Biotechnologische Verfahren zur Nutzung nachwachsender Rohstoffe

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"We will harness the sun and the winds and the soil to fuel our cars and run our factories."

Barack Obama inauguration speech January 2009

Contents

The chaos in the units of energy

- k(Kilo) = 10^3, M(Mega) = 10^6, G(Giga) = 10^9,
  T(Terra)= 10^{12}, P(Peta)= 10^{15}, E(Exa)= 10^{18}
- 1 Kilo Watt hour (kWh) = 3600 Kilo Watt second = 3.6 Mega Watt sec = 3.6 Mega Joule; 1 TWa [1 Terra Watt year] = 31.5 EJoule,
- 1 cal(orie) = 4.19 Joule (1 Calorie = 1 Cal = 1000 cal)
- 1 TC (1 metric ton of coal equivalent) = 8.14 $\times 10^3$ kWh (caloric value)
- 1 ton crude oil (= 7.36 barrel oil) = 11.63 $\times 10^3$ kWh (caloric value)
- 1 m^3 natural gas (0.7 kg) = 10 kWh (caloric value)
- 1 ton dry biomass = 5 $\times 10^3$ kWh (caloric value)
- 1 Quad = 10^{15} Btu = 1.055 $\times 10^{18}$ Joule = 2.93 $\times 10^{11}$ kWh
- 1 Btu (British Thermal Unit) = 1055 Joule = 2.93 $\times 10^{-4}$ kWh

modified after Dr. Michael Dittmar/ETH Zürich

Order of magnitude of energy

- Energy of motion of a mosquito: 0.16 µJ
- Energy of the human heart for one heartbeat: 1 J
- Physiological caloric value of 1 g fat: 38 kJ
- Energy of motion of a human being during walking (1.4 m/s): 73.5 J
- Energy of motion of a car of 1t weight at 100 km/h: 386 kJ
- Per diem energy consumption of an adult woman (70 kg body weight, no motion): 6.3 MJ
- Energy release during combustion of 1 litre gasoline: 32 MJ
- Energy content of a lightning: 1 - 28 GJ
- Explosive force of the atomic bomb “fat man” over Nagasaki: 84 TJ
- Complete conversion of 1 kg matter ($E = m \cdot c^2$): $89.9 \cdot 10^{18}$ J
- Explosive force of the largest hydrogen bomb: $210 \cdot 10^{18}$ J
- Primary energy demand of Germany in 2004: $14.4 \cdot 10^{21}$ J
- Global primary energy demand in 2004: $430 \cdot 10^{21}$ J
- Per diem amount of energy emitted by the sun towards the earth: $10.7 \cdot 10^{24}$ J
- Energy generation of the sun per second: $384 \cdot 10^{27}$ J

Source: Wikipedia

Order of magnitude of power

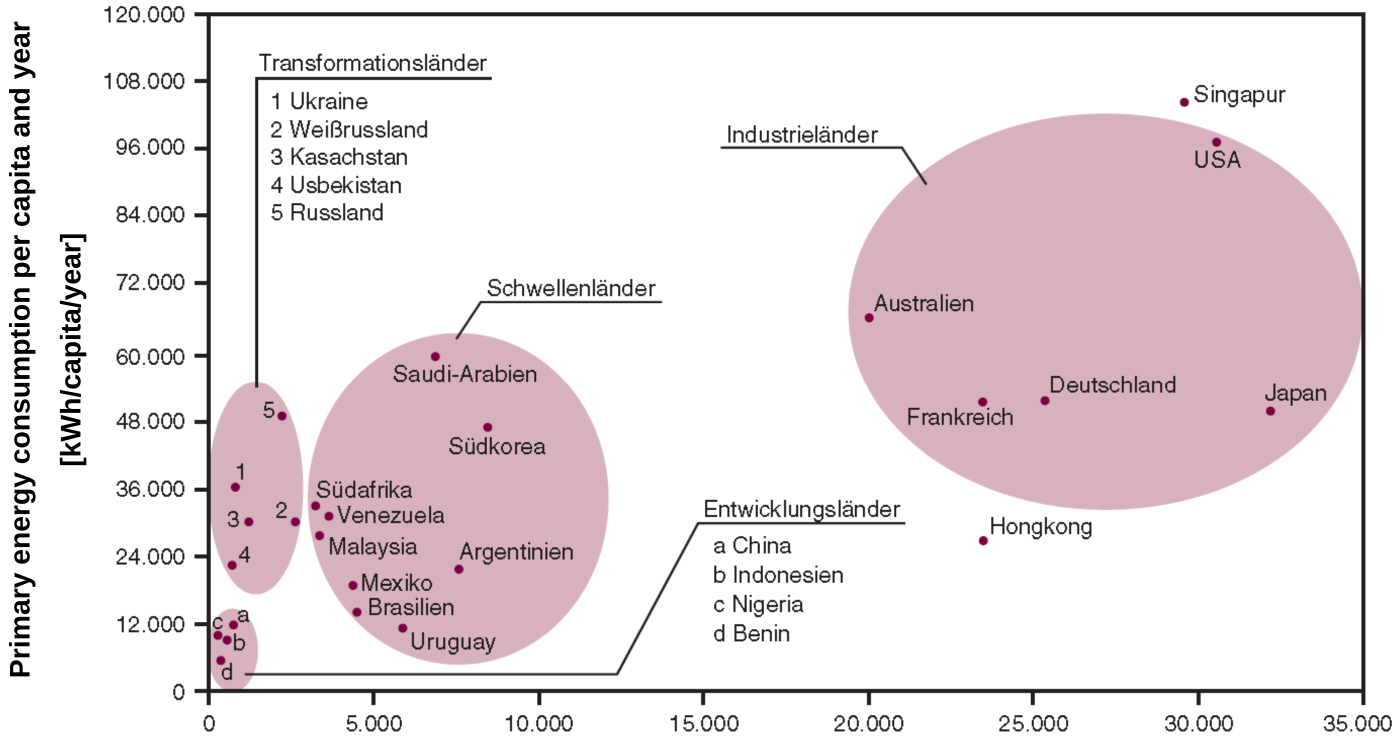
- Household electric light bulb: ca. 60 W
- Continuous output of a human being: 70 W
- Power output of an adult human being: ca. 200 W
- Refrigerator (during operation of compressor): ca. 200 W
- Continuous output of a horse (horse power, PS): ca. 735 W (historical definition: lifting 75 kg for 1 metre in 1 second)
- Electric fan heater: ca. 2 kW
- Central heating of a single family house (max. capacity): ca. 15 - 20 kW
- Car (max. capacity): 30 - 200 kW
- Wind power plant: ca. 800 - 3000 kW
- ICE 3 train (max. capacity): ca. 16 MW
- Coal power plant: ca. 500 - 800 MW
- Nuclear power plant: ca. 800 - 1500 MW
- Luminous flux of the sun: $3.86 \cdot 10^{26}$ W

Source: Wikipedia

Contents

Energy consumption as function of income, both per capita and year

Year 1997; Source: modified after WRI (2001) und World Bank (2001c)



Gross domestic product per capita and year

[US $/capita/year]

Population and GDP estimates

Region	2000 Popul. [10^6]	2000 pcGDP [10^3\$]	2025 Popul. [10^6]	2025 pcGDP [10^3\$]	2050 Popul. [10^6]	2050 pcGDP [10^3\$]
North America	306	30.6	370	40	440	50
Latin America	517	6.7	700	20	820	35
Europe	727	14.7	710	30	660	40
Africa	799	2.0	1260	12	1800	25
Asia	3716	3.6	4760	20	5310	35
World	**6065**	**6.3**	**7800**	**20**	**9030**	**33**

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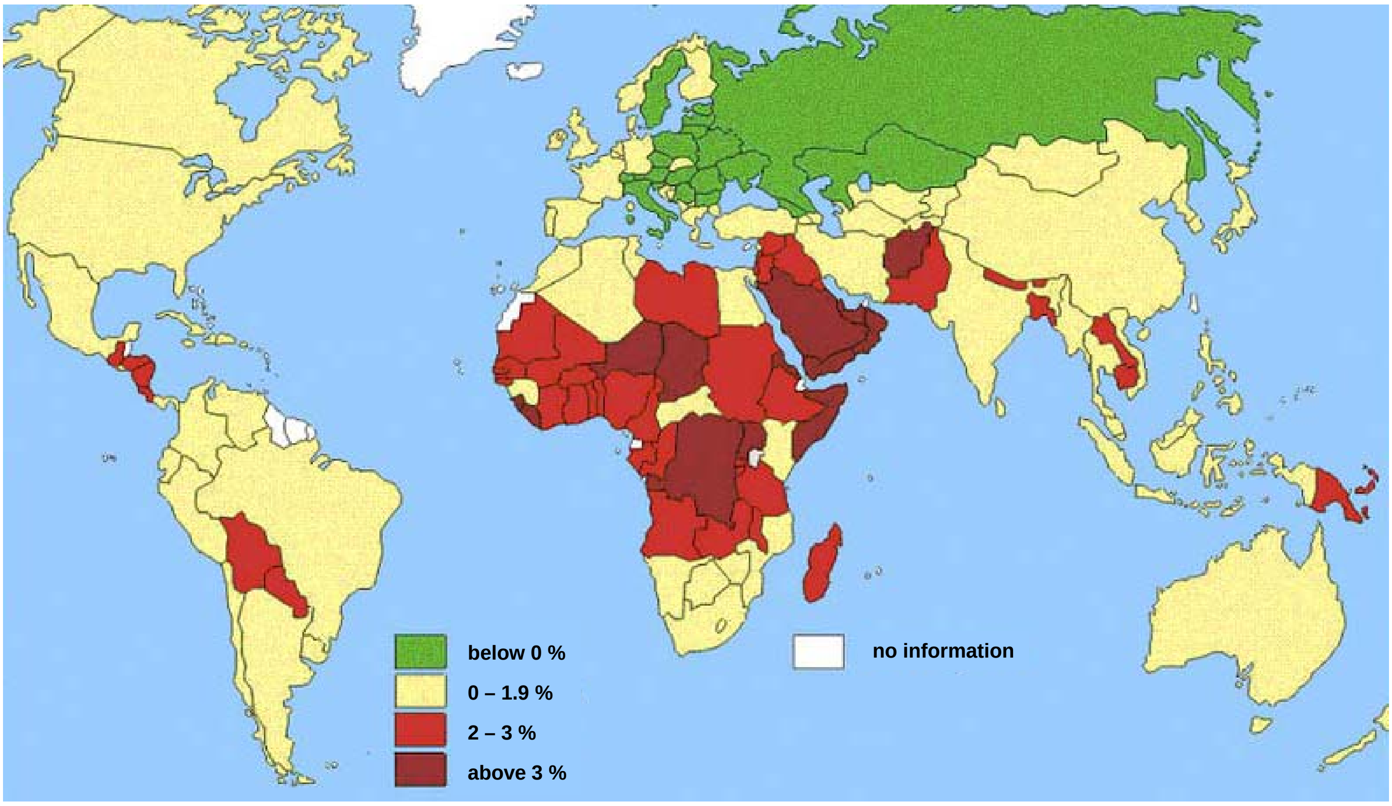
pcGDP: per capita gross domestic product = Bruttosozialprodukt

Regional distribution of population growth 2000 - 2005



www.wikipedia.de

Medium term economic trends

Much slower growth in the developed world

Accelerating growth in the developing world

World population stabilizing at 9-10 billion

6-7 X world GDP growth over next 50 or so years
(in constant dollars)

5-6 X existing production capacity for most commodities (steel, chemicals, lumber, etc.)

3.5 X increase in energy demand

7 X increase in electricity demand

J. Siirola, Eastman

Contents

1) Fundamentals

2) Total energy and material demand

3) Availability of resources

4) Life style of the population

5) CO_2 increase and global warming

6) Availability of solar energy

7) Necessity of exploit biomass

8) Fundamentals of photosynthesis

9) Type of biomass and yields

Global reduced carbon

	Reserves
Recoverable oil:	120 GTC
Recoverable gas:	75 GTC
Recoverable coal:	925 GTC
Estimated oil shale:	225 GTC
Estimated tar sands:	250 GTC
Possible methane hydrates:	??? GTC

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Global carbon storage

Terrestrial biomass:	500 GTC
Peat and soil carbon:	2000 GTC
Atmospheric CO_2 (380ppm$_v$):	750 GTC
Estimated oceanic inorganic carbon (30ppm):	40000 GTC
Estimated limestone / dolomite / chalk:	100000000 GTC

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Global carbon turnover

- Annual terrestrial biomass production: 60 GTC/year
  (more than half in tropical forest and tropical savanna)
- Current cultivated crop production: 6 GTC/year
  (future crop requirement: 9 GTC/year in 2055)
- Carbon emissions: 7 GTC/year
  (growing to 26 GTC/year in 2055)
- Organic chemical production: 0.3 GTC/year
  (future chemical demand: 1.5 GTC/year)

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Global Oxidized Carbon

- Current cultivated crop production: 6 GTC/year
  (Future crop requirement: 9 GTC/year in 2055)
- Future energy requirement : 26 GTC/year
  (same energy mix)
- Future energy requirement : 37 GTC/year
  (from coal or biomass; plus significant energy requirement to dehydrate biomass)
- Future transportation fuel: 12 GTC/year
  (carbon content only)

