Conventional and Modern Forms of Energy Production

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Content

Energy sources are sometimes classified under headings such as **renewable**, traditional, modern, commercial and conventional. The terminology is rather ambiguous, since it depends very much on the context. For example, wind energy is clearly renewable, but is it traditional? Windmills have been used for several centuries, making it traditional, but wind has been used to generate electricity only in this century, so perhaps it is modern. In different areas of a country a source may be classified differently. For example, fuel wood in rural areas is often non-commercial, whereas in towns it generally has to be bought.

Renewable means that a source is not depleted by use – wind is always renewable, while biomass can be renewable if regrowth is matched by consumption. Fossil fuels are nonrenewable, as they will eventually be depleted (i.e. run out) as there is no viable way to produce more of them. Another classification, **new and renewable**, covers all the renewable forms of energy plus ocean and geothermal. Some energy analysts also include nuclear energy in this category, though clearly not because it is renewable.

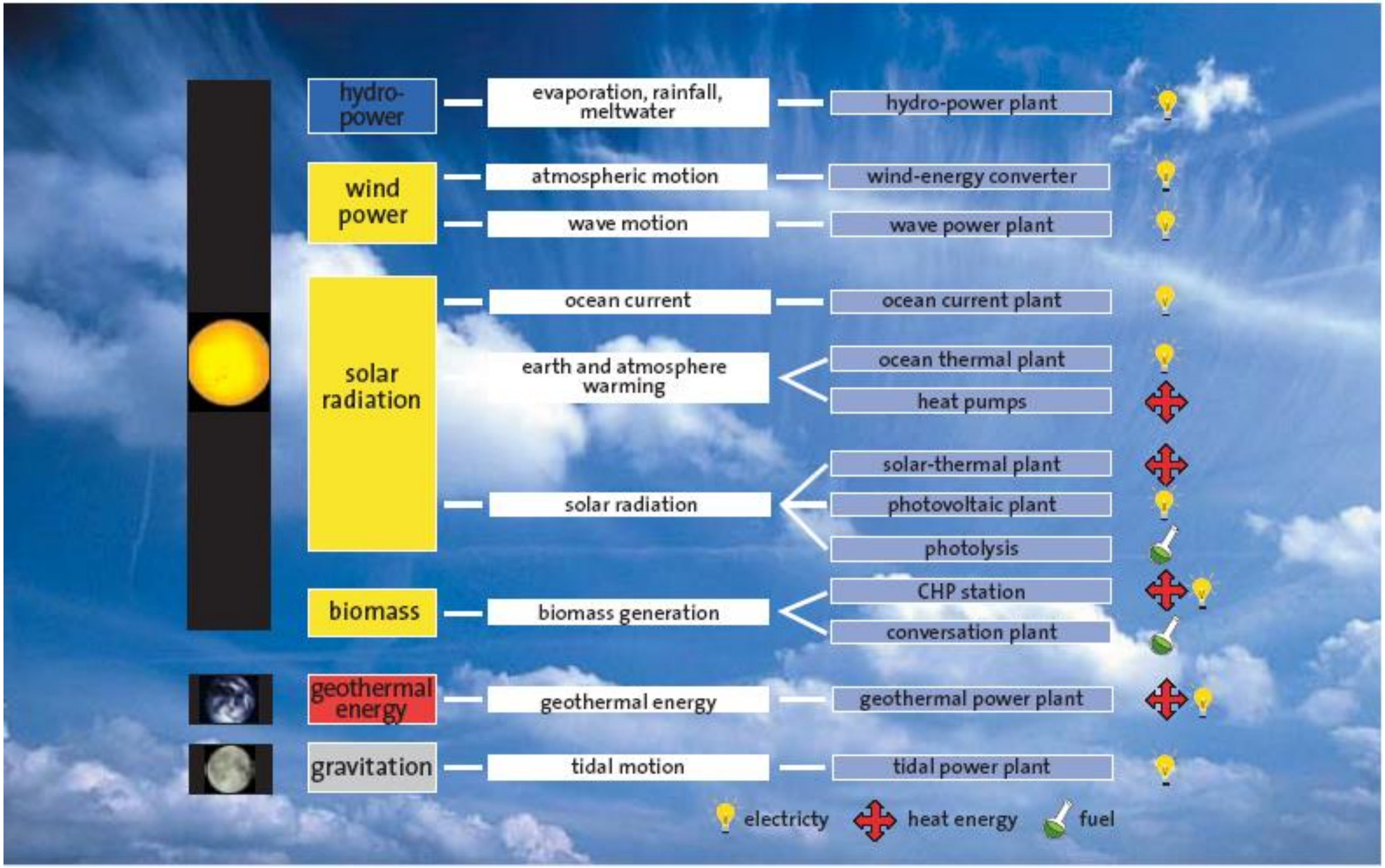
Whether an energy resource is **traditional** or **non-traditional** depends very much on the user's perspective. Many biomass users would be regarded as using a traditional source (that is, what they have always used) and they would regard using fossil fuels as non-traditional. However, it can be the conversion technology rather than the resource which determines the classification. Wood can be regarded as a traditional energy resource, but if it is used in a gasifier it produces a non-traditional energy source. Similar difficulties arise when categorising energy sources as **conventional** and **non-conventional**.

Commercial energy refers to those energy sources for which have to be paid for. This always includes the fossil fuels and some new and renewable sources. Biomass is usually classified as **non-commercial** – however, this depends again on where you are in the world. Table demonstrates that a fuel can be placed in more than one category and that there are no hard and fast rules. Classification depends on circumstances, and an energy analyst should be prepared to exercise some flexibility and make clear what fuel classification is being used.

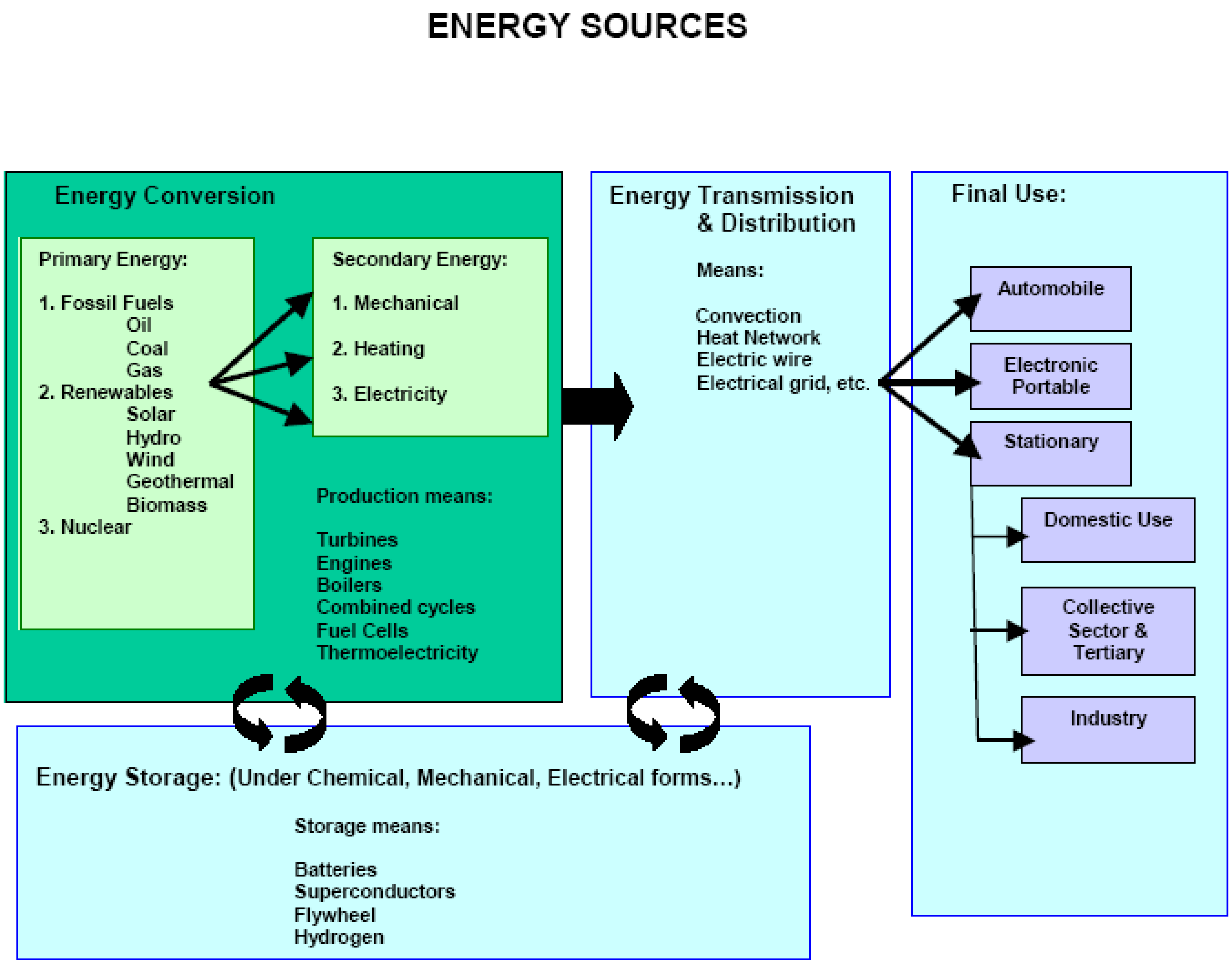
Energy supply terminology by different classifications

Resource	Familiarity			Reproducibility		Monetisation	
	Conventional	Traditional	Non-Conventional	Renewable	Non-Renewable	Commercial	Non-Commercial
Large scale hydropower	◆			◆		◆	
Coal	◆				◆	◆	
Oil and gas	◆				◆	◆	
Nuclear	◆				◆	◆	
Fuelwood		◆	◆	◆		◆	◆
Agricultural residue		◆	◆	◆			◆
Animal dung		◆	◆	◆		◆	◆
Animal labour	◆	◆		◆		◆	◆
Industrial waste		◆	◆		◆	◆	
Solar thermal		◆	◆	◆		◆	◆
Solar photovoltaic			◆	◆		◆	
Wind		◆	◆	◆		◆	◆
Small-scale hydropower		◆	◆	◆		◆	◆
Biogas			◆	◆		◆	

Energy sources



Energy ssytem



Energy Sources

- **Primary Energy sources-**
  - Fossil fuels (oil, natural gas, coal)
  - Nuclear energy
  - Falling water, geothermal, solar
- **Secondary Energy sources-**
  - Sources derived from a primary source like…
    - Electricity
    - Gasoline
    - Alcohol fuels (gasohol)

Relation Type	**Formula**
Work as force times distance	$W = F \cdot d$
Kinetic Energy	K.E. = $\frac{1}{2}mv^2$
(Grav.) Potential Energy	$E = mgh$
Heat Content	$\Delta E = c_p m \Delta T$
Power	$P = \Delta E/\Delta t$
Mass-energy	$E = mc^2$
Radiative Flux	$F = \sigma T^4$

SI units for energy

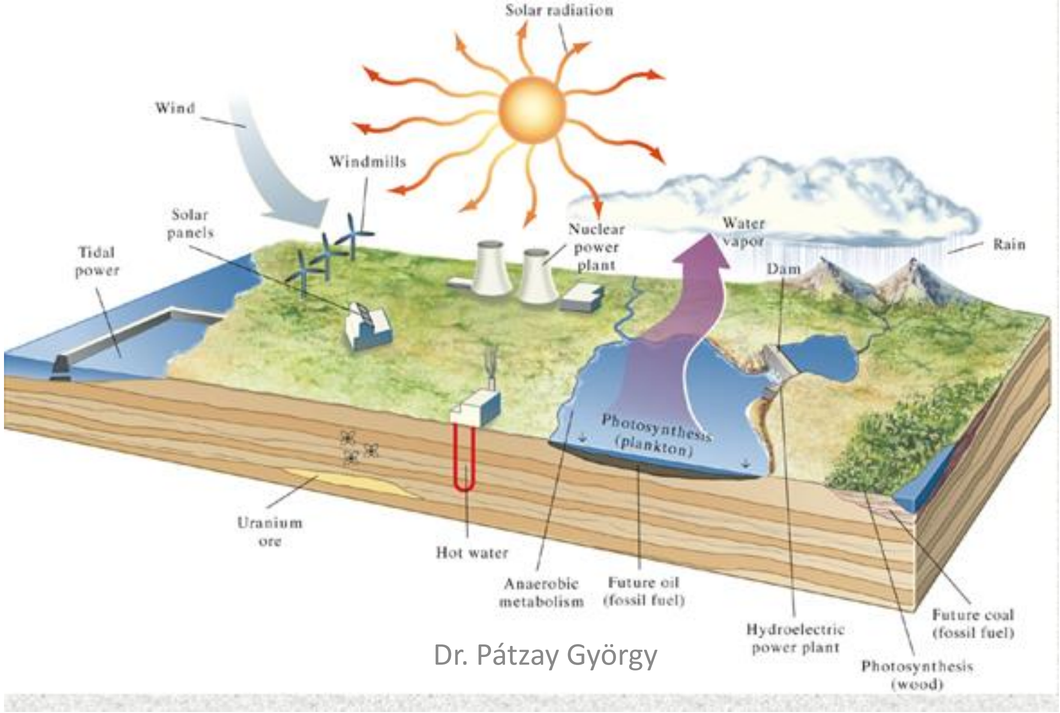
- The SI unit of energy is a Joule: 1 $kg*m^2/s^2$ = 1 Newton*m (Newton is the unit of Force)
  - mass * velocity ^{2}
  - mass * g * height (on earth, g = 9.81 m/s^2)
  - for an ideal gas = $c_v k_B T$ (c_v =3/2 for a monatomic gas)
- **Power** is energy per time: 1 Watt = 1 Joule/s = 1 $kg*m^2/s^3$
  - most commonly used in electricity, but also for vehicles in horsepower (acceleration time)

Other units for energy

Energy conversion			
Unit	**Quantity**	**to**	**Note**
1 calorie =	4.1868000	Joule	
1 kiloWatt hour = kWh =	3600000	Joule	A power of 1 kW for a duration of 1 hour.
1 British Thermal Unit = btu	1055.06	Joule	It is a is a unit of energy used in North America.
1 ton oil equivalent = 1 toe	4.19E+010	Joule	It is the rounded-off amount of energy that would be produced by burning one metric ton of crude oil.
1 ton coal equivalent	2.93E+10	Joule	
1 ton oil equivalent = 1 toe	1 / 7.33	Barrel of oil	or 1 / 7.1 or 1 / 7.4 ...
1 cubic meter of natural gas	3.70E+07	Joule	or roughly 1000 btu/ft3
1000 Watts for one year	3.16E+010	Joule	for the 2000 Watt society
1000 Watts for one year	8.77E+006	kWh	for the 2000 Watt society
1 horsepower	7.46E+002	Watts	

Energy is Conserved

- Conservation of Energy is different from Energy Conservation, the latter being about using energy wisely
- Conservation of Energy means energy is neither created nor destroyed. The amount of energy in the Universe is constant!!
- Don’t we *create* energy at a power plant?
  – No, we simply *transform* energy at our power plants
- Doesn’t the sun *create* energy?
  – Nope—it *exchanges* mass for energy
- Though the total energy of a system is constant, the *form* of the energy can change



Energy sources and properties

- Potential
- Kinetic
- Gravitational
- Elastic strain
- Electrochemical
- Electrostatic
- Electromagnetic
- Nuclear fission and fusion
- Chemical
  - Stored in chemical bonds
- Thermal
  - Sensible heat
  - Latent heat

Energy conversion

- ❑ Laws of Thermodynamics provide limits
- ❑ Heat and work are not the same
- ❑ Maximum work output (or minimum work input) only occurs in idealized reversible processes
- ❑ All real processes are irreversible
- ❑ Losses always occur to the degrade the efficiency of energy conversion and reduce work/power producing potential

Energy conversion

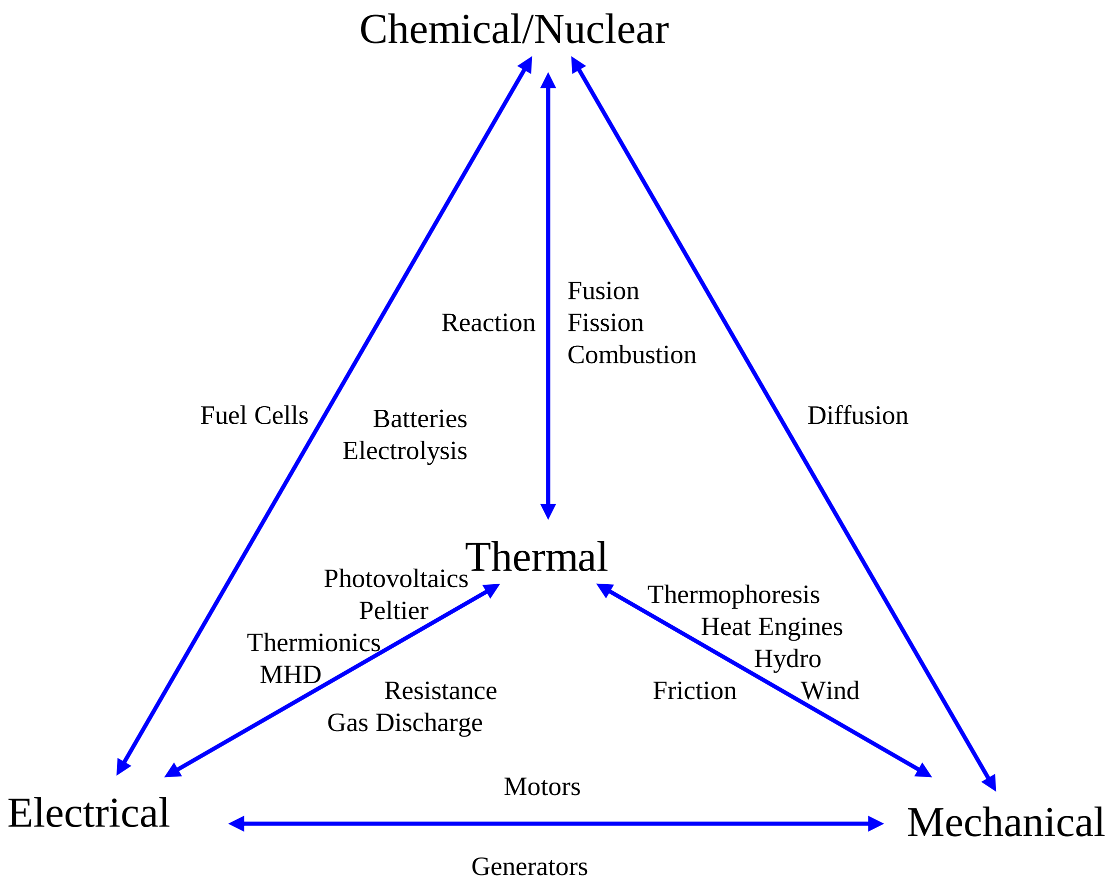
- ❑ Laws of Thermodynamics provide performance limits for reversible processes
  - for heat to work/power conversion, e.g. Carnot
  - for work to work conversion, e.g. zero current fuel cell operation
- ❑ Thermodynamics characterizes equilibrium and quasi-static processes but tells us nothing about rates
- ❑ Rates are governed by constitutive laws that link gradients and transport properties

