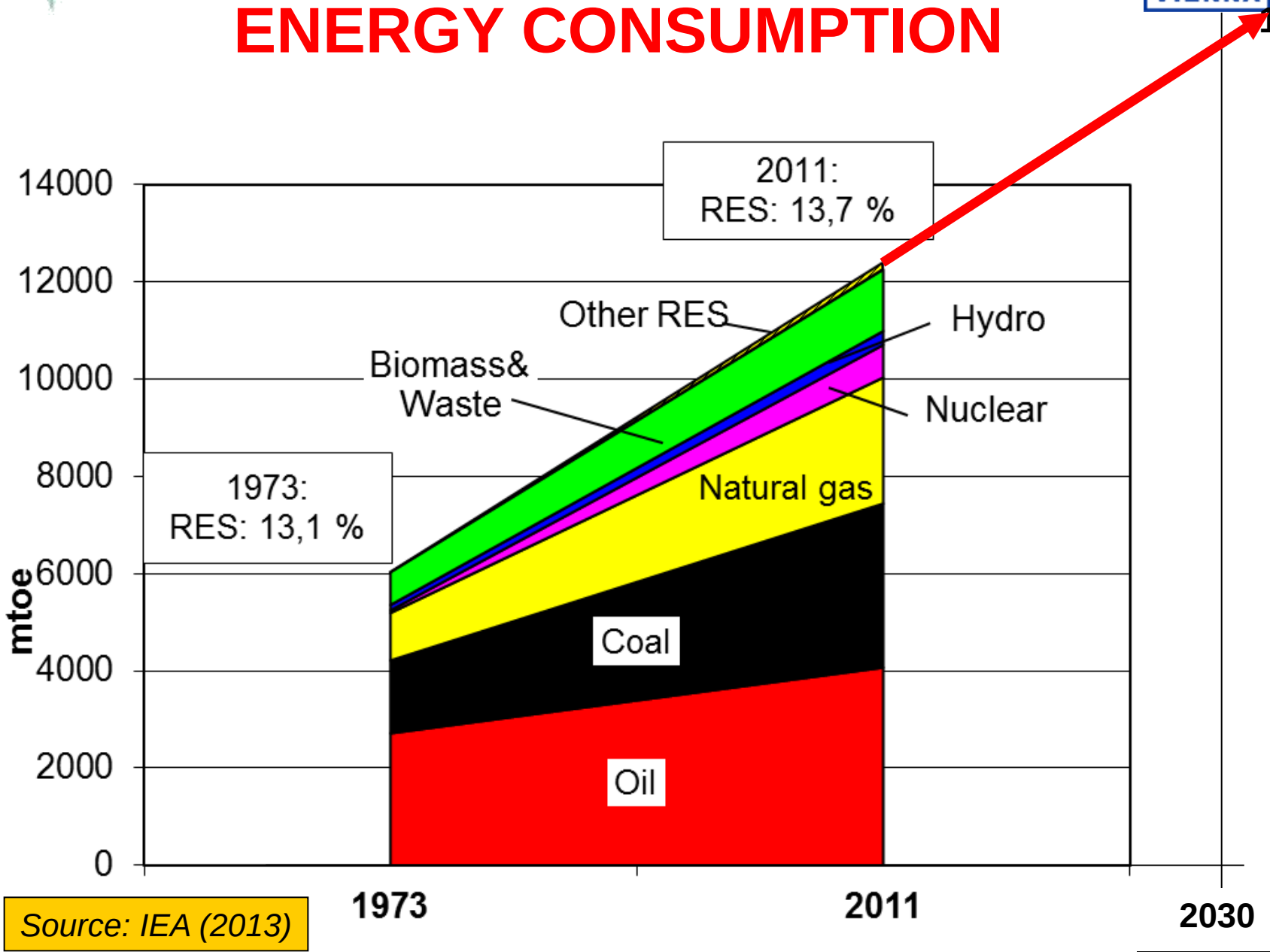
Energy Access

Climate Change

Energy Security

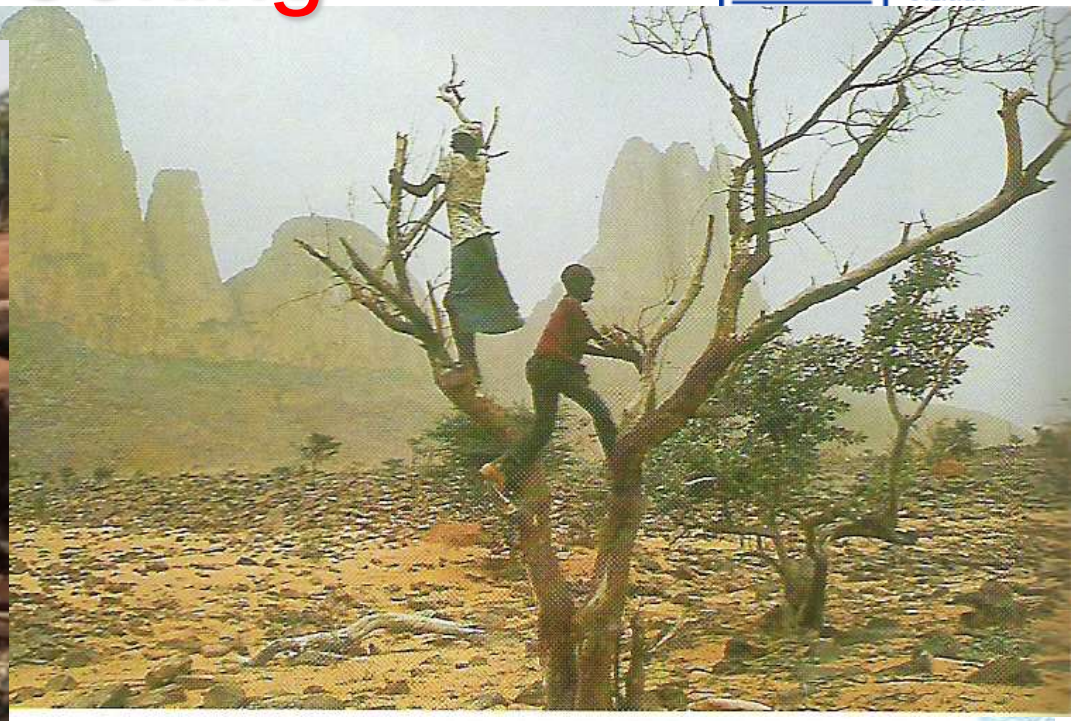
Air Pollution Health Impacts

WORLD-WIDE TREND IN PRIMARY ENERGY CONSUMPTION



Source: IEA (2013)

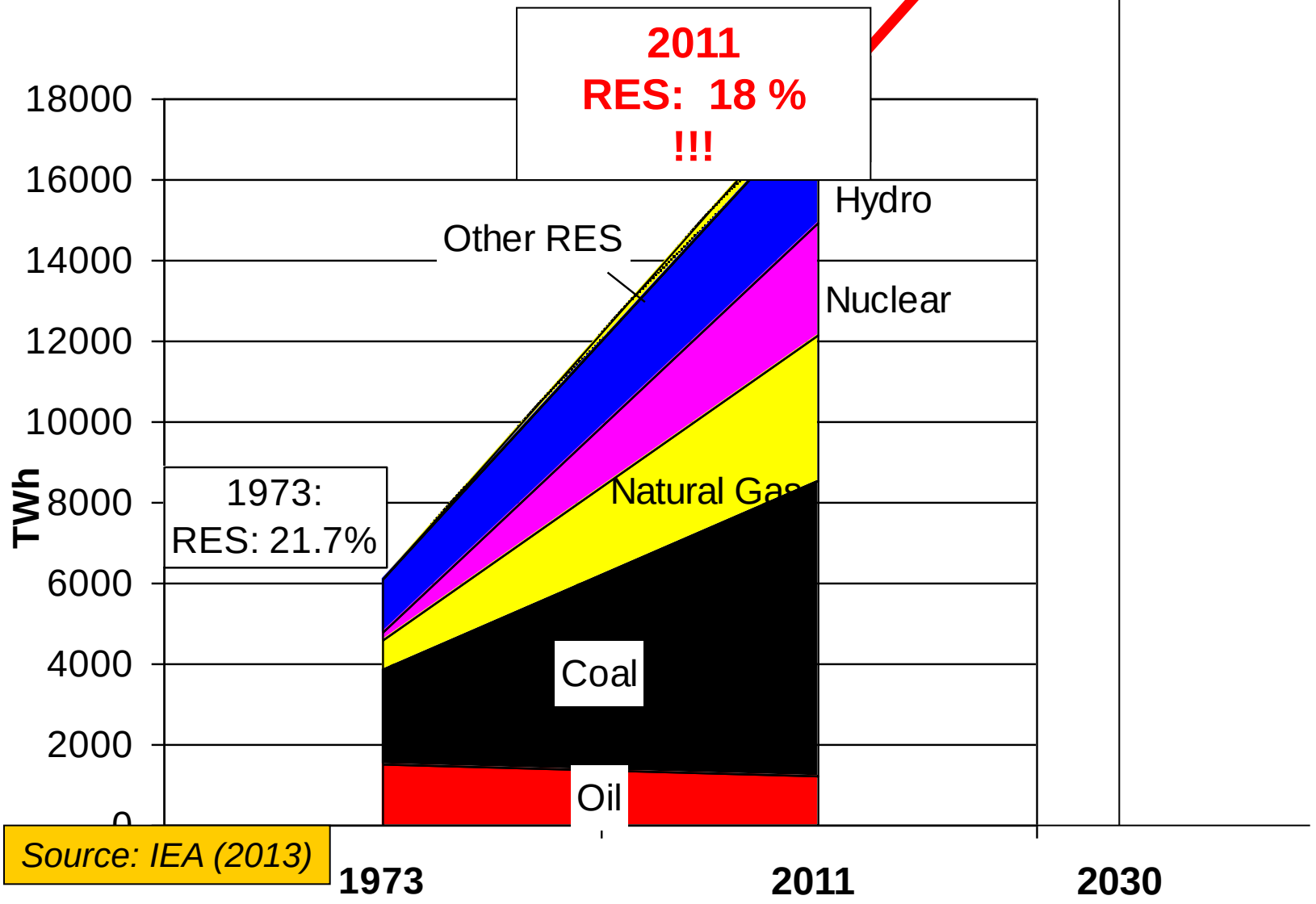
Wood for Cooking



Source: Modi, 2011 and Yumkella, 2013

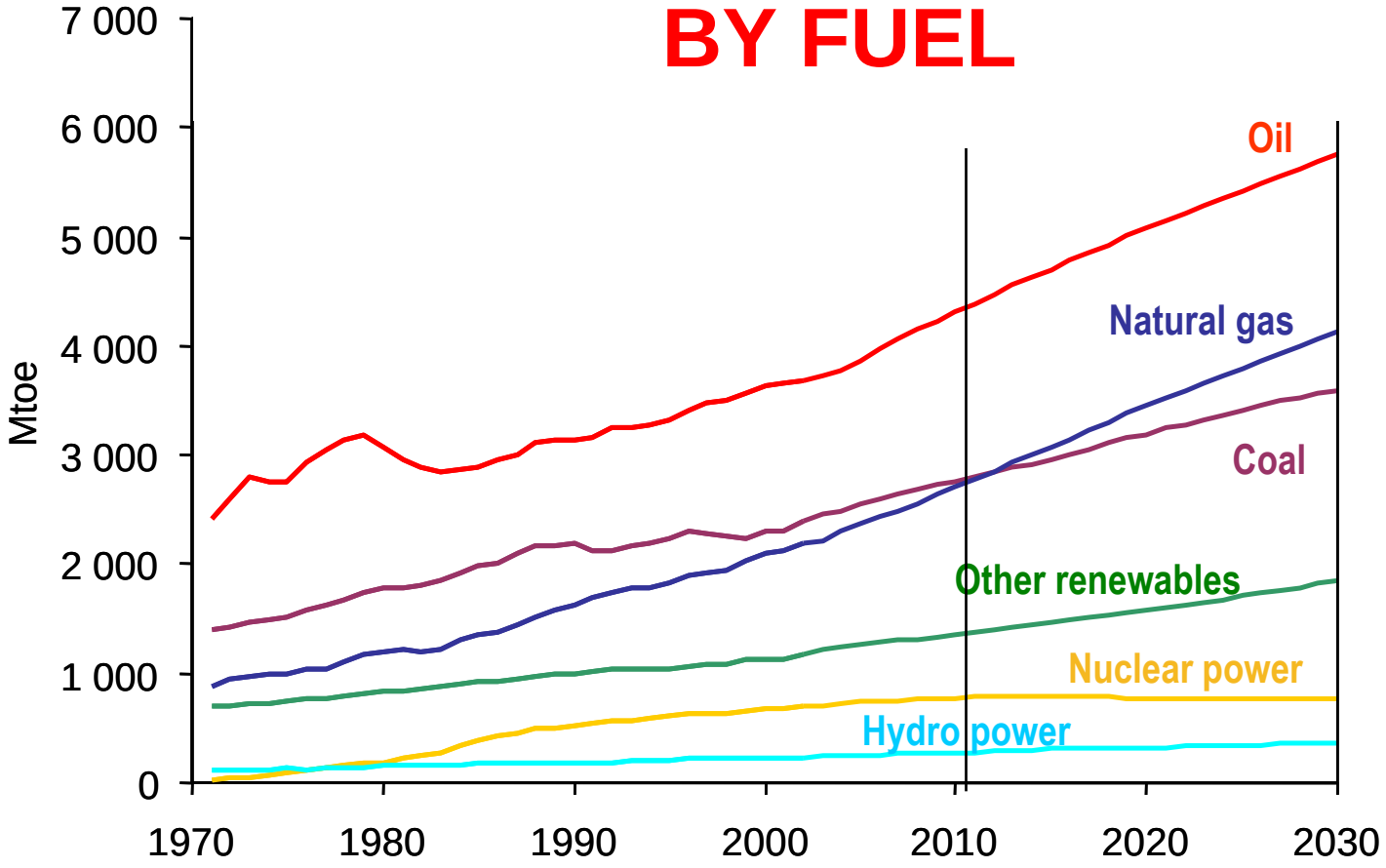
WORLD-WIDE TREND IN ELECTRICITY CONSUMPTION

24000 TWh !



Source: IEA (2013)

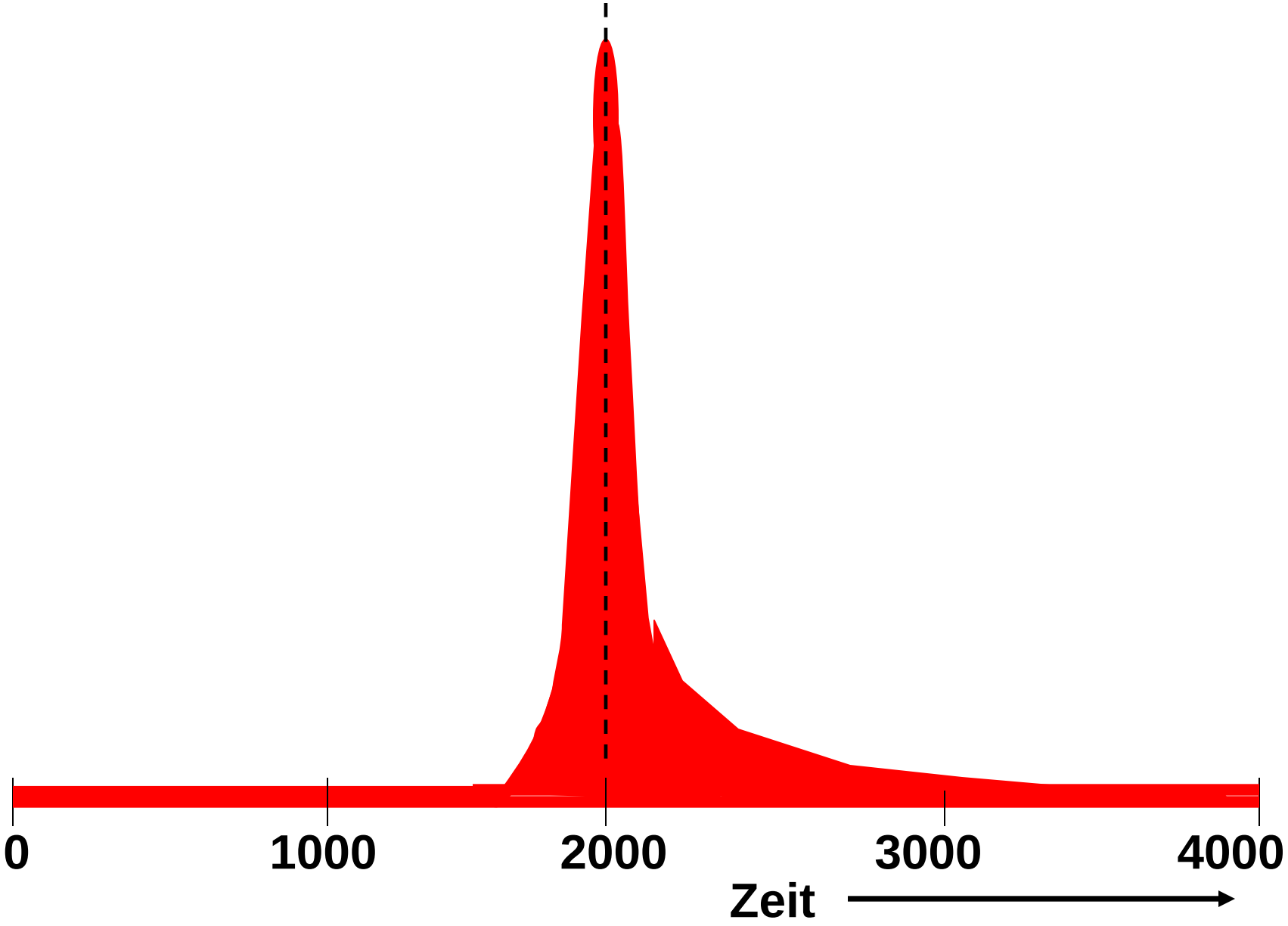
PRIMARY ENERGY: TRENDS BY FUEL



IEA: Fossil fuels will continue to dominate the global energy mix, while oil remains the leading fuel!