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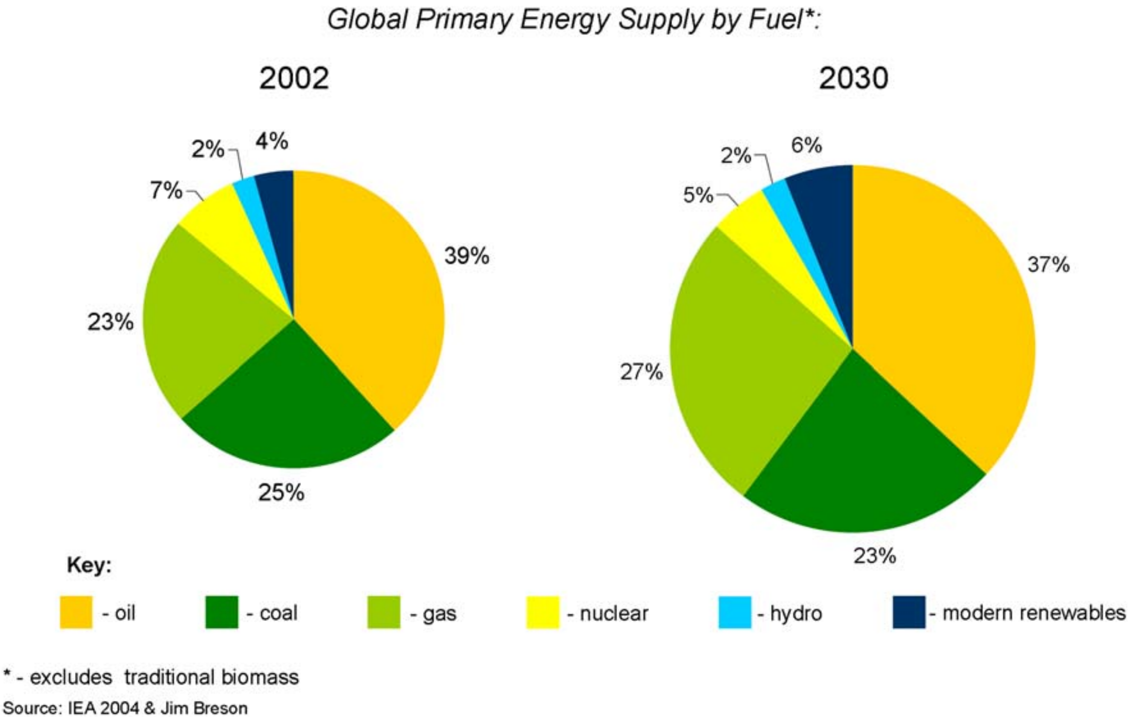
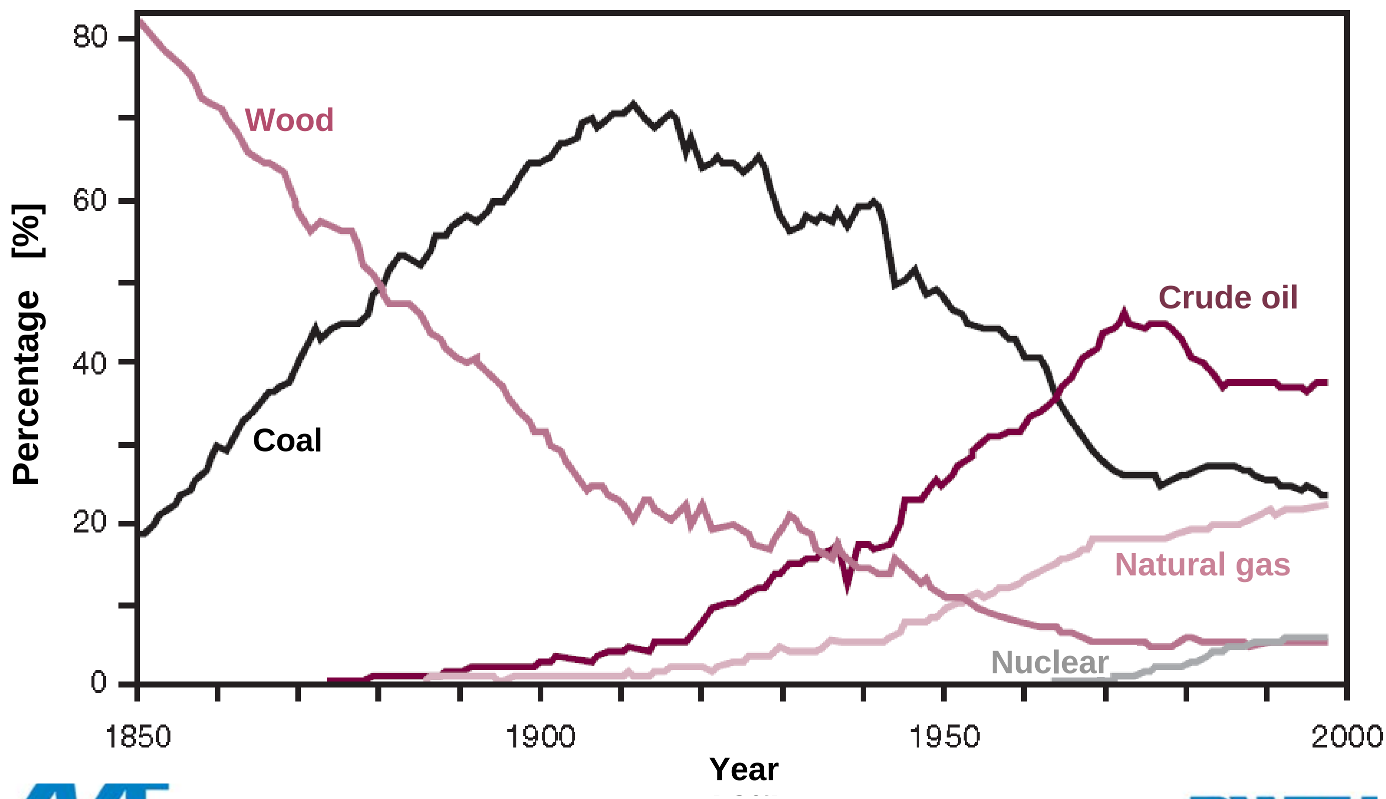
Current and predicted energy use

Current global average use 13 TW (3.3 TW USA)



Portion of different energy sources on world primary energy demand

Source: Nakicenovic et al., 1998



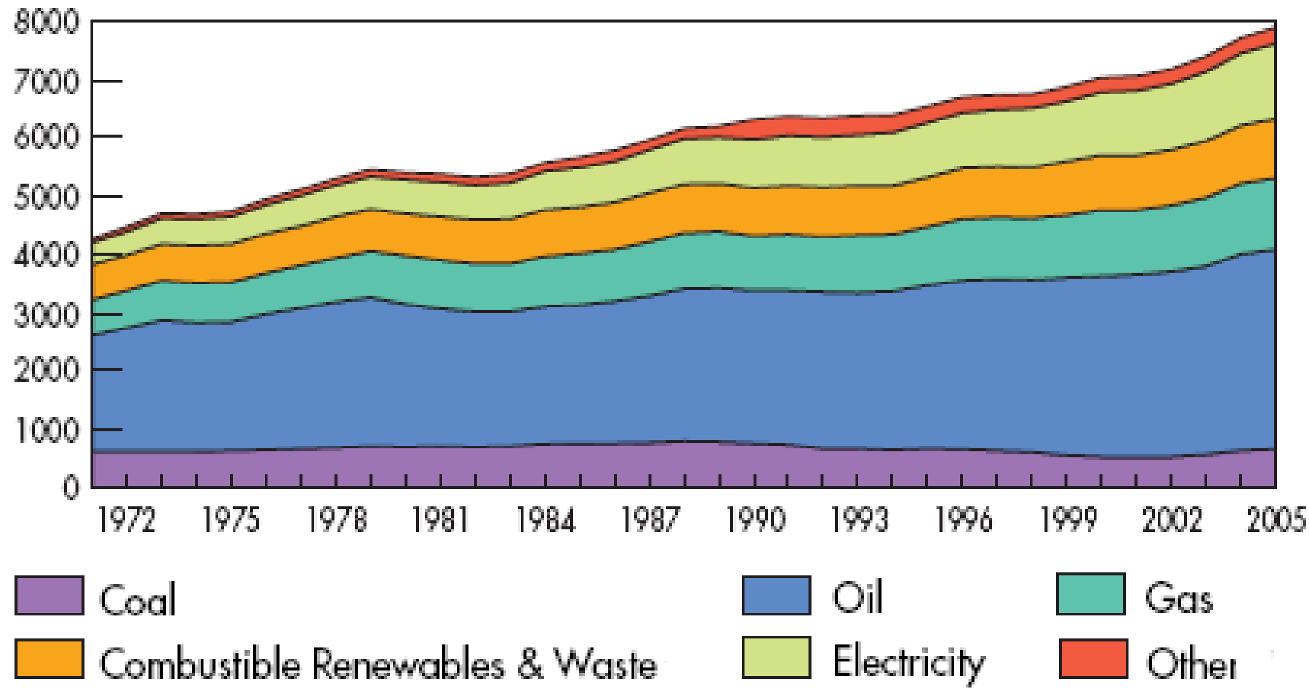
Proportions of various energy sources in the world's total primary energy supply in 2005

Source of energy	Energy (EJ)	Share
Coal	121	25.3%
Oil	168	35.0%
Natural gas	99	20.7%
Nuclear	30	6.3%
Hydropower	11	2.2%
Combustible renewables and waste	48	10.0%
Others	2	0.5%
Total	479	100%

IEA. Key world energy statistics. Paris. Available at: http:// www.iea.org/textbase/nppdf/free/2007/key_stats_2007.pdf

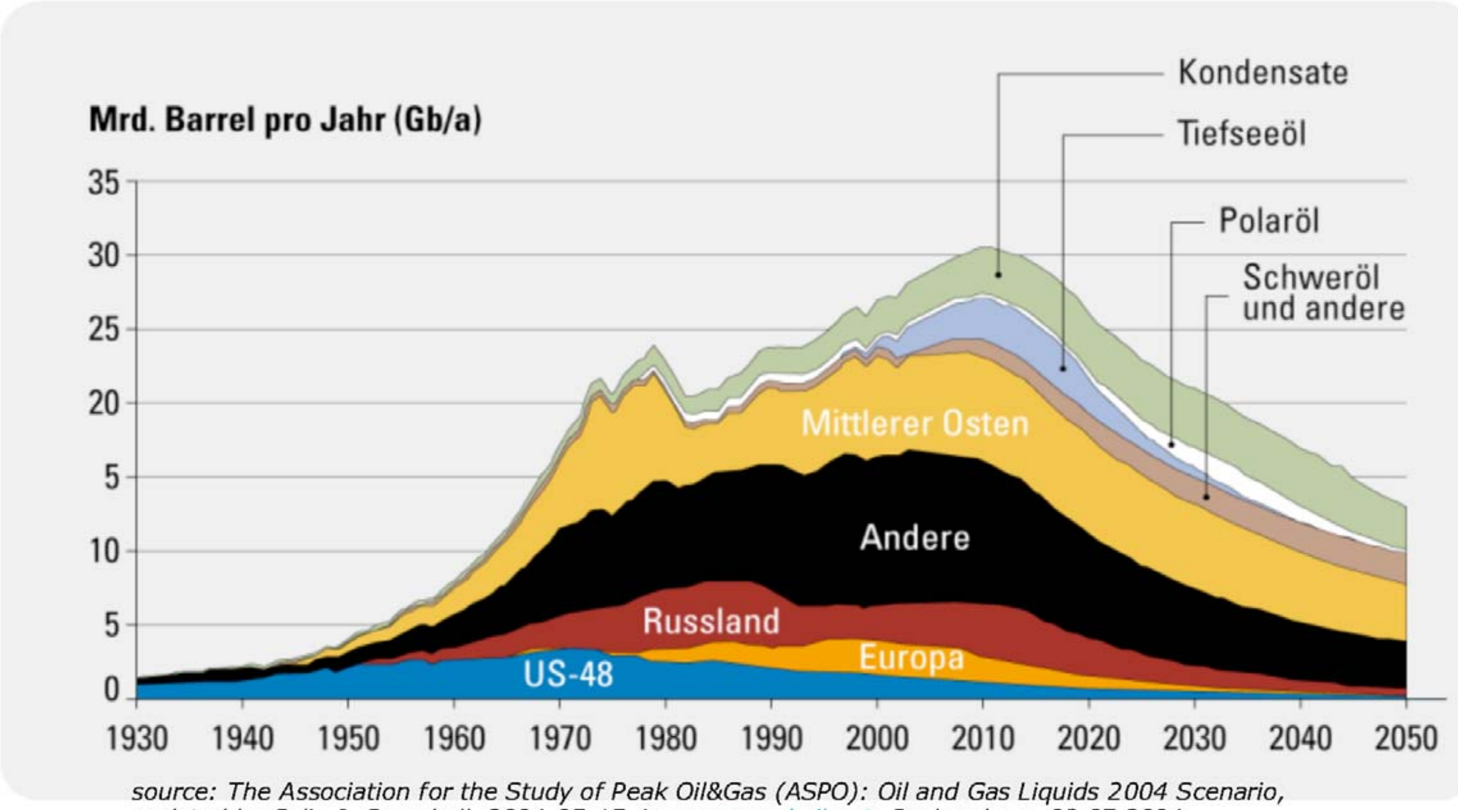
World total primary energy consumption

Evolution from 1971 to 2005 of World Total Final Consumption by fuel (Mtoe)



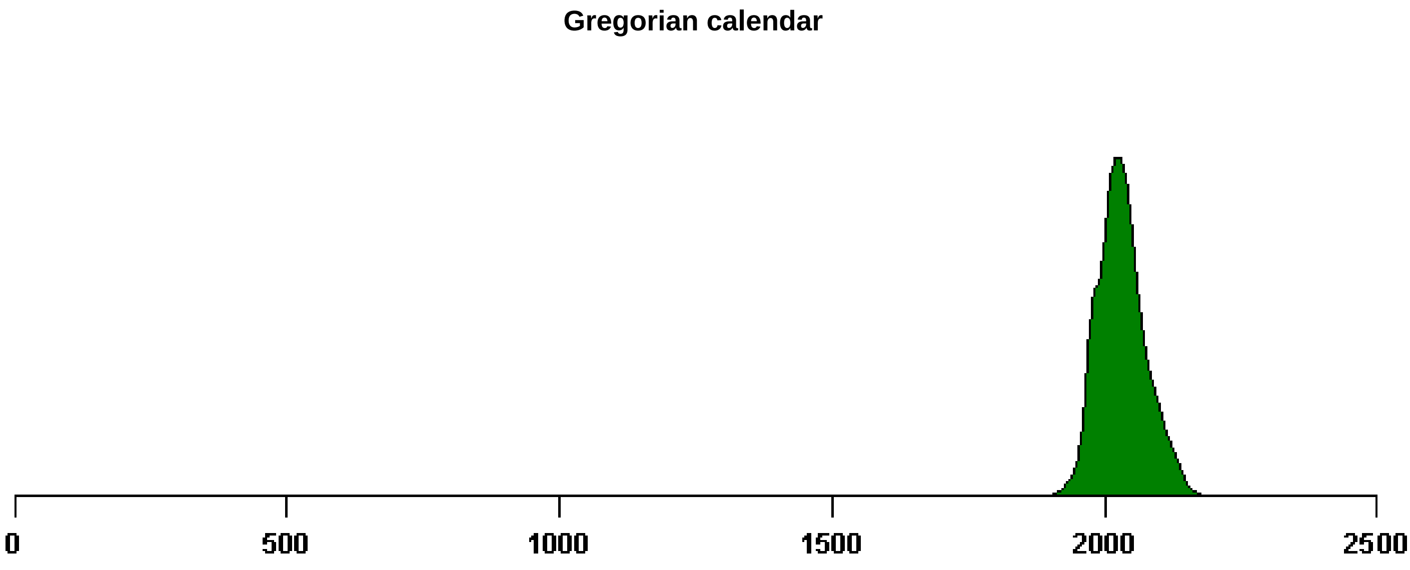
IEA. Key world energy statistics. Paris. Available at: http:// www.iea.org/textbase/nppdf/free/2007/key_stats_2007.pdf

History and forecast of crude oil production



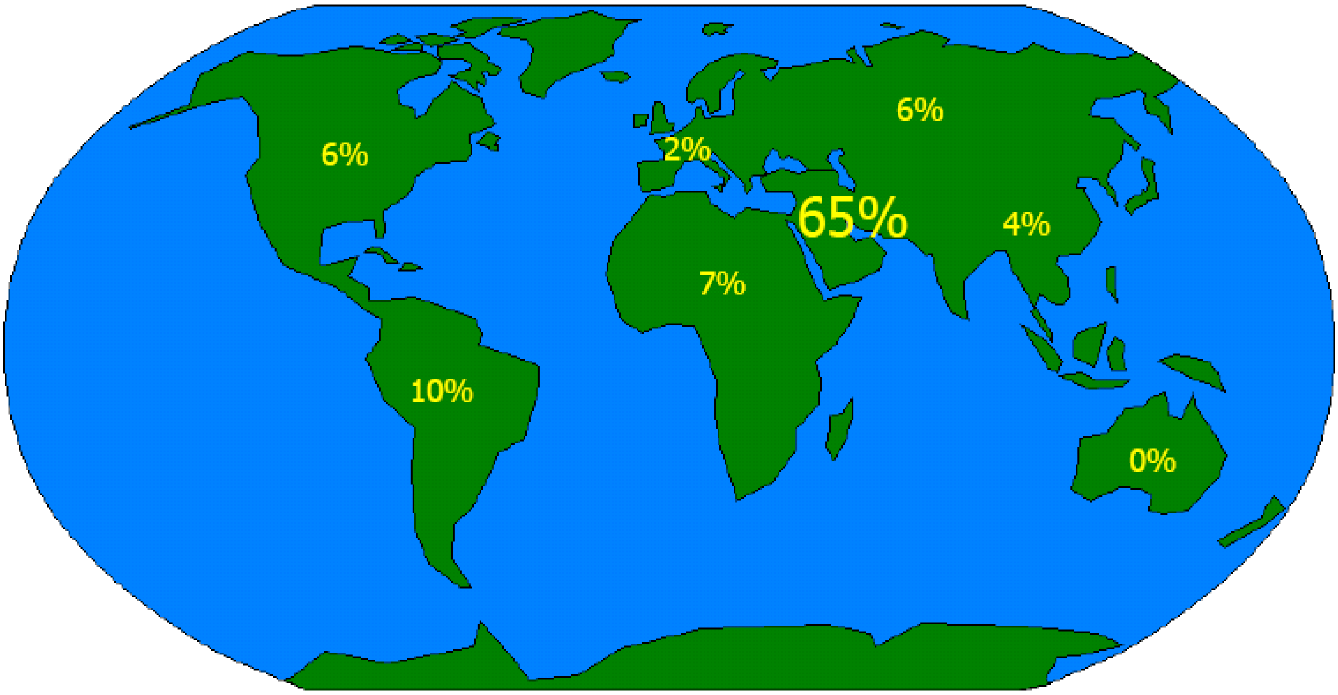
source: The Association for the Study of Peak Oil&Gas (ASPO): Oil and Gas Liquids 2004 Scenario, updated by Colin J. Campbell, 2004-05-15, in: www.peakoil.net, Recherche v. 08.07.2004