Energy Flows and Balances

- **Energy flow or transfer by**
  - sensible heat transfer by temperature gradients (conduction, convection, radiation)
  - latent heat transfer via phase change
  - mass transfer -- diffusive or convective
  - momentum transfer – KE-PE energy exchange
  - chemical reaction – enthalpy and free energy
  - work transfer – compressive, electrochemical, etc.
- **Energy balances**
  - overall conservation law

    input – output = accumulation
  - boundary fluxes – heat and work
  - internal accumulation or depletion to *E*
  - steady state versus transient processes –

Energy Transformations



Energy transformations are inherently inefficient

2^{nd} Law of Thermodynamics

"Entropy always increases"
"Heat flows from hot to cold"

For heat engines, limitation is

Carnot efficiency:

$\varepsilon = 1 - T_C / T_H$

For a turbine using 600 K steam, cooled by room temperature (300 K), the limiting efficiency of the turbine is

$\varepsilon = (600 - 300) / 600 = 50\%$

In fuel-fired electricity production half the input energy is *inevitably* lost

Conversions	Energies	Efficiencies
Large electricity generators	M → e	98–99
Large power-plant boilers	c → t	90–98
Large electric motors	e → m	90–97
Best home natural-gas furnaces	c → t	90–96
Dry-cell batteries	c → e	85–95
Human lactation	c → c	85–95
Overshot waterwheels	m → m	60–85
Small electric motors	e → m	60–75
Large steam turbines	t → m	40–45
Improved wood stoves	c → t	25–45
Large gas turbines	c → m	35–40
Diesel engines	c → m	30–35
Mammalian postnatal growth	c → c	30–35
Best photovoltaic cells	r → e	20–30
Best large steam engines	c → m	20–25
Internal combustion engines	c → m	15–25
High-pressure sodium lamps	e → r	15–20
Mammalian muscles	c → m	15–20
Traditional stoves	c → t	10–15
Fluorescent lights	e → r	10–12
Steam locomotives	c → m	3–6
Peak crop photosynthesis	r → c	4–5
Incandescent light bulbs	e → r	2–5
Paraffin candles	c → r	1–2
Most productive ecosystems	r → c	1–2
Global photosynthetic mean	r → c	0.3

From V. Smil, "Energies", 1999

Typical conversion efficiencies of different energy conversion technologies

converter	form of input energy	form of output energy	typical efficiency
petrol engine	chemical	mechanical	20-25 %
diesel engine	chemical	mechanical	30-45 %
electric motor	electrical	mechanical	80-95 %
boiler and turbine	thermal	mechanical	7-40 %
hydraulic pump	mechanical	potential	40-80 %
hydro turbine	potential	mechanical	70-99 %
hydro turbine	kinetic	mechanical	30-70 %
generator	mechanical	electrical	80-95 %
battery	chemical	electrical	80-90 %
solar cell	light	electrical	8-15 %
solar collector	light	thermal	25-65 %
electric lamp	electrical	light	5 %
water pump	mechanical	potential	60 %
water heater	electrical	thermal	90-92 %
lpg stove	chemical	thermal	60-70 %
wood stove	chemical	thermal	12-30 %
charcoal stove	chemical	thermal	20-30 %
charcoal kiln	chemical	chemical	25-40 %

CONVERSION TECHNOLOGY	form of input energy	form of output energy	typical efficienc
photosynthesis	solar radiation	chemical	3-6%
mammal metabolism	chemical	chemical	10.00%
charcoal kiln	chemical	chemical	25-40%
natural gas power plant (combined cycle)	thermal	electrical	58.00%
nuclear power plant (steam turbine)	thermal	electrical	30–36%
fossil fuel power plant (steam turbine)	thermal	electrical	30–48%
solar cell	solar radiation	electrical	8-15%
battery	chemical	electrical	80-90%
generator	mechanical	electrical	80-95%
electric lamp	electrical	light	5.00%
petrol engine	chemical	mechanical	20-25%
diesel engine	chemical	mechanical	30-45%
hydro turbine	kinetic	mechanical	30-70%
boiler and turbine	thermal	mechanical	7-40%
hydro turbine	potential	mechanical	70-99%
electric motor	electrical	mechanical	80-95%
water pump	mechanical	potential	60.00%
hydraulic pump	mechanical	potential	40-80%
electric stove	electrical	thermal	30.00%
wood stove	chemical	thermal	12-30%
charcoal stove	chemical	thermal	20-30%
solar collector	solar radiation	thermal	25-65%
lpg stove	chemical	thermal	60-70%

It takes energy to make energy.

(All fuel conversion processes lose energy.)

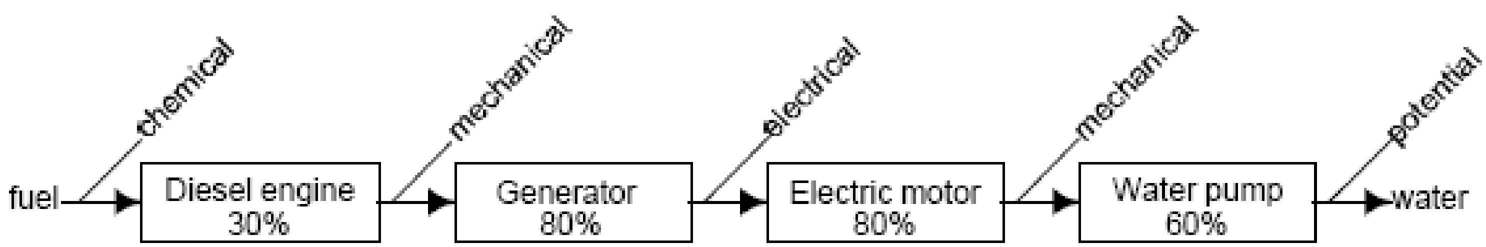
Process	Conversion Type	Efficiency
Dry Cell Battery	Chemical to Electrical	85-95%
Natural Gas to Compressed	Chemical to Chemical	85%
Crude Oil to Gasoline	Chemical to Chemical	79%
Natural Gas to H_2	Chemical to Chemical	60%
Coal to Gasoline	Chemical to Chemical	50%
Grid Electric to H_2	Chemical to Chemical	22%
Photo-Voltaic	Radiative to Electrical	15-25%
Soybean to Bio-Diesel	Chemical to Chemical	30%
Corn to Ethanol	Chemical to Chemical	5-10%
Plant Photosynthesis	Radiative to Chemical	4-5%

Not all processes have the same efficiency.

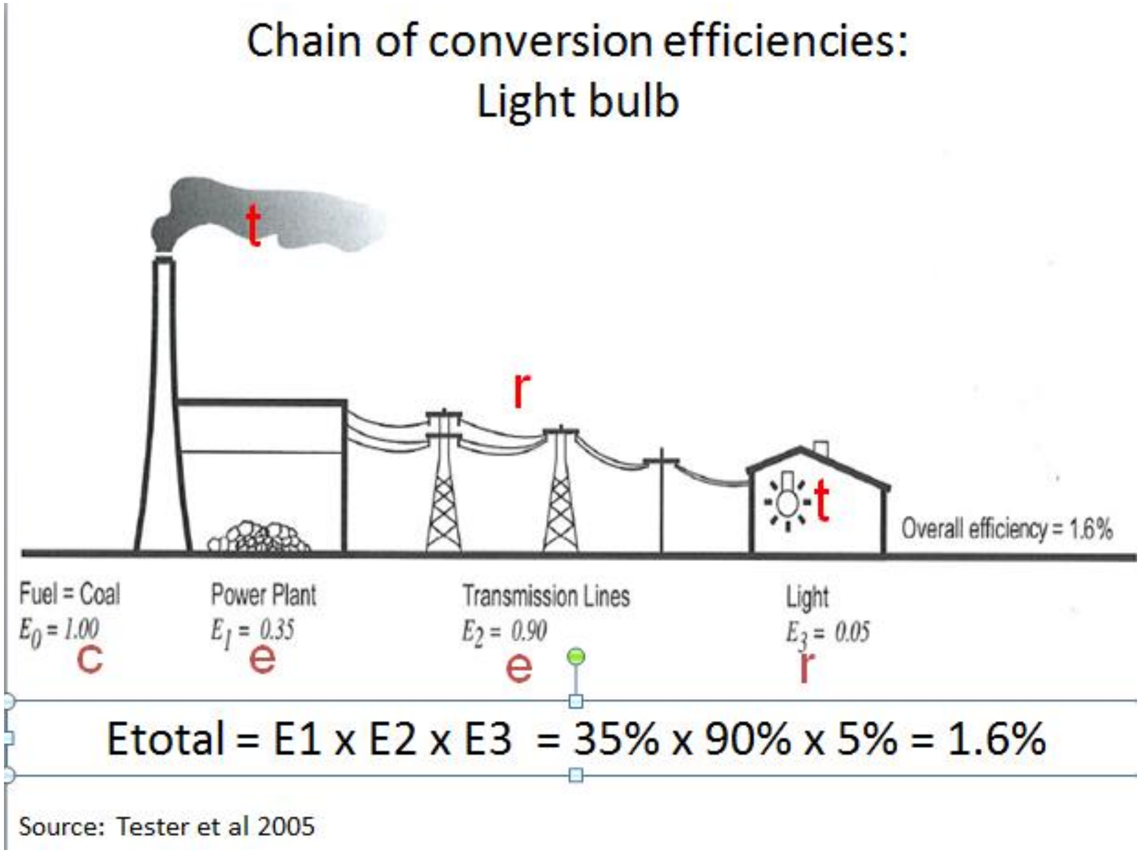
(Thermal engines are less efficient than electrical engines.)

Process	Conversion Type	Efficiency
Large Electric Generator	Mechanical to Electrical	98-99%
Large Electric Motor	Electrical to Mechanical	90-97%
Home Gas Furnace	Chemical to Thermal	90-96%
Small Electric Motor	Electrical to Mechanical	60-75%
Fuel Cell	Chemical to Electrical	50-60%
Large Steam Turbine	Thermal to Mechanical	40-45%
Diesel Engine	Thermal to Mechanical	30-35%
Gasoline Engine	Thermal to Mechanical	15-25%
Florescent Lights	Electrical to Radiative	15-25%
Incandescent Lights	Electrical to Radiative	2-5%

Efficiency of an energy conversion system



Overall system efficiency = 30% x 80% x 80% x 60% = 12%



Energy sources

- The total efficiency is the product of all conversion efficiencies:

$$E_{total} = E_1 \times E_2 \times E_3 \times E_4 \times E_5 \times E_6 \times \ldots$$

- Total losses can be (and are) tremendous
- Most losses are in the form of radiated heat, heat exhaust
- But can also be non-edible biomass or non-work bodily functions (depending on final goal of energy)

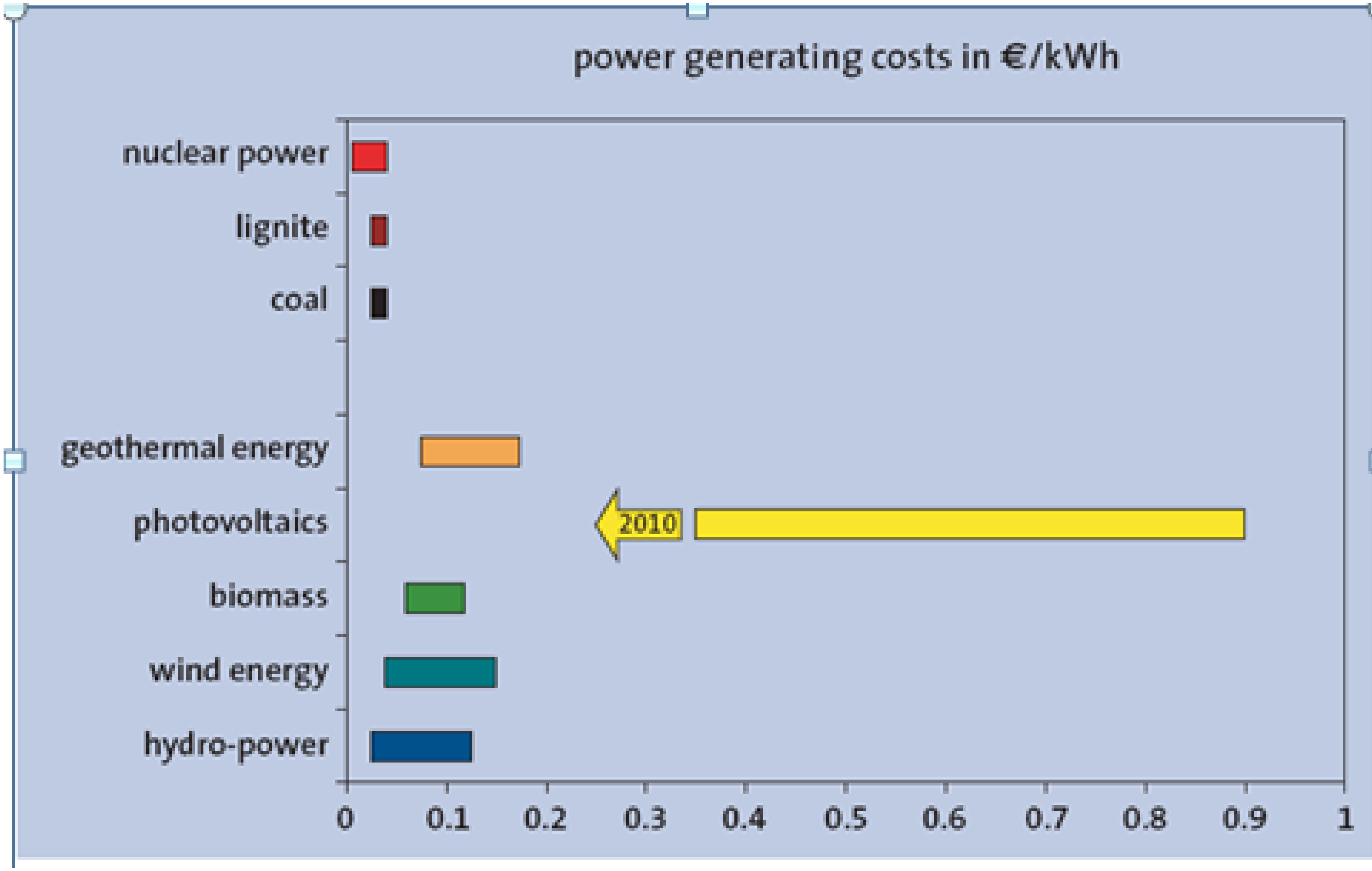
Power densities

Fuel	Power density in kW/m^2
uranium (heat flow density at burner element casing of a nuclear reactor)	650.0
coal (heat flow density at steam generator tubes of a power station)	500.0
hydro-electric (at v = 6 m/s)	108.0
tidal currents (average)	0.002
wave energy (wave height 1.5 m)	14.5
wind energy (at v = 6 m/s)	0.13
solar energy	> 1.37 (ø Germany 0.11)
geothermal energy (normal heat flow)	0.00006

Typical power and energy quantities

- Power
  - Cell phone - 1-3 W
  - Laptop - 50 W
  - Basal human metabolism - 80 W
  - Sprinter - 1.6 kW
  - Microwave oven - 300 W
  - Sunlight - 1 kW/m^2 at noon on a clear day
  - Average home electricity use - 1-2 kW
  - Car engine (100 hp) - 75 kW
  - UC Davis electricity usage- 25 MW
  - 747 in flight- 65 MW
  - Large coal or nuclear power plant - 1000 MW
  - Total US electricity - 1 x 10^6 MW
  - Total power of sun - 2.8 x 10^{20} MW
- Energy
  - AA battery (5 Wh) - 18 kJ
  - Laptop battery - 160 kJ
  - Big Mac - 2.4 MJ
  - 1 kWh = 3.6 MJ
  - 1 kg coal - 29 MJ
  - 1 kg H_2 - 120 MJ
  - 1 gallon gasoline - 120 MJ
  - 1 kg uranium - 78,300,000 MJ
  - Hurricane - 10^9 MJ

Electricity generation costs



Area of different energy transformation technologies

Technology	1000 MWe area
Nuclear	8,8 km^2
Coal	18,13-32,26 km^2
Water	72,5 km^2
Photovoltaic	103,6 km^2
Wind	259 km^2
Biomass	2590 km^2
Geotermal	7,8 km^2
Gas turbine/fuel cell	Case dependent

Area

Technology	Specific power km²/GW	avaibility %	Specific energy Km²/GWh
Water	4000	30	13333
Biomass (direct fire)	4879	80	6098
wind	242	30	806,7
Solar – PV (flat plate)	50	20	250
Coal	96	70	137
solar – Thermal (parabolic trough)	22	34	65
Geotermal	34	90	38
Natural gas	15	40	37,5
Oil	7	30	23,3
Nuclear	12	90	13,3

Forrás: "Renewable Energy Technology Characterizations," DOE's Office of Utility Technologies, Energy Efficiency and Renewable Energy, and EPRI, 1997; "Generic Environmental Impact Statement for License Renewal of Nuclear Plants," NRC, 1996; "The Most Frequently Asked Questions About Wind Energy," American Wind Energy Association, 2002; "PV FAQ's," DOE, Energy Efficiency and Renewable Energy, 2004; Capacity factors from Global Decisions/Energy Information Administration.