Source: IEA (2012)

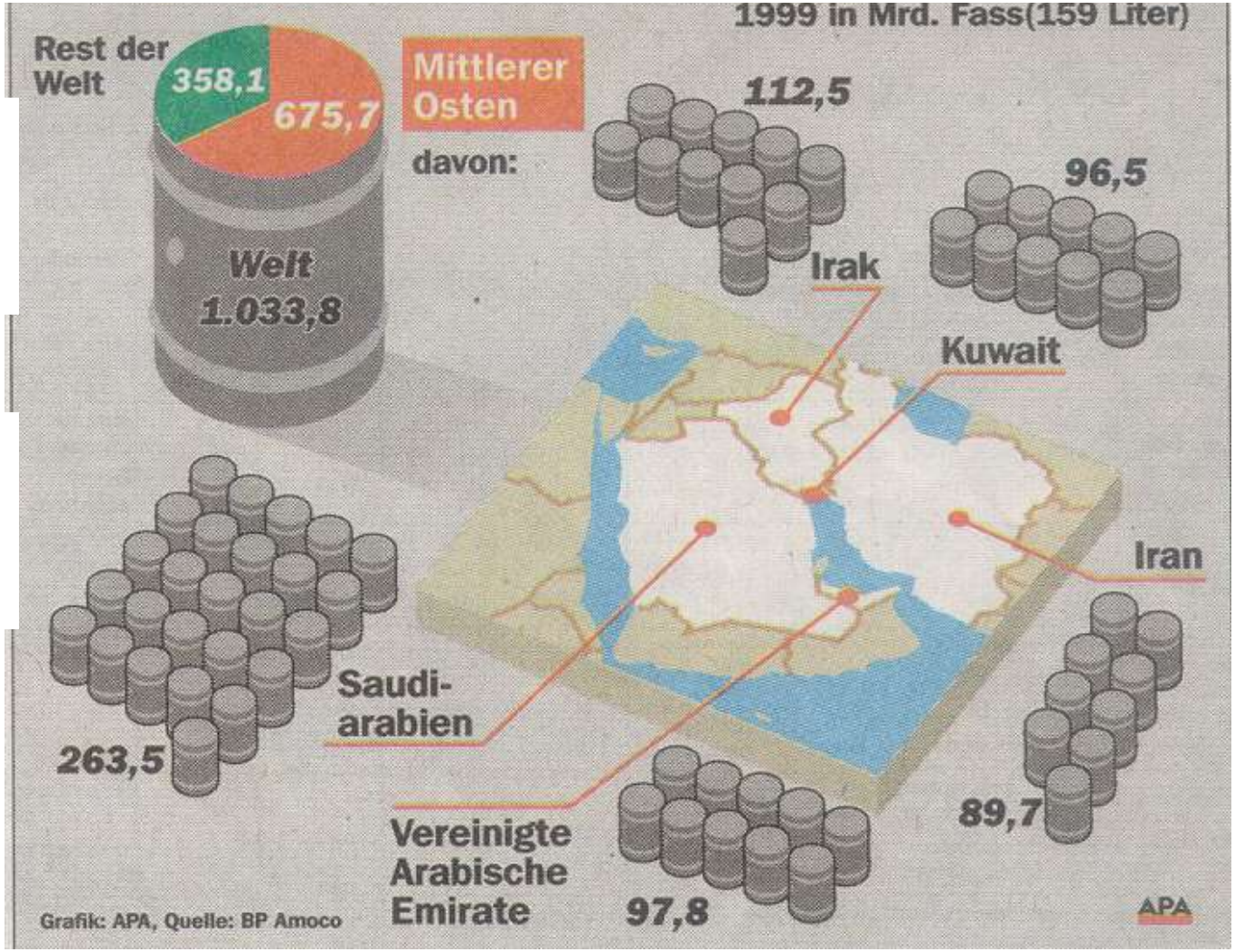
Oil consumption over time



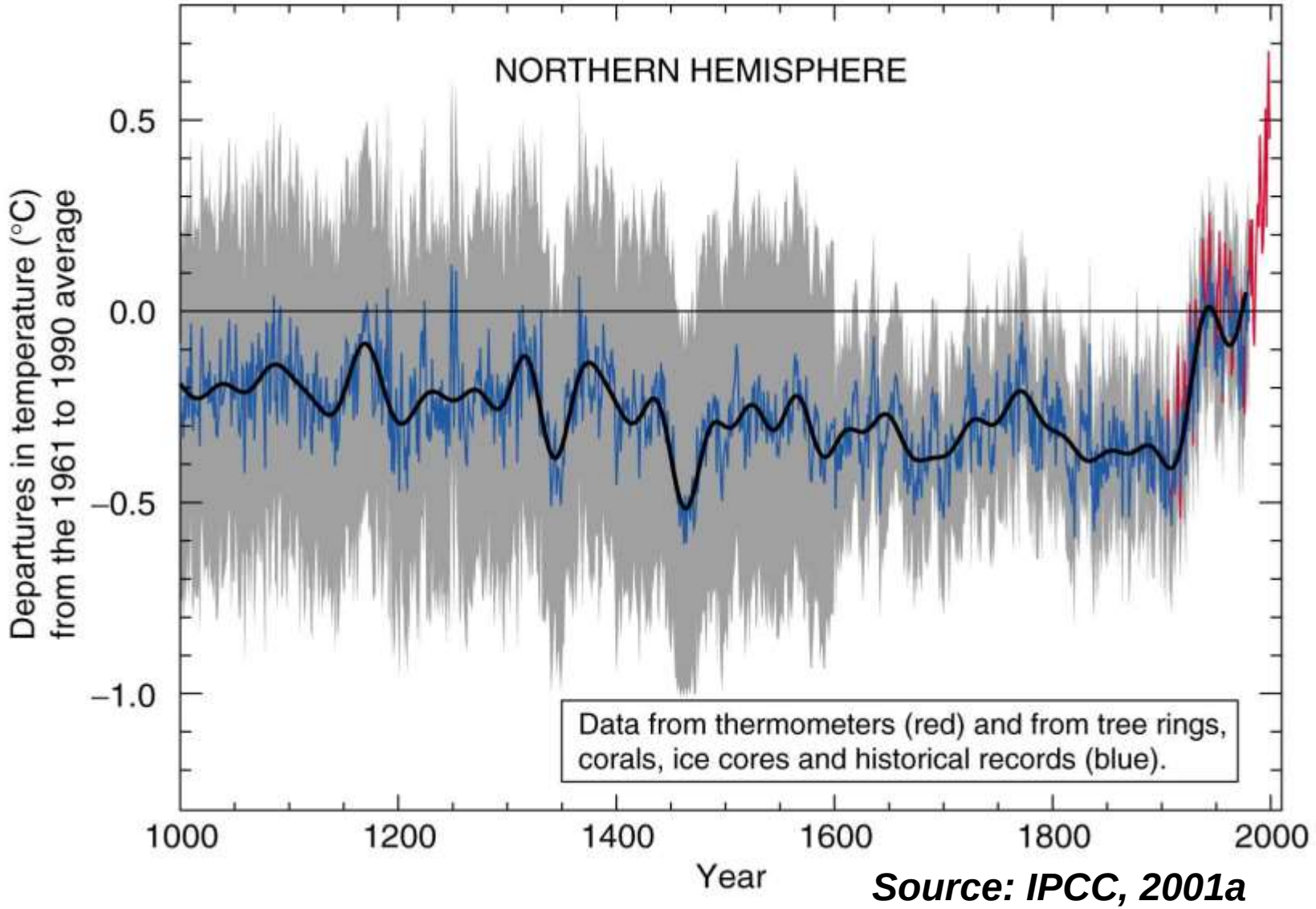
Oil reserves in the Middle East

Middle East: 2/3

Rest of world: 1/3



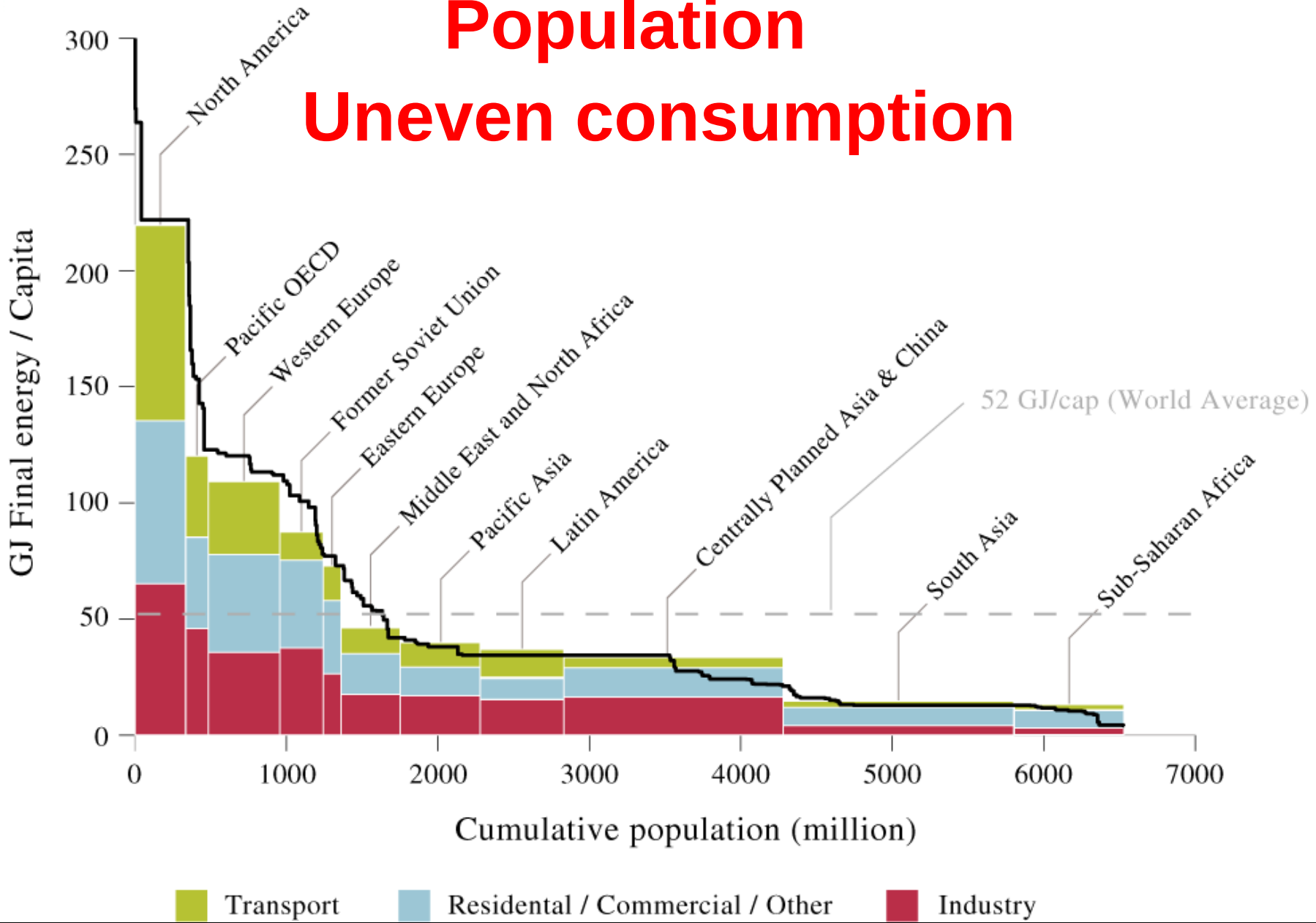
Variations of Earth's Surface temperature in the past 1000 years



Source: IPCC, 2001a

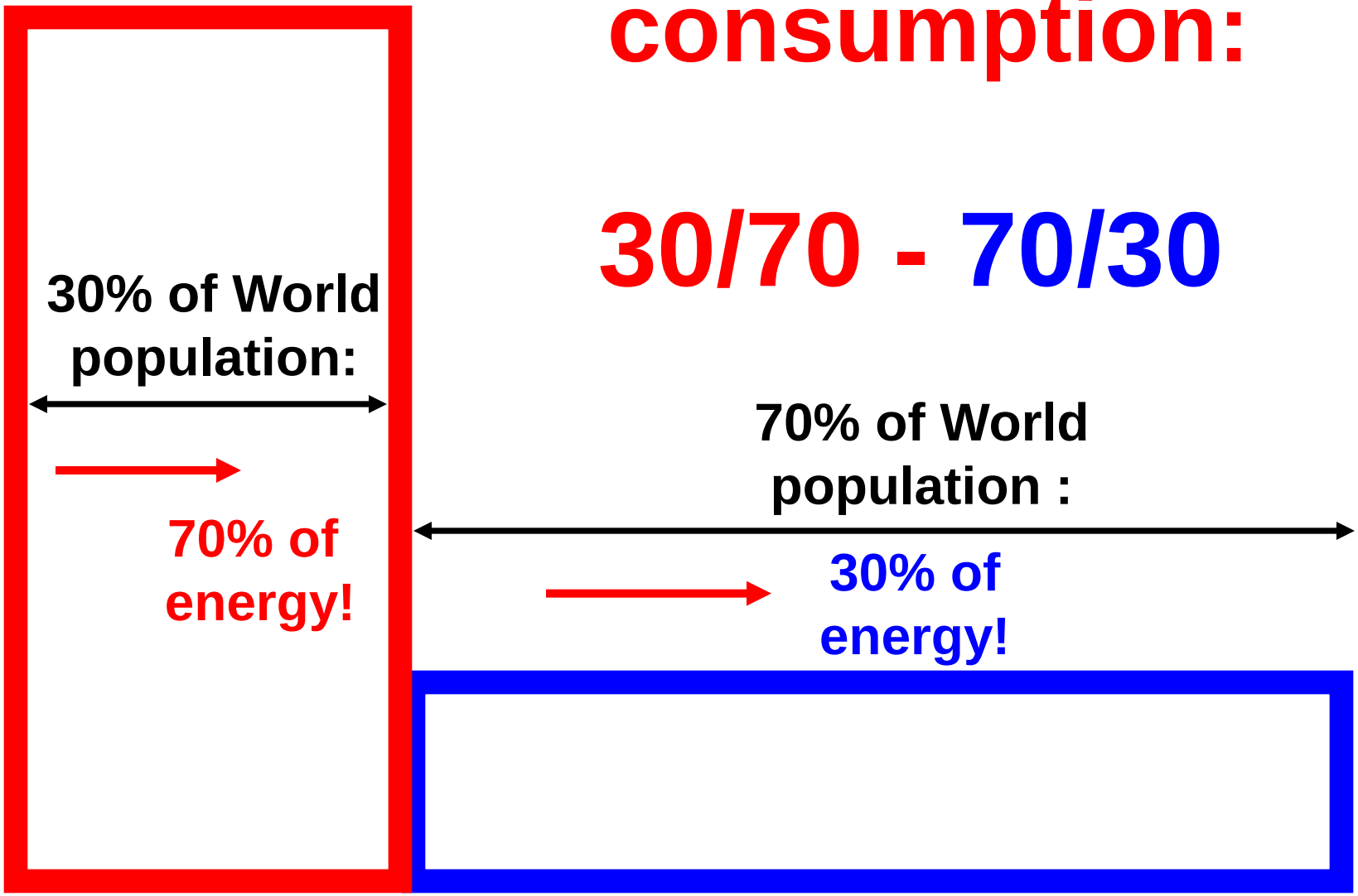
Per Capita Final Energy & Population

Uneven consumption



Uneven consumption:

30/70 - 70/30

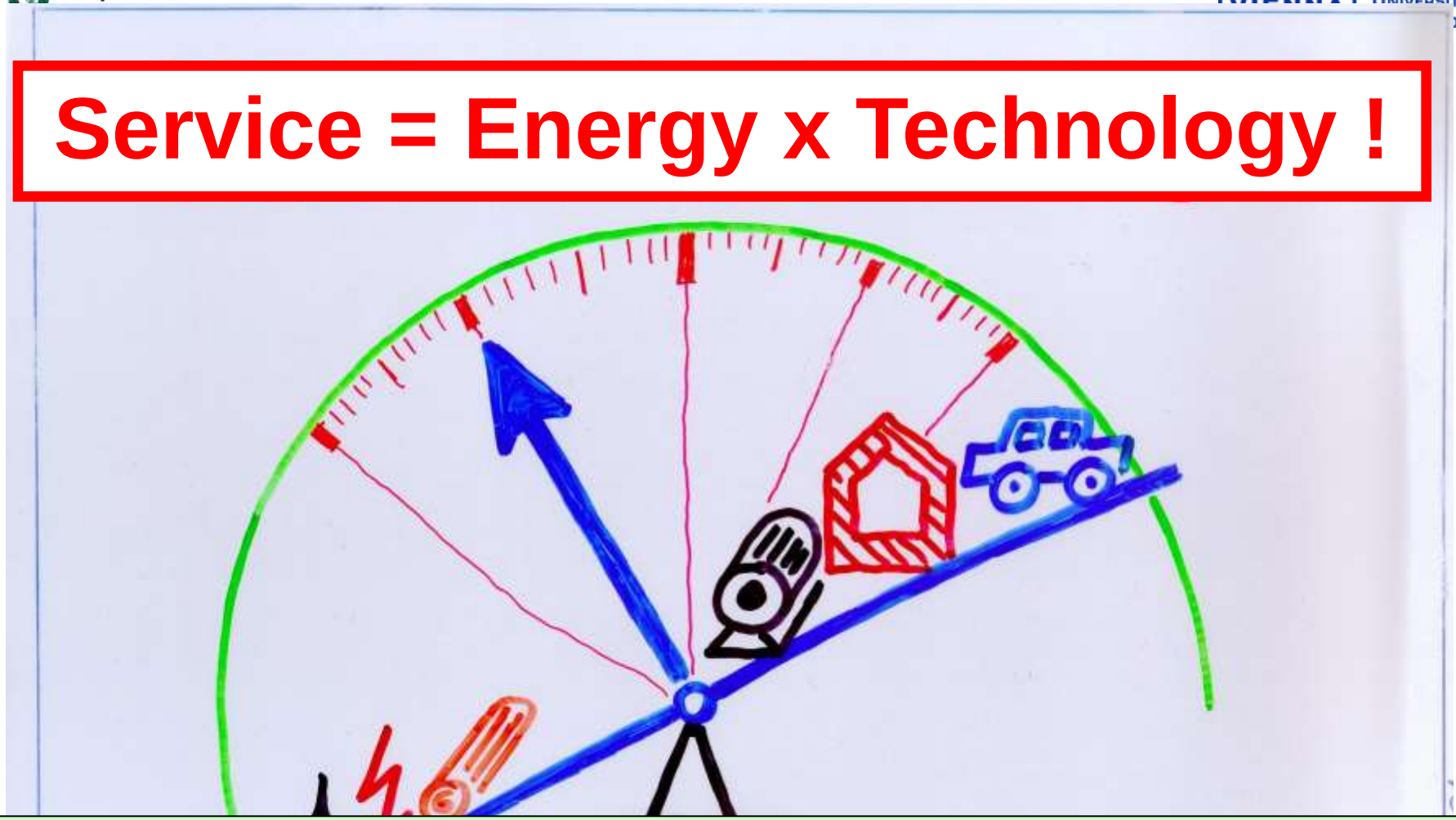


2. The basic concept of providing energy services

- There is no interest to consume energy. There is a demand for energy services: clean shirts, warm and bright rooms, cold beer, hot coffee.
- Inputs: Energy, Technology, human capital, environment
- Energy services are produced :

$$S = E \ \eta (T)$$

Service = Energy x Technology !



- ***But currently the balance is biased tremendously: To much energy, far to less technical efficiency!***

What are energy services?

Direct energy services:

- Lighting
- Heating, cooking
- Mobility, Transport
- …

Indirect energy services:

- Food
- Shoes, Shirts
- Communication
- What you can buy in a super market!

The energy chain

Categories of energy:

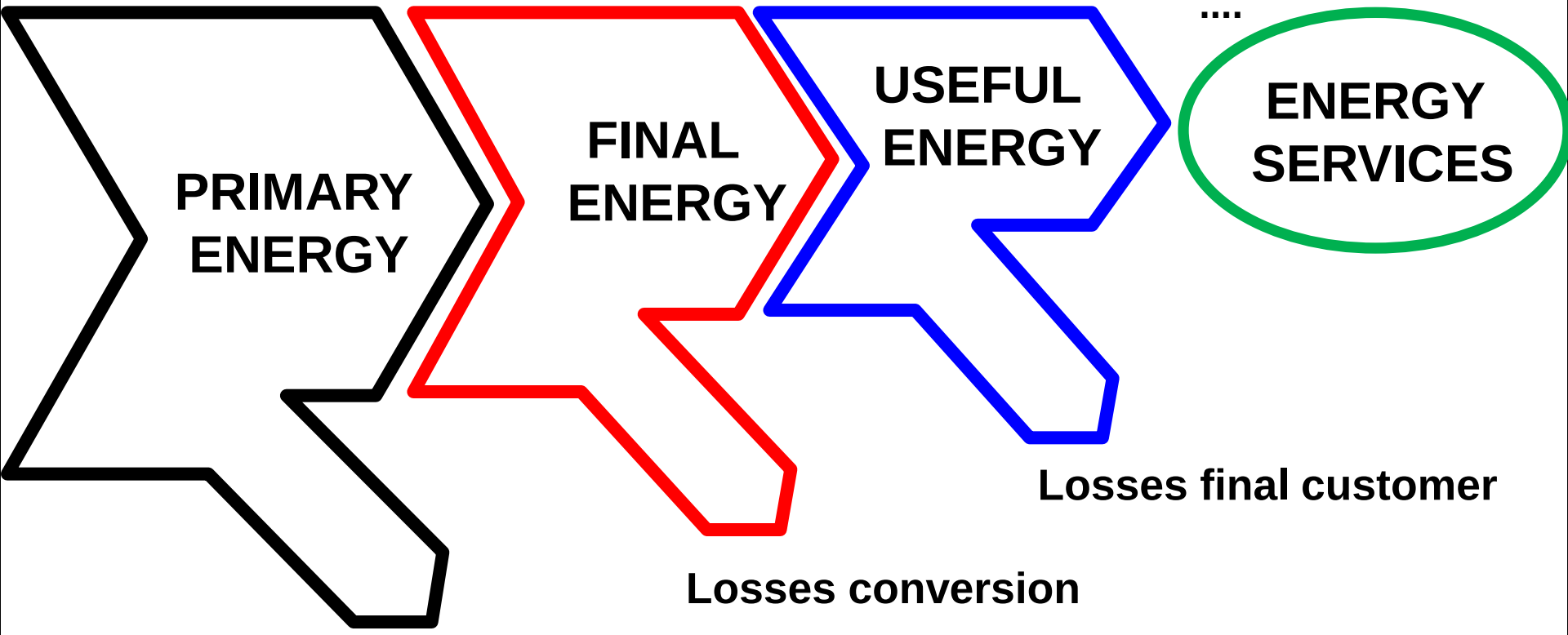
Crude oil, wood, coal, natural gas, solar, hydro, nuclear

Gasoline, electricity, pellets, district heat

Heat, light, mechanical work,

Warm and bright rooms, mobility

....



Losses final customer

Losses conversion

Losses exploration and transport

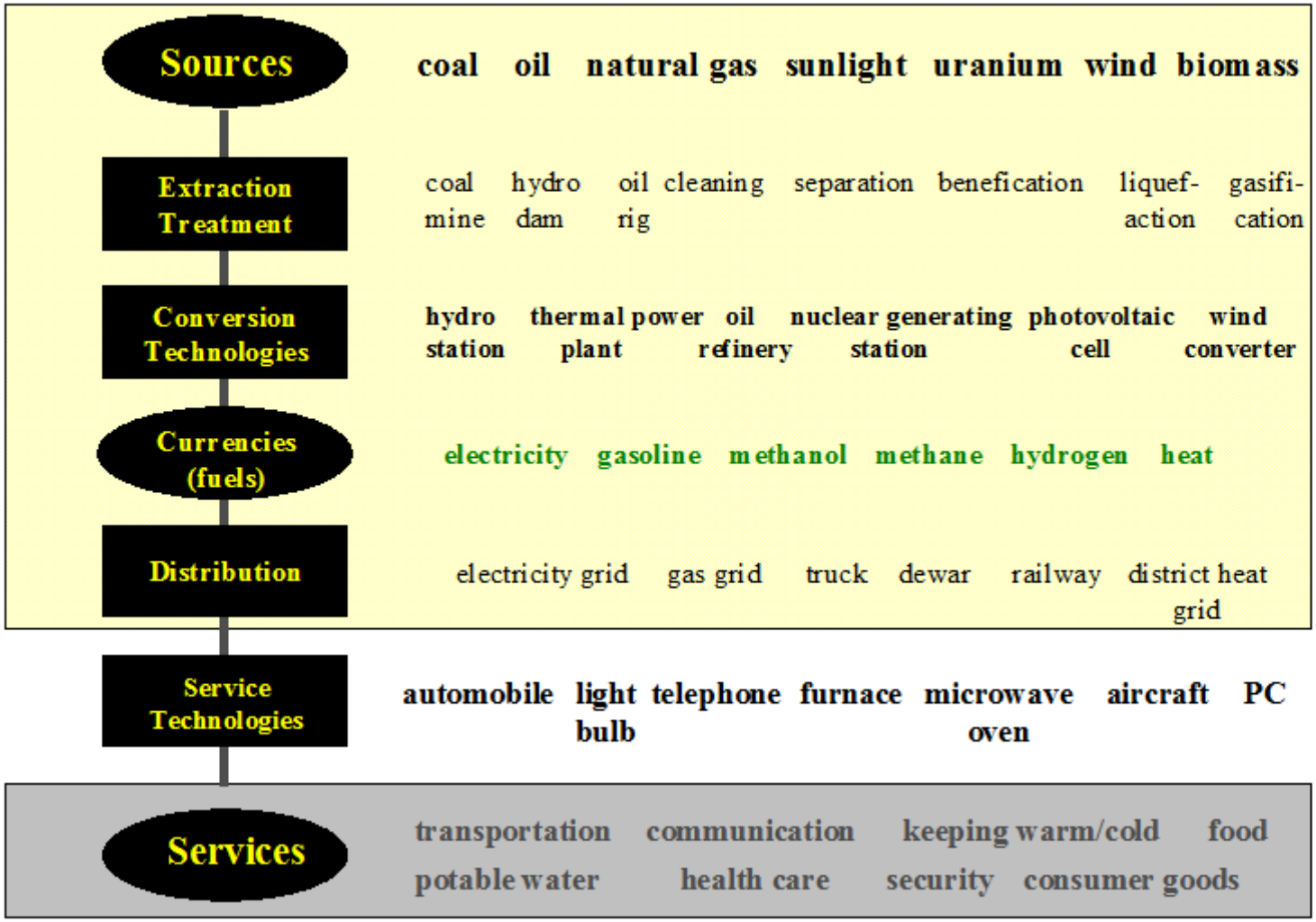
Source: Nakicenovic/Haas (2010)

3. What is an energy system?

- An energy system comprises an energy supply and an end-use sector.
- The supply sector consists of processes for extracting energy resources, converting these into more desirable and sustainable forms of energy and delivering these to places where the demand exists.
- The end-use sector provides services such as cooking, illumination, transportation and consumer goods.
- The purpose of the energy system is the fulfillment of demand for energy services.

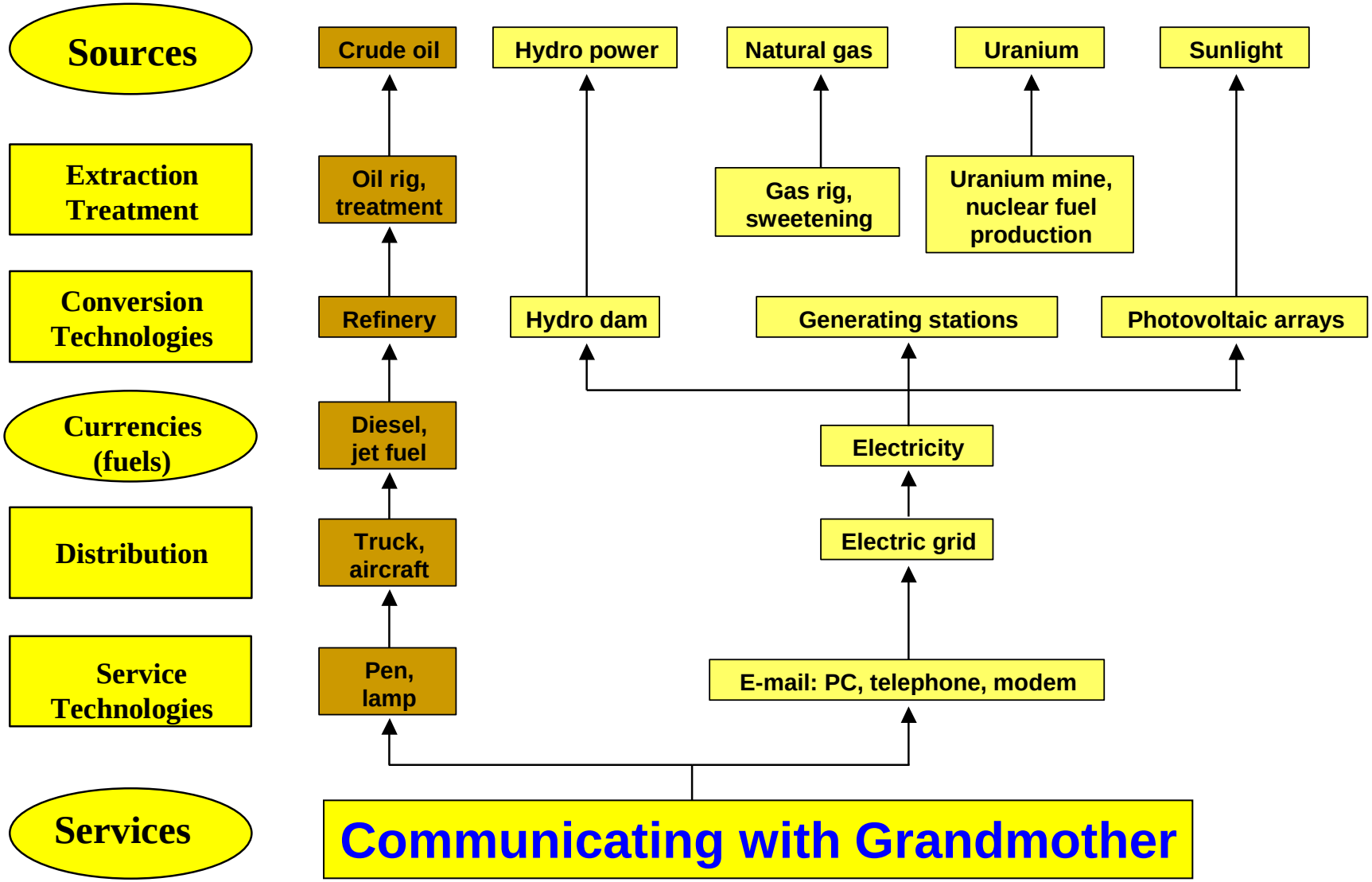
3. What is an energy system?

Architecture of the Energy System



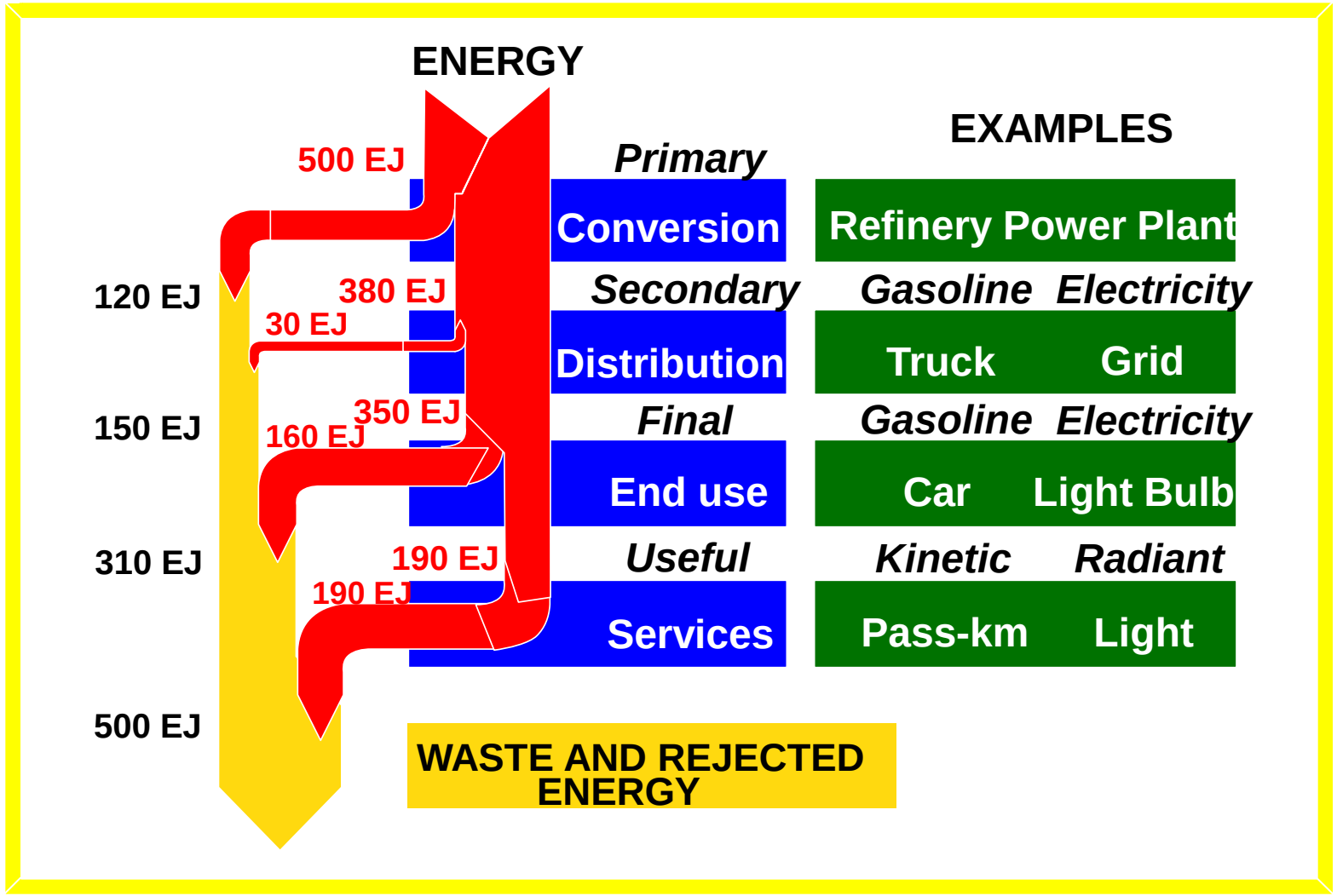
Source: Nakicenovic et al (1997)

ARCHITECTURE OF THE ENERGY SYSTEM: EXAMPLE!