Crude oil utilization in the period of 2500 years



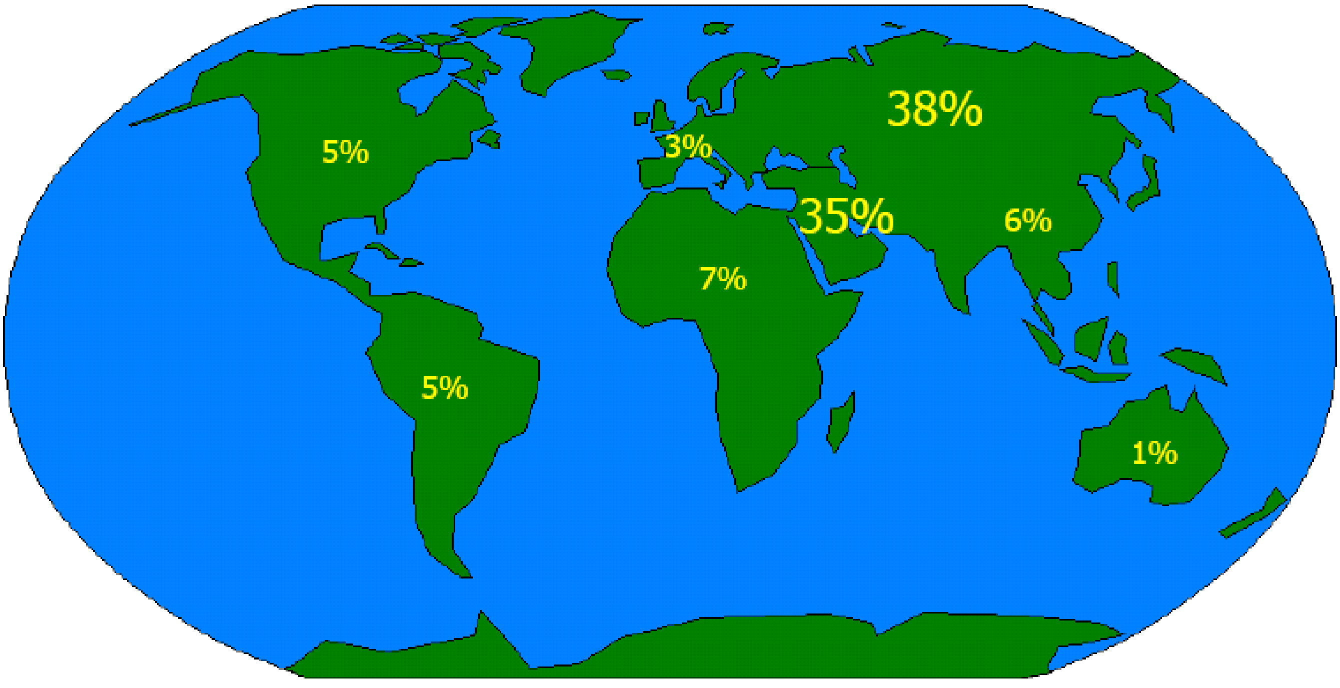
Source: BGR

Global distribution of crude oil reserves



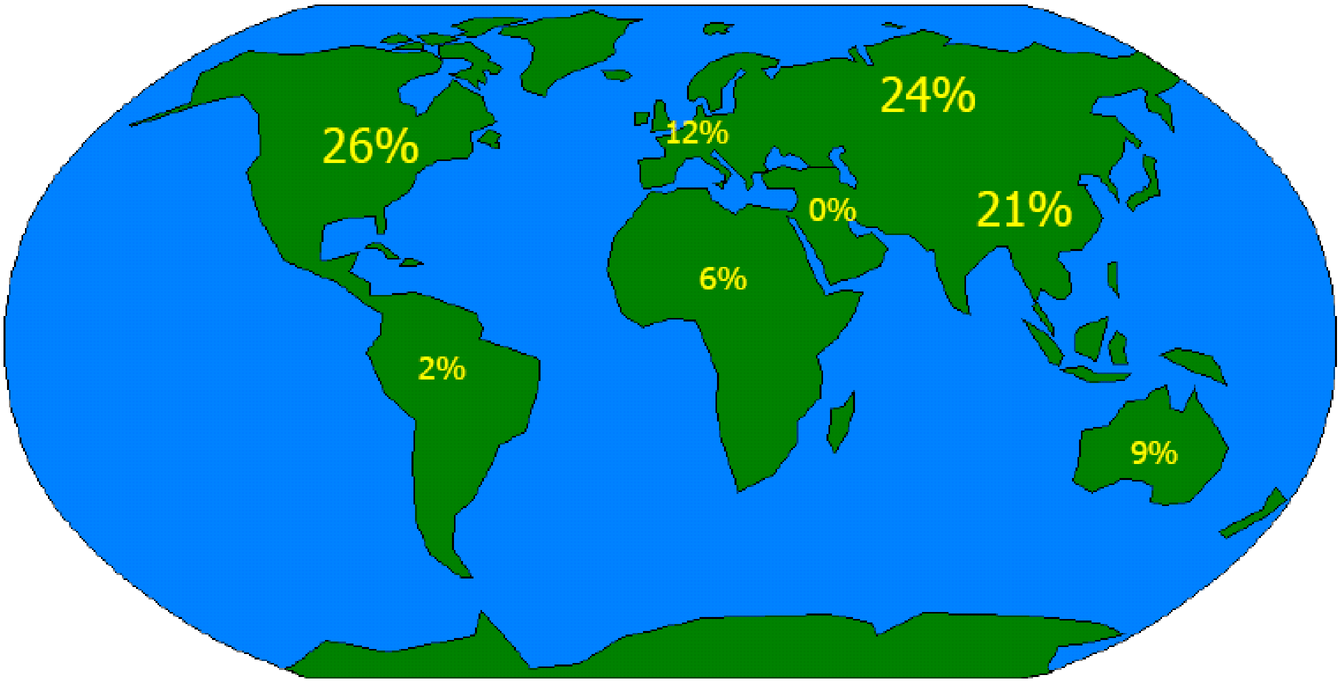
Source: Biomasse-Vorlesung ITC-C PV, KIT

Global distribution of natural gas reserves



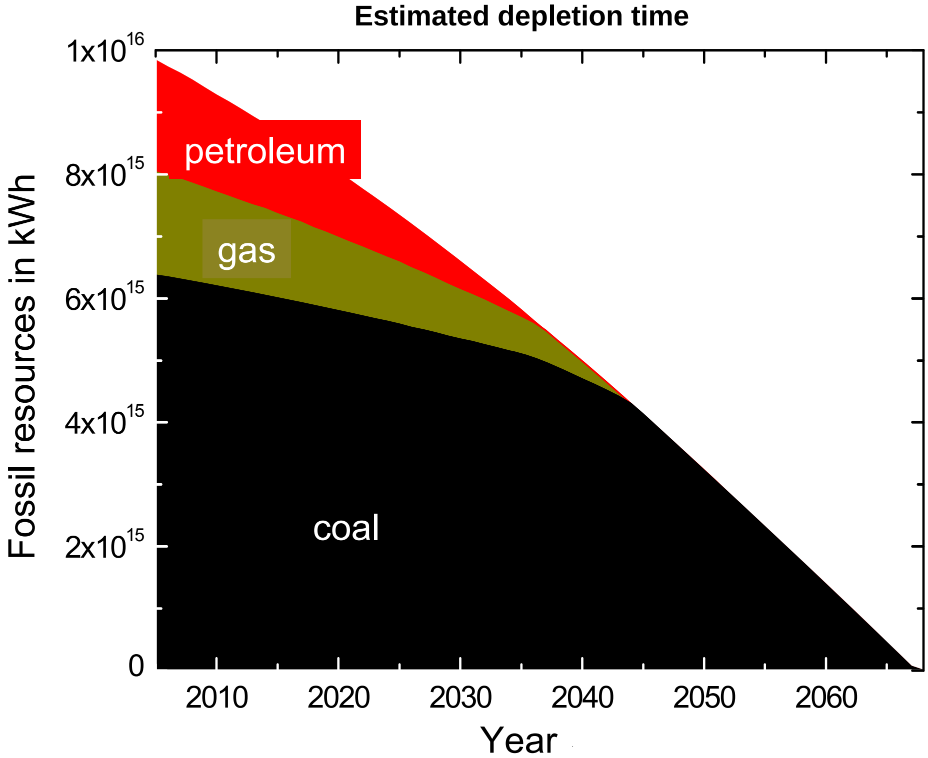
Source: Biomasse-Vorlesung ITC-C PV, KIT

Global distribution of coal reserves



Source: Biomasse-Vorlesung ITC-C PV, KIT

Fossil resources are limited



Much earlier the prices will increase to such a high level that processes used today will not be economically feasible anymore.

Estimated depletion time of fossil fuels (coal, oil, and gas), if no other energy sources would be used

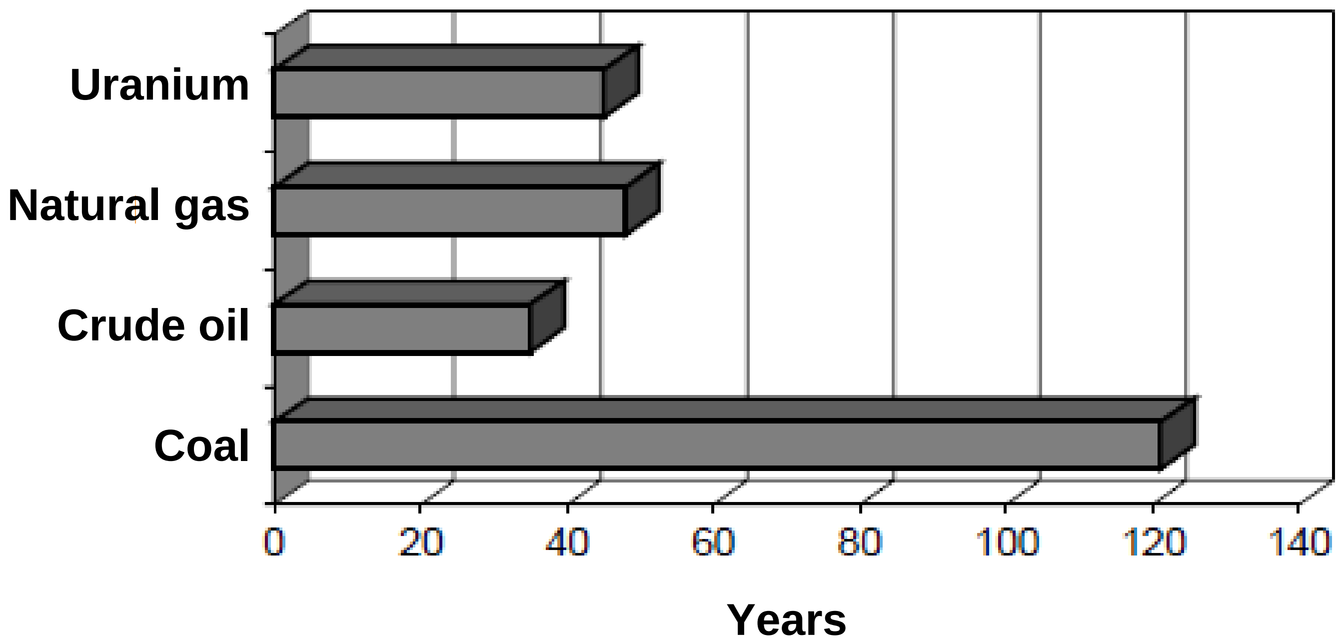
German: “Reichweite”

Estimated resources of fossil fuels **9.84×10^{15} kWh**

	Global world population	Use of energy	Depletion time
Today	6.50 bn	19 069 kWh/capita	79 a
Perspective for the future			
Low UN population prospect for 2050	7.79 bn	27 200 kWh/capita	46 a
Medium UN population prospect for 2050	9.19 bn	27 200 kWh/capita	39 a
High UN population prospect for 2050	10.76 bn	27 200 kWh/capita	34 a

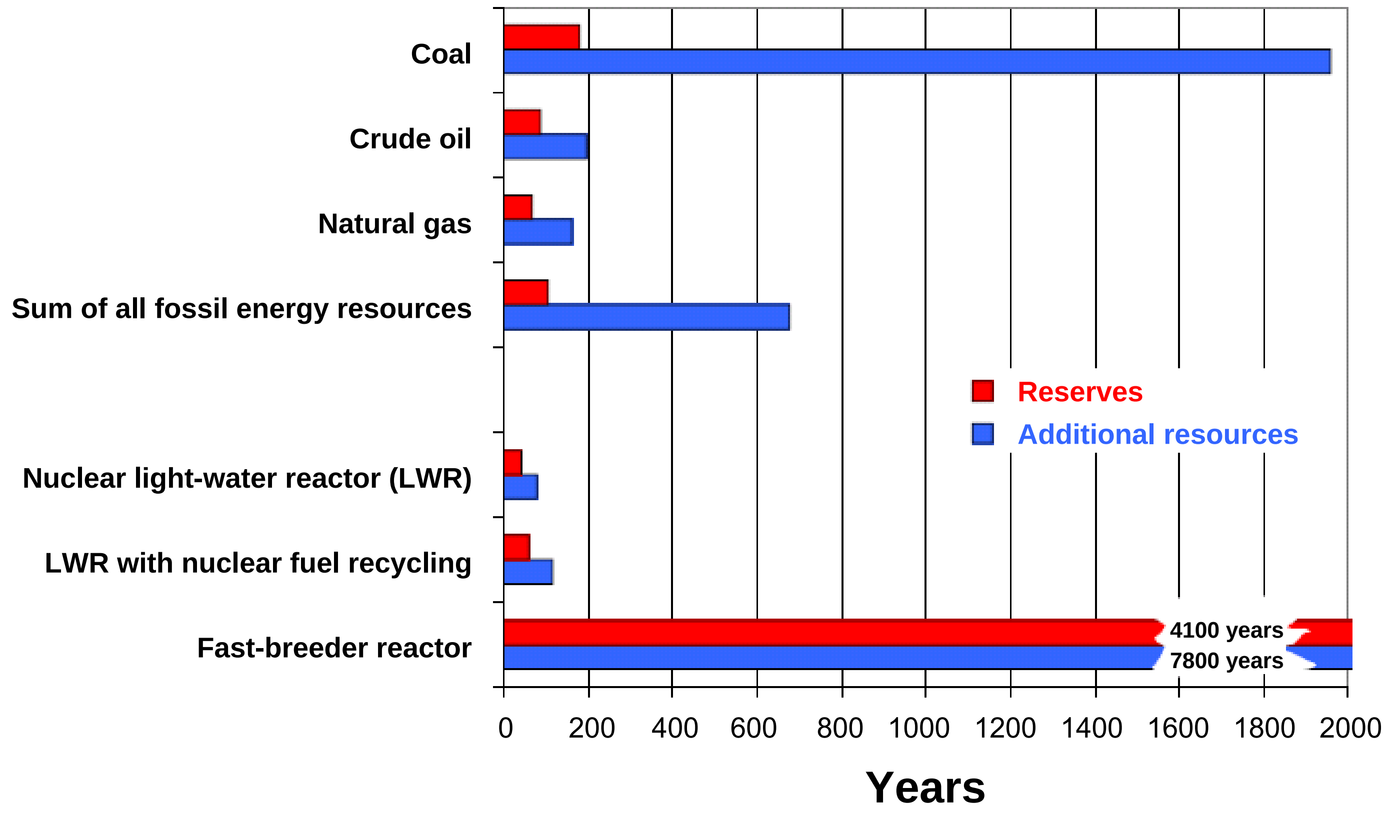
http://www.gvst.de/site/steinkohle/pdf/GVSt_JB-2006.pdf, 28.06.2007