Energy consumption in the EU for the production of a number of products

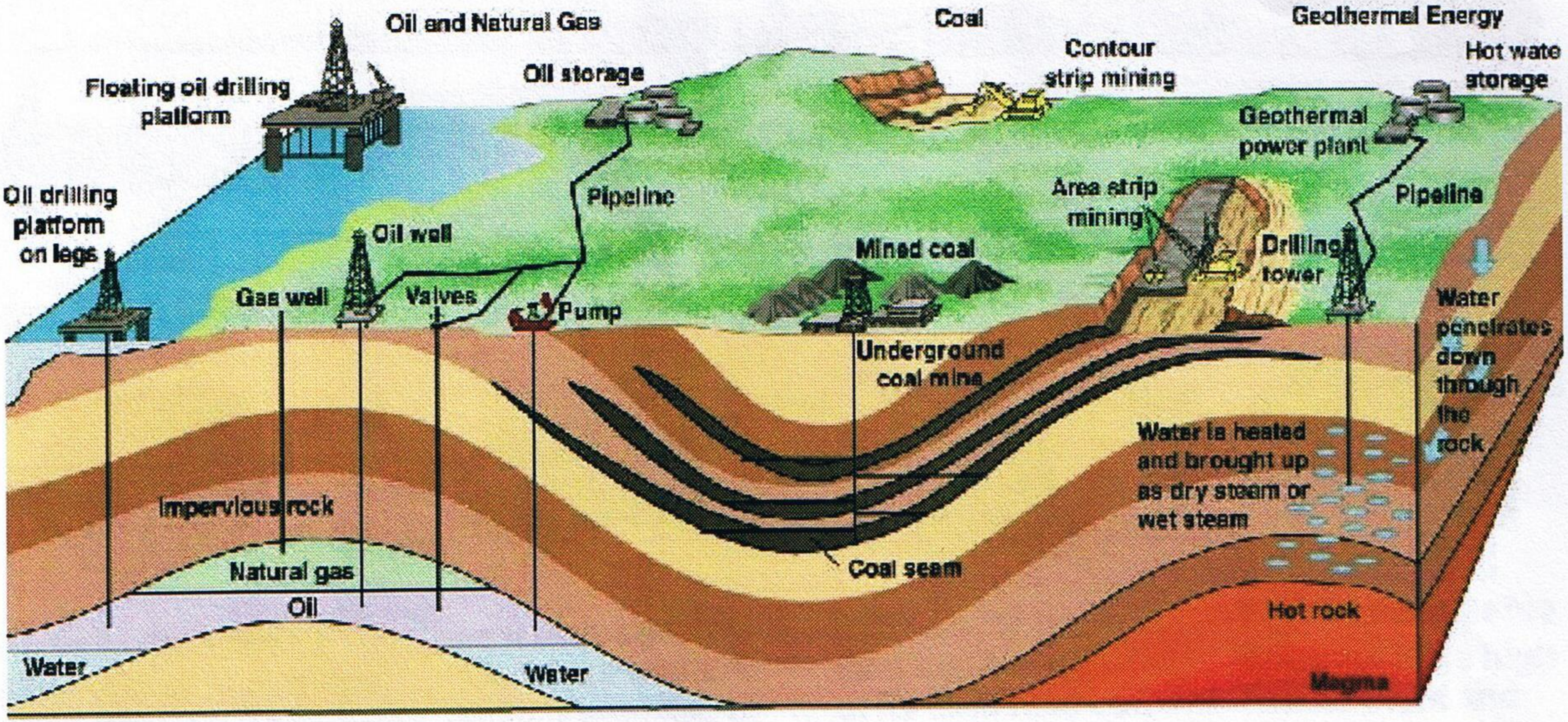
product	resources	production volume (ktonne)	primary energy demand (PJ)	(% of total)	energy intensity* (GJ/tonne)
steel	ore, scrap	137,774	2635	5.7	19.1
aluminium	alumina	2,319	369	0.8	159.1
copper	ore, scrap	1,266	14	0.0	11.1
zinc	ore	1,719	67	0.1	39.0
alumina	bauxite	4,900	72	0.2	14.7
ammonia	fossil fuels	12,479	443	1.0	35.5
chlorine	salt	8,490	287	0.6	33.8
soda ash	salt	5,750	75	0.2	13.0
phosphor	ore	240	40	0.1	166.7
methanol	natural gas	2,000	34	0.1	17.0
oil products	crude oil	463,725	1421	3.1	3.1
petro-chemicals	HC feedstocks	27,734	2237	4.8	80.7
styrene	ethylene, benzene	3,000	27	0.1	9.0
VCM	ethylene, chlorine	4,360	36	0.1	8.3
poly-ethylene	ethylene	5,955	36	0.1	6.0
poly-propylene	propylene	2,440	29	0.1	11.9
PVC	VCM	3,930	23	0.1	5.9
cement	limestone	171,922	665	1.4	3.9
building bricks	clay	47,760	133.5	0.3	2.8
glass	sand, cullets	20,410	181.9	0.4	8.9
paper	pulp, waste paper	35,010	778.0	1.7	22.2

*Calculated by dividing the total primary energy demand by the production volume of a product

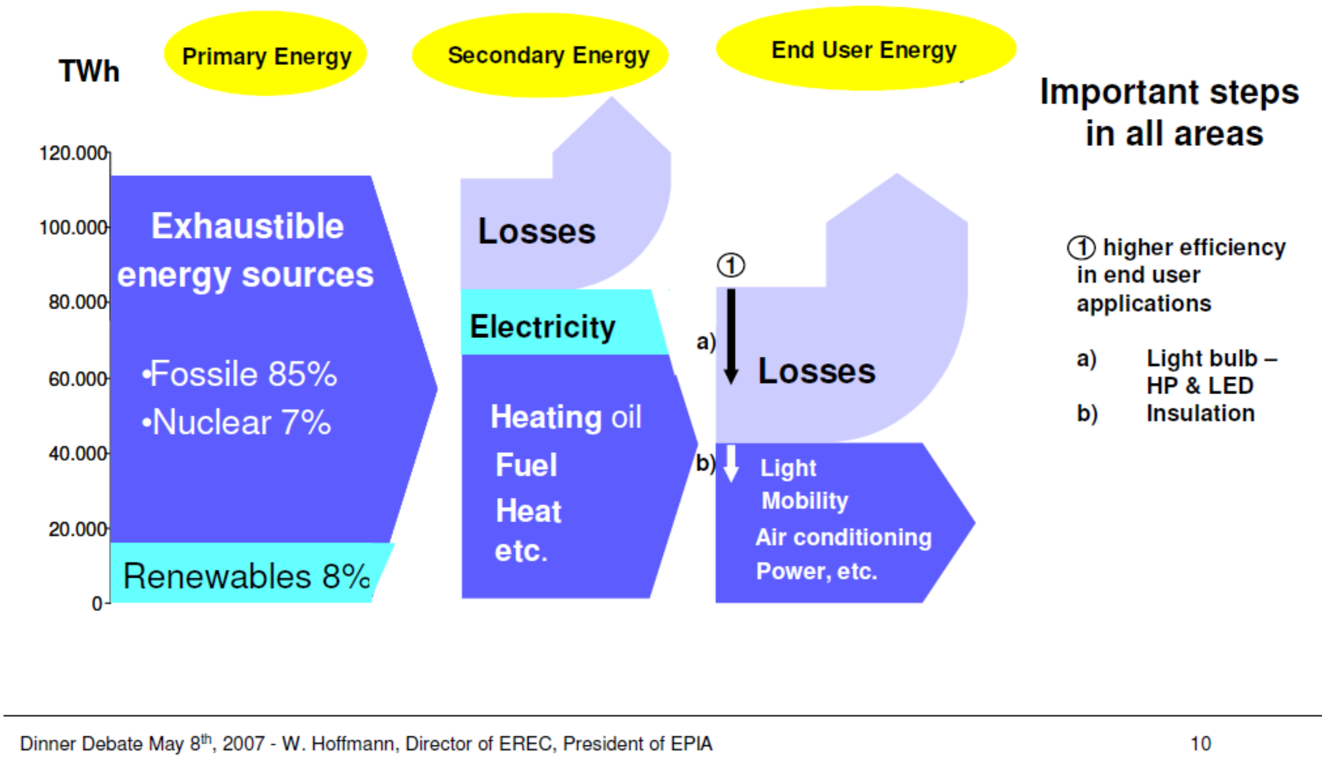
Source: Potentials for improved use of industrial energy and materials - E. Worrell, 1994

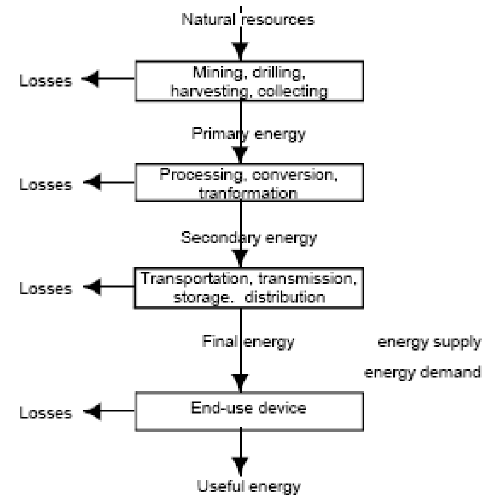
Material	**Specific energy“costs” (MJ/kg)**	**Raw material**
aluminium	230-340	bauxite
brick	2-5	clay
cement	5-9	clay, limestone
copper	60-125	sulfide copper ore
glass	18-35	sand, clay
iron	20-25	ron ore
limestone	0,07-0,1	limestone
nickel	70-230	sulfide nickel ore
paper	25-50	Wood cellulose
polietilene	87-115	crude oil
polistyrol	62-108	crude oil
PVC	85-107	crude oil
sand	0,08-0,1	river bottom
silicium	200-250	silicium-dioxide
steel	20-50	pig iron
sulfuric acid	2-3	sulfur
titan	900-950	titan ore
water	0,001-0,01	Rivers, lakes, ground water
wood	3-7	forest

Energy sources overview



The energy chain





Chemical technology in energy production

Chemical energy → Heat energy

$CH_4 + 2\ O_2 = CO_2 + 2\ H_2O$

HV: $5{,}55 \cdot 10^4$ kJ/kg LHV: $4{,}99 \cdot 10^4$ kJ/kg

Nuclear energy → Heat energy

$${}^{235}_{92}U + n \rightarrow {}^{236}_{92}U^* \rightarrow {}^{90}_{36}Kr^* + {}^{143}_{56}Ba^* + 3n$$

Energy by nuclear fission. $8{,}21 \cdot 10^{10}$ kJ / kg ^{235}U

Chemical energy→heat energy→mechanical energy→electric energy

Nuclear energy→ heat energy→mechanical energy→electric energy

Fossil fuels Elemental composition

Composition of all fossil fuels is variable.. but processing = driving off oxygen

- ***Solid:***

  peat (60% C, 5% H, > 30% O *in mineral by weight…* + water)

  C:H:O ~ (1 : 1 : 0.4)

  coal (lignite: lowest energy content

  sub-bituminous: ~60% C, 5% H, 25% O - *looks like peat*

  bituminous: ~80% C, 5% H, 12% O

  anthracite: > 90% C, < 4% H, < 2% O *by weight*

  for bituminous: C:H:O ~ (1 : 0.8 : 0.1)

- ***Liquid:*** crude oil - *very little oxygen*

  C:H:O ~ (1 : 1 : 0.02)

- ***Gas:*** natural gas …mostly CH_4, i.e. **C:H:O ~ (1 : 4 : 0)**

*refined petroleum **C:H ~ 1 : 2 : 0**… separate light hydrocarbons in processing*

Fossil fuels Elemental composition, energy density

	C:H:O	Energy density (MJ/kg)
Dry biomass (or peat)	1 : 2 : 1	10-30
Coal	1 : 0.8 : 0.1	20-35
Crude oil	1 : 1 : 0.015	~42
Refined petroleum	1 : 2 : 0	44-47
Natural gas	1 : 4 : 0	50

Processing of fossil fuels in Earth drives off oxygen, lowers total energy content ... but tends to increase energy density in stuff that remains.

Fossil fuels

How are they transported?

Coal: Railroads. Typically little international sea transport at present (except for shipping from Australia to China)

Oil: Pipelines, ships (oil tankers)

Gas: Pipelines (gas phase), also ships (if compressed until it liquifies. "LNG" = liquified natural gas)

NIMBY issues with LNG: highly explosive, dangerous, no one wants an LNG terminal near them

FOSSIL/ORGANIC FUELS

COAL, OIL, NATURAL GAS.
OIL SHALE, TAR SAND, PEAT.
“BIOMASS” .. Young, “renewable”.

- Formed due to the fossilization of *organic* matter, under ground (although evidence of earth mantel inorganic methane is rising).
- All formed of carbon and hydrogen, some with little oxygen, plus sulfur, mercury and other minerals, and non combustibles.
- Most require some form of processing: sulfur removal, grinding and washing, oil refining, gas desulfurization.

COAL

(fossilized vegetations)

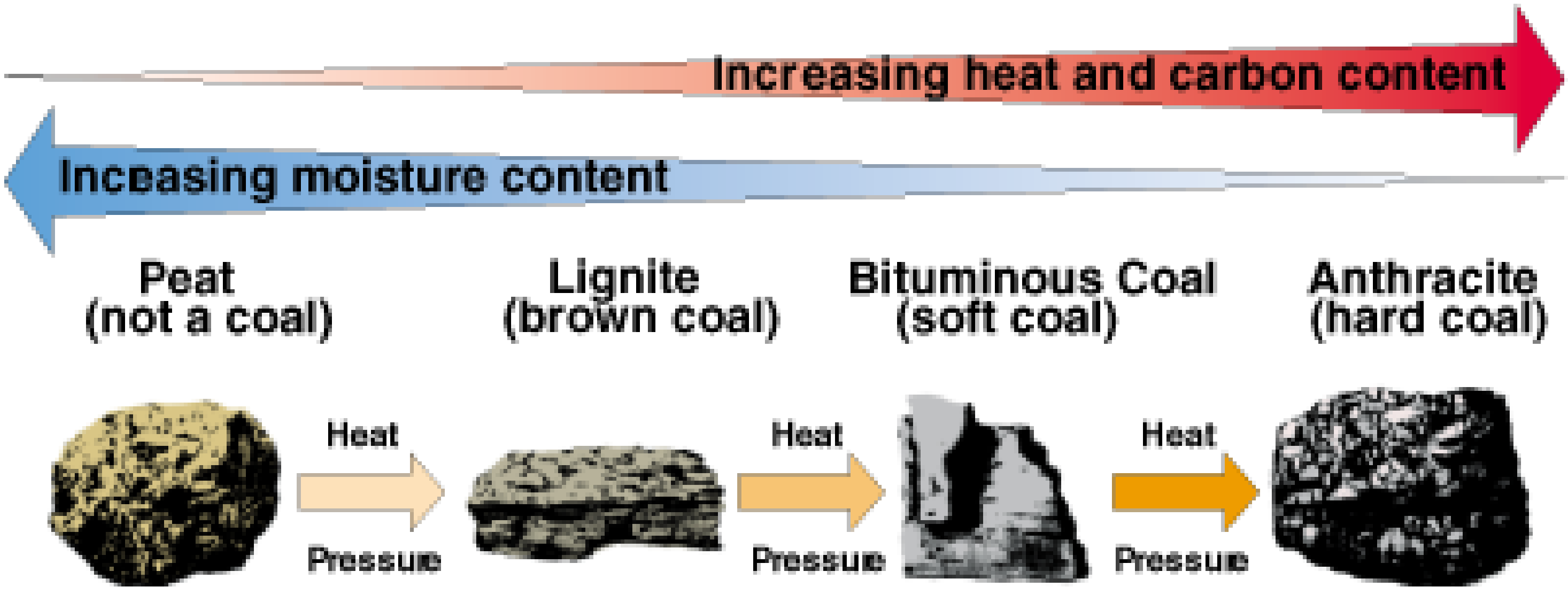
lignite, subbituminous, bituminous, anthracite.

- Coal is carbon + hydrogen (CH_m, $m < 1$) + sulfur (up to 10% by weight) + nitrogen + ash (non combustibles).
- Some sulfur can be washed away before combustion, but mostly is scrubbed from combustion products using limestone.
- In fluidized bed combustors, pulverized coal is mixed with limestone and burned at lower temperature in blowing air.
- In gasification, rich burning in oxygen and water forms syngas ($CO+H_2$), desulfurization before combustion or gas separation.

Coal

fossil fuel, from **swamp plants** of Carboniferous period (ending **286 million** years ago).

Stages of coal forming over millions of years



Fossil fuels

Coal comes from plants

- *Solid:* coal

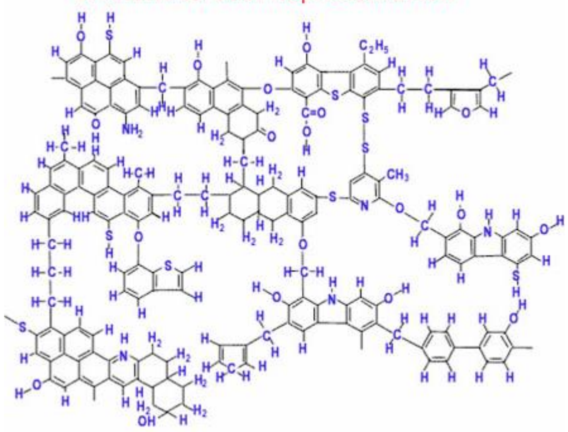
anthracite

bituminous

sub-bituminous

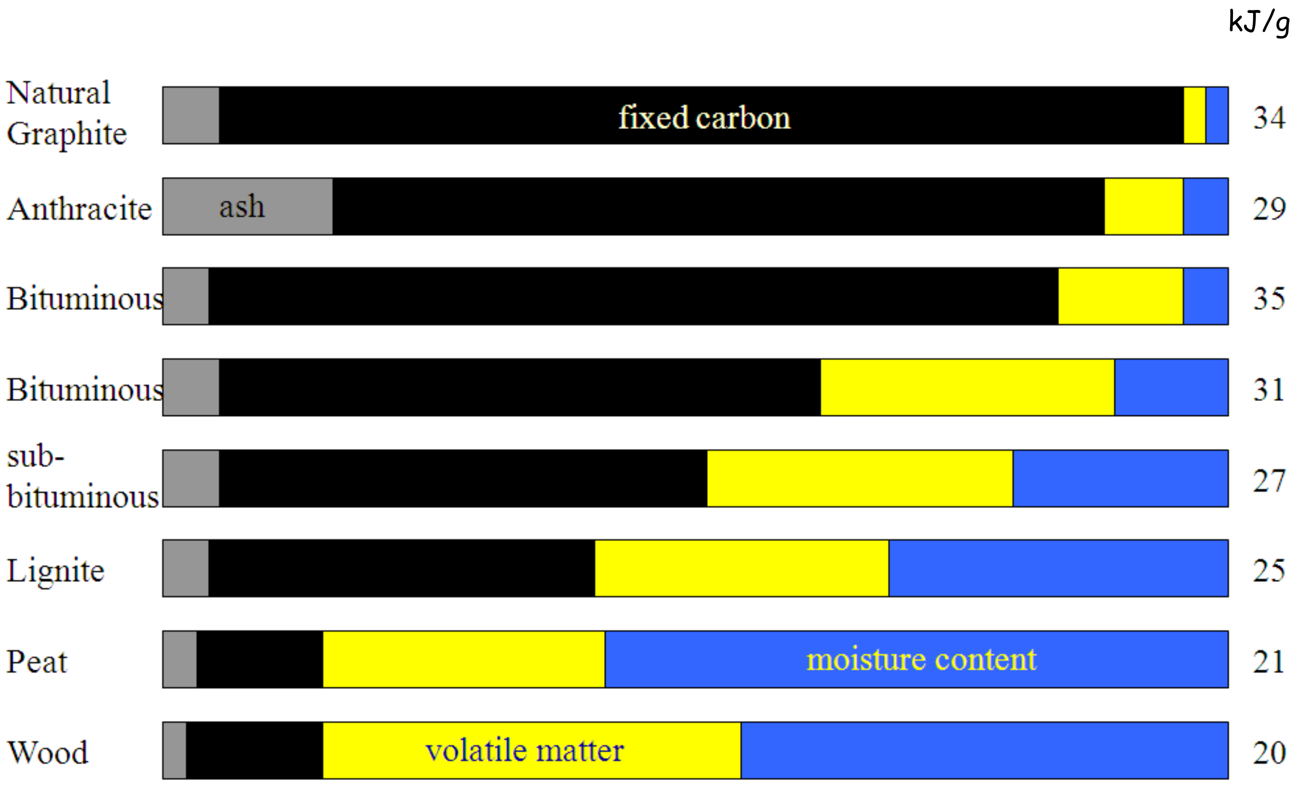
lignite

Bituminous Coal Representation



peat

Coal types and composition



Ranks of Coal

- Lignite: A brownish-black coal of low quality (i.e., low heat content per unit) with high inherent moisture and volatile matter. Energy content is lower 4000 BTU/lb.