Source: Nakicenovic/Haas (2010)

Global Energy Flows



4. Units ("Currencies") and conversion factors for measuring energy demand

Units for Orders of Magnitude

Symbol	Name	Magnitude	Number	Expression
P	Peta	1E+15	1 000 000 000 000 000	quadrillion
T	Tera	1E+12	1 000 000 000 000	trillion*
G	Giga	1E+09	1 000 000 000	billion
M	Mega	1E+06	1 000 000	million
K	Kilo	1E+03	1 000	thousand
h	Hekto	1E+02	100	hundred
da	Deka	1E+01	10	ten
-		1E+00	1	one
d	Dezi	1E-01	0.1	tenth
c	Centi	1E-02	0.01	hundredth
m	Milli	1E-03	0.001	thousandth
µ	Mikro	1E-06	0.000 001	millionth
n	Nano	1E-09	0.000 000 001	billionth
p	Piko	1E-12	0.000 000 000 001	trillionth

* UK: milliard = 1E+12

Source: Nakicenovic/Haas (2005)

Some basic reflections:

1 Wh = 3600 Ws = 3600 J =3.6 kJ

1 kg oe = 11.63 kWh = (X 3.6) 41.87 MJ

(1 BTU = 1055 J)

1 Cal = 4.19 J

Useful conversion factors on country level

1 TWh = 3.6 PJ = 0.086 Mtoe

1 PJ = 0.2778 TWh = 0.0239 Mtoe

1 Mtoe = 41.87 PJ = 11.63 TWh

(10^{12} BTU = 1.055 PJ)

Example 1:

World energy consumption (PE):

12000 Mtoe = 500 000 PJ = 500 EJ (Exa-Joule)

Example 2:

World electricity consumption (PE):

000 TWh = 000 PJ

Examples:

Selected countries :

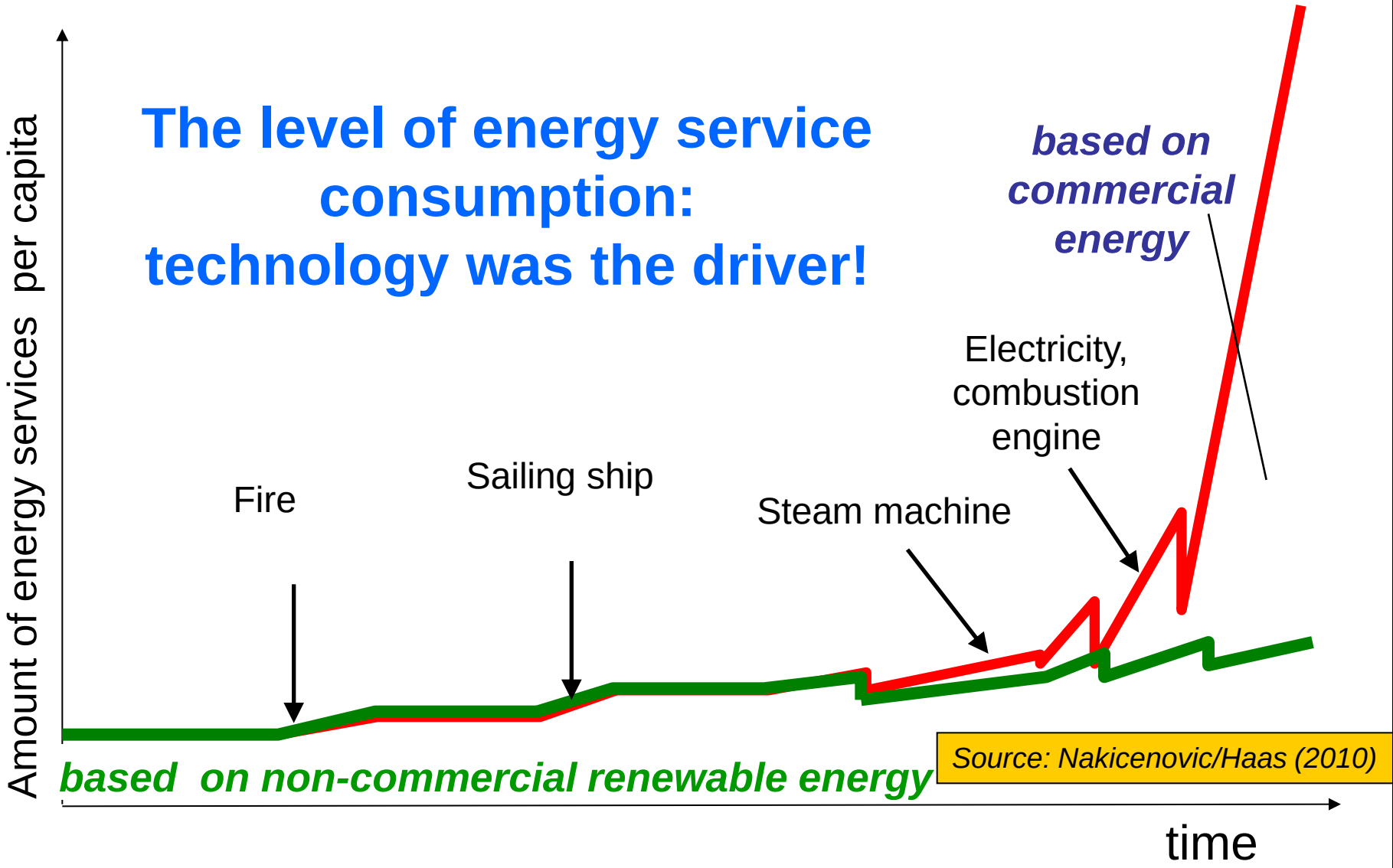
Austria: 32.4 Mtoe PE, Losses to FE: 21%, 65.8 TWh electricity
Czech Republic: 43.4 Mtoe PE, Losses to FE: 21%, 57.0 TWh electricity

In which country is share of electricity on final energy highest?

Conversion factors for energy

From : \ To :	PJ	Gcal	Mtoe	10^12 BTU	TWh
	multiply by				
PJ	1	238800	0.0239	0.9479	0.2778
Gcal	4.1868×10^{-6}	1	10^{-7}	3.968×10^{-6}	1.163×10^{-6}
Mtoe	41.868	10^{7}	1	39.68	11.63
10^12 BTU	1.055	252000	0.0252	1	0.2931
TWh	3.6	860000	0.086	3.412	1

5. Dynamics: Why history is important



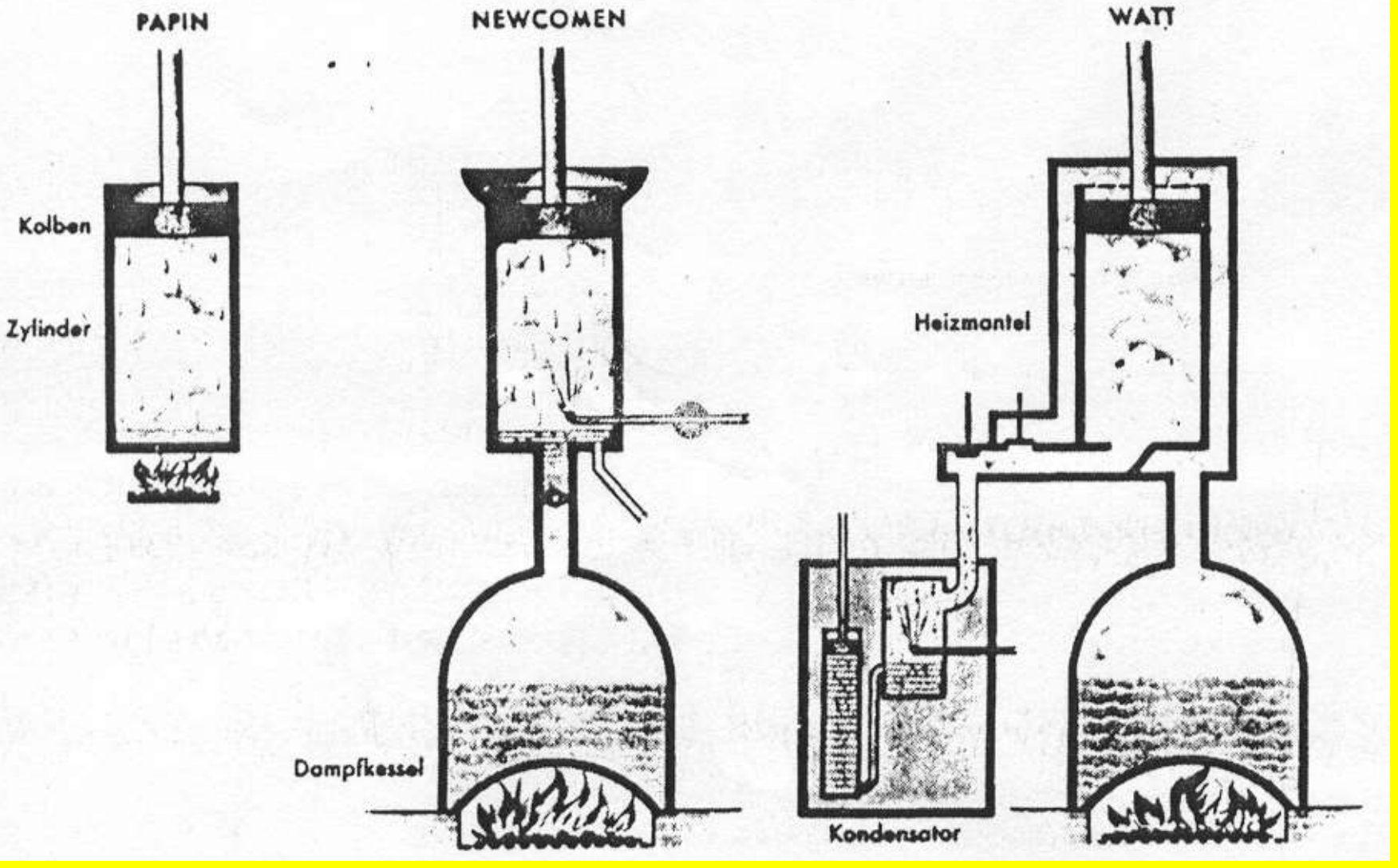
From Antiquity to the Steam Age

For the longest period in history:
Main sources of energy human and animal work, biomass (fire), mechanical wind and water.

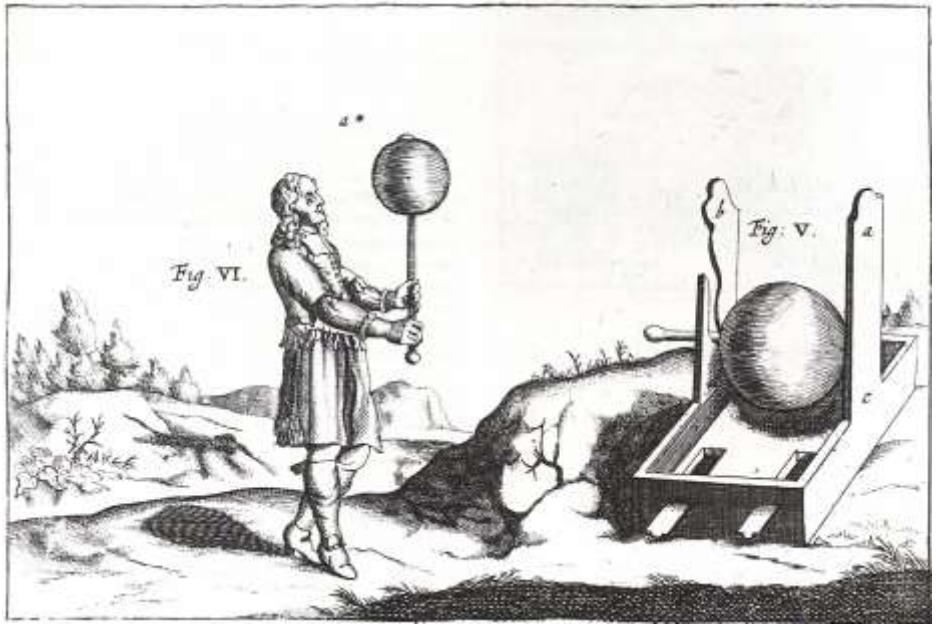
Reasons for the humble improvements in energy use and technologies:

- Work of many served only a few due to generally highly hierarchal social structures
- General dislike of purpose-oriented technology
- Low population densities and lack of population growth to accumulate knowledge!

Steam Engine



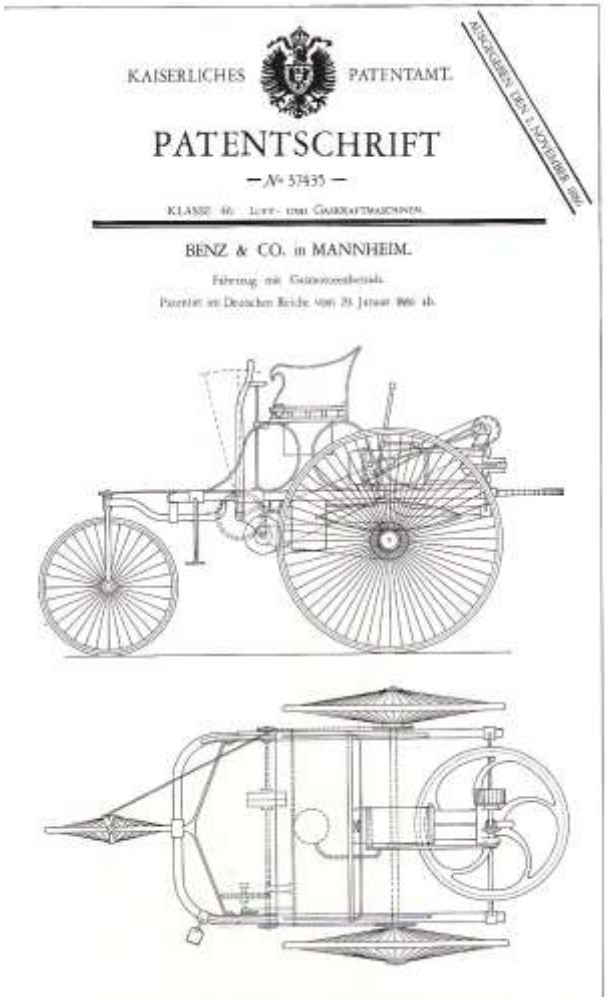
Electricity – THE energy carrier



Otto v. Guericke

Electricity – THE universal technology for providing energy services

A new era of mobility: oil and combustion engine


KAISERLICHES PATENTAMT.

PATENTSCHRIFT

— № 37435 —

BENZ & CO. in MANNHEIM.