Estimated depletion time of non renewable resources



from Offner 1997

Estimated depletion time of non renewable resources



Source: Biomasse-Vorlesung ITC-C PV, KIT

Contents

The vision of the 2000 W per capita energy consumption society

Current per capita energy consumption in Germany: 5000 W *

Physiological power: 100 W

⇒ Every citizen has 50 “energy slaves”

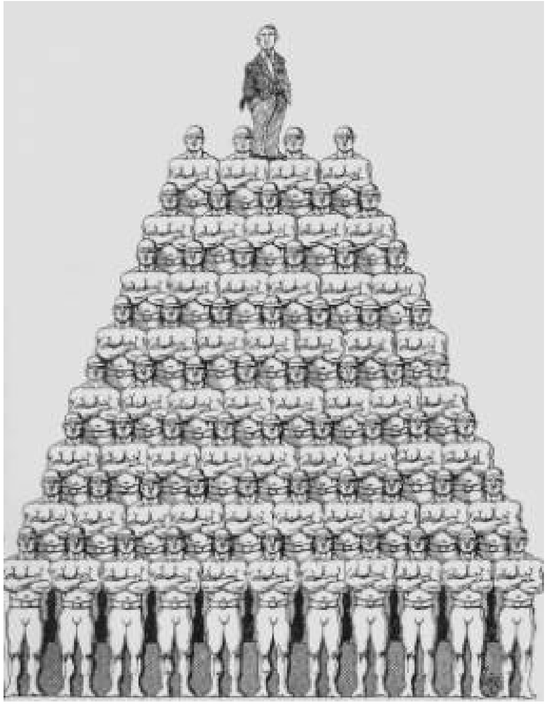
Rom: 5 slaves in rich families

Vision:

2000 W society

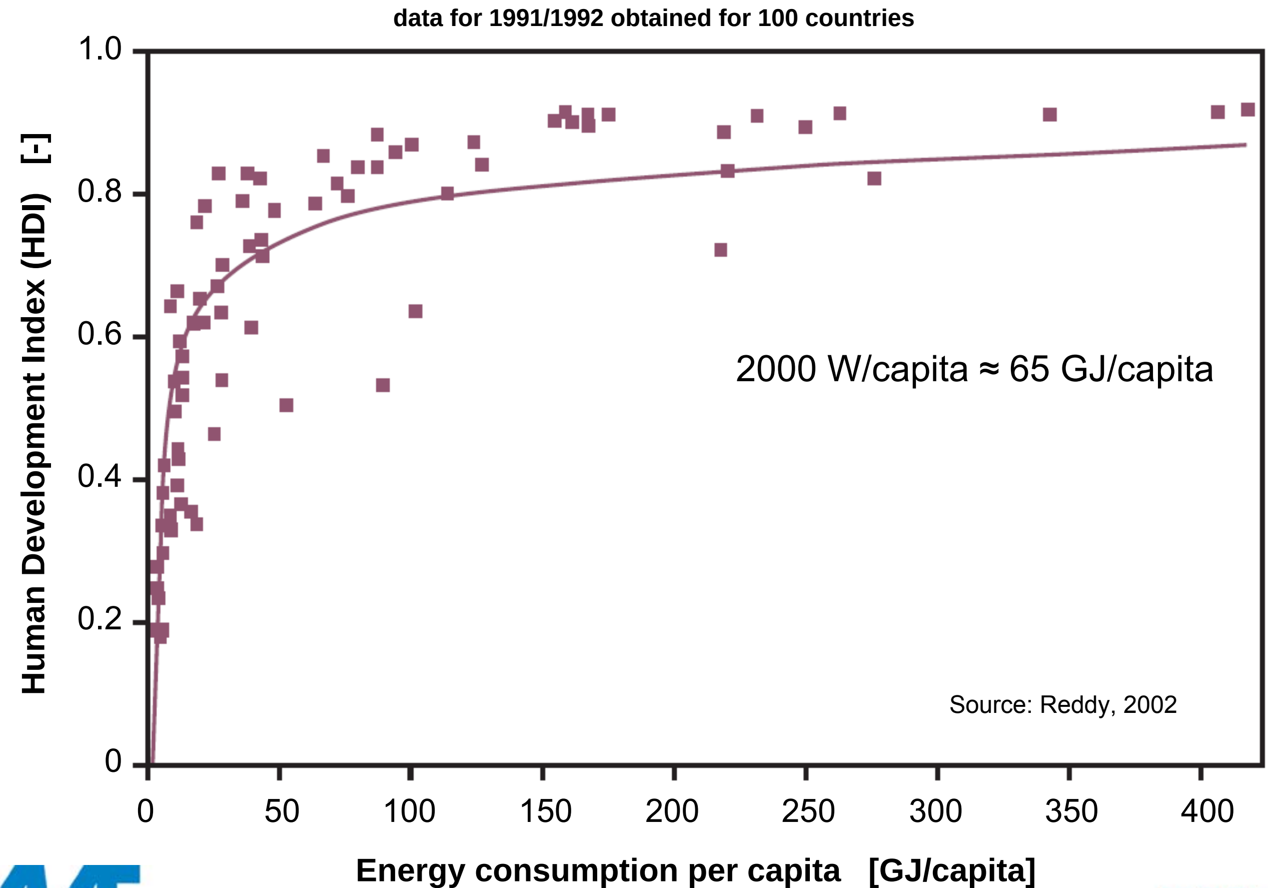
This refers to the current global value

This refers to the value in Germany 1960 !



*** without “grey energy”, i.e. required for the manufacturing of a product, about 1 kWh/EUR in Germany**

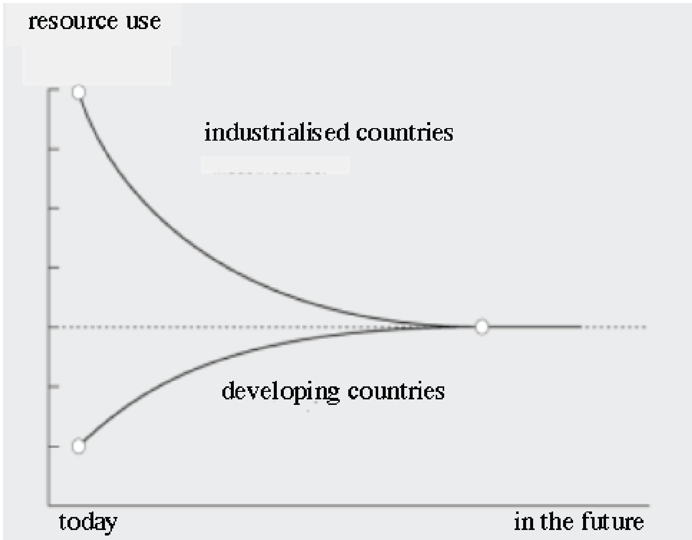
Relation between Human Development Index and energy consumption



The vision of the 2000 W per capita energy consumption society

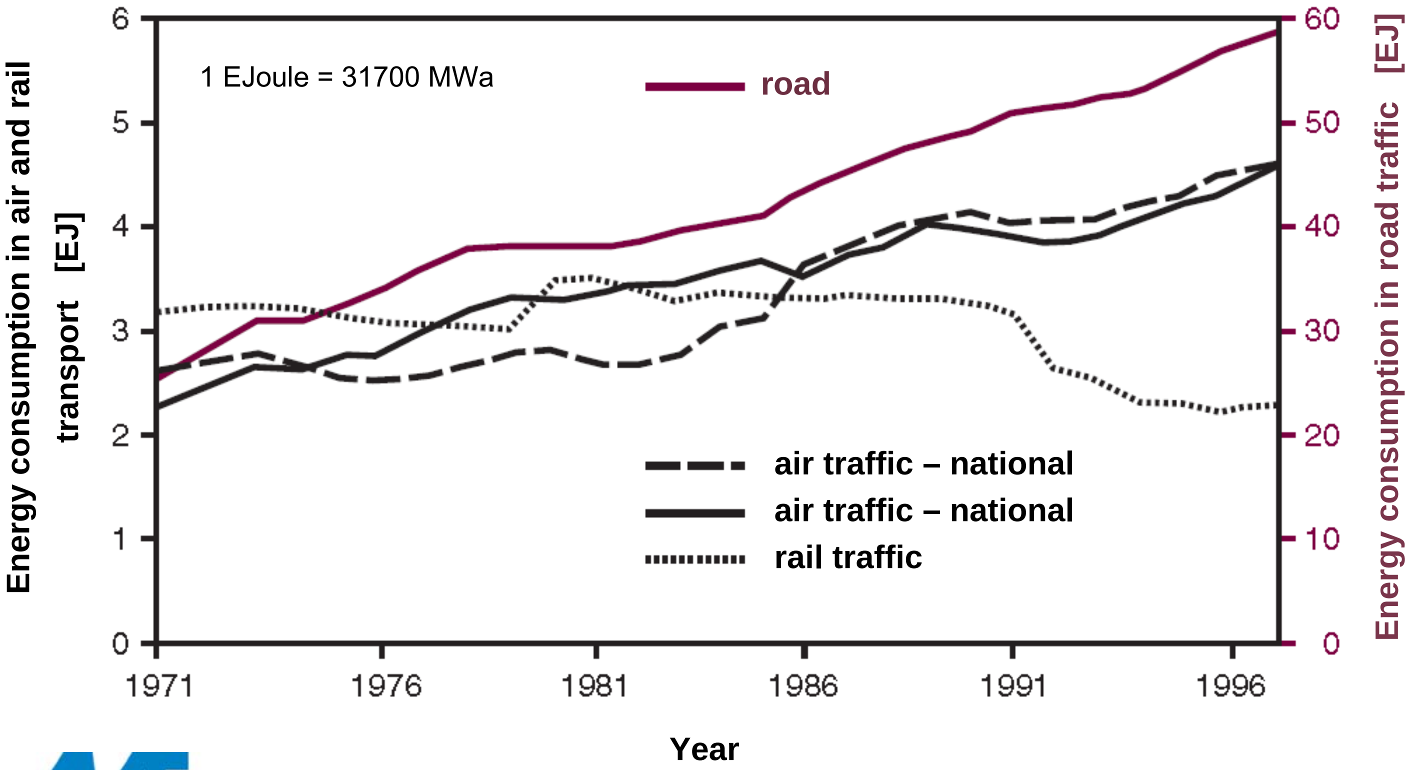
(Swiss „White Book for R&D of energy-efficient technologies“, March 2004)

- In the middle ages “Europeans” already consumed 1000 W/capita (K. Heinloth; “die Energiefrage”)
- 2000 W/capita (ca. 65 GJ/cap) is equivalent to 1/3 of the current European per capita energy consumption (current world average 70 GJ/capita)
- If the growth domestic product per capita grows until 2050 by 2/3, than the 2000 W/capita concept would require an increase in energy efficiency of a factor of 4 - 5.
- This requires large efforts and changes in the innovation system and (!) changes in life style.



Global energy consumption in the transport sector

Source: WRI et al., 2002



Development of meat production in Germany, the EU and globally

values in 1000 tons

year	world	EU (15)	Germany
1970	100.624	21.857	5.490
1975	115.765	25.189	6.185
1980	136.682	29.265	6.960
1985	154.421	30.979	7.234
1990	179.958	32.975	7.246
1995	206.755	34.234	5.822
2000	235.122	35.975	6.263
2005	265.106	36.744	6.884
Increase versus 1970 (%)	136,5	95,4	25,4

source: FAO data base

Performance loss during meat production

- Global harvest of cereals: 2,060 Mio. t / year
- Global meat production: 226 Mio. t / year
- Factor of feed utilization for meat production: 5
- Meat production requires: 1,130 Mio. t plant material / year

⇒ i.e. roughly 50 % of the global cereal production is required for meat production (in Germany 67 %)

⇒ not only “fuel or food”, but also “fuel or meat” discussion ?!

Performance loss	
Bread:	1:1
Fish:	1:1.5
Pork:	1:3
Chicken:	1:4
Milk:	1:5
Beef:	1:10
Average:	1:7

http://www.muenchen.de/Rathaus/rgu/vorsorge_schutz/biostadt/nachhaltige_ernaehrg/202796/index.html

Source: Biomasse-Vorlesung ITC-C PV, KIT

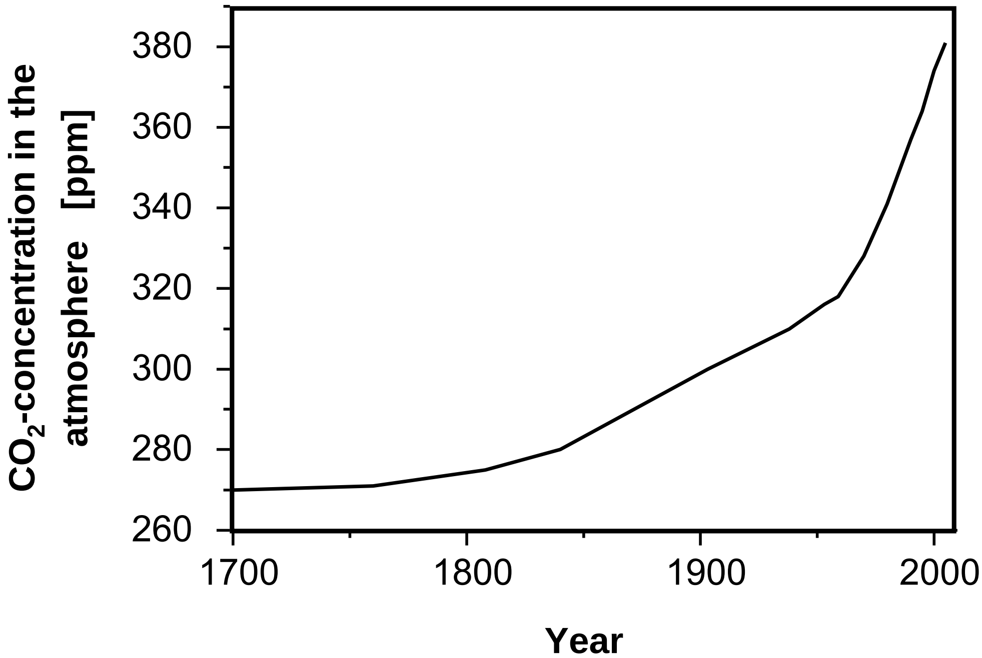
Animal production in the United States and the fossil energy required to produce 1 kcal of animal protein

Livestock and animal products	Production volume [$\cdot 10^6$]	Ratio of energy input to protein output [kcal]
Lamb	7	57:1
Beef cattle	74	40:1
Eggs	77 000	39:1
Swine	60	14:1
Dairy (milk)	13	14:1
Turkeys	273	10:1
Broilers	8000	4:1

Pimentel & Pimentel, Sustainability of meat-based and plant-based diets and the environment. American Journal of Clinical Nutrition (2003), 78(3), 660S-663S