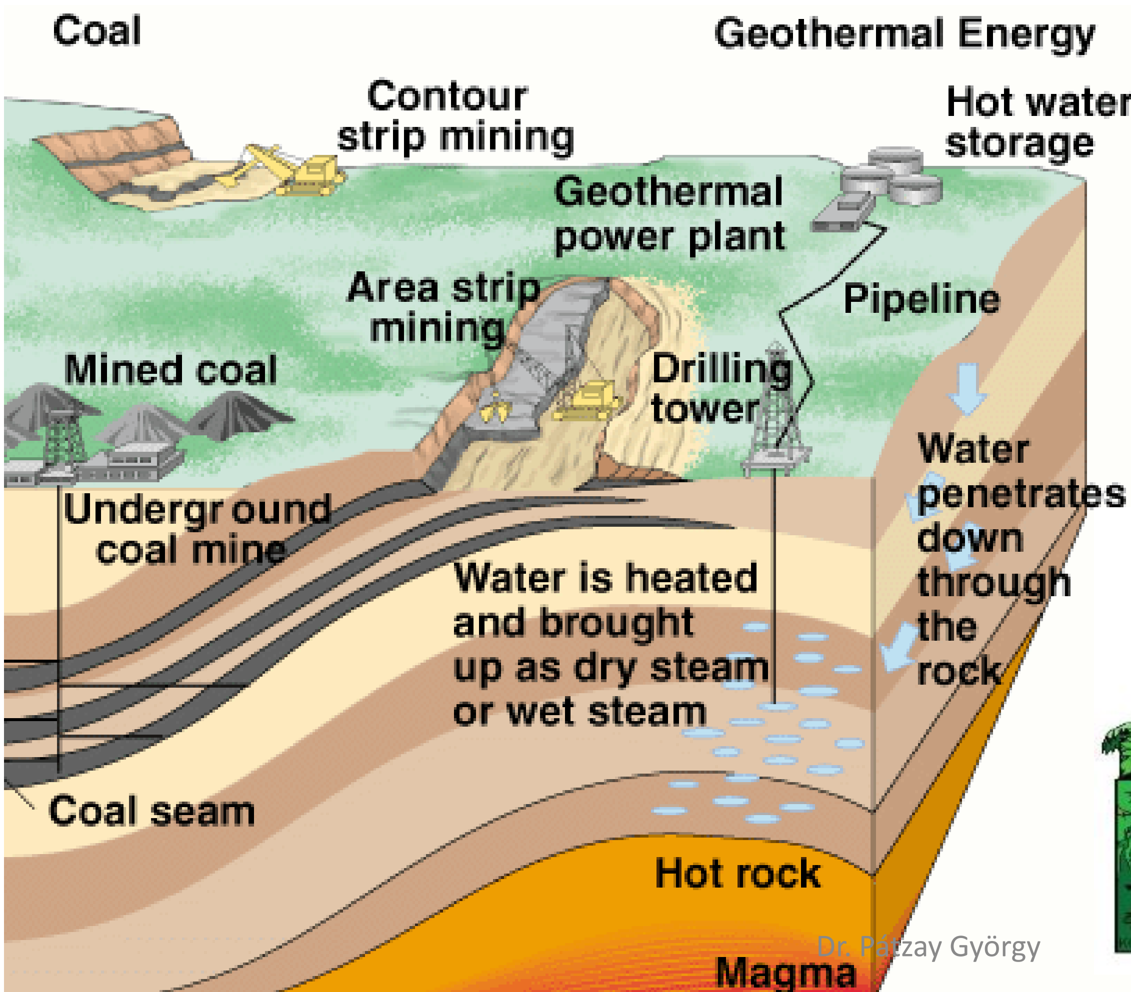
- Subbituminous: Black lignite, is dull black and generally contains 20 to 30 percent moisture Energy content is 8,300 BTU/lb.

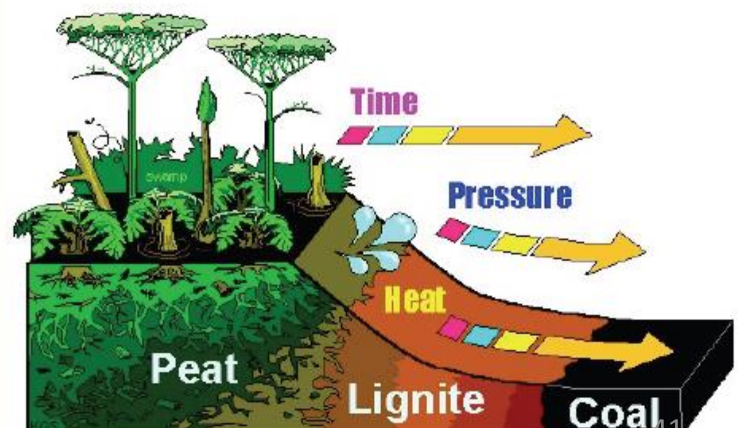
- Bituminous: most common coal is dense and black (often with well-defined bands of bright and dull material). Its moisture content usually is less than 20 percent. Energy content about 10,500 Btu / lb.

- Anthracite :A hard, black lustrous coal, often referred to as hard coal, containing a high percentage of fixed carbon and a low percentage of volatile matter. Energy content of about 14,000 Btu/lb.

www.uvawise.edu/philosophy/Hist%20295/ Powerpoint%5CCoal.ppt

Extraction by Mining





Coal advantages and disadvantages

Pros

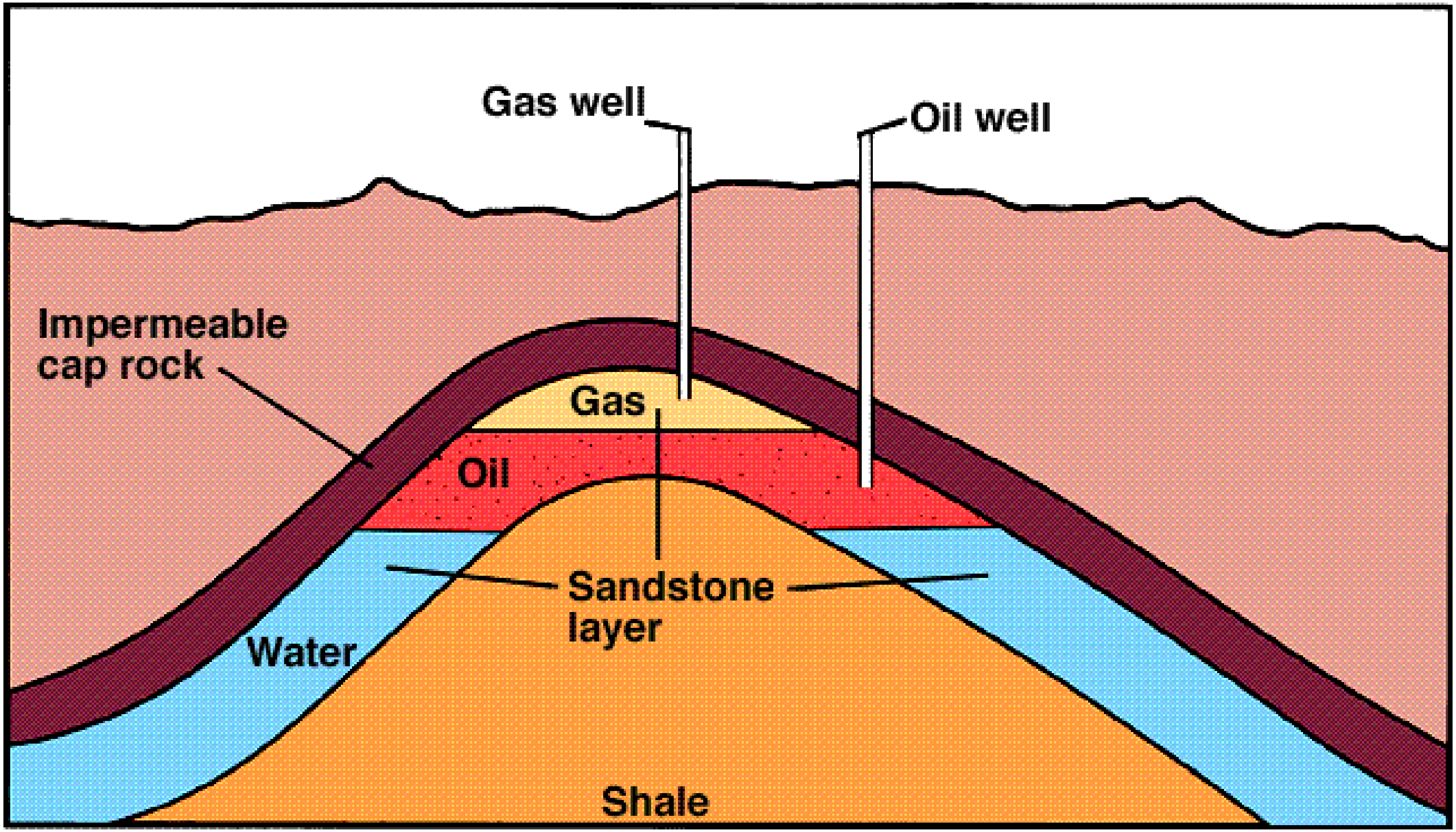
- Most abundant fossil fuel
- Major world reserves
- 120 yrs. at current consumption rates
- High net energy yield

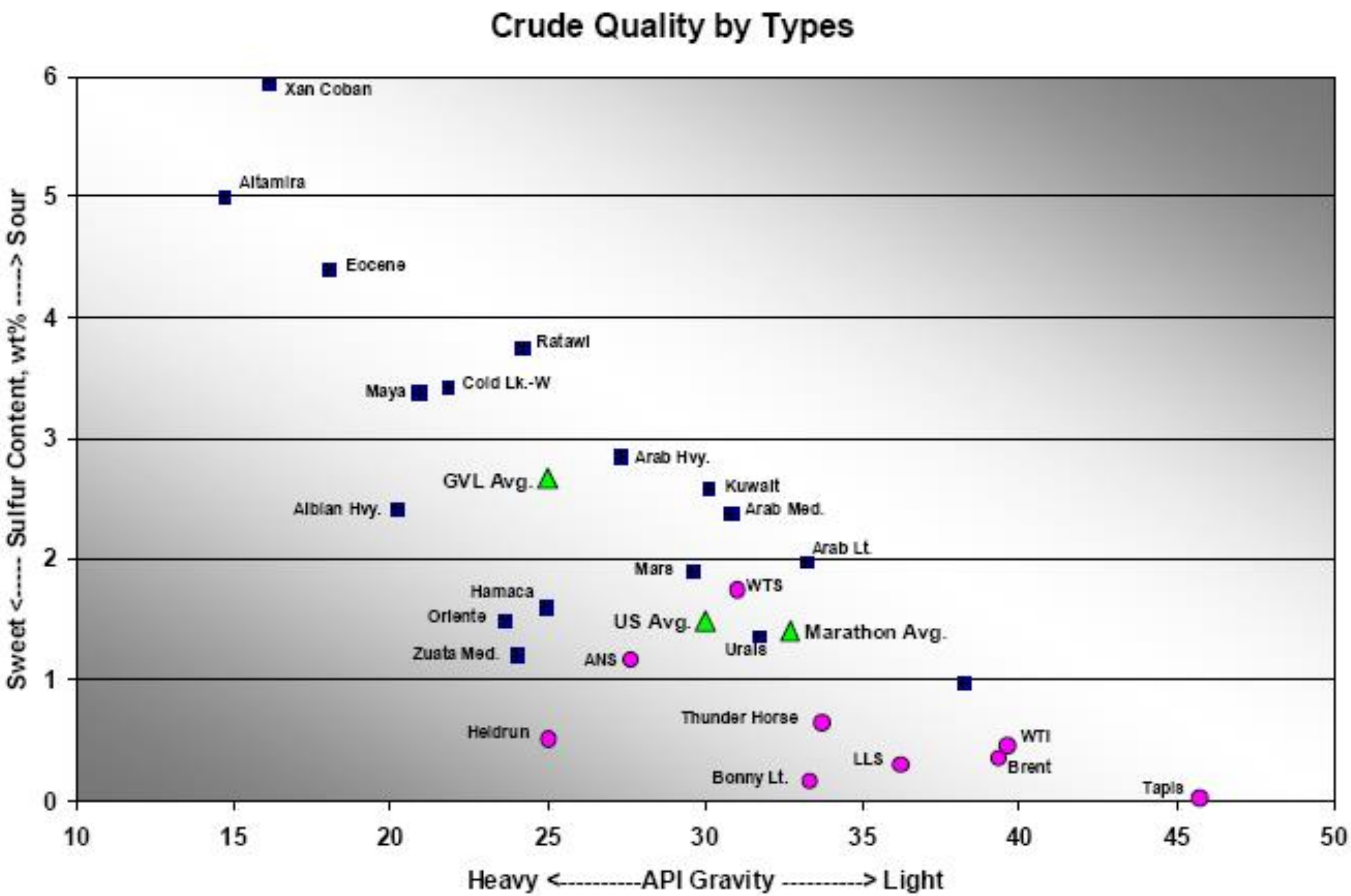
Cons

- Dirtiest fuel, highest carbon dioxide
- Major environmental degradation
- Major threat to health

www.bio.miami.edu/beck/esc101/Chapter14&15.ppt

Crude Oil and Natural Gas Pool




Crude Quality by Types
Sweet <----- Sulfur Content, wt% -----> Sour
Heavy <---------API Gravity ---------> Light
Xan Coban
Altamira
Eocene
Ratawi
Maya
Cold Lk.-W
Arab Hvy.
GVL Avg.
Kuwait
Albian Hvy.
Arab Med.
Arab Lt.
Mars
WTS
Hamaca
Oriente
US Avg.
Marathon Avg.
Urals
Zuata Med.
ANS
Thunder Horse
Heidrun
WTI
LLS
Brent
Bonny Lt.
Tapis
0
1
2
3
4
5
6
10
15
20
25
30
35
40
45
50

OIL

(or petroleum, liquid rock, fossilized marine life. algae)

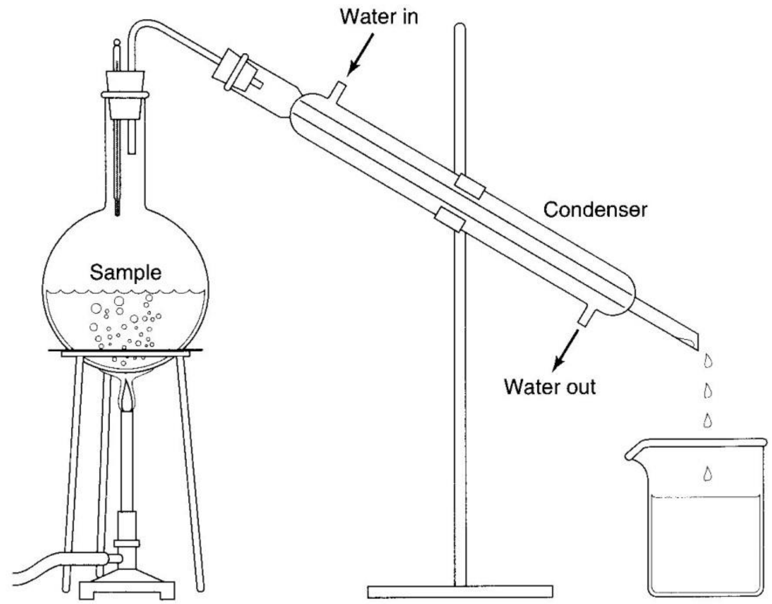
- Made up of many organic compounds + hydrogen + nitrogen + sulfur. Sweet and sour refer to the amount of sulfur. CH_m, $1 < m < 2$.

- "Light oil" is generally composed of three hydrocarbon families:

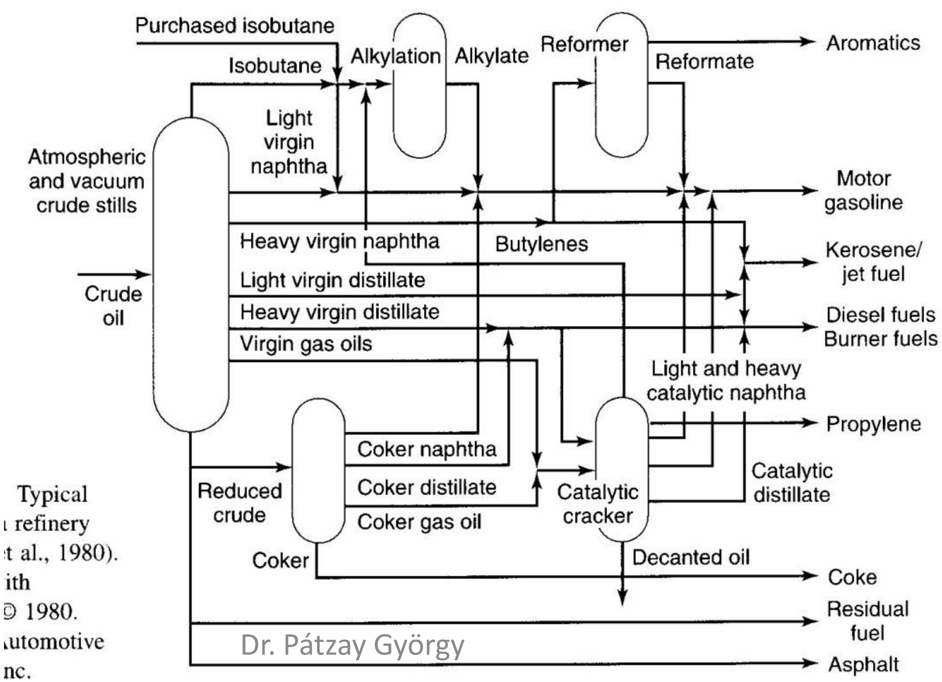
  - Saturated hydrocarbons: paraffins (or normal alkanes), C_nH_{2n+2}, with gas, n = 1-4, liquid, n = 5-15, and solids, n > 15.
  - Unsaturated hydrocarbons, or aromatics, like benzene, C_6H_6, toluene, C_7H_8 and nephthalene, $C_{10}H_8$.
  - Resin and asphaltenes, heavier hydrocarbons rich in nitrogen, oxygen, sulfur and vanadium.