Oil products in vehicles end of 19th century, begin of 20th century

Energy crises

Wood crises:

- 7000 – 0 BT: Deforestation along coasts;
- 1500 – 1700: England, Germany
- Today: Africa, India…

major reasons:

- non-sustainable use;
- distance to place of use, transport, lack of infrastructure,
- inefficient use;

Coal crises:

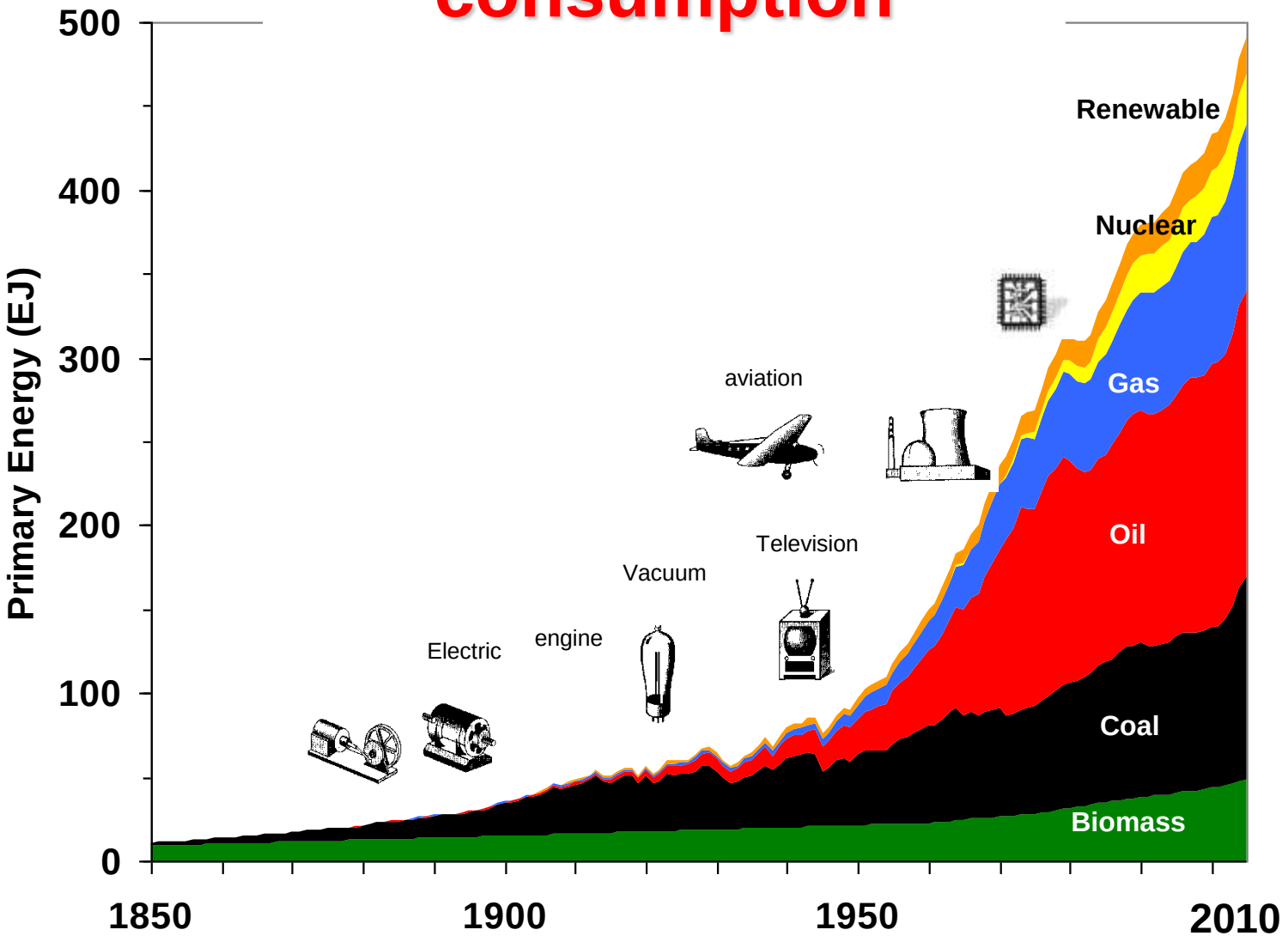
- 1870…

Oil crises:

- 1973, 1979, 2005 (?) …

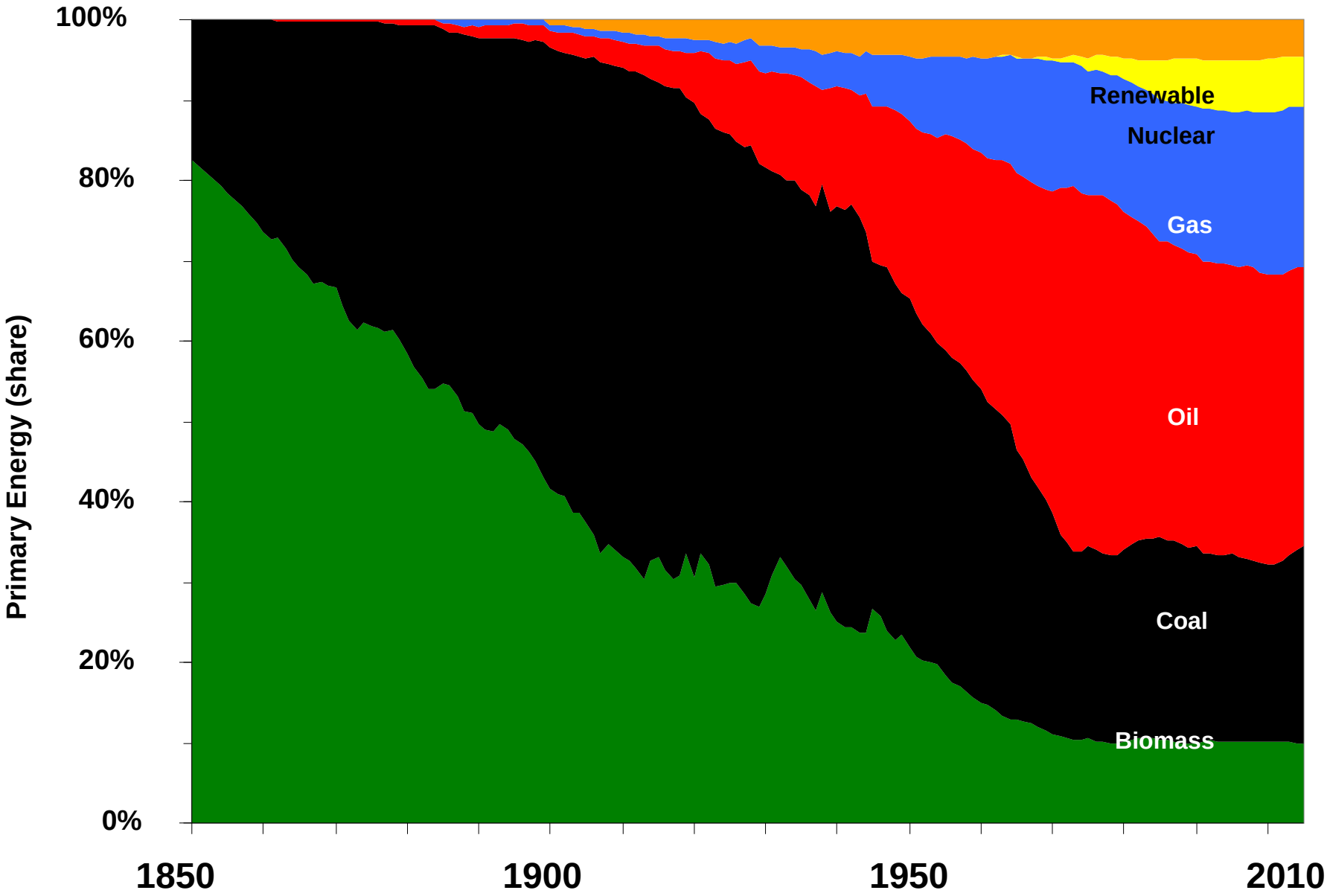
Source: Nakicenovic/Haas (2010)

World Primary Energy consumption



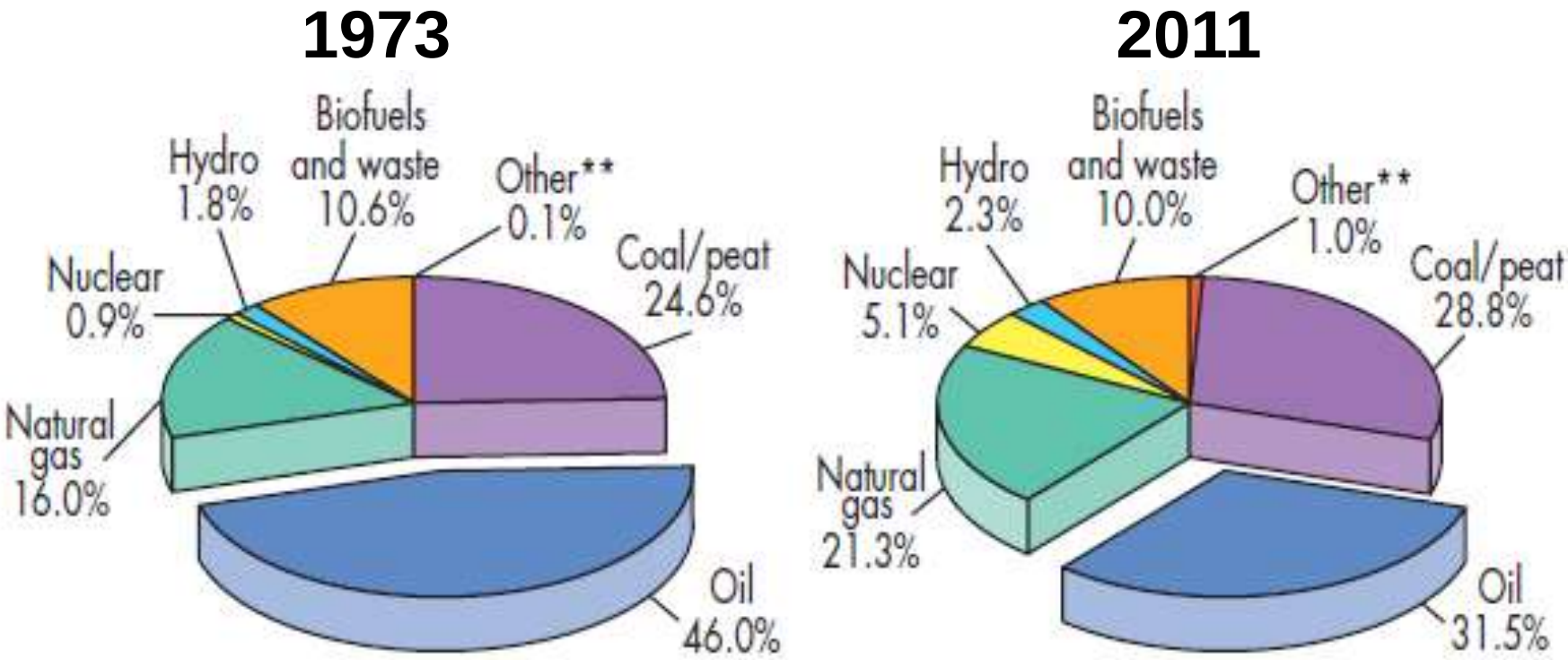
Source: GEA (2012)

Shares of PE world-wide



Source: GEA (2012)

World: Primary energy



6115 Mtoe

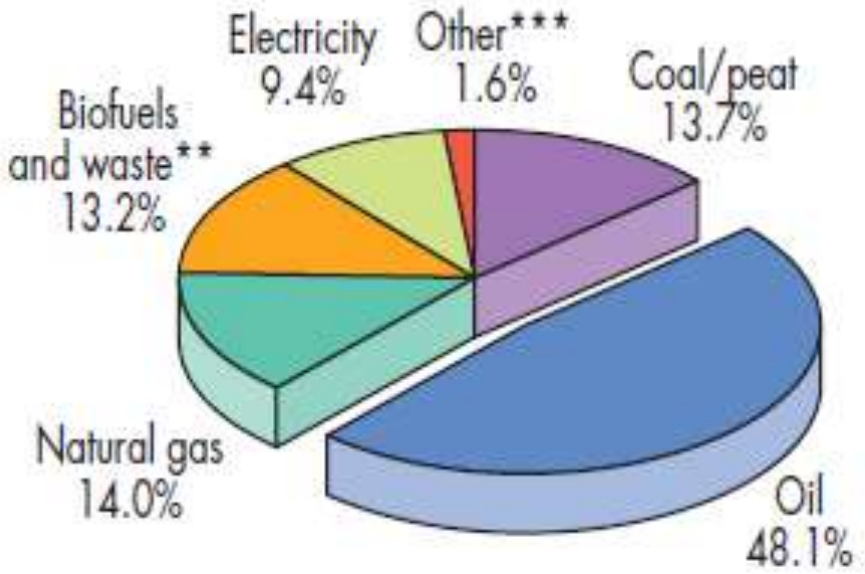
13100 Mtoe

- ***Total primary energy demand more than doubled between 1973 and 2011;***
- ***Oil down (more than -30%!!!), Gas up (+30%)***

Source: IEA 2013

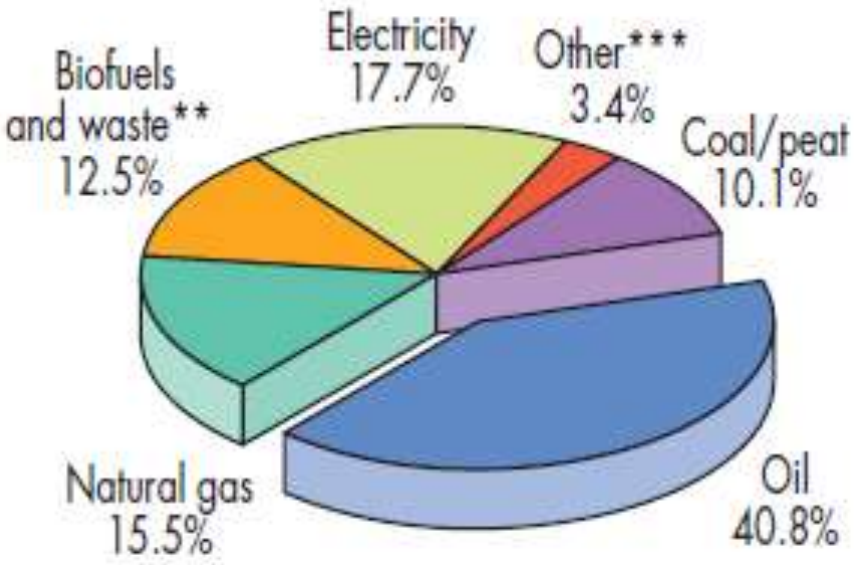
World: Final energy

1973



4674 Mtoe

2011



8918 Mtoe

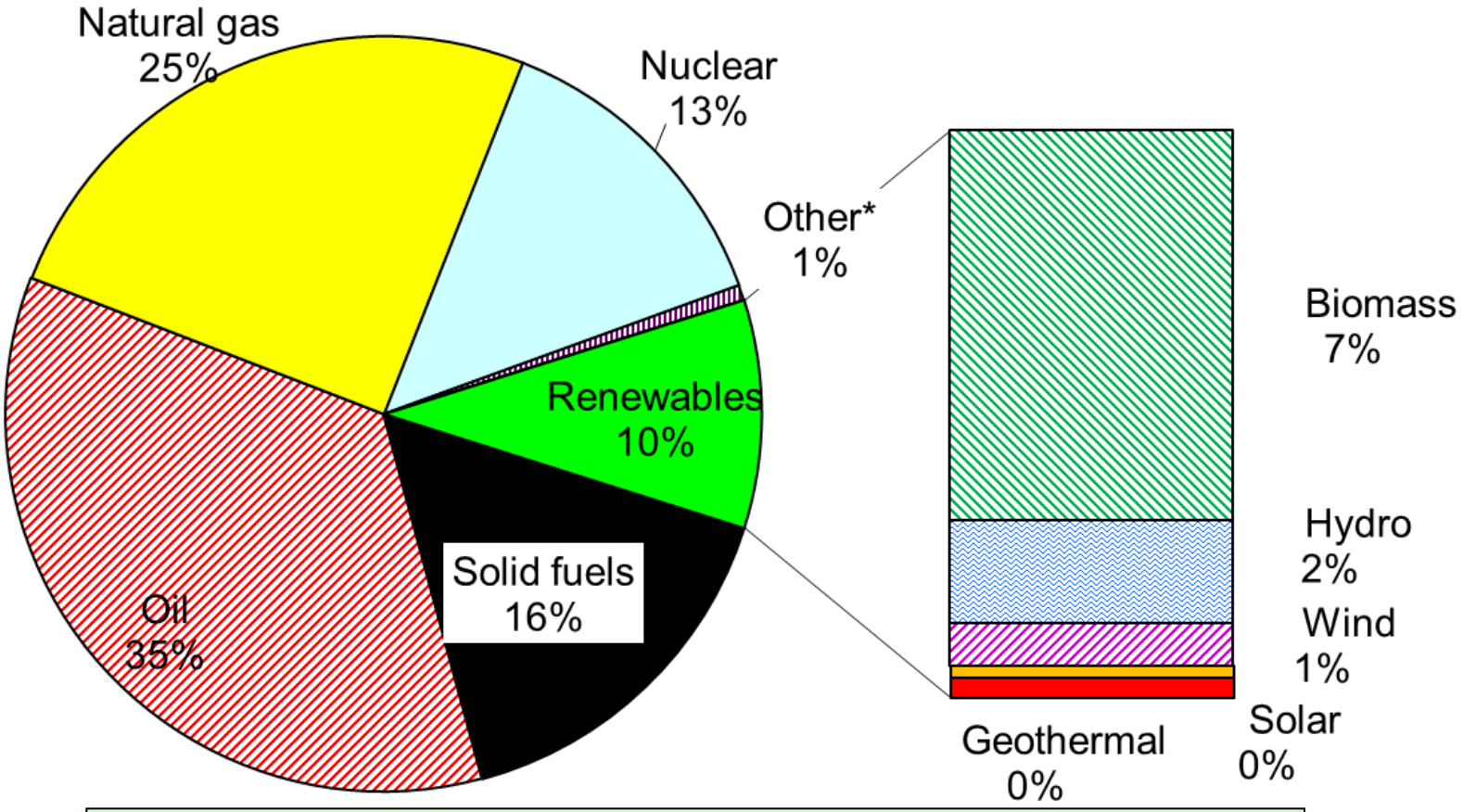
- ***The share of electricity increases continuously: In 2011 almost double of 1973***
- ***Share of oil decreased less than 20%***