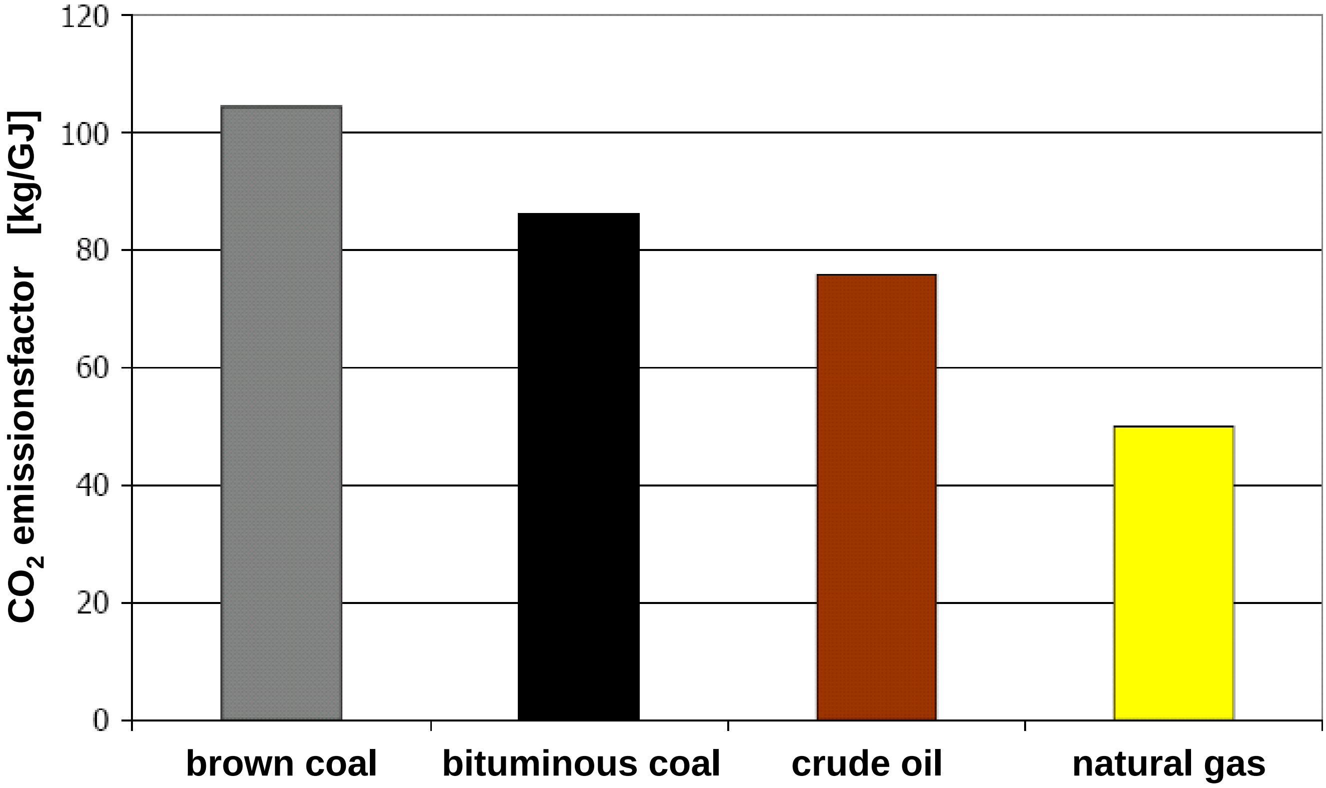
Contents

Increase of CO_2-emissions & global warming



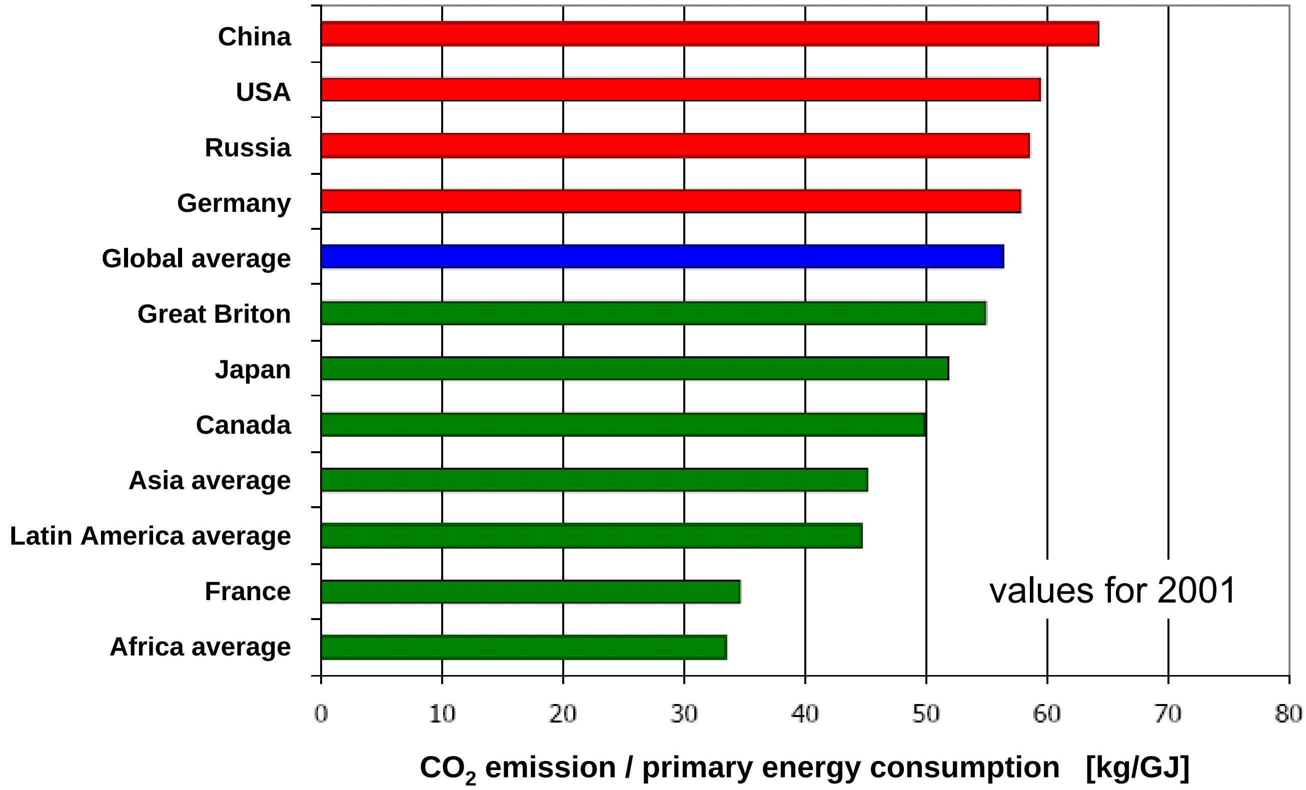
Source: Deutsche Stiftung Weltbevölkerung, NOAA, BMWi, IEA, 2006

CO_2-emissions of different fossil fuels



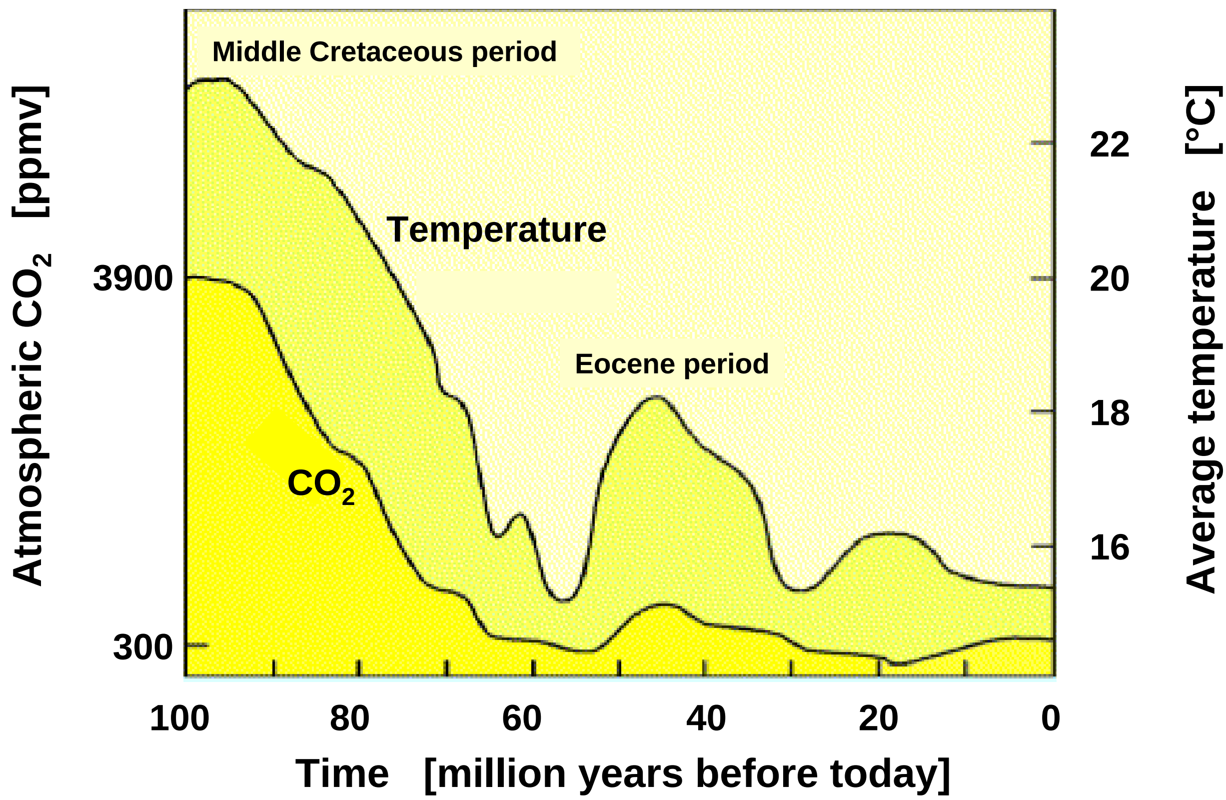
Source: Biomasse-Vorlesung ITC-C PV, KIT

Specific CO_2-emissions of different countries



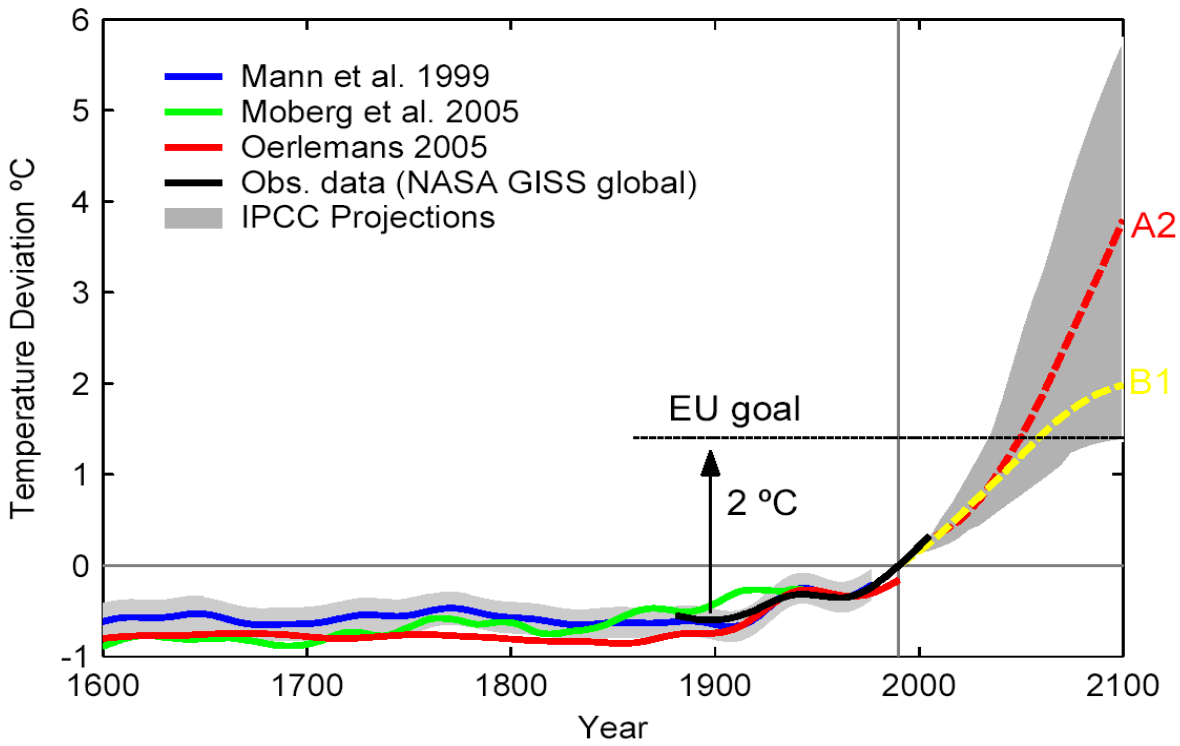
Source: Biomasse-Vorlesung ITC-C PV, KIT

Correlation between temperature and atmospheric CO_2 content



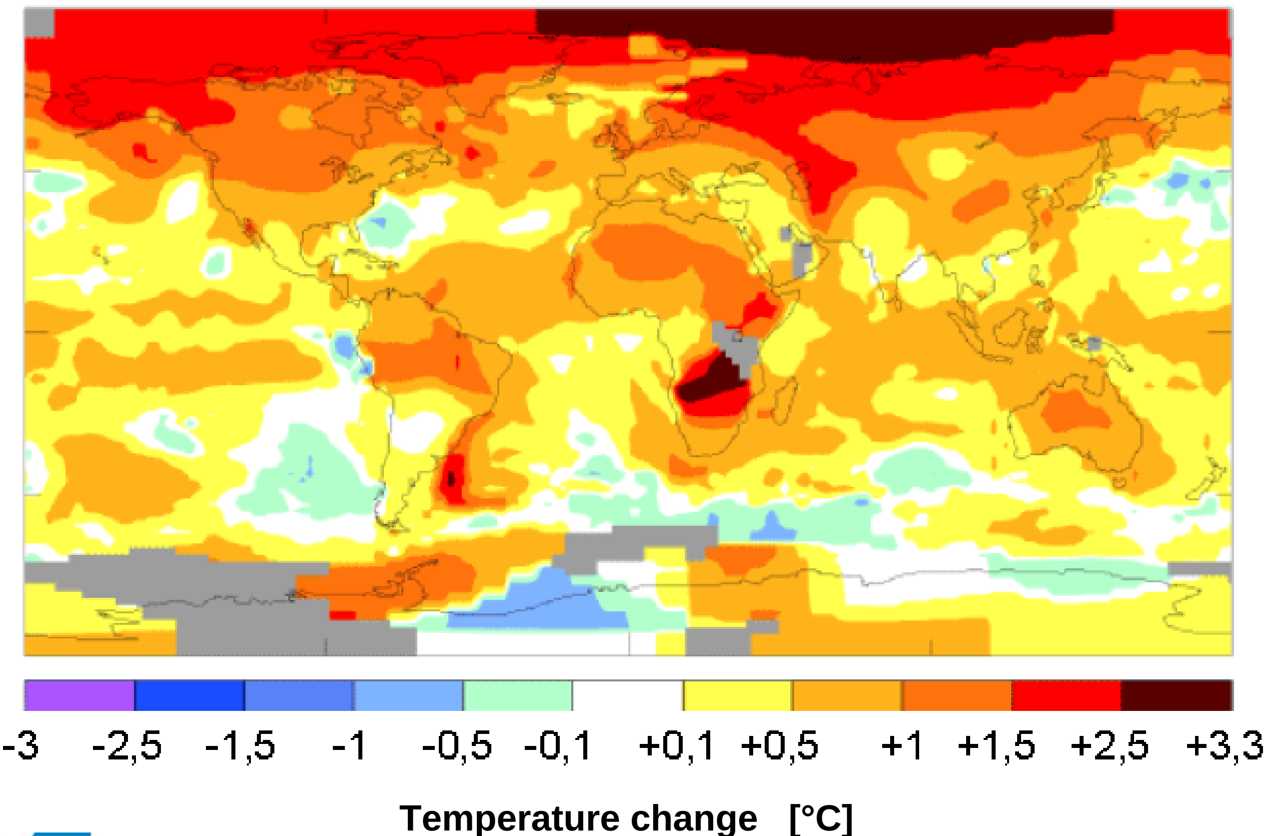
Skinner, B.J. & Porter, S.C. (1999): The dynamic earth.
An introduction to physical geology. - 575 S.; John Wiley and Sons.

Temperature increase due to human CO_2-release



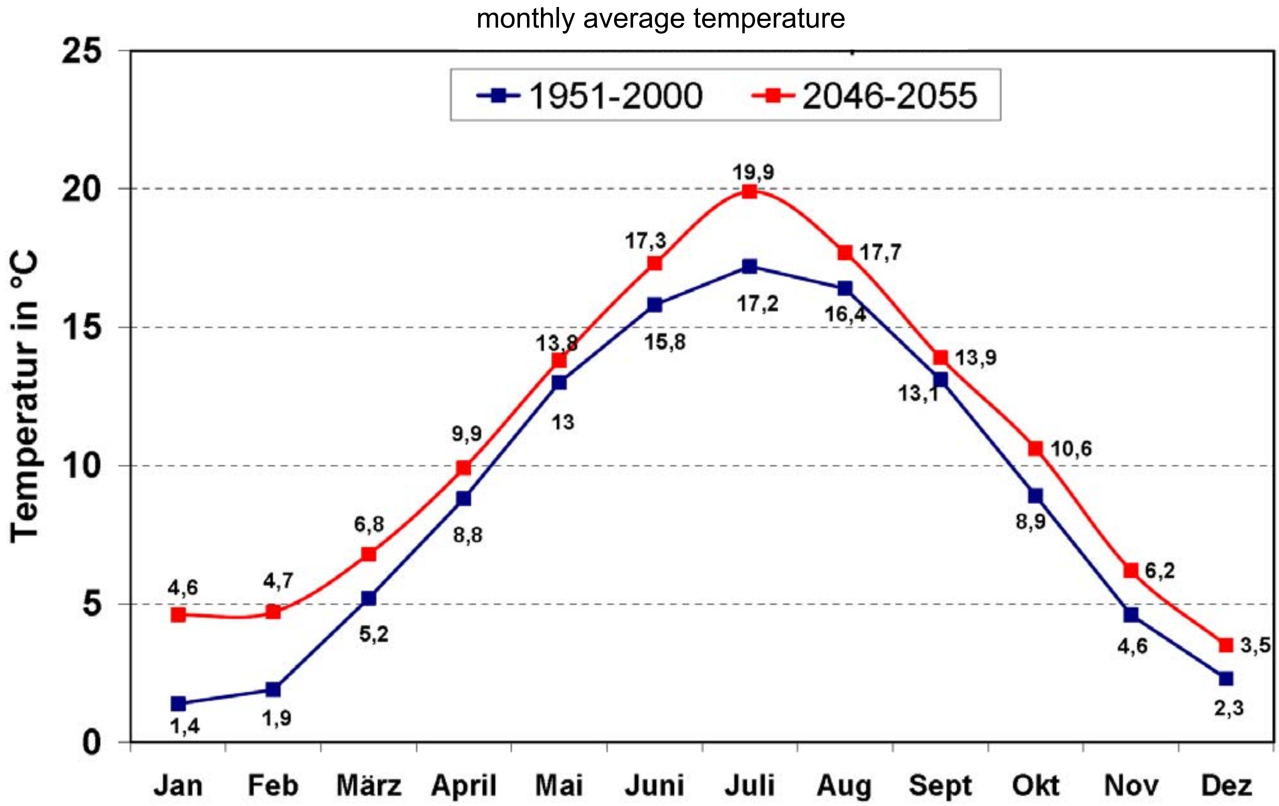
WISSENSCHAFTLICHER BEIRAT DER BUNDESREGIERUNG
GLOBALE UMWELTVERÄNDERUNGEN

Estimated distribution of global warming



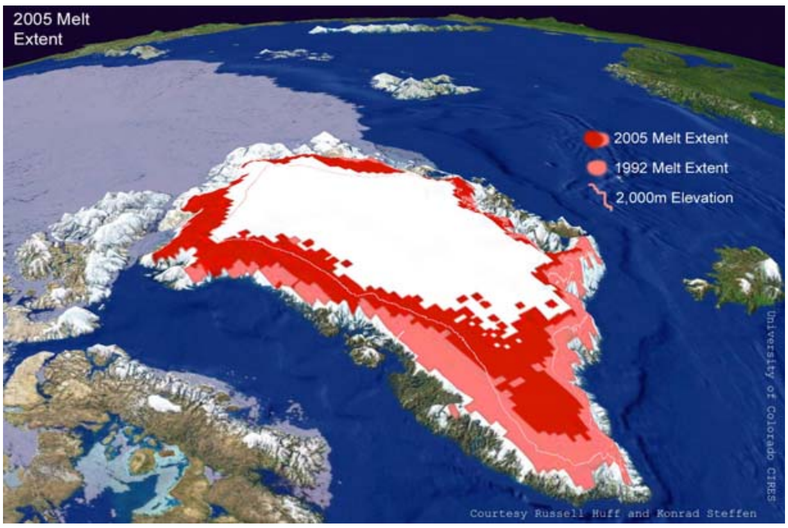
Source: Arbeitskreis KL/WA, 2007

Temperature change in North Rhine Westphalia



Source: F. Salehi, data from Landesumweltamt Nordrhein-Westfalen

Global warming can already be observed in Greenland

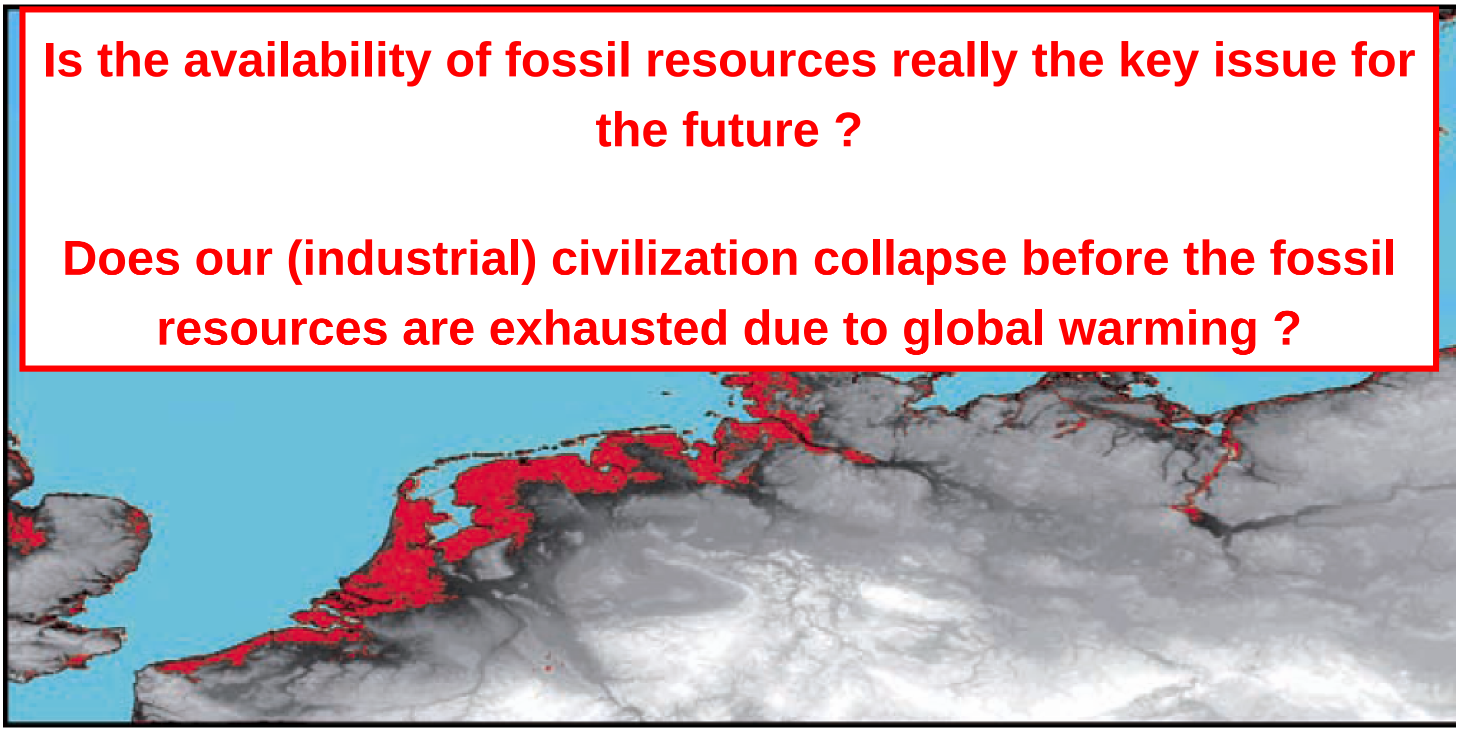


Endangered coastal areas in Europe

- Increase of mean sea level in the last century (1961-2003): 1.8 cm / decade
- Currently measured: 3.1 cm / decade

Is the availability of fossil resources really the key issue for the future ?

Does our (industrial) civilization collapse before the fossil resources are exhausted due to global warming ?



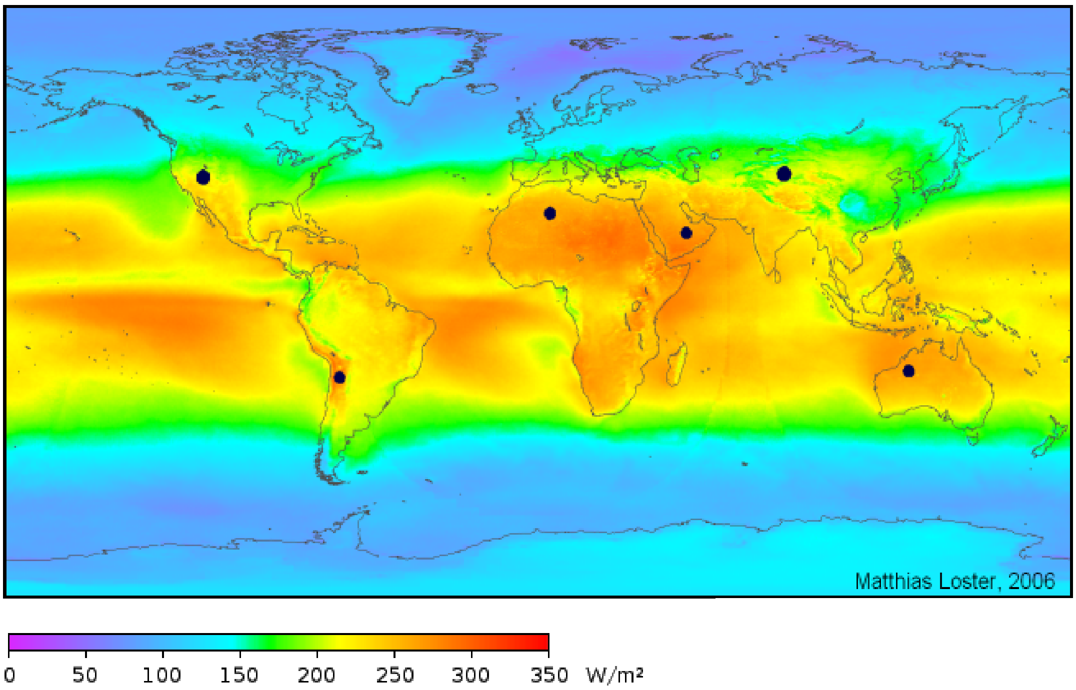
Contents

Facts on solar energy

- 90 - 167 Petawatt (10^{15} W) of energy arrives in total on the earths surface from the sun.
- This is roughly about 5000 times the amount currently consumed (world primary energy demand).
- Average intensity of solar energy flux at the outer surface of the atmosphere is 1367 W/m^2
- Maximal irradiance at the surface of the earth is about 1000 W/m^2.
- The irradiance at the surface of the earth, averaged over the whole globe over 24 h is about 165 W/m^2.

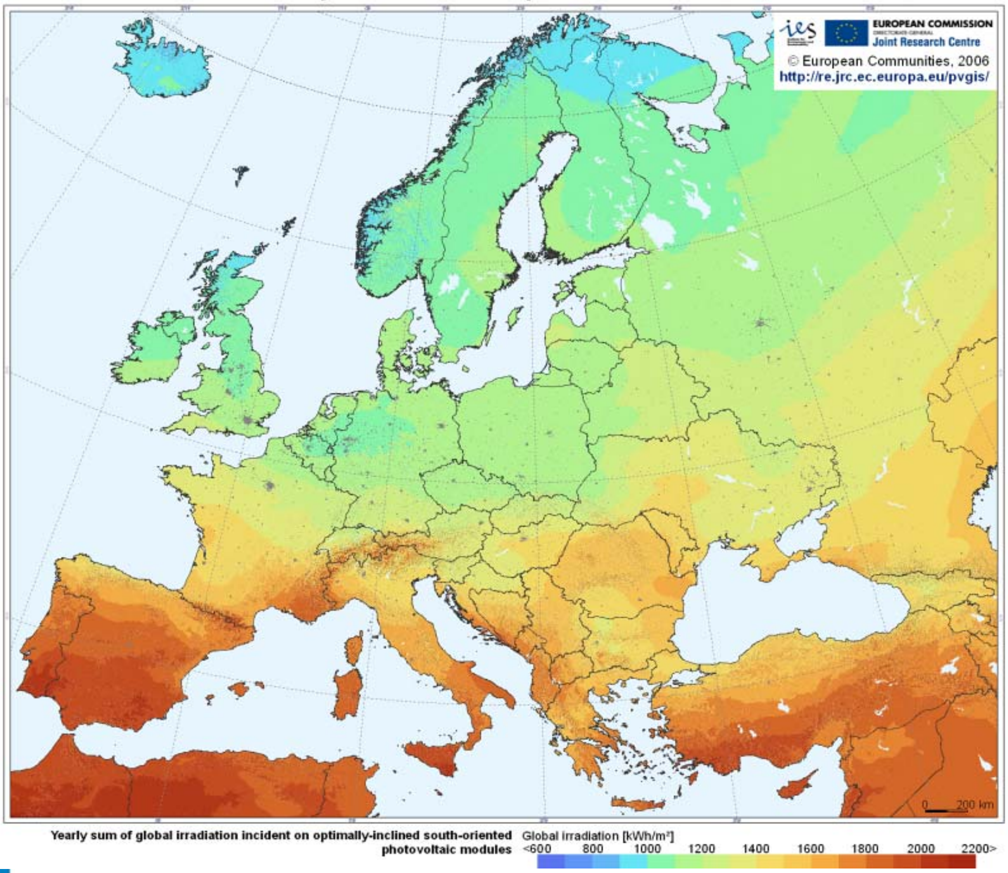
Distribution of solar irradiance on the globe

Average values over 24 h for 1991 – 1993, respective weather conditions were taken into account by using data from weather satellites



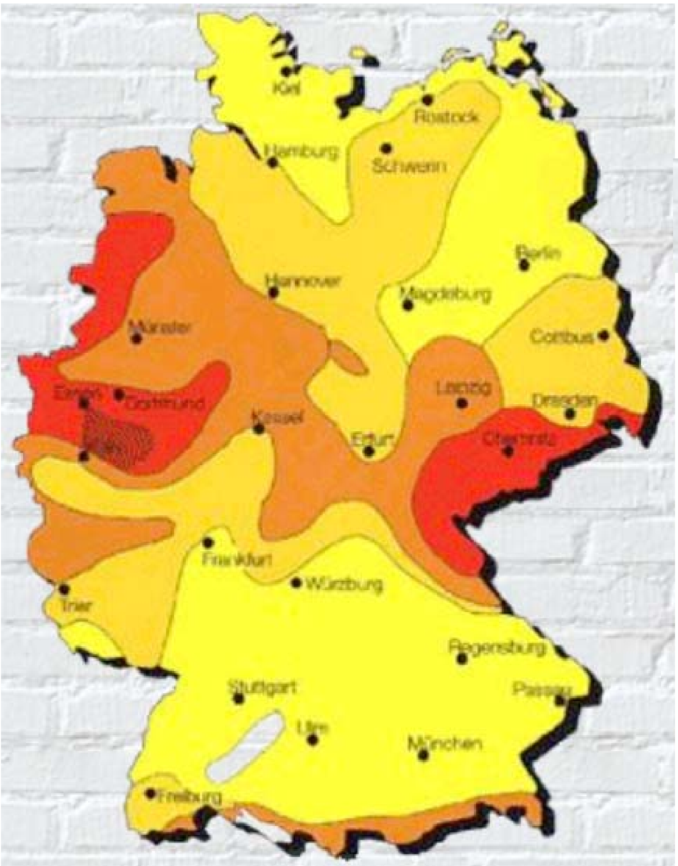
The primary energy demand of the world could be satisfied in form of electricity, if the black spots would be solar power plants (with an efficiency of 8 %).