- Refining: distillation (separation of lighter components), catalytic cracking (heating) and reforming (with steam or hydrogen). Products are typically refinery gas, LPG, gasoline (mostly octane C_8H_{18}), aviation fuels (JPx) diesels, heating and lube oils ….

16



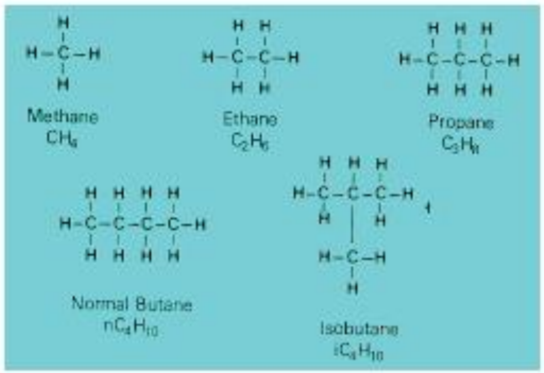
' Distillation
ude oil into

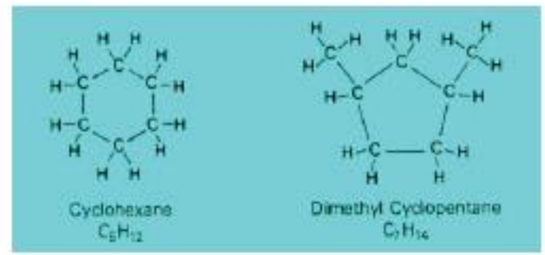


Typical
ı refinery
:t al., 1980).
ith
Ͽ 1980.
ıutomotive
nc.

Molecular composition

Crude oil: also complex – a mixture of hydrocarbons C_nH_m of various lengths to > C_{70} (with some impurities, e.g. sulfur at S:C ~ .004-.02: 1)

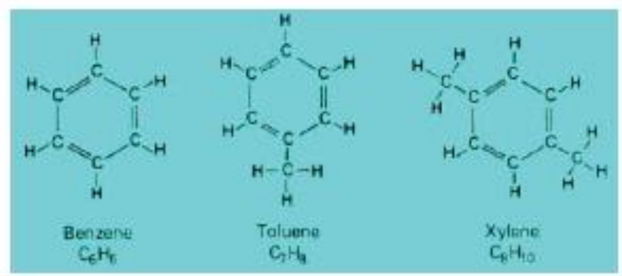




Naphthenes

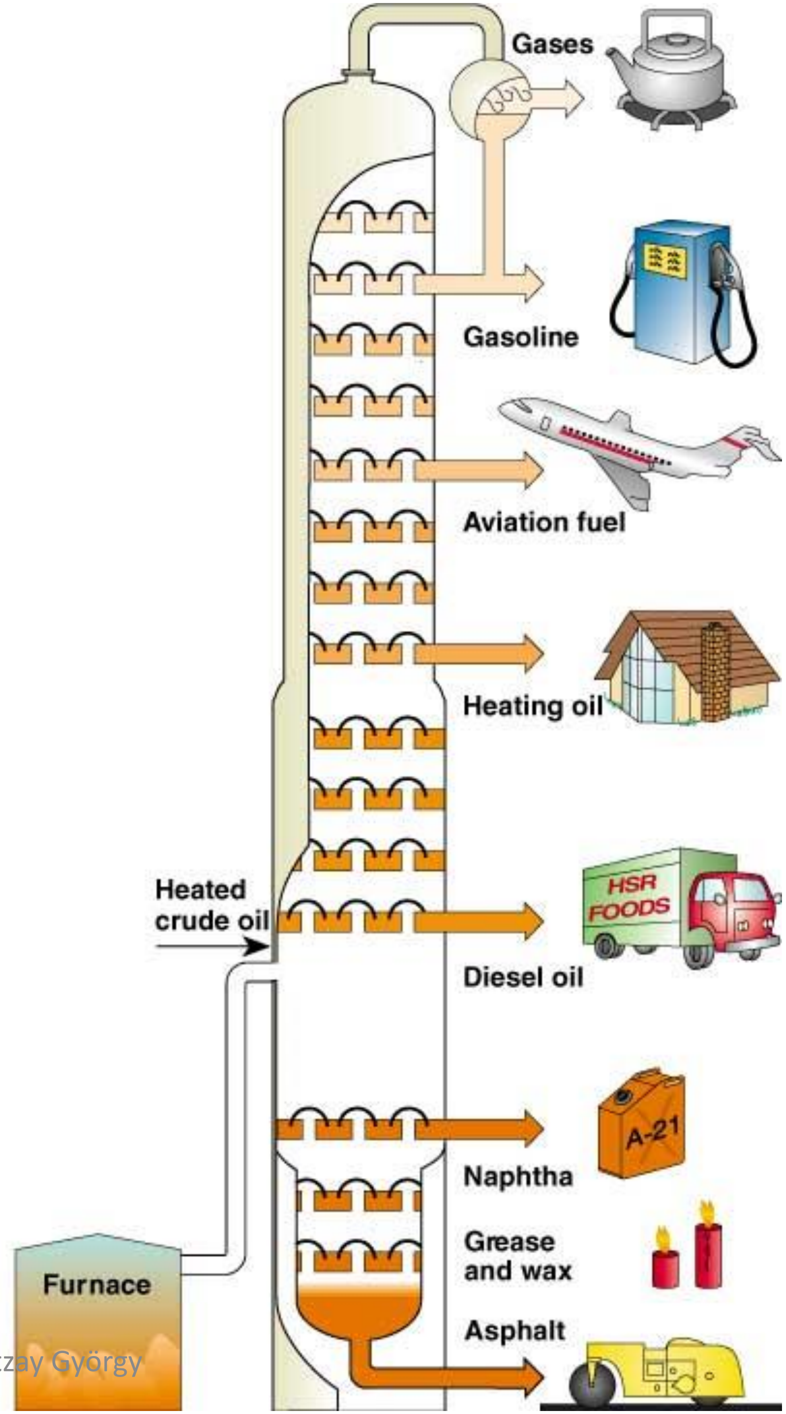
Paraffins

All Cs want to make 4 bonds. “Saturated” means no double C bonds – no extra place where a new atom could be incorporated in chain. (Most Cs in saturated hydrocarbons are linked to 2 Hs, 2 Cs).

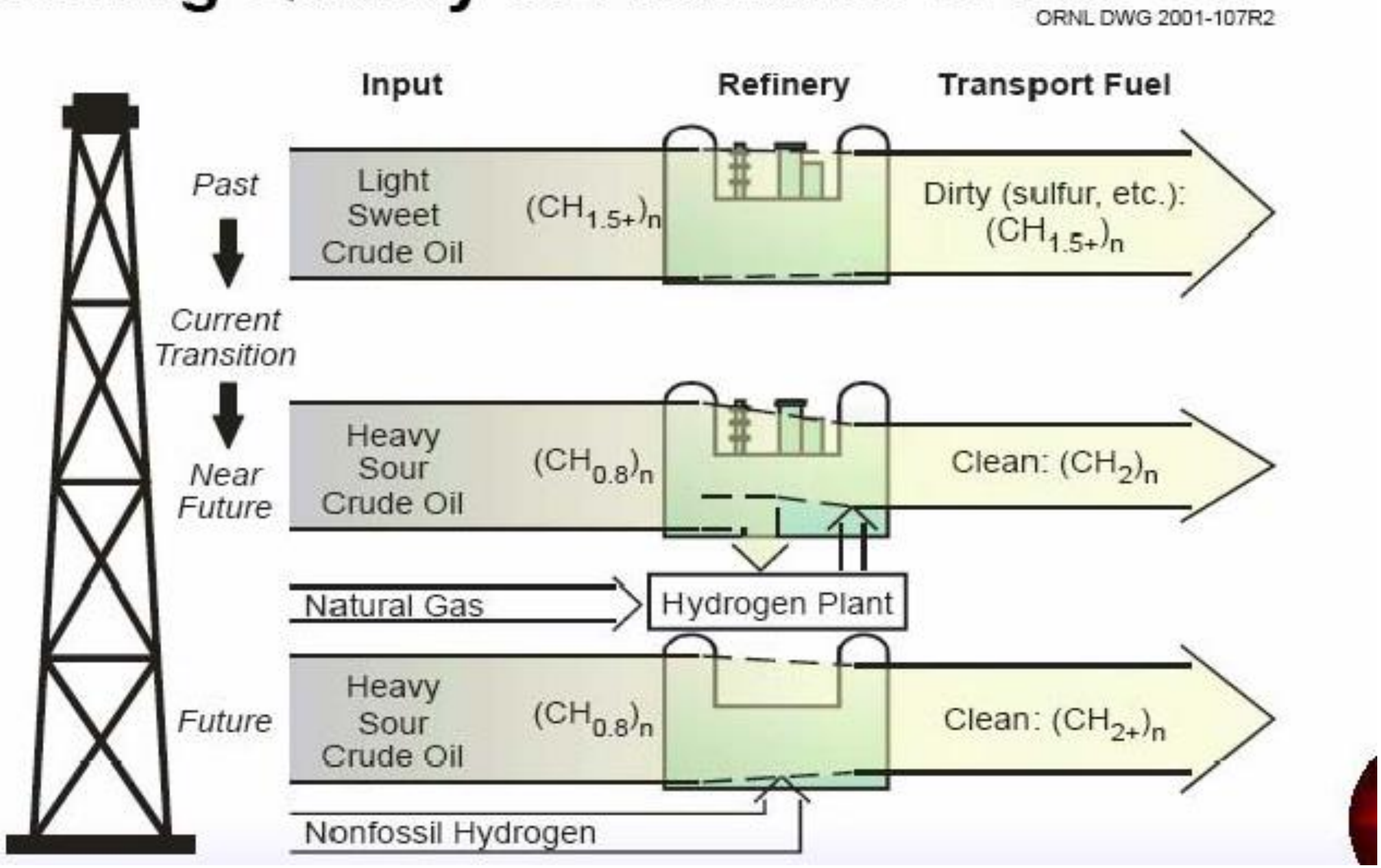


Aromatics

Refining crude oil.
Based on their boiling points, components are removed at various levels
in distillation column.



A Large Demand for Hydrogen is due to the Declining Quality of Available Crude Oil



Non-Conventional "Heavy" Oil

(all require intensive processing)

Oil Shale:

impermeable hard rock containing (organic, non petroleum) kerogen (pre-oil), which pyrolyzes into oil + (organic, petroleum) bitumen that liquifies with heating.

Tar and Tar Sand:

a mixture of sand and bitumen (coal-like) can be reformed into oil components.

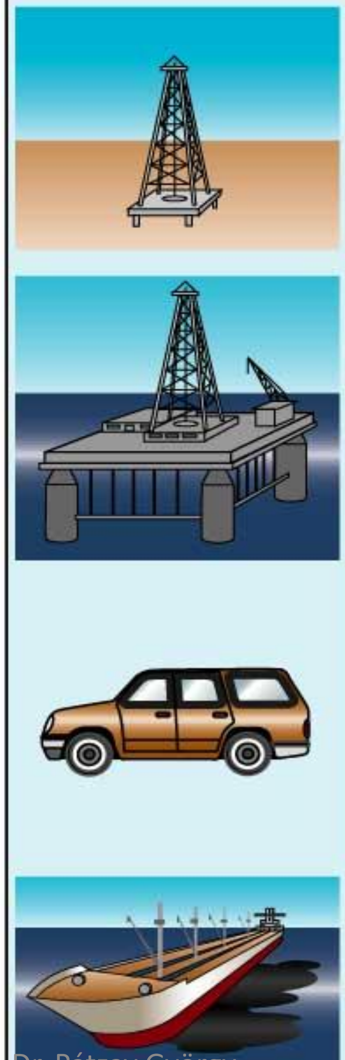
Peat:

"Duff" material in forests and woodland ..

Advantages and disadvantages of using oil as an energy resource

Advantages

- Ample supply for 35–84 years
- Low cost (with huge subsidies)
- High net energy yield
- Easily transported within and between countries



Disadvantages

- Need to find substitute within 50 years
- Artificially low price encourages waste and discourages search for alternatives
- Air pollution when burned
- Releases CO_2 when burned
- Moderate water pollution

NATURAL GAS

- Mostly methane, CH_4, ethane C_2H_6, some propane, C_3H_8, and little butane, C_4H_8, with small fractions of higher hydrocarbons, may contain sulfur, oxygen, CO_2 at small quantities.
- Requires least processing.
- Biogenic Gas: near surface, difficult to exploit.
- **Methane hydrides/hydrates**, found in deep oceans, and permafrost, encapsulated in water (estimated to exceed 2 orders of magnitude of proven gas reserves) in ice like structures.

Natural Gas

- fossil fuel;
- mixture of 50–90% methane (**CH_4**), smaller amounts of ethane (C_2H_6), propane (C_3H_8), & butane (C_4H_{10}), and hydrogen sulfide (H_2S);
- typically transported by pipelines;

Methane (**CH_4**) is a greenhouse gas!

Advantages and disadvantages of using oil as an energy resource

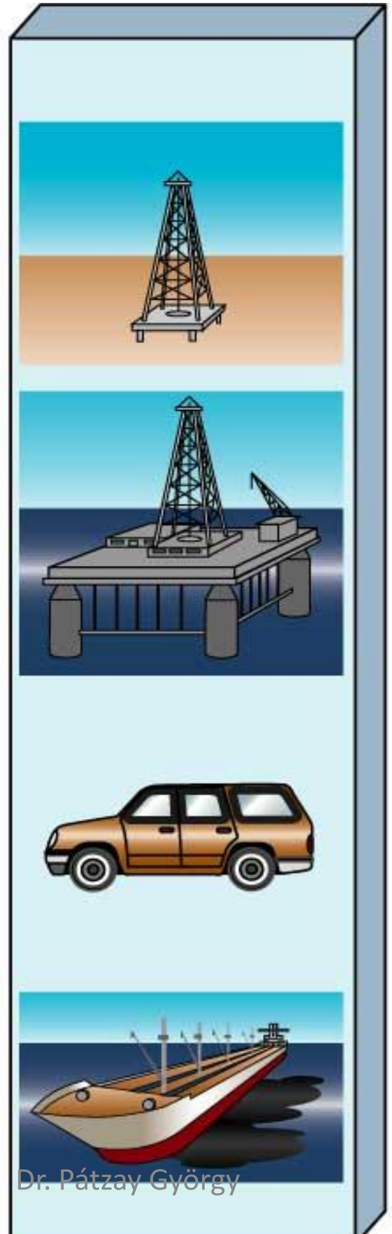
Advantages

Ample supply for 35–84 years

Low cost (with huge subsidies)

High net energy yield

Easily transported within and between countries



Disadvantages

Need to find substitute within 50 years

Artificially low price encourages waste and discourages search for alternatives

Air pollution when burned

Releases CO_2 when burned

Moderate water pollution

One way to classify fuels is through their heating value, In this table it is the *LHV*, in MJ/kg fuel.

Commercial Fuels

Natural gas			36-42
Gasoline			47.4
Kerosene			46.4
No. 2 oil			45.5
No. 6 oil			42.5
Anthracite coal			32-34
Bituminous coal			28-36
Subbituminous coal			20-25
Lignite			14-18

Biomass Fuels

Wood (fir)			21
Grain			14
Manure			13

Fuel combustion - Fuel Type

- Solid
  - Coal
    - $\eta_{combustion}$= 89%
  - Wood
    - $\eta_{combustion}$= 74%
- Liquid
  - Number 2 fuel oil
    - $\eta_{combustion}$= 88%
  - Number 6 fuel oil
    - $\eta_{combustion}$= 88%
- Gas
  - Natural gas
    - $\eta_{combustion}$= 85%

Fuel combustion

Fuel combustion

- $CH_4 + 3\ O_2 = CO_2 + 2\ H_2O$ – natural gas
- $C_8H_{12} + 11O_2 = 8\ CO_2 + 6\ H_2O$ – gasoline
- $C_6H_{12}O_6 + 6O_2 = 6\ CO_2 + 6\ H_2O$– cellulosic biomass

Theoretical Air

- In a perfect world air and fuel would mix completely and complete combustion would occur
  - Each molecule of fuel would find exactly the correct amount of oxygen for the combustion reaction to take place
    - This is referred to as stoichiometric combustion

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{Energy Release}$$

- For most combustion processes air is used as the source for oxygen
  - Air contains approximately 79% nitrogen (N_2), which does not enter into the combustion reaction

Classic Boiler Efficiency

- For a steam generating unit, efficiency is defined as the heat absorbed by the steam divided by the energy input from the fuel, direct method

$$\eta_{boiler} = \frac{energy\ desired}{energy\ that\ costs}(100)$$

$$\eta_{boiler} = \frac{\dot{m}_{steam}\left(h_{steam} - h_{feedwater}\right)}{\dot{m}_{fuel}\,HHV_{fuel}}(100)$$

Indirect Efficiency

- Boiler efficiency can also be determined in an indirect manner
  - By determining the magnitude of the losses
  - The primary losses are typically
    - Shell loss
    - Blowdown loss
    - Stack loss

$$\eta_{indirect} = 100\% - \sum_{losses}\lambda_i$$

$$\eta_{indirect} = 100\% - \lambda_{shell} - \lambda_{blowdown} - \lambda_{stack} - \lambda_{misc}$$

Excess Air

- In reality there is insufficient
  - Reaction _T_ime to allow the combustion to complete
  - Insufficient reaction _T_emperature to drive the chemical reaction to completion
  - Insufficient mixing or _T_urbulence to allow the fuel and oxygen to react
- As a result more air than is theoretically required is added to the combustion process to insure all of the fuel has an opportunity to react
  - This excess air enters the combustion chamber at ambient temperature and is immediately heated to near the flame temperature
  - The air then passes across the heat exchange surfaces and gives up a portion of its energy to the boiling water
  - The excess air then exits the boiler at stack temperature
    - The net result is ambient air has been heated from, for example, 50°F to 550°F with no useable effects, this is a system loss.

Excess Air

- 100% theoretical air (0% excess oxygen):

$$CH_4 + (1.0)2O_2 + (1.0)(2)(3.76)N_2 \rightarrow CO_2 + 2H_2O + (1.0)(2)(3.76)N_2$$

- 150% theoretical air (6.5% oxygen in the flue gas):

$$CH_4 + (1.5)2O_2 + (1.5)(2)(3.76)N_2 \rightarrow CO_2 + 2H_2O + (1.0)O_2 + (1.5)(2)(3.76)N_2$$

Fireing technology

Excess air calculation from measured data

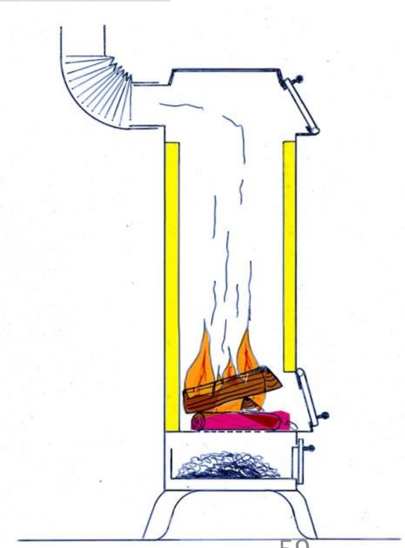
From equations: $V_{'d} = V_{o'd} + (\lambda-1)\, L_o'$,

and

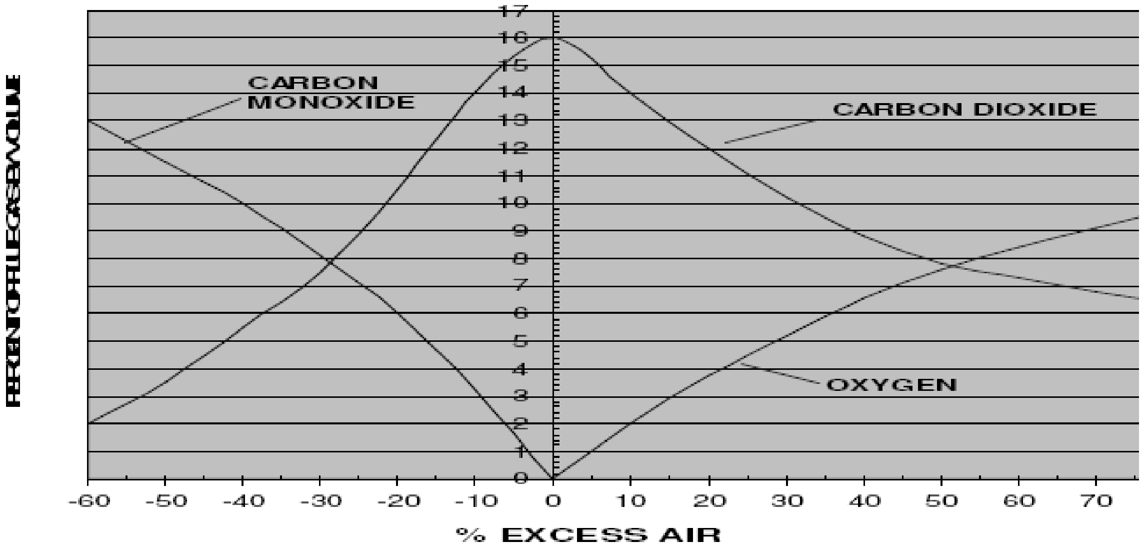
$$0.21 \cdot (\lambda-1)\, Lo' = O_{2fluegas} \cdot (V_{o'd} + (\lambda-1) \cdot L_o')$$

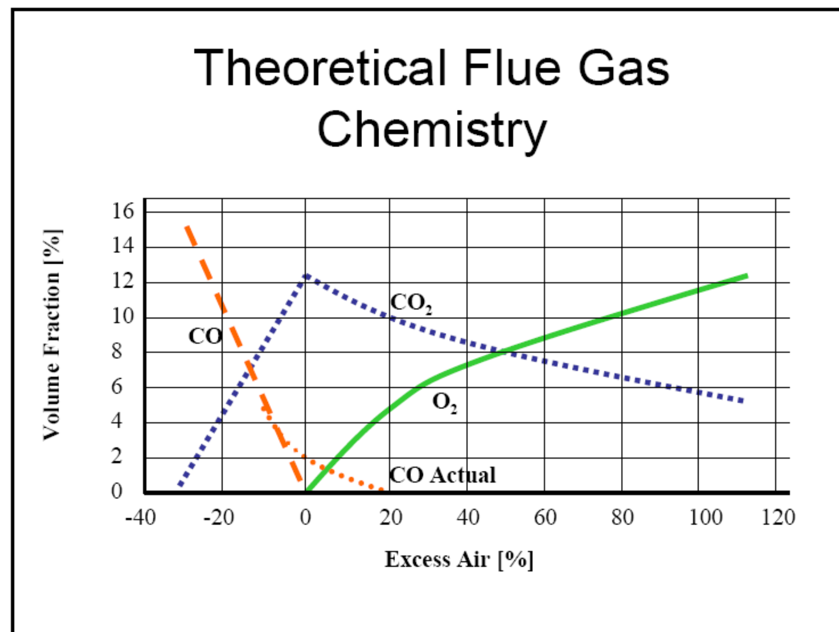
taking into account that $V_{o'd} \approx L_o'$ can get:

$$\lambda = \frac{21}{21 - O_{2\,fluegas}}$$



AIR:FUEL RATIO **FLUE GAS ANALYSIS**



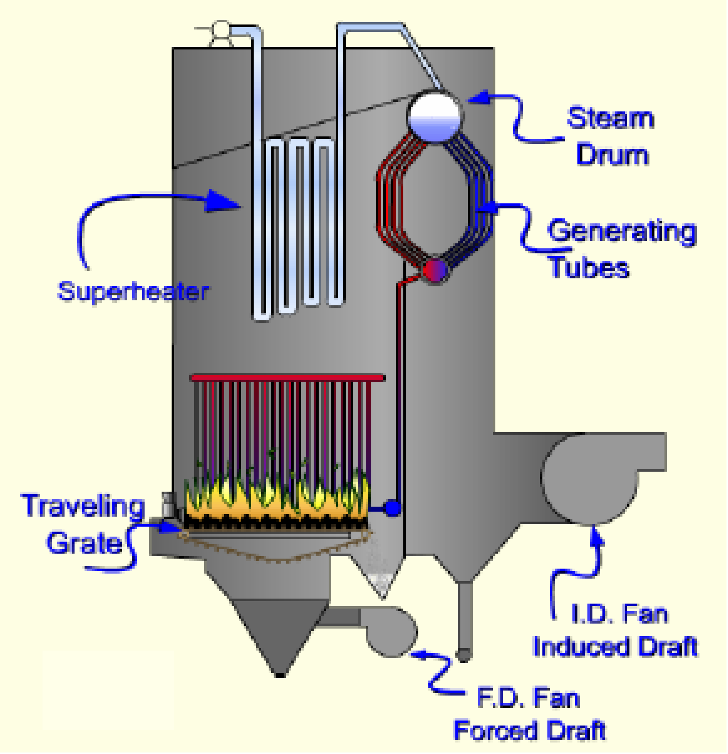


Determination of optimal excess air factor

Depends on several conditions:

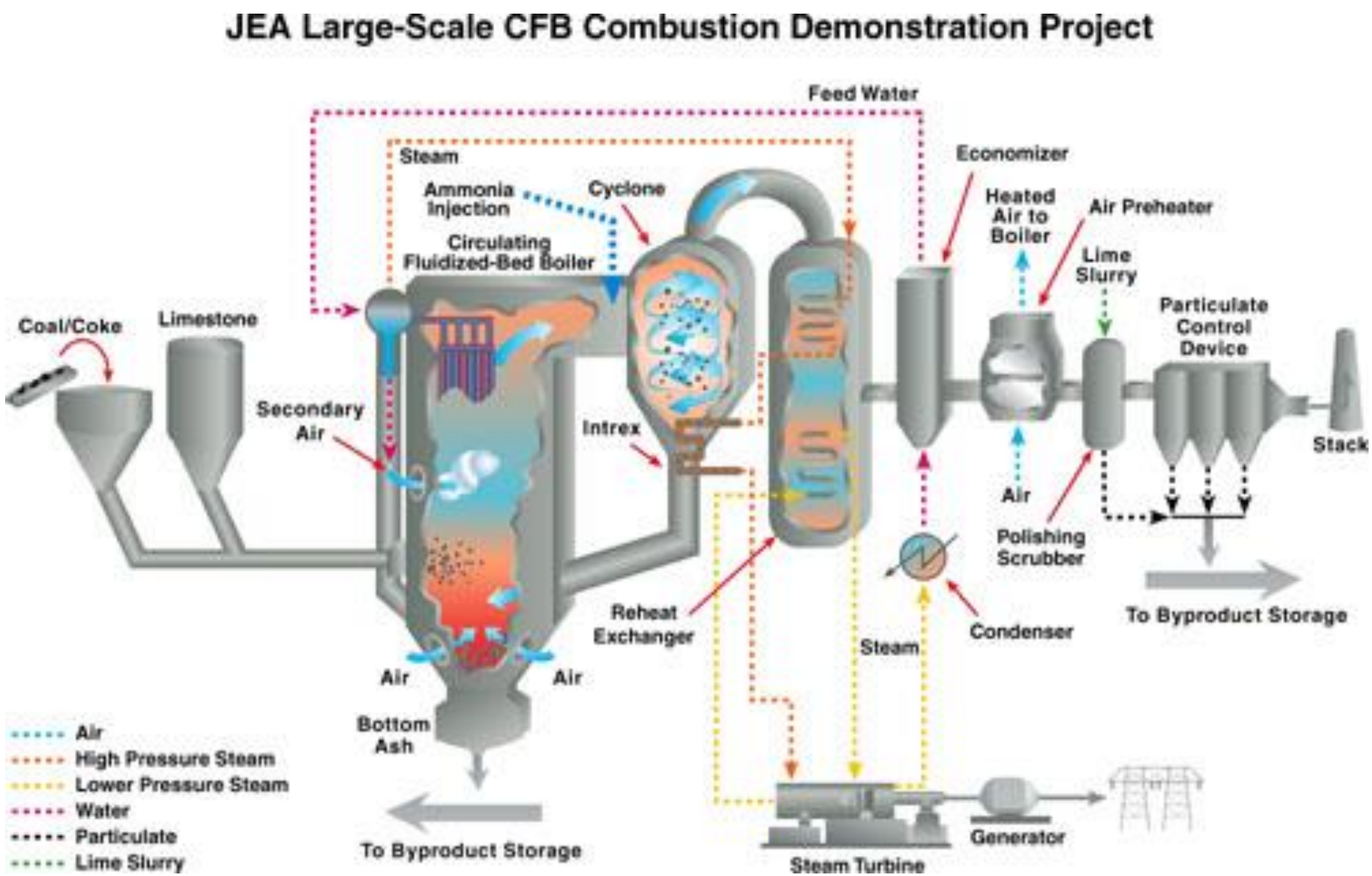
- Fuel type, combustion system, burner construction, pollutant emission limits, etc.
- Some usual values of the excess air factor :

fuel	λ
gas	1.03 - 1.3
oil	1.1 - 1.4
coarse solid fuel	1.4 - 2.0
pulverized solid fuel	1.2 – 1.5

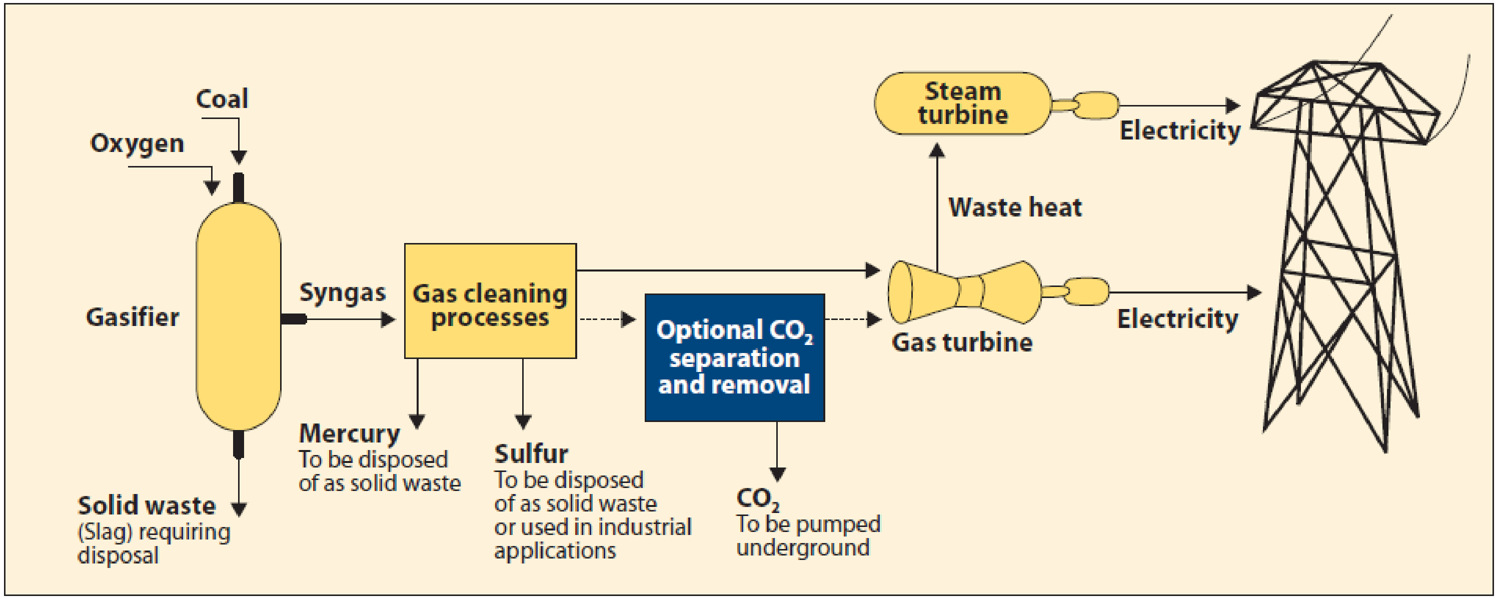


Travelling grate coal fireing

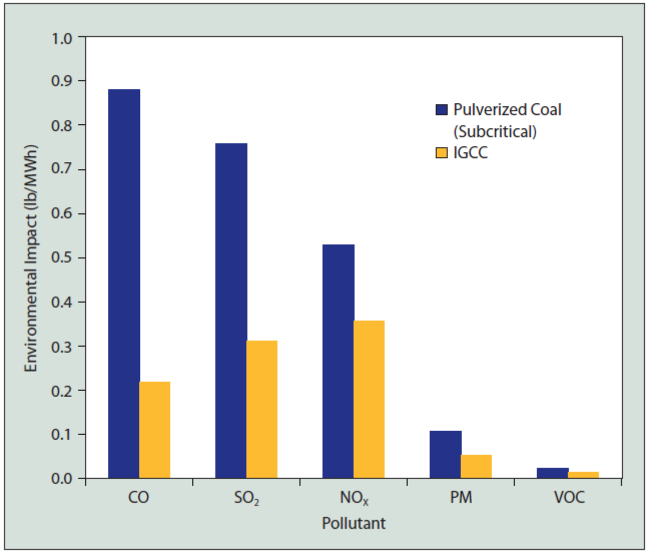
Fluid Bed Combustion



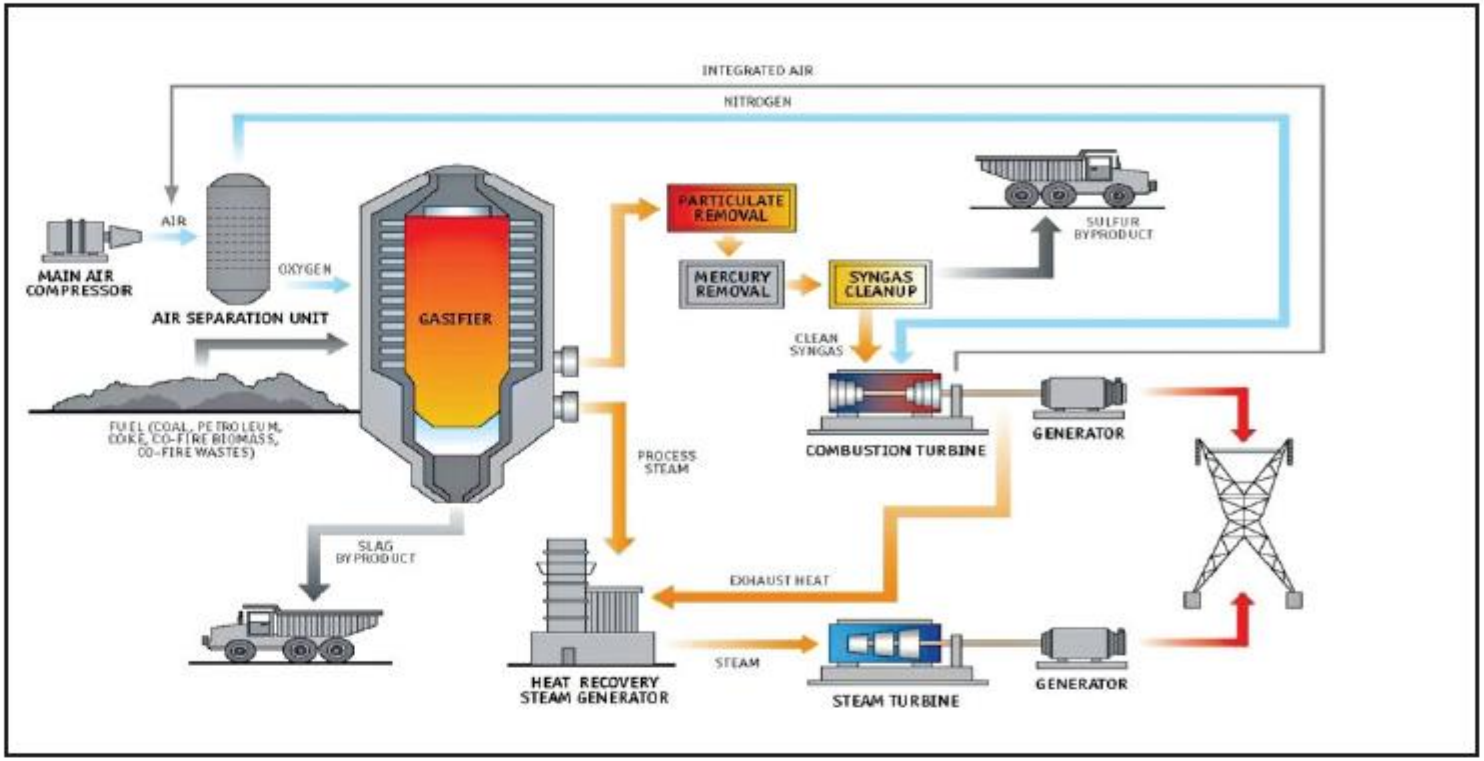
IGCC



Coal
Oxygen
Gasifier
Syngas
Gas cleaning processes
Optional CO_2 separation and removal
Steam turbine
Electricity
Waste heat
Gas turbine
Electricity
Mercury
To be disposed of as solid waste
Sulfur
To be disposed of as solid waste or used in industrial applications
CO_2
To be pumped underground
Solid waste
(Slag) requiring disposal