*** Other includes Solar, Geothermal, Wind

Source: IEA 2013

4.2. Energy in Europe

EU-27: Primary energy consumption

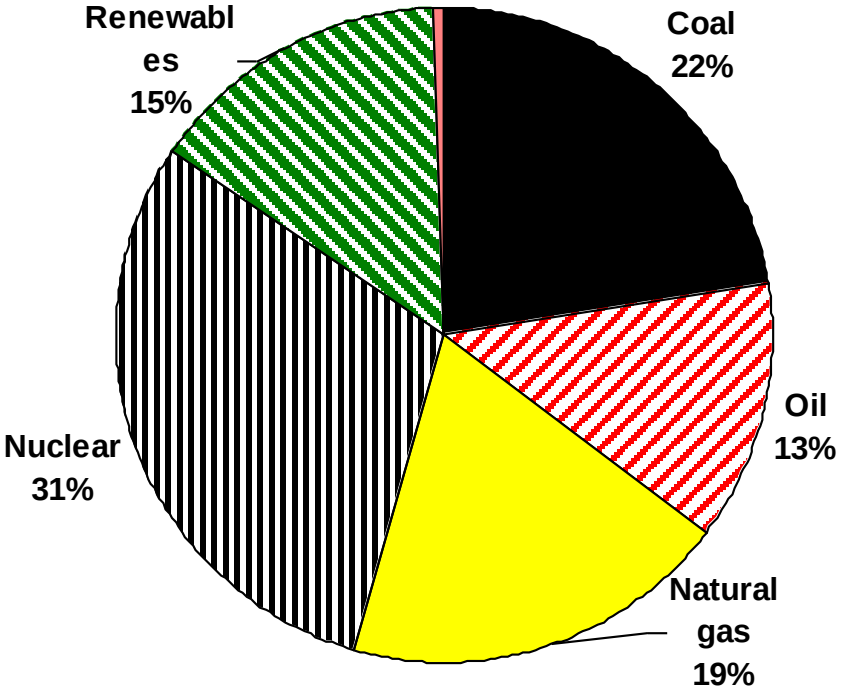


- ***about 10% share of RES in 2010;***
- ***EU-target from 1997: 12% by 2010!***

Source: EUROSTAT (2013)

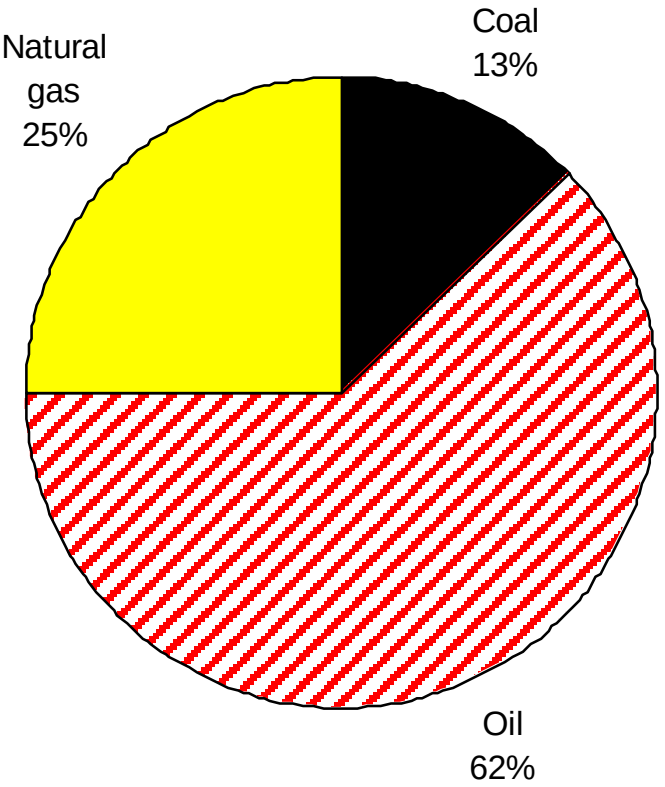
Primary Energy EU-27: origin of resources

Indigenous:



Total 2010: ca. 870 Mtoe

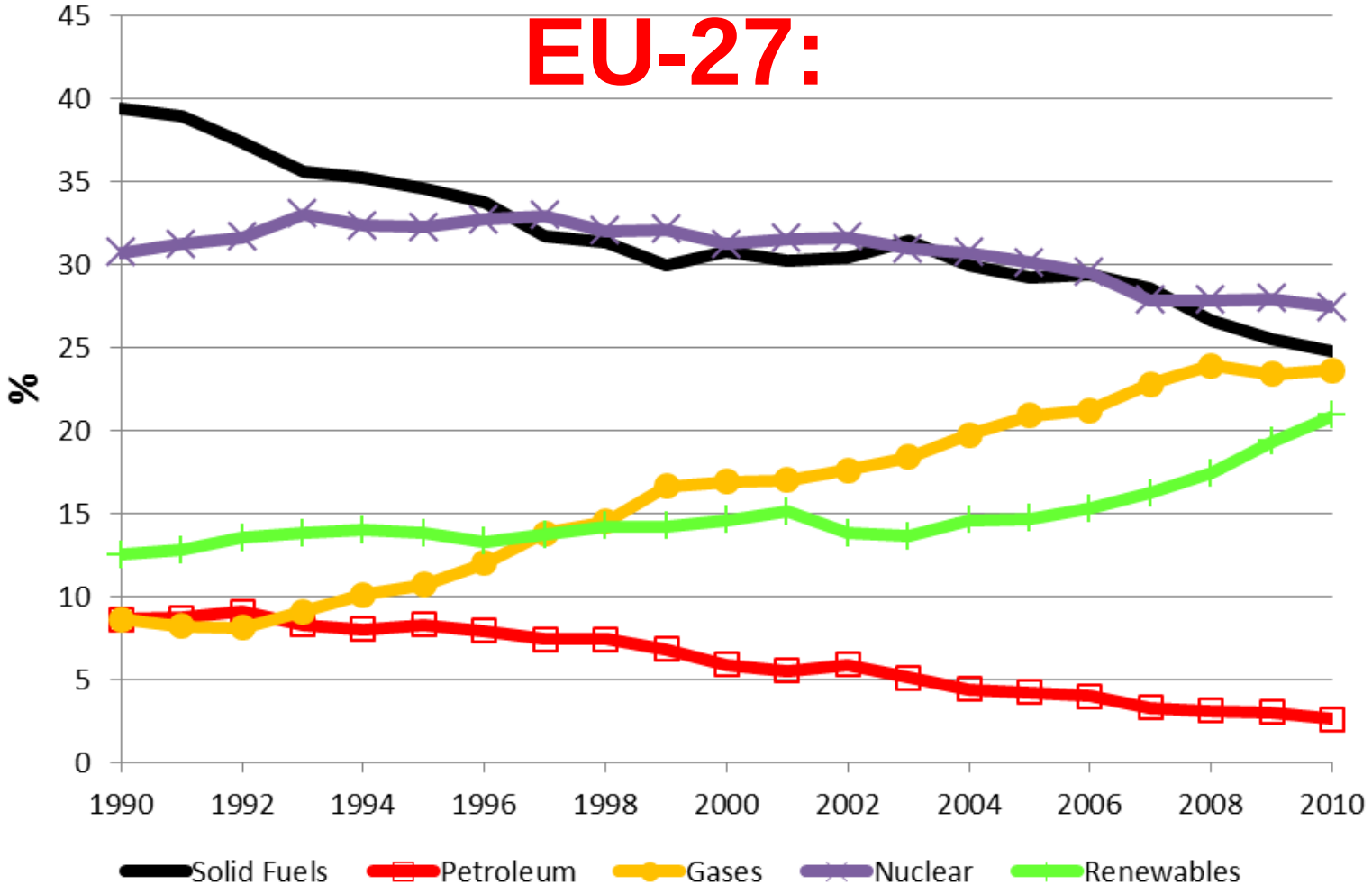
Imports:



Total 2010: ca. 1000 Mtoe

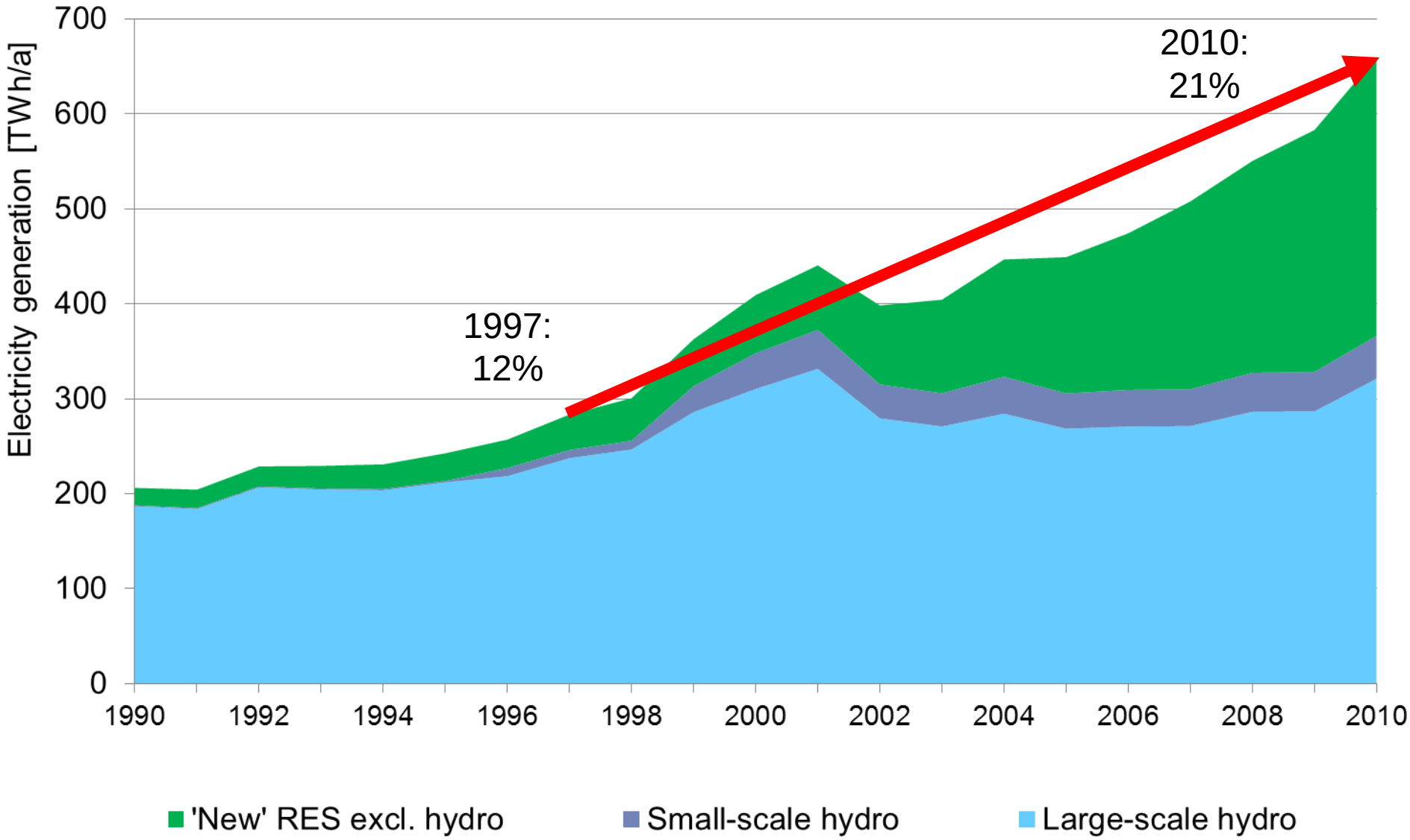
Source: EUROSTAT (2013)

Electricity generation EU-27:

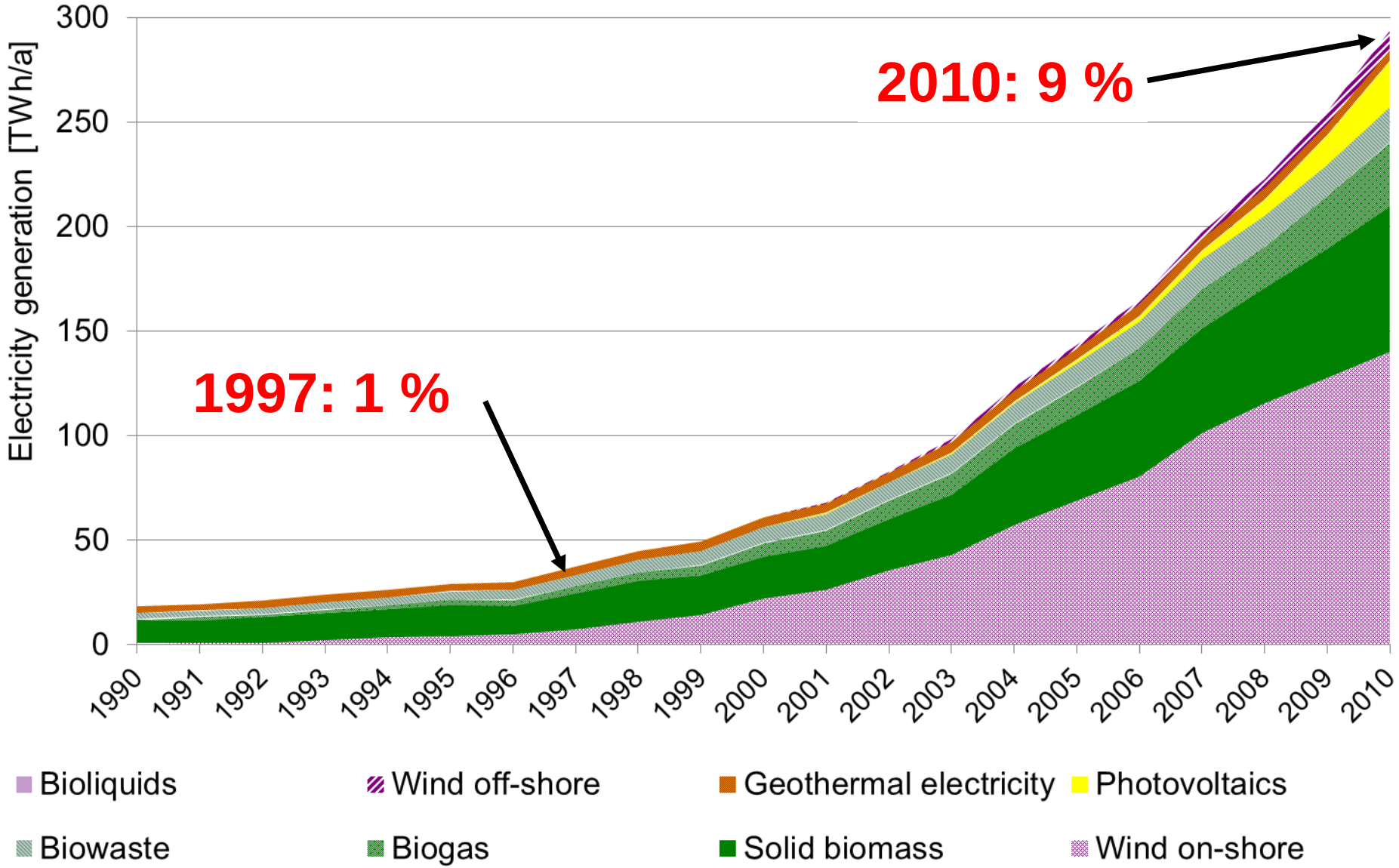


- ***steepest increase: natural gas;***
- ***RES from 12% to 21% in 2010;***
- ***Oil phasing out***

RES for electricity generation EU-27

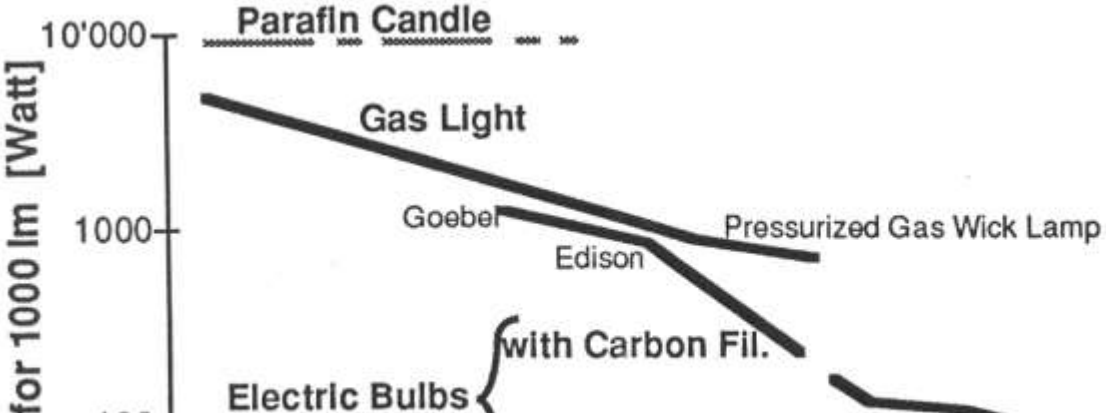


EU-27: Electricity generation from „new“ RES



6. Drivers of energy consumption

The example of LIGHTING



Most Important driver: Technological progress!