Solar irradiance in European countries



http://re.jrc.ec.europa.eu/pvgis/cmaps/eur.htm

Regional distribution of sunshine duration in Germany

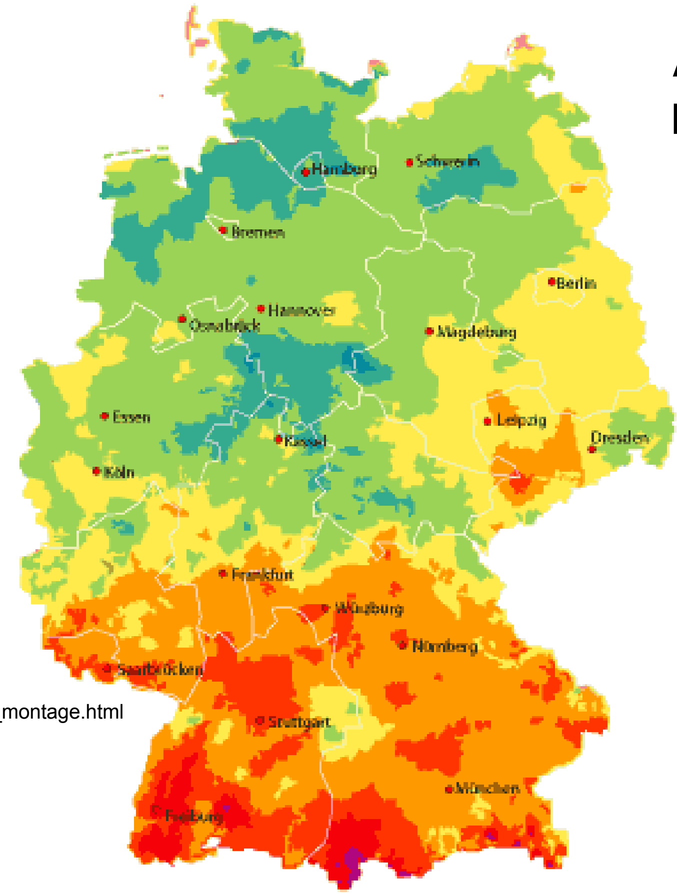


hours sunshine per year

1300 - 1400	1600 - 1700
1400 - 1500	1700 - 1800
1500 - 1600	1800 - 1900

http://knightsathome.de/photovoltaik/html/funktion.html

Regional differences of sunshine intensity in Germany



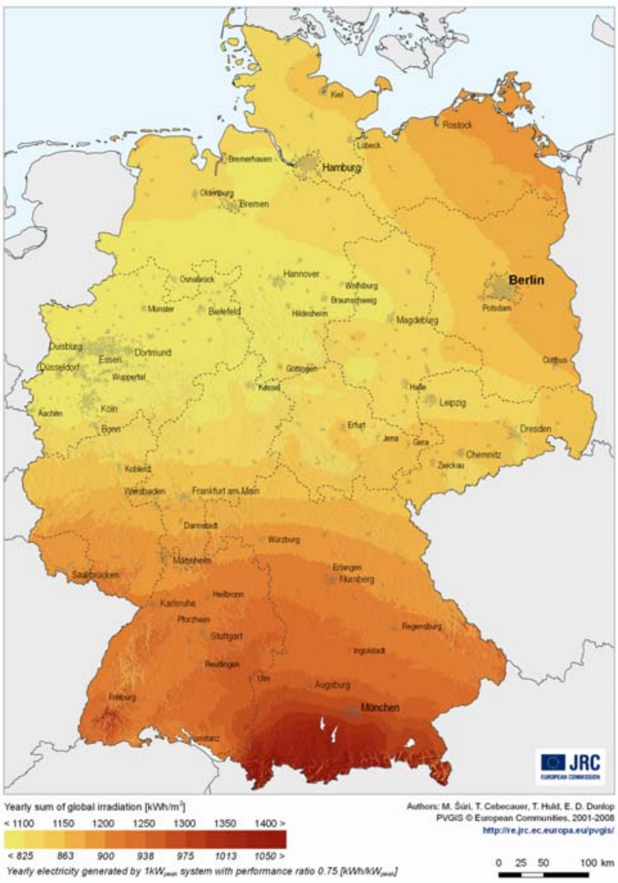
Average annual values

[kWh/m²]	[W/m²]
1250	142.7
1200	137.0
1150	131.3
1100	125.6
1050	119.9
1000	114.2
950	108.5
900	102.7
850	97.0

http://www.gerber.tv/photovoltaik_montage.html

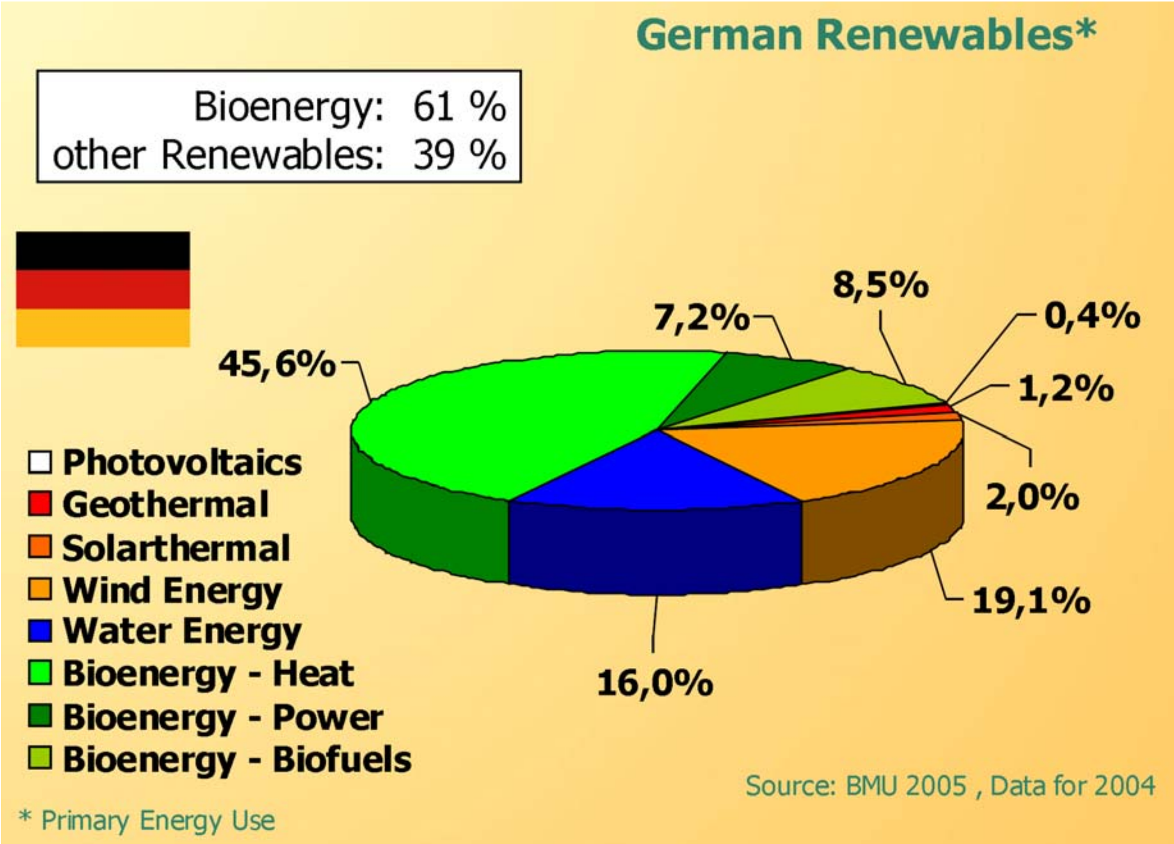
German irradiation and solar electricity potential

Values estimated for optimally inclined photovoltaic modules

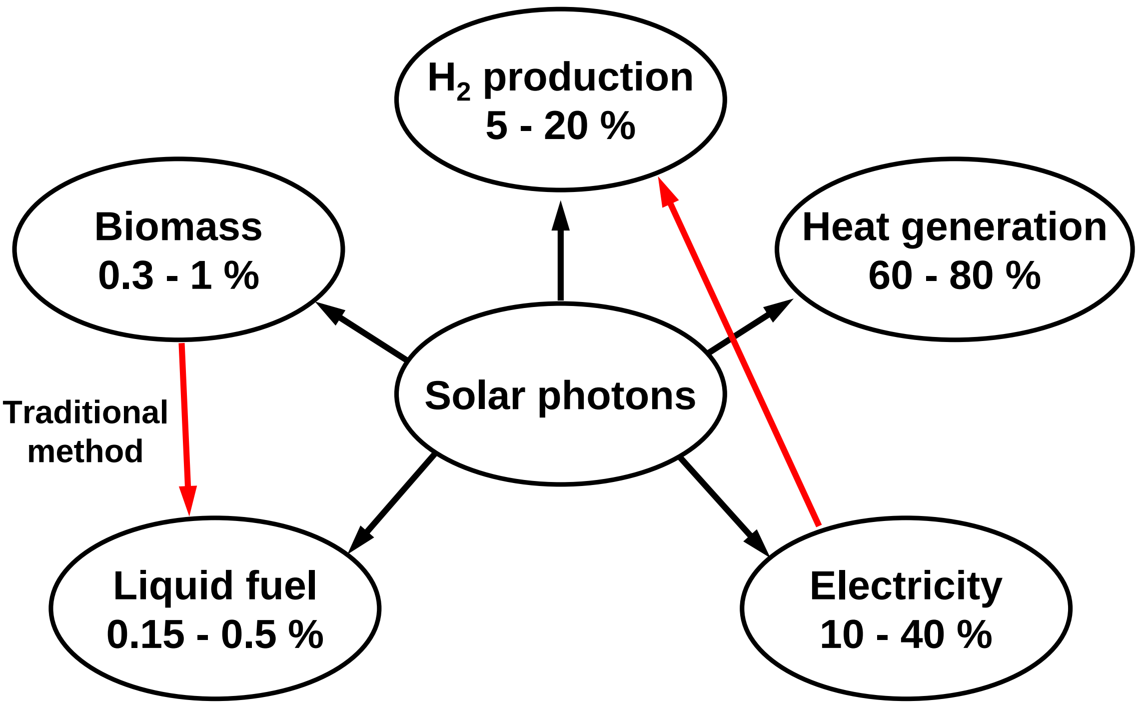


http://re.jrc.ec.europa.eu/pvgis/cmaps/eur.htm

State-of-the-art in German bioenergy



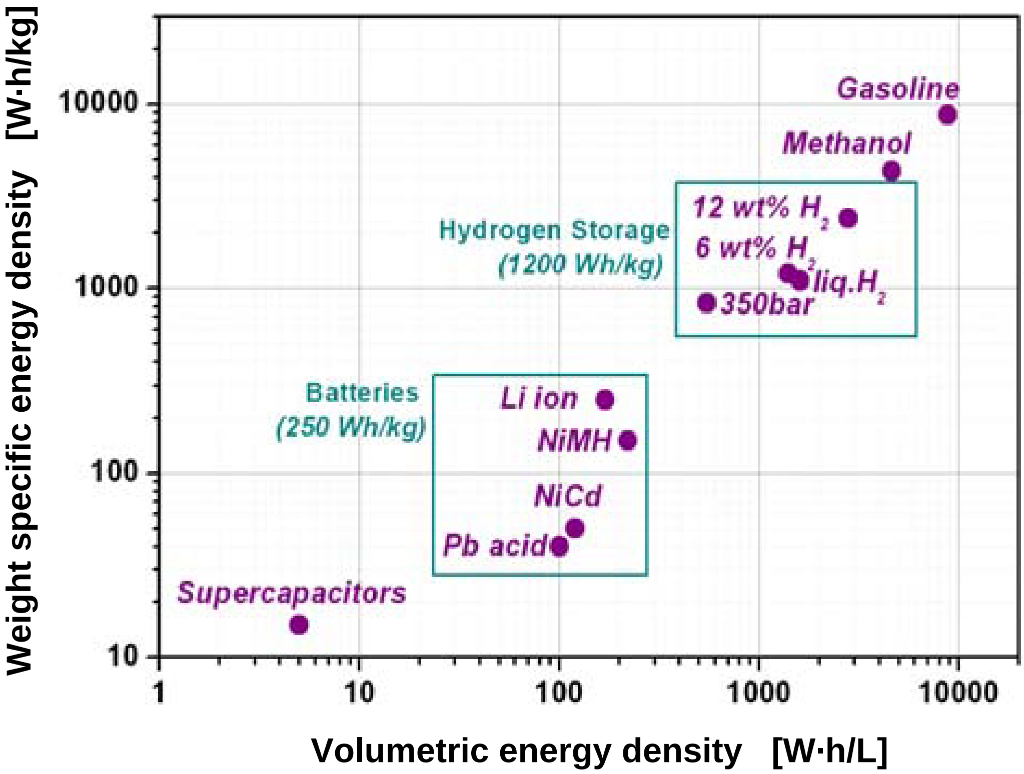
Efficiencies of solar energy recovery



Contents

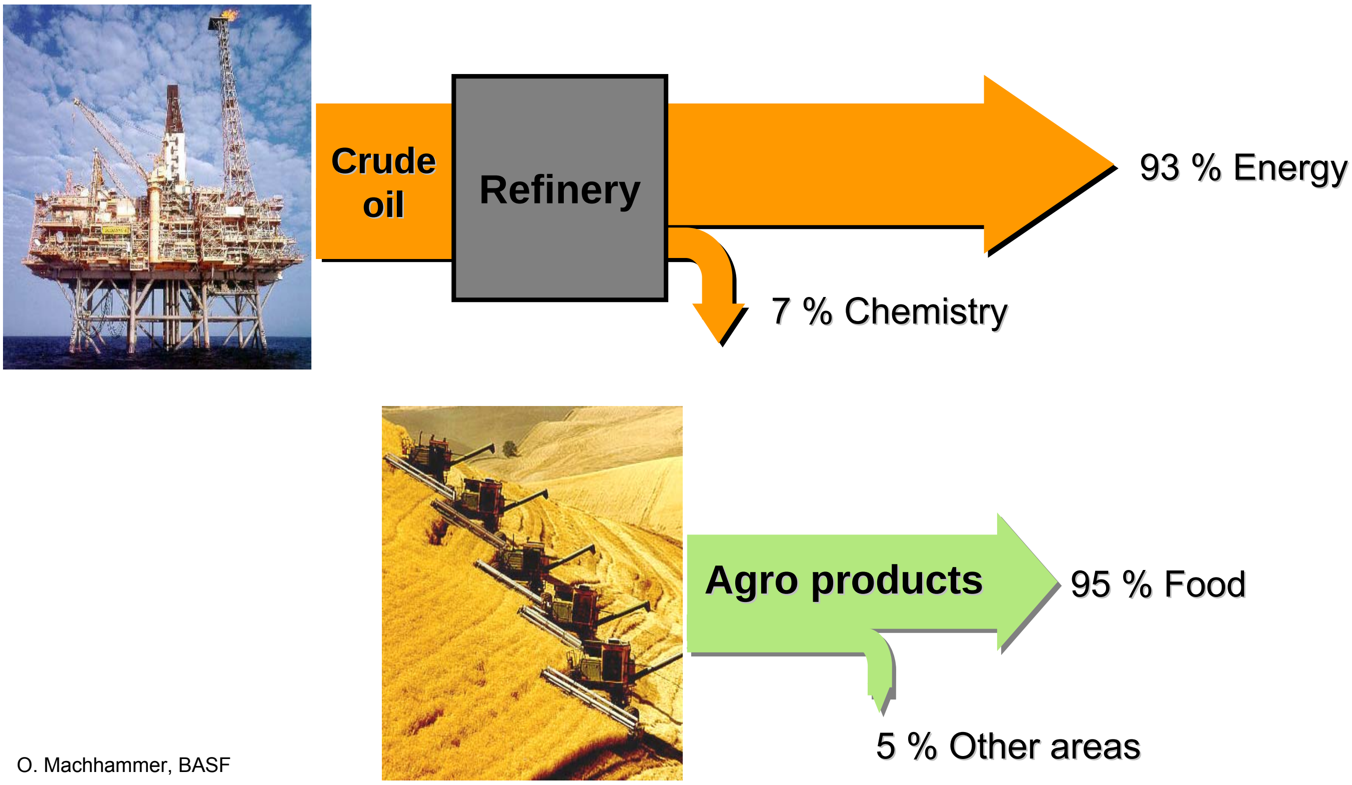
Energy density of different storage methods for energy

Liquid fuels have an extraordinary high energy density and are, therefore, well suited for mobile applications.



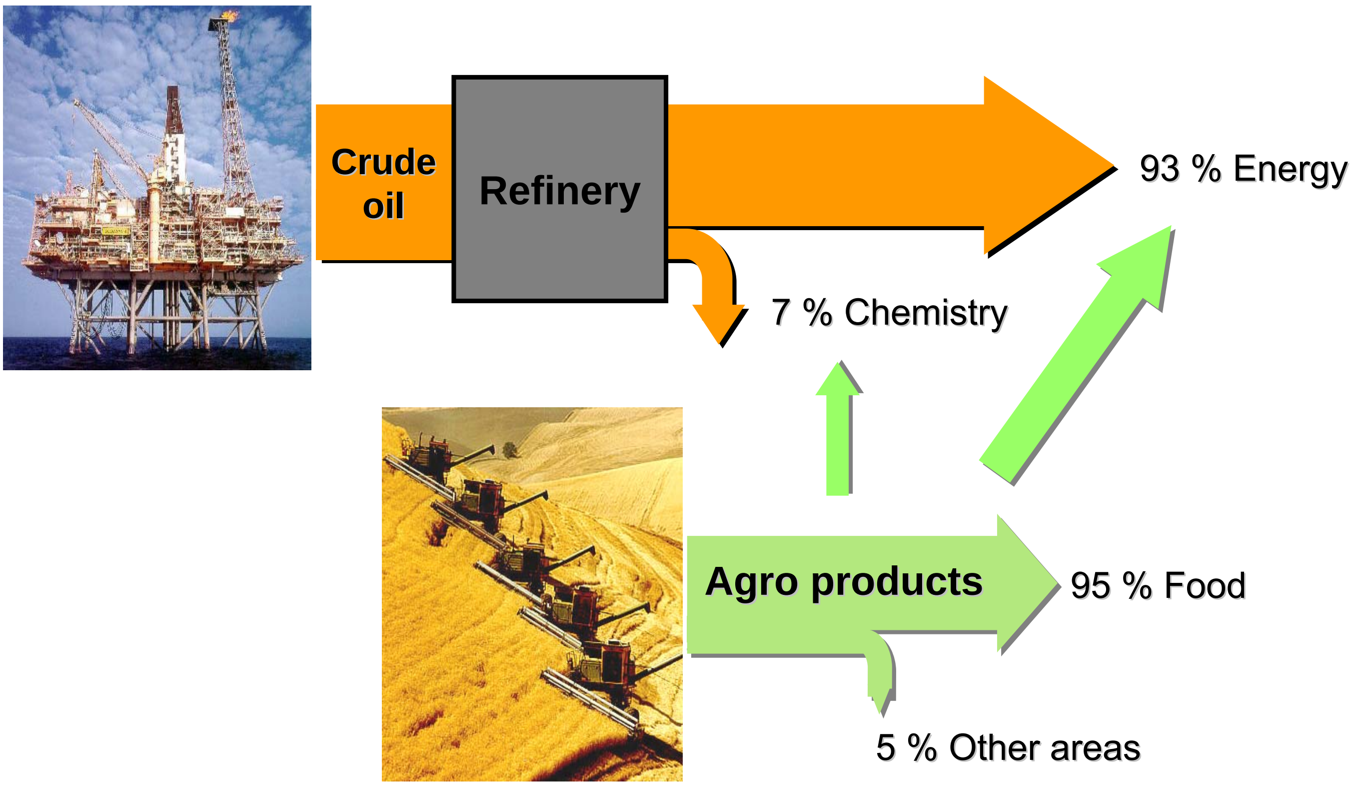
Source: Fichtner, INT, FZK

Current use of raw material



O. Machhammer, BASF

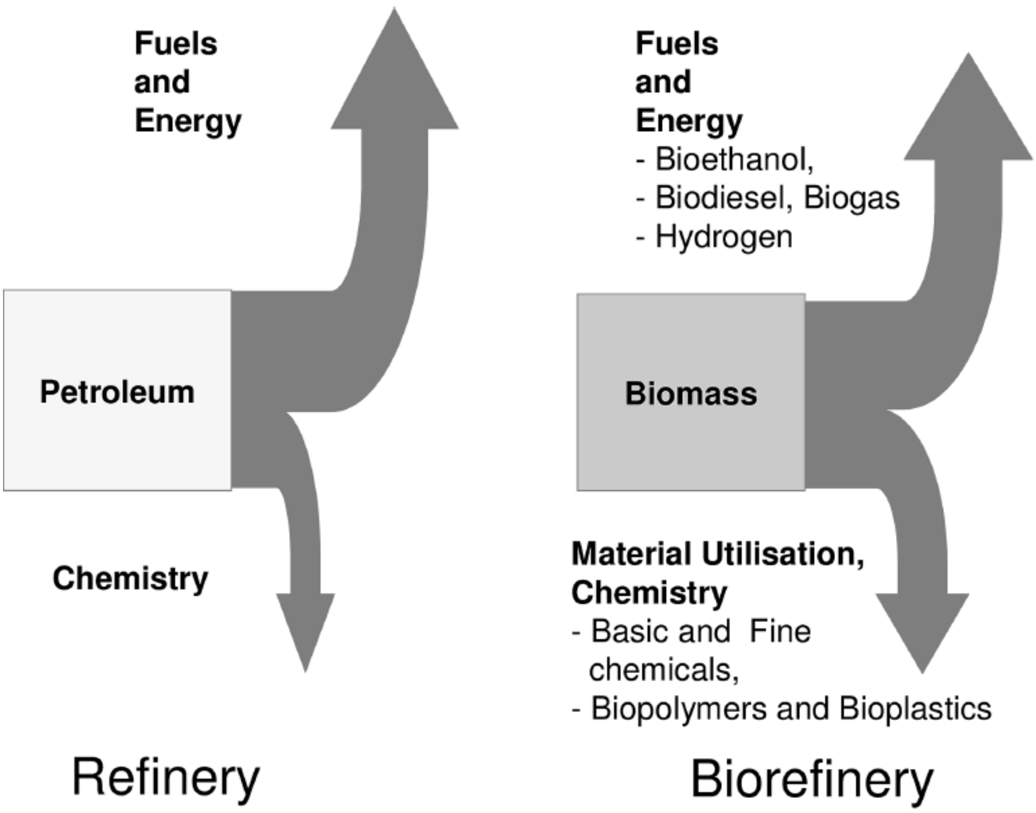
Change of raw material in industry



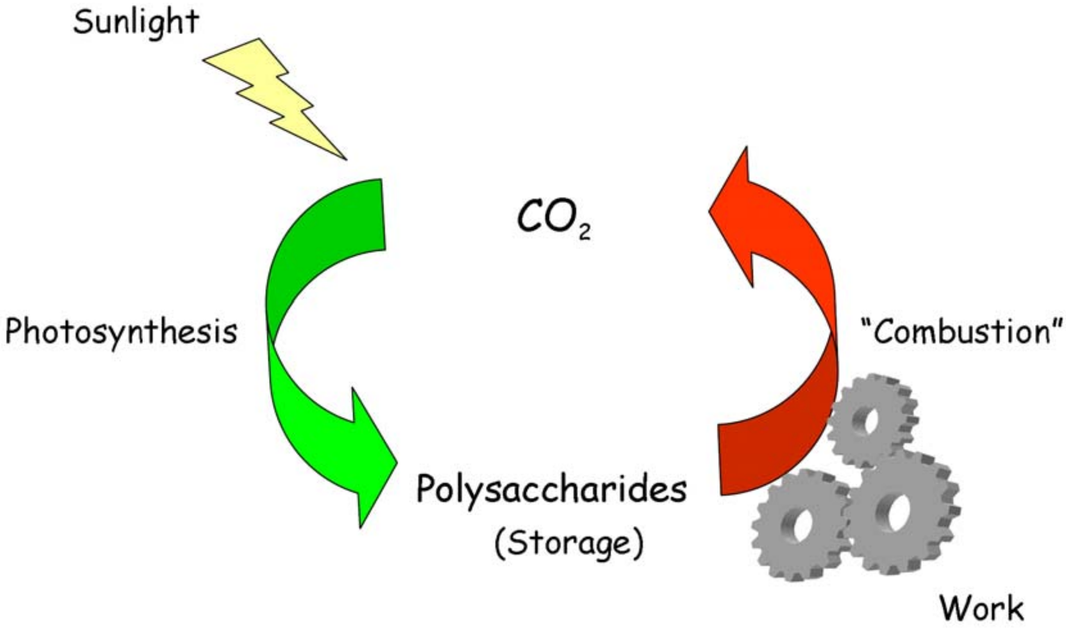
Farmers – the oil sheiks of the future ?

Quelle: WAZ

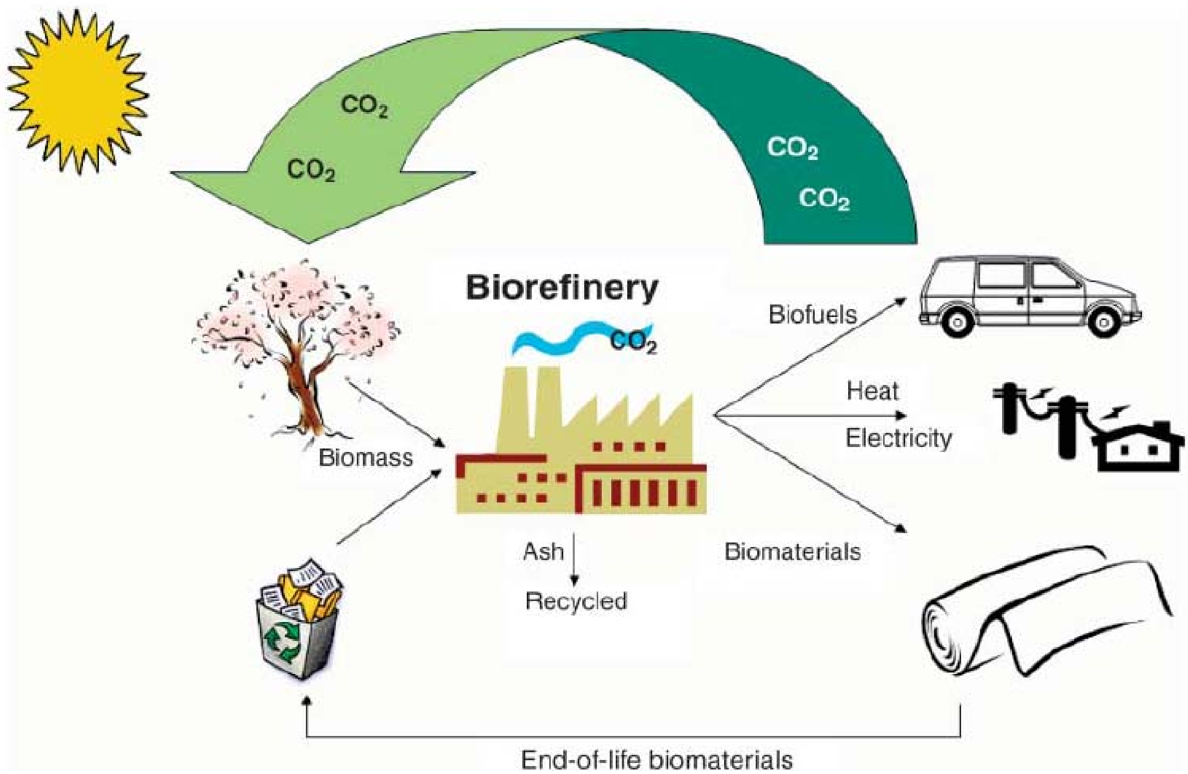
Biorefinery in contrast to a conventional Refinery



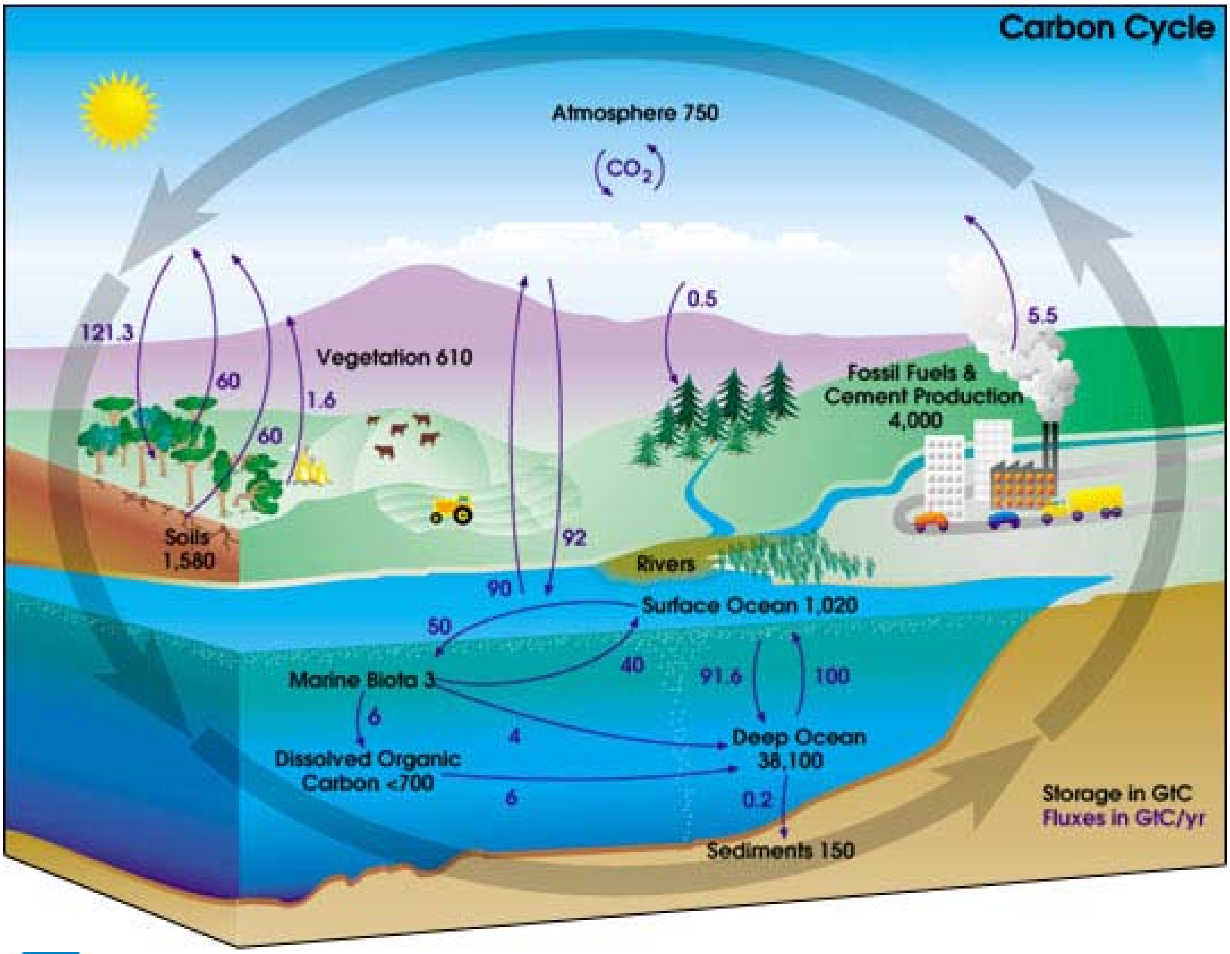
Combustion of biomass provides carbon neutral energy



Vision of the sustainable fully integrated agro-biofuel-biomaterial-biopower cycle



from Ragauskas *et al*. 2006


Carbon Cycle
Atmosphere 750
CO2
121.3
60
60
1.6
Vegetation 610
90
92
0.5
5.5
Fossil Fuels &
Cement Production
4,000
Soils
1,580
Rivers
Surface Ocean 1,020
50
40
Marine Biota 3
91.6
100
6
4
Deep Ocean
38,100
Dissolved Organic
Carbon <700
6
0.2
Sediments 150
Storage in GtC
Fluxes in GtC/yr