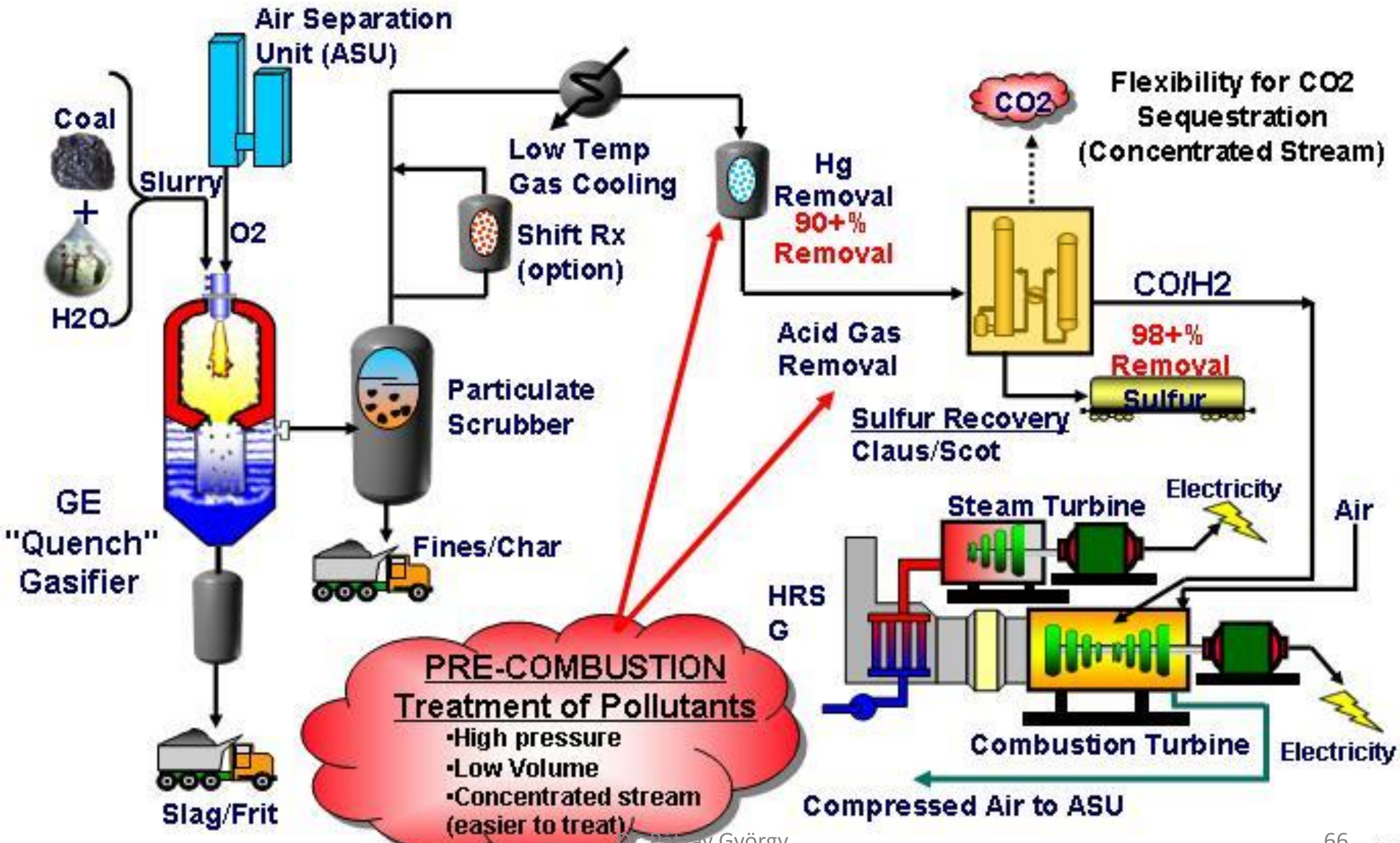


Environmental Impact (lb/MWh)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Pulverized Coal (Subcritical)
IGCC
CO
SO_2
NO_x
PM
VOC
Pollutant

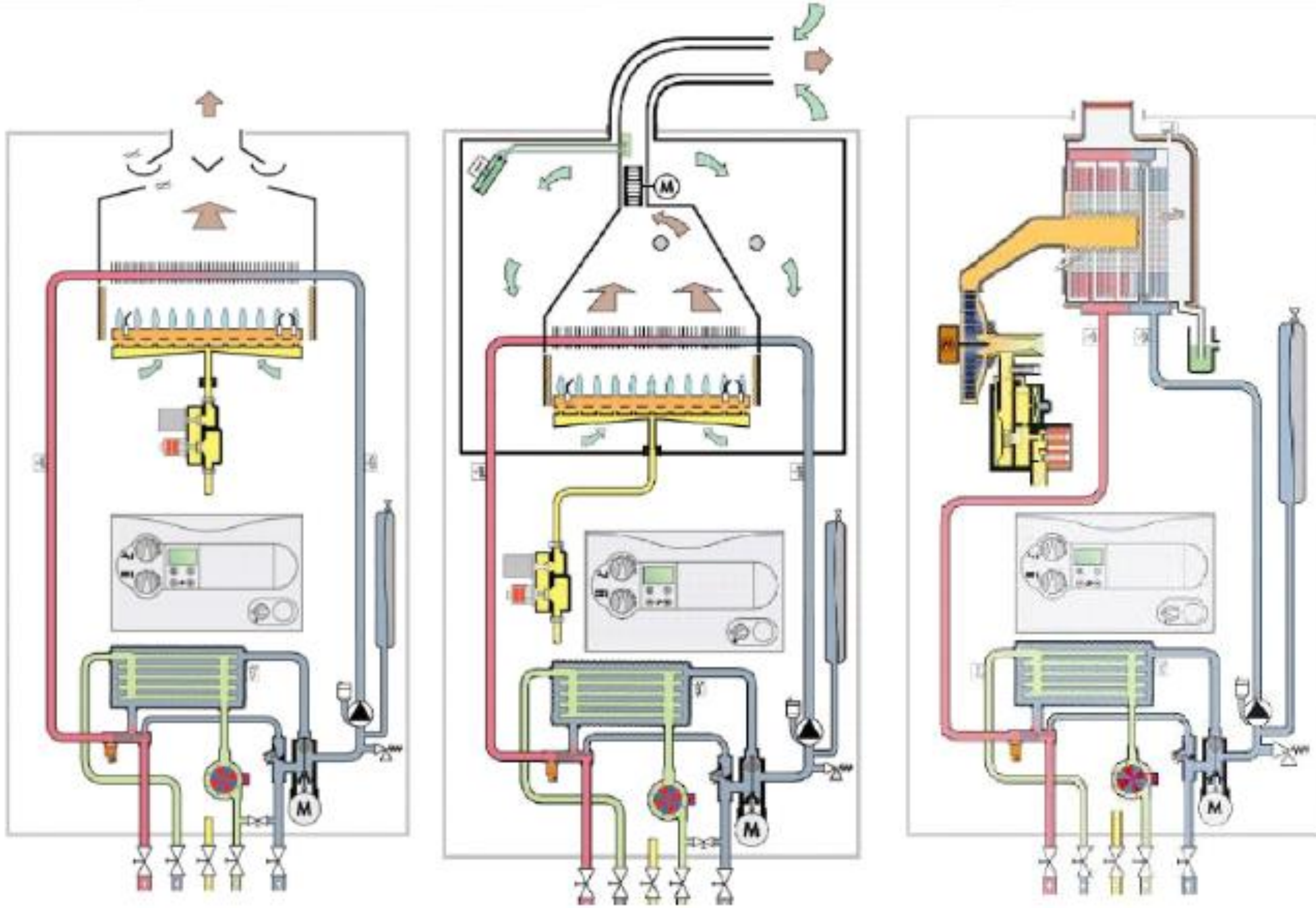


Simplified IGCC flow diagram

IGCC Overview



Courtesy Eastman Gasification Services



Open

Closed

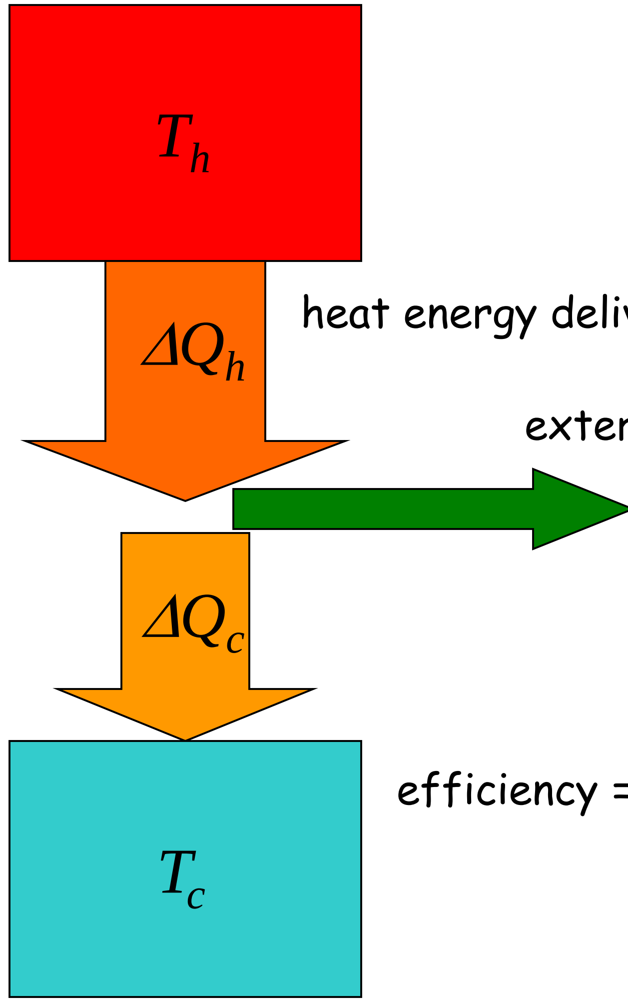
Condensing type

Combustion system

Examples for different combustion air supply

How much work can be extracted from heat?

Hot *source* of energy



heat energy delivered from source

externally delivered work:

$$\Delta W = \Delta Q_h - \Delta Q_c$$

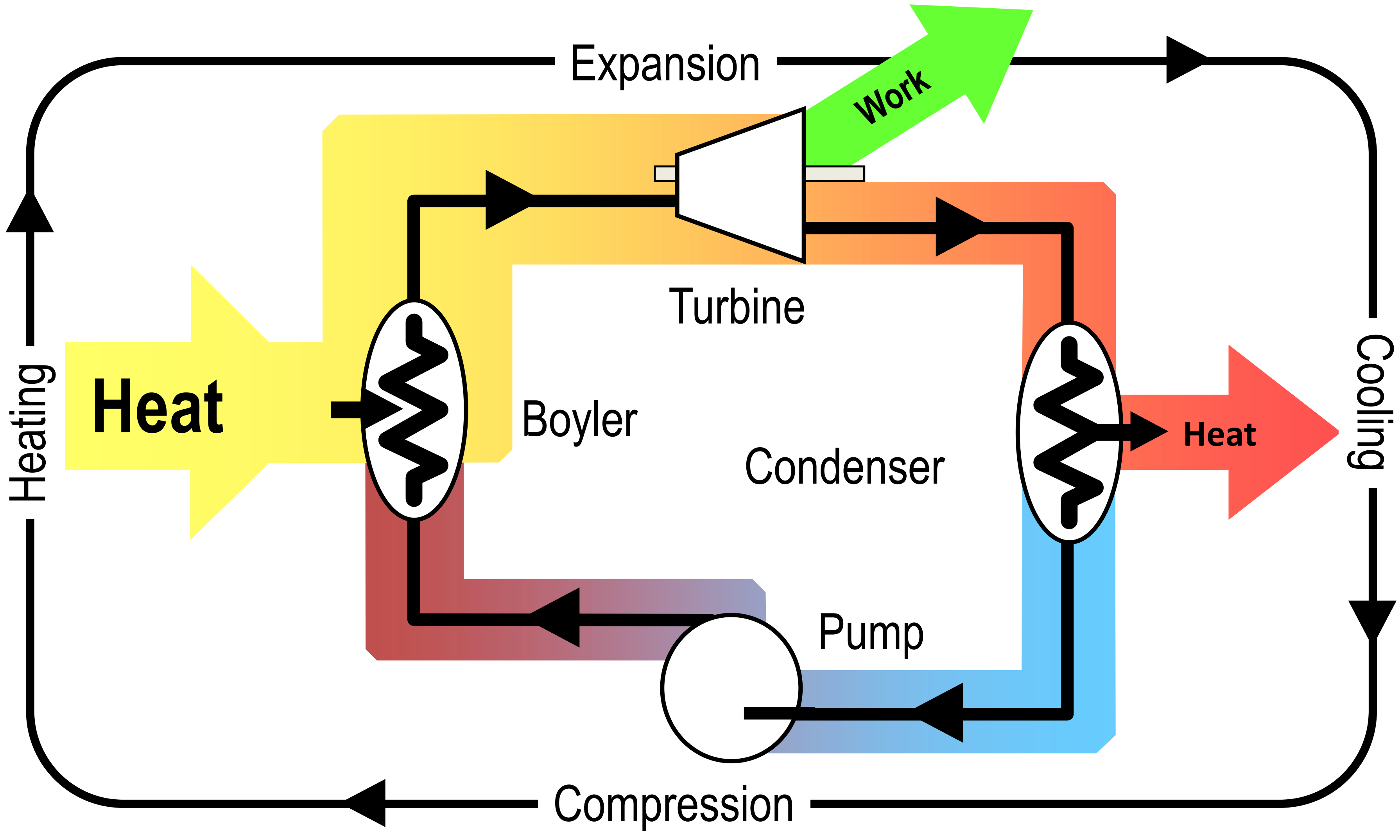
conservation of energy

heat energy delivered to sink

$$\text{efficiency} = \frac{\Delta W}{\Delta Q_h} = \frac{\text{work done}}{\text{heat supplied}}$$

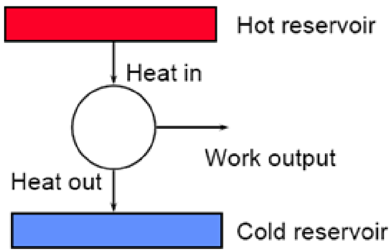
Cold *sink* of energy

Power plant. . .



Expansion
Work
Turbine
Heating
Heat
Boyler
Condenser
Heat
Cooling
Pump
Compression

Carnot efficiency



Power plant efficiency

$$\eta_{Carnot} = 1 - \frac{T_0}{T_1}$$

So the maximum efficiency is:

maximum efficiency = $\Delta W_{max}/\Delta Q_h = (1 - T_c/T_h) = (T_h - T_c)/T_h$

this and similar formulas *must* have the temperature in Kelvin

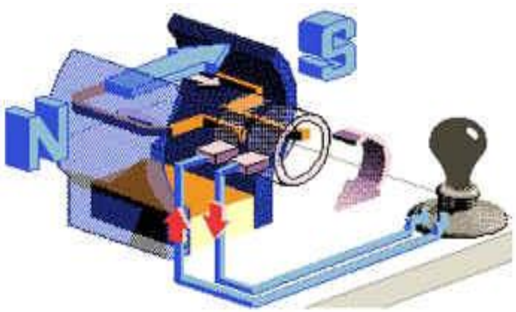
So perfect efficiency is only possible if T_c is zero (in °K)

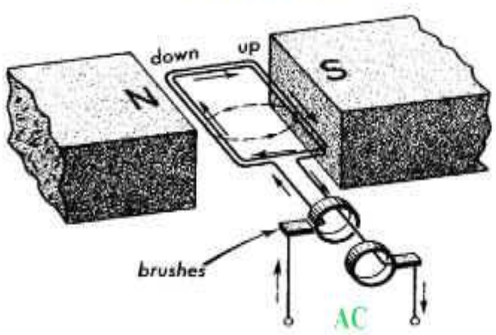
In general, this is not true

As $T_c \rightarrow T_h$, the efficiency drops to zero: no work can be extracted

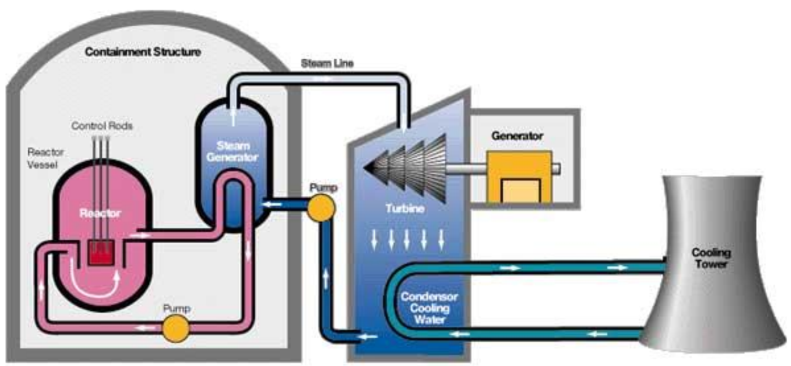
A coal fire burning at 825 °K delivers heat energy to a reservoir at 300 °Kmax efficiency is (825 – 300)/825 = 525/825 = 64%. This power station can not possibly achieve a higher efficiency based on these temperatures. A car engine running at 400 °K delivers heat energy to the ambient 290 °K air max efficiency is (400 – 290)/400 = 110/400 = 27.5% not too far from reality

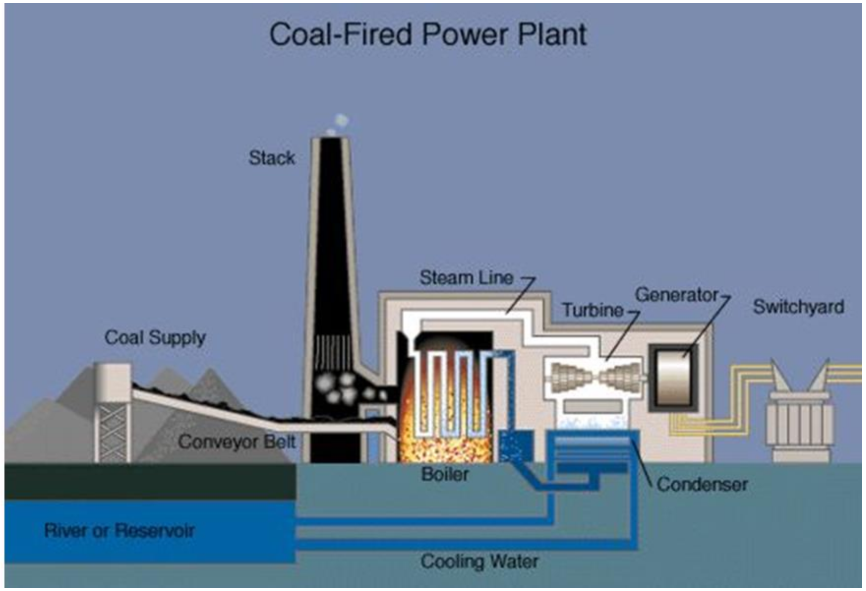
Power plants





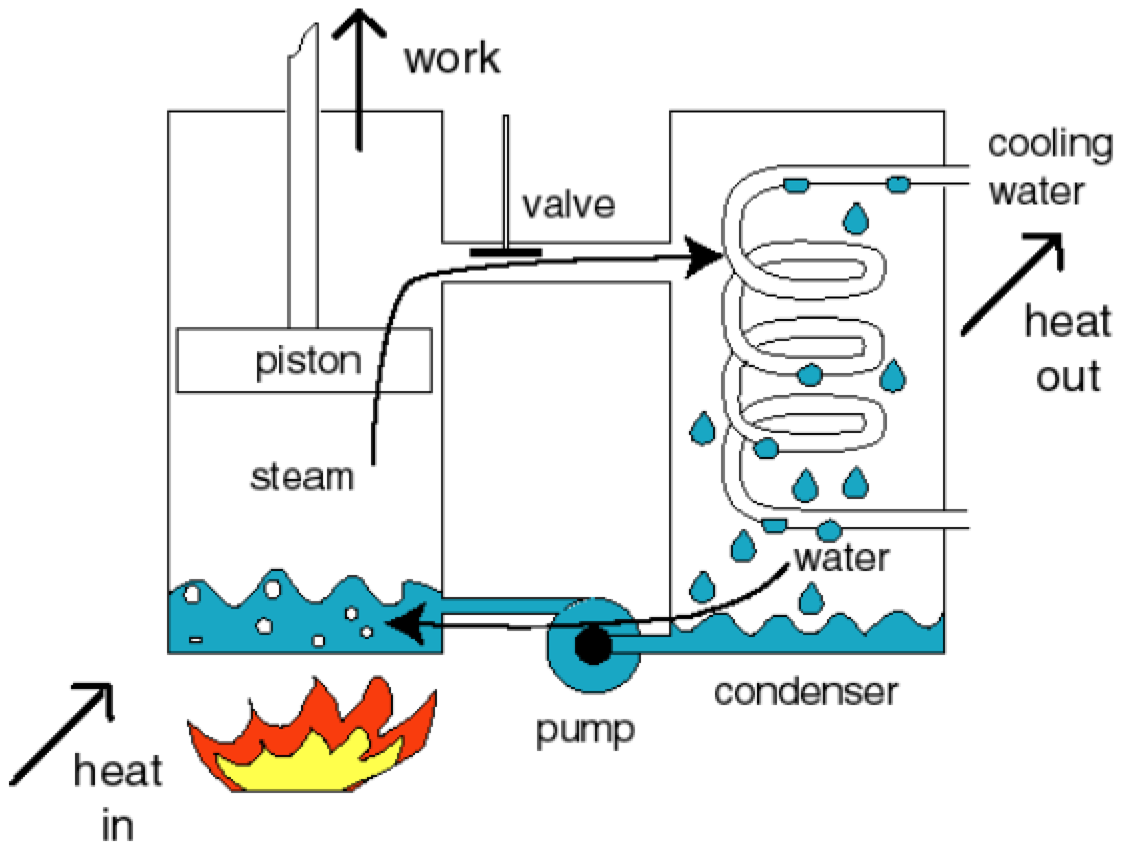
Nuclear Plant





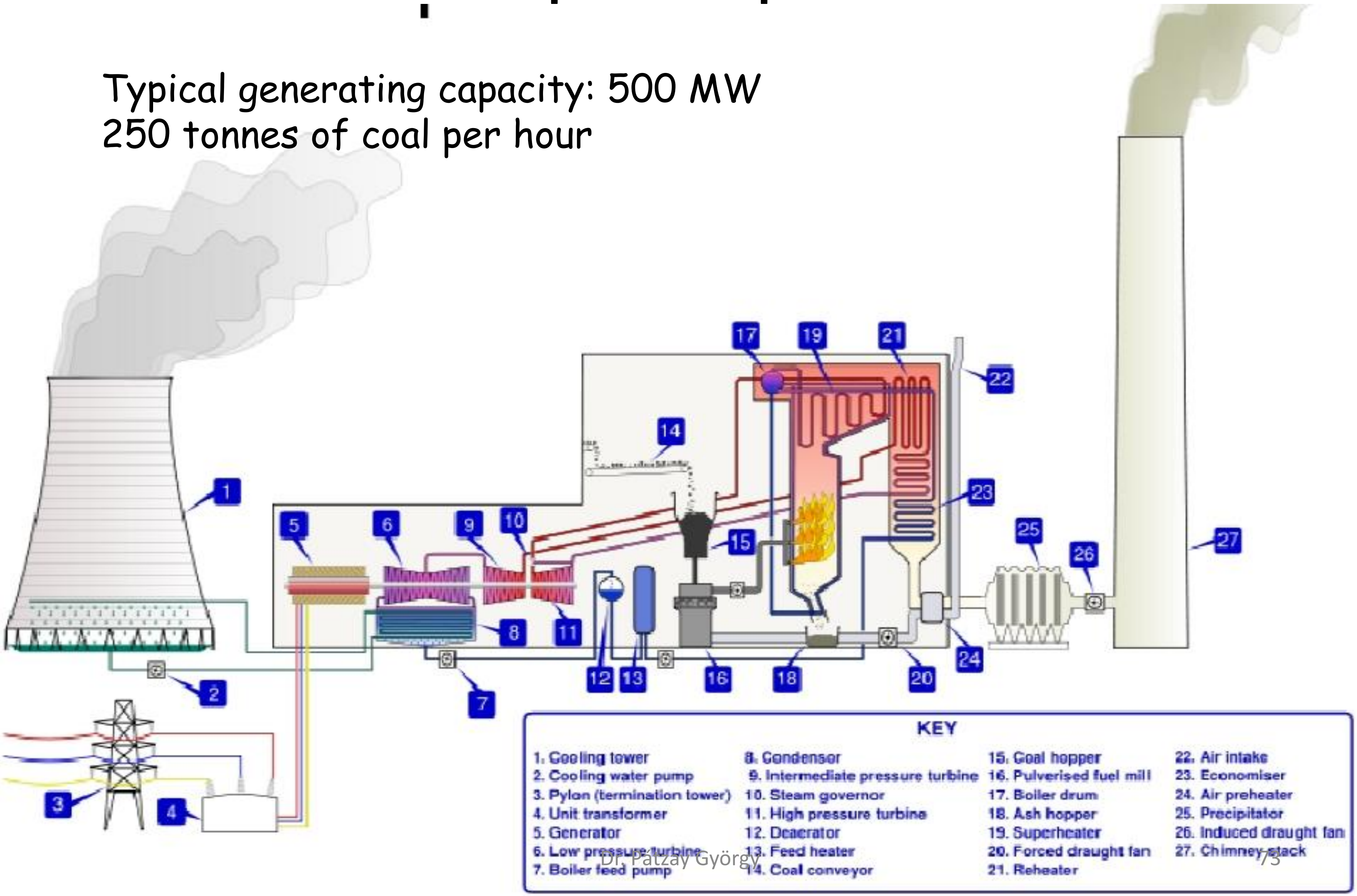
First modern steam engine:

James Watt, 1769 (patent), 1774 (prod.)
Higher efficiency than Newcomen by introducing separate condense
Reduces wasted heat by not requiring heating and cooling entire cylinder



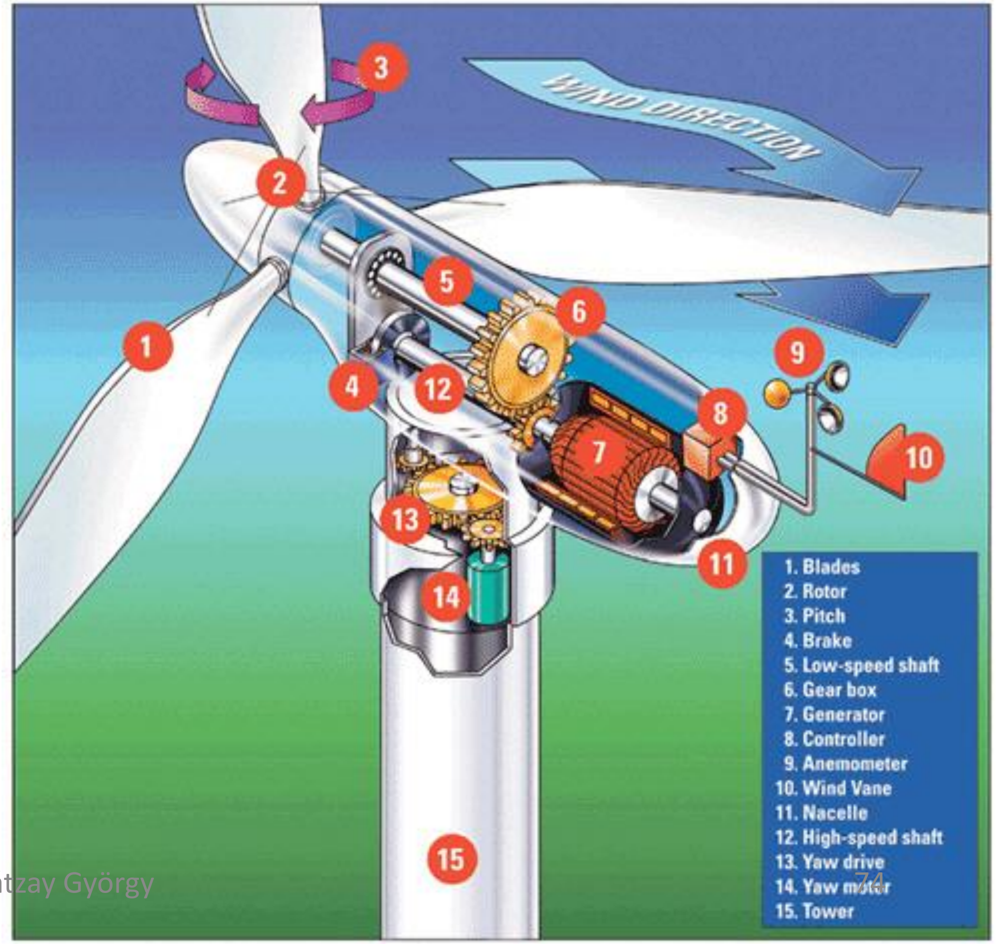
Coal power plant

Typical generating capacity: 500 MW
250 tonnes of coal per hour



Wind power

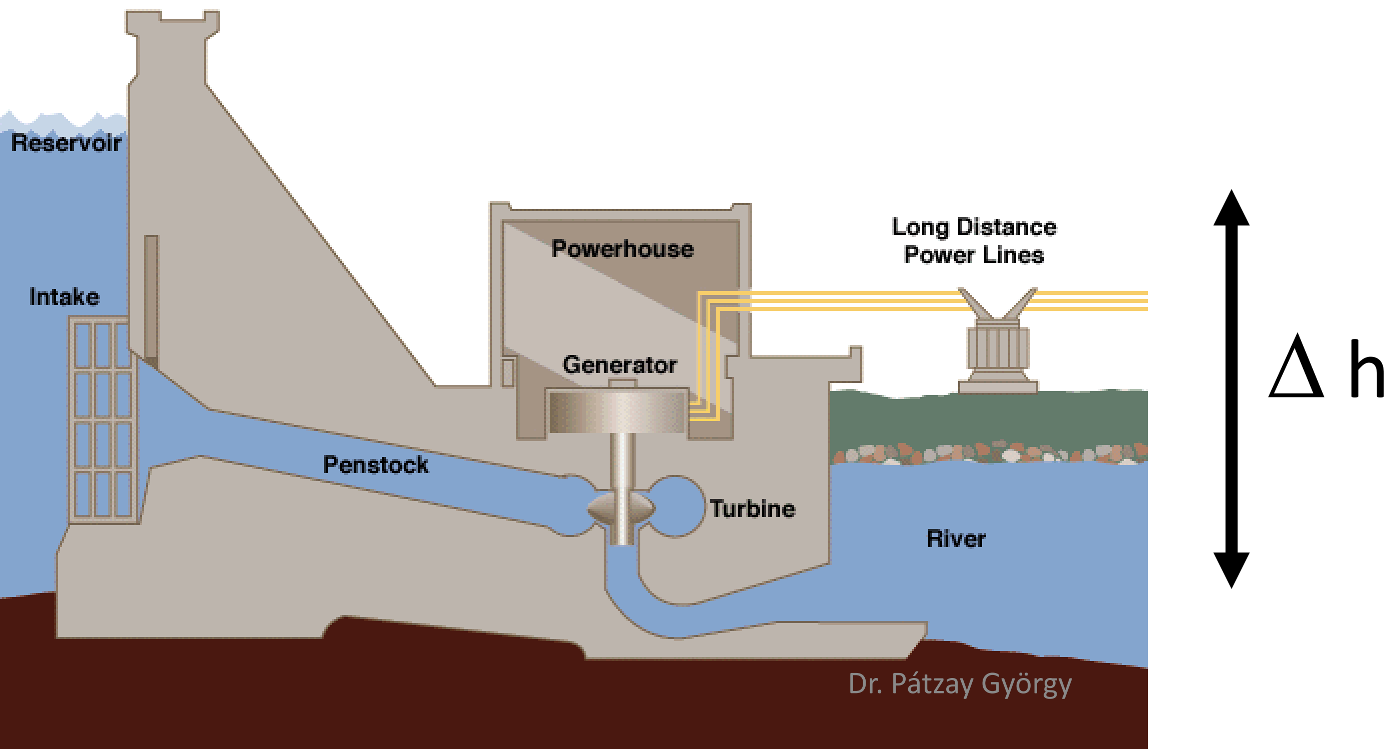
- Power = 0.47 x h x D^2 x v^3 Watts
  - h = efficiency ~ 30% (59% theoretical maximum)
  - D = Diameter (40 meters)
  - v = wind speed (13 m/s)
  - P = 500 kW



Hydroelectricity (hydro)

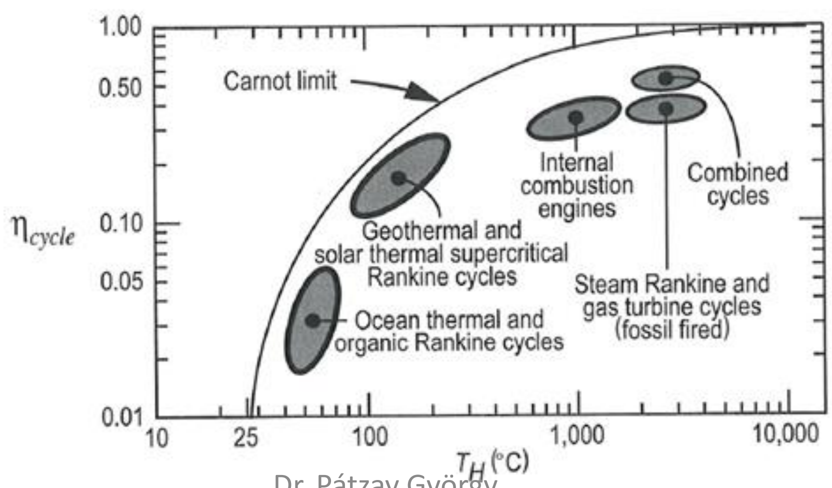
Uses difference in potential gravitational energy of water above and below dam

- $E = m \times g \times D\,h + m \times D\,v^2 / 2$
- $P = h \times r \times g \times D\,h \times$ (flow in m^3/s)
- r is the density of water = 1000 kg /m^3
- Efficiency h can be close to 90%

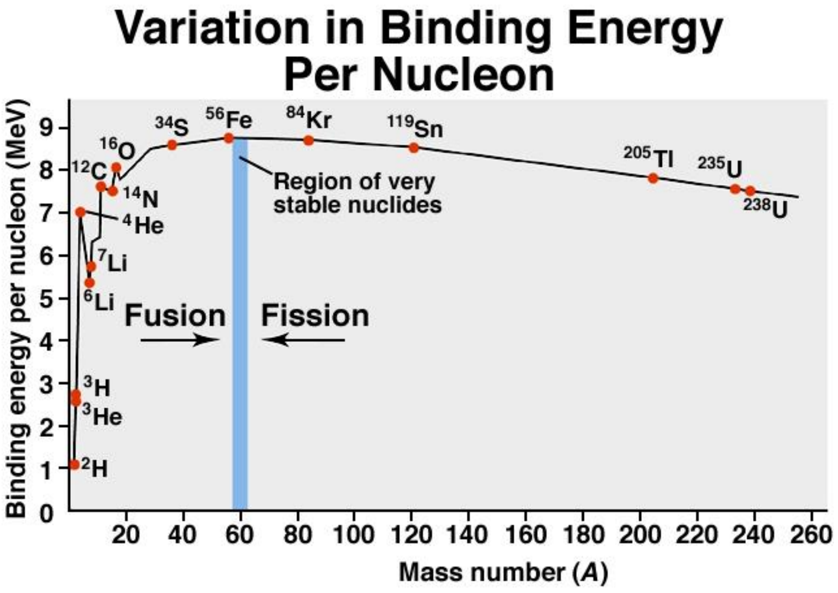