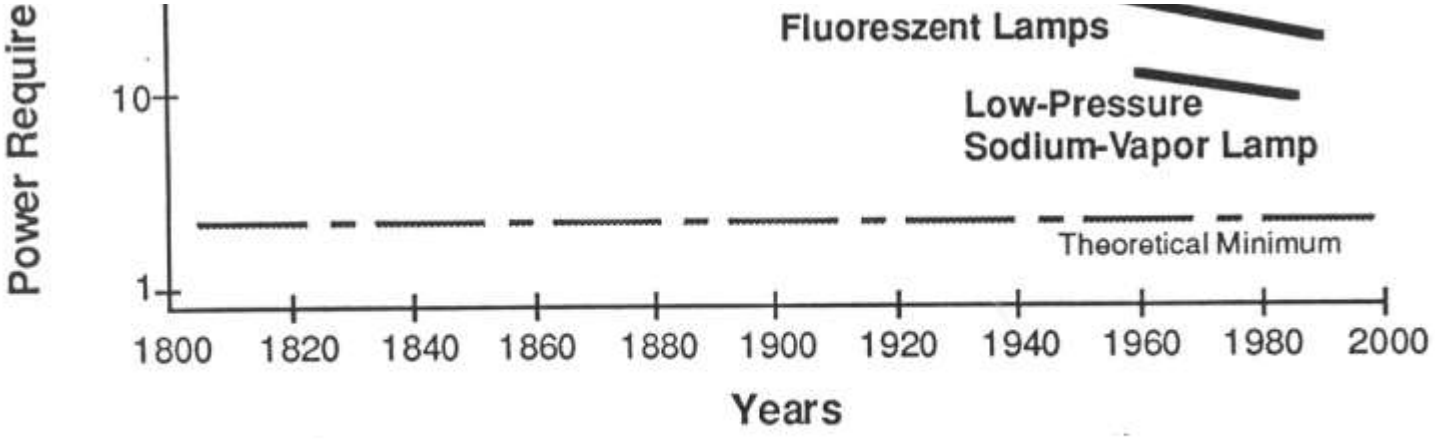
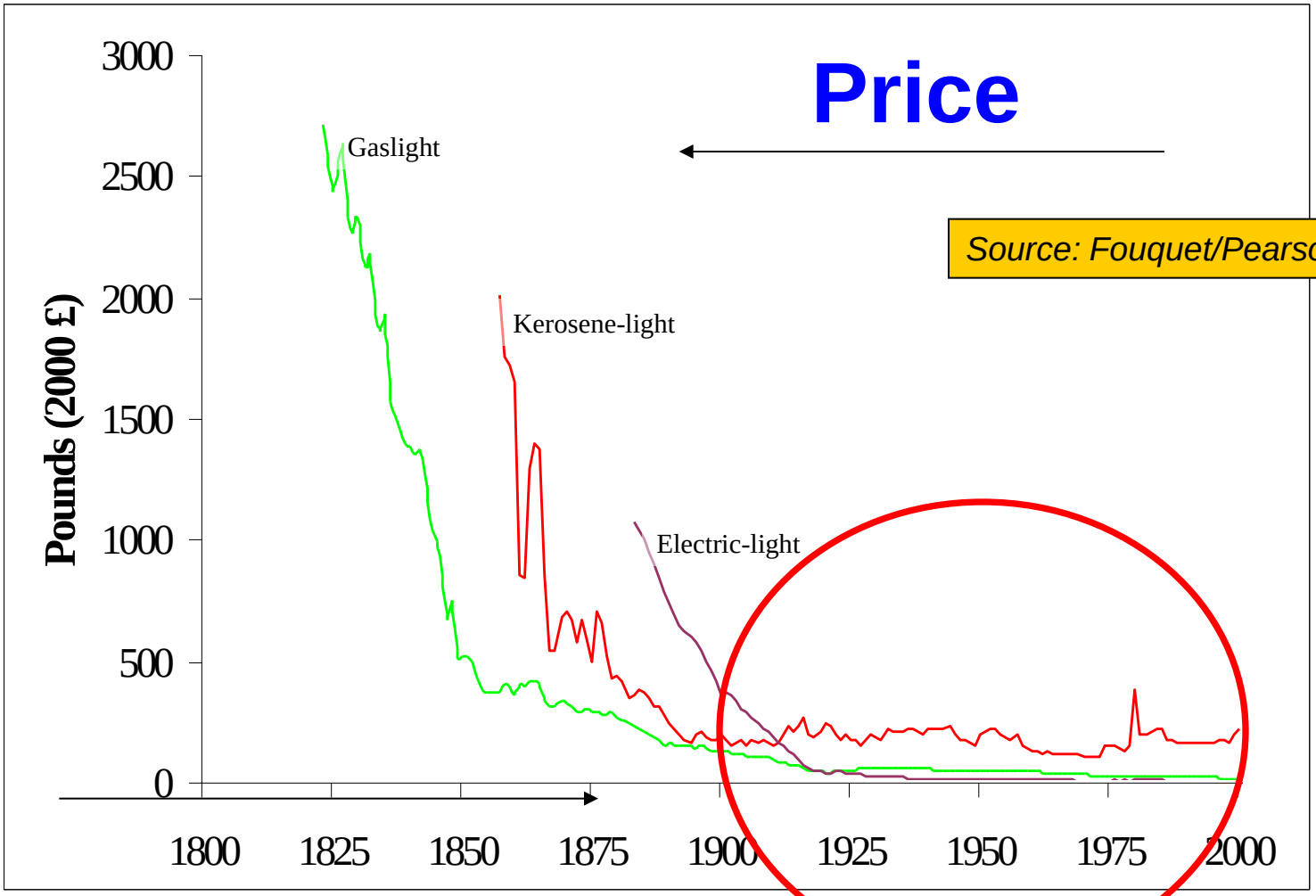


Figure 1: Technical development lead to a rapid decrease of power requirement for producing the same amount of light

The example of LIGHTING

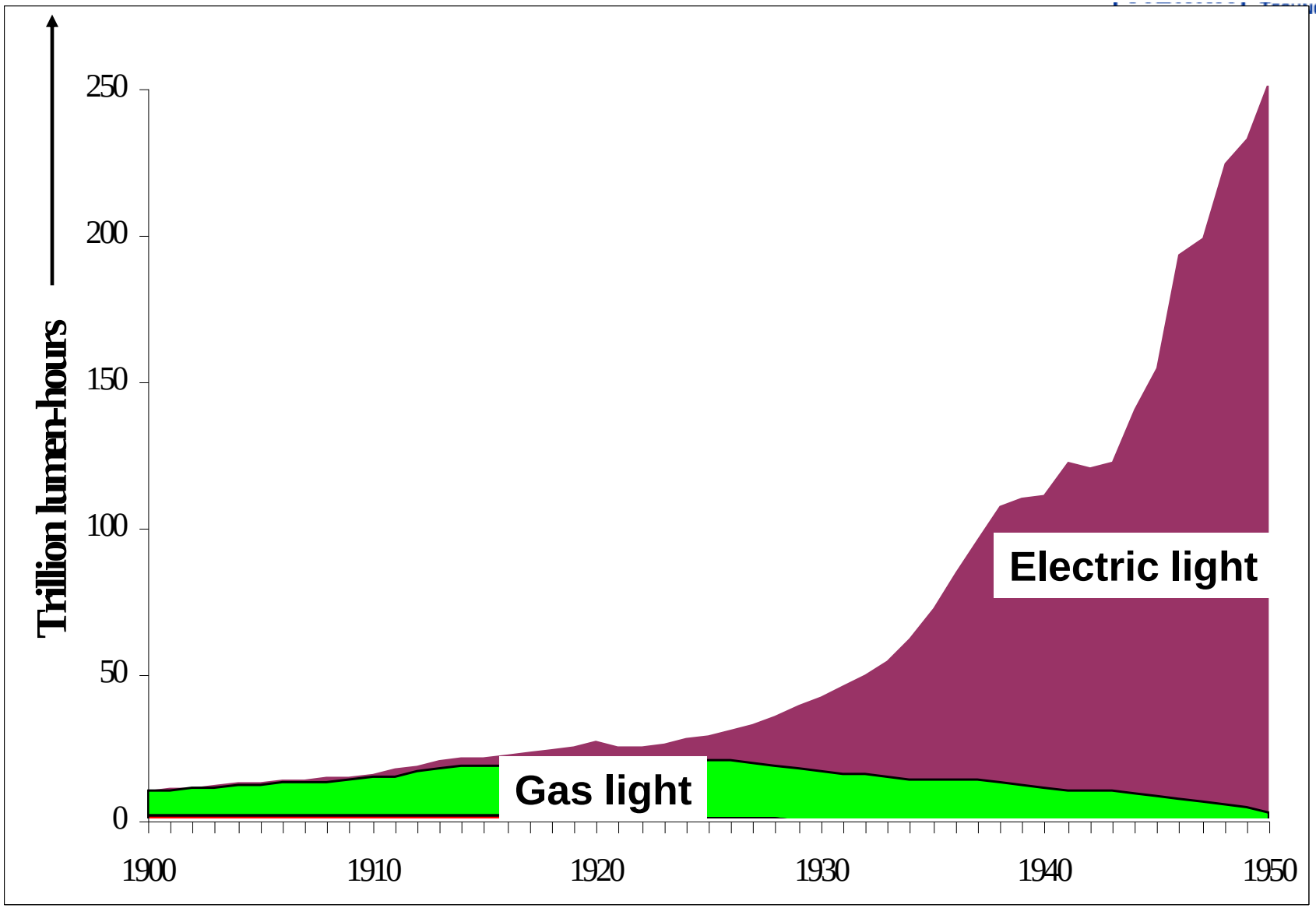
Figure 6. Price of Lighting from Gas, Kerosene and Electricity in the United Kingdom (per million lumen-hours), 1800-2000



Source: Fouquet/Pearson (2005)

Source: authors' own estimates – see Sections II.1.3-5 and II.3

The example of LIGHTING



Source: authors' own estimates – see Sections II.2.3-5 and II.3 Trillion: 10^{12} (i.e. one million million)

Source: Fouquet/Pearson (2005)

6. indicators of energy consumption

Further useful basic definitions:

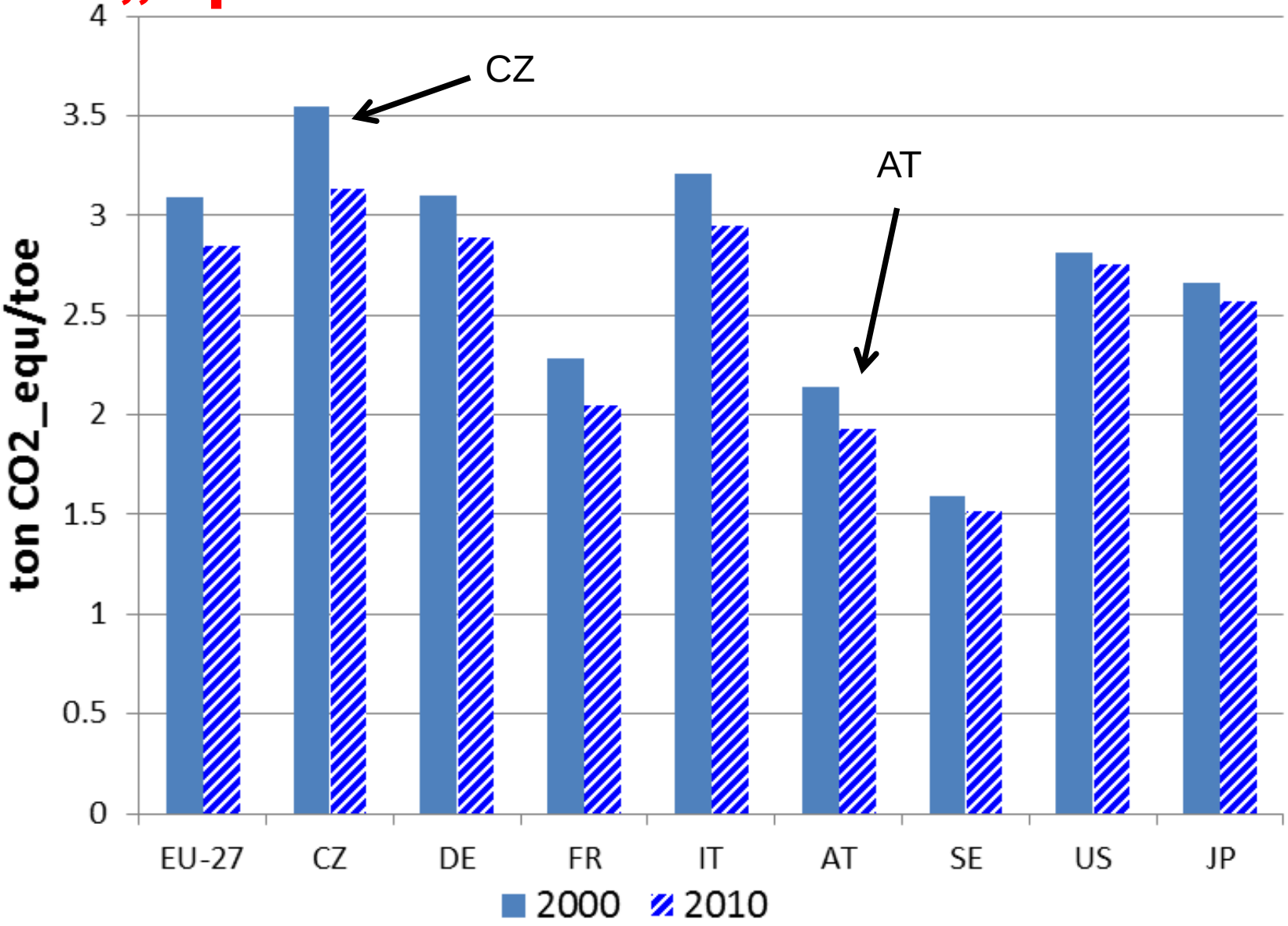
GDP…Gross Domestic product (EUR or $):

Total of all economic values produced in a country

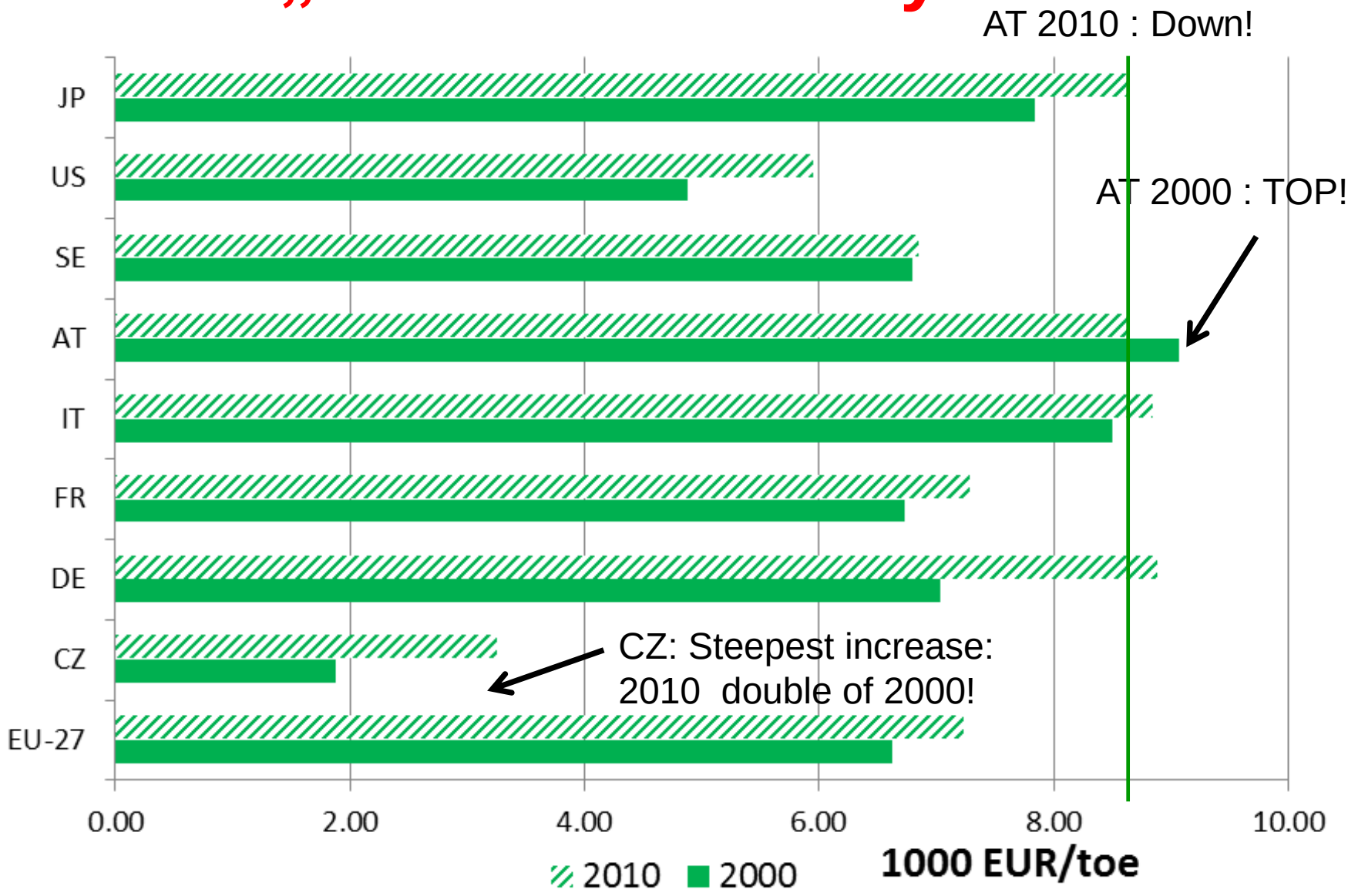
An indicator for measuring technological progress is Intensity:

Intensity is defined as Unit of energy consumption per GDP (e.g. MJ/1000 EUR)

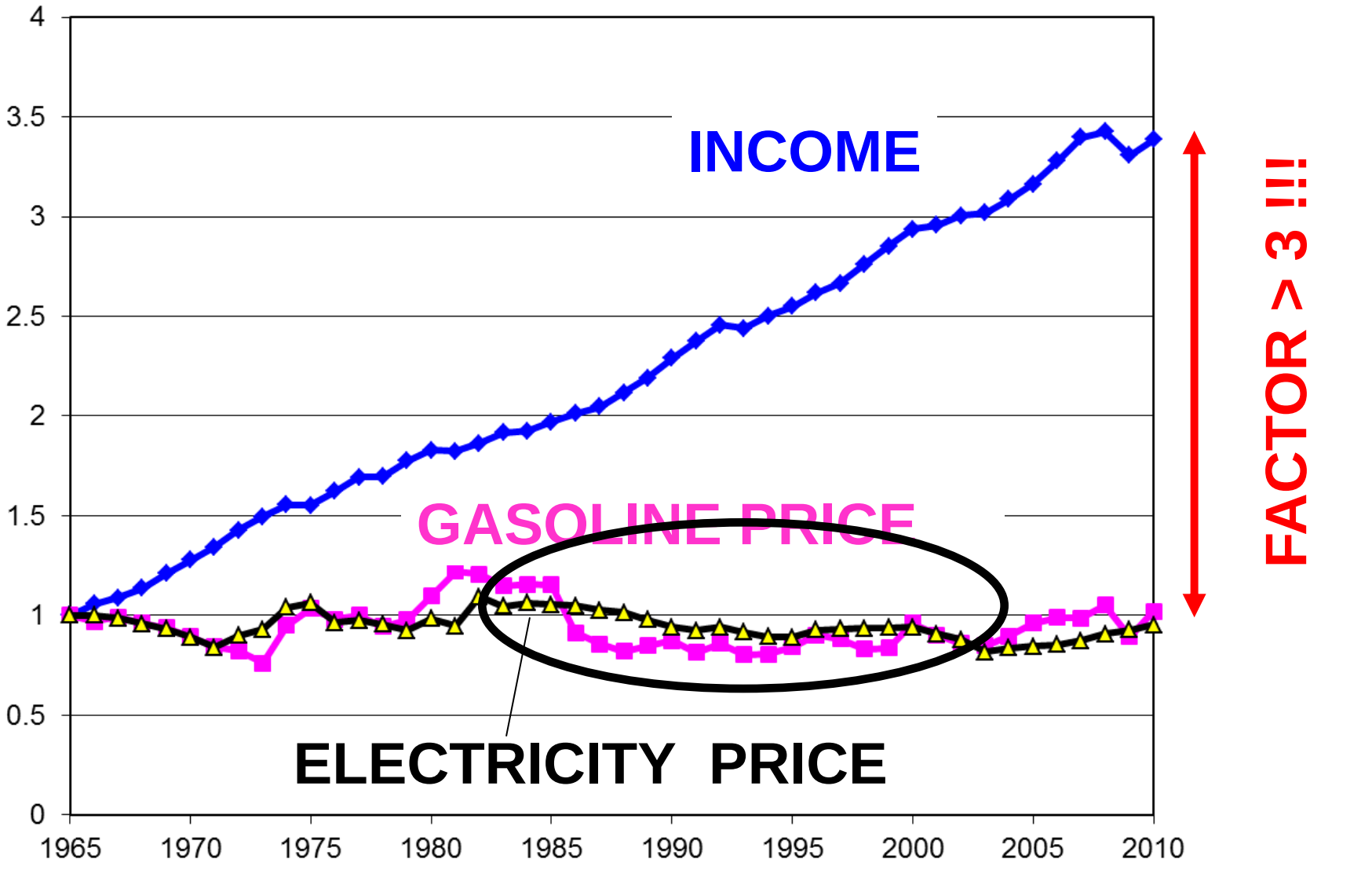
Indicator „Specific GHG emissions“



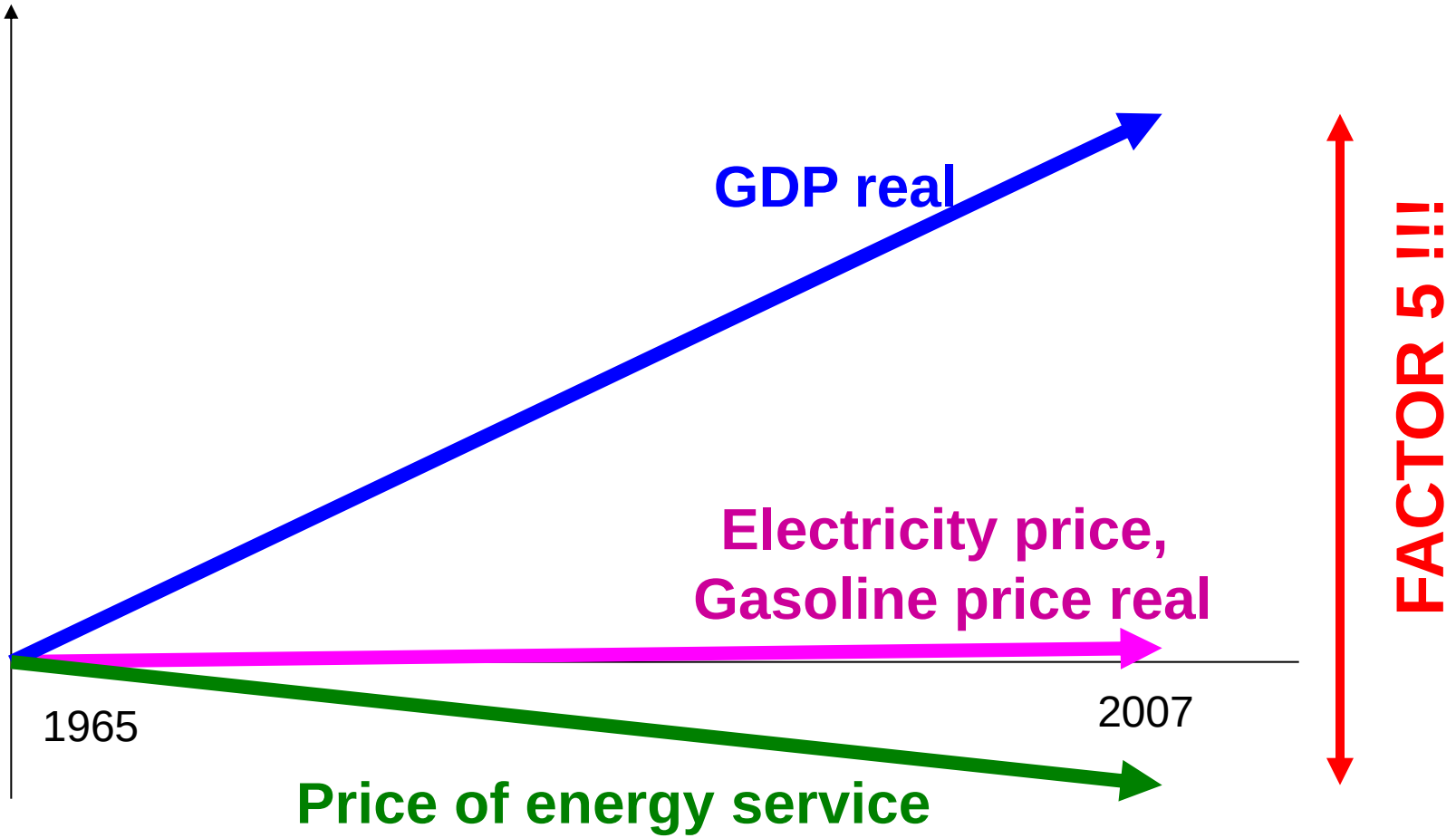
Indicator „Service efficiency“



Income vs Energy prices



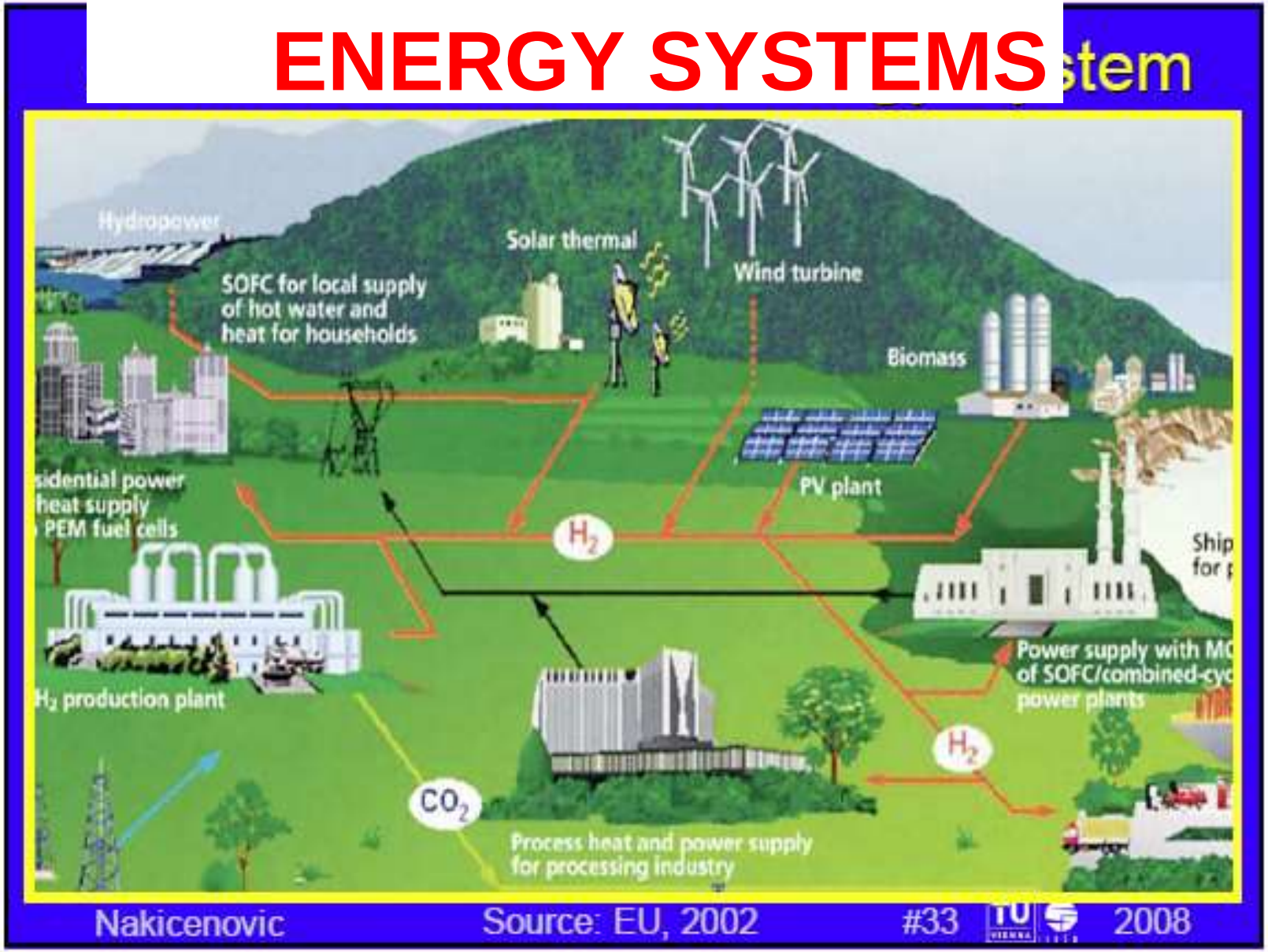
Indicators Austria: Income vs price of energy service



In the long run: technology was the driver:

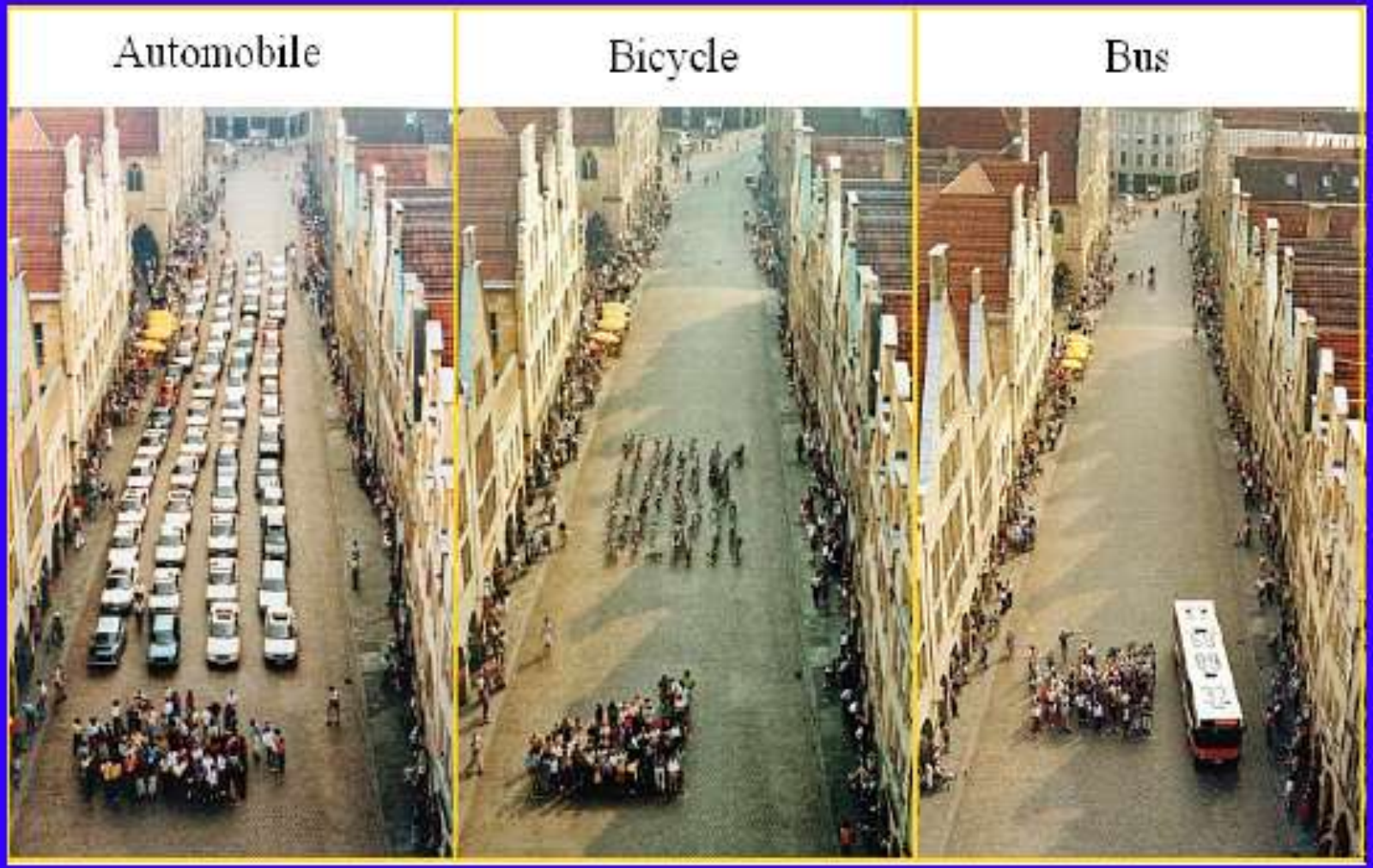
- → Cheaper energy (better exploration transport, Infrastructure technologies
- → Cheaper services (better lighting, heating, cooking technologies
- → Higher GDP: More services are produced in shorter time with less man-hours

7. VISIONS OF FUTURE ENERGY SYSTEMS



Verbund liegt die Stärke: Im Stromnetz der Zukunft sollen Solar- und Windenergie aus der Wüste
Wasserkraft in Skandinavien und regenerativen Erzeugungskapazitäten in ganz Europa vernetzt werden

Area Occupied by Various Transport Modes



References:

- EU/DGTREN/EUROSTAT (2012): Key trends in Energy and Transport
- EU: http://www.europa.eu.int/comm/energy/index_en.html (2012)
- Fouquet/Pearson: Seven centuries of energy service: Lighting The Energy Journal (2006)
- Fouquet/Pearson: Long run trends in energy service: Transport (2003)
- GEA: Global Energy assessment (2012)
- Haas et al: Towards Sustainable energy systems, Energy Policy, (2008)
- Nakicenovic/Haas: Scripts Energy Economics, 2012
- IEA: World Energy Outlook 2012 (Paris, 2012)
- IEA: Key world energy indicators 2011 (Paris, 2011)
- Nakicenovic et al: Energy Primer, IIASA (1997);

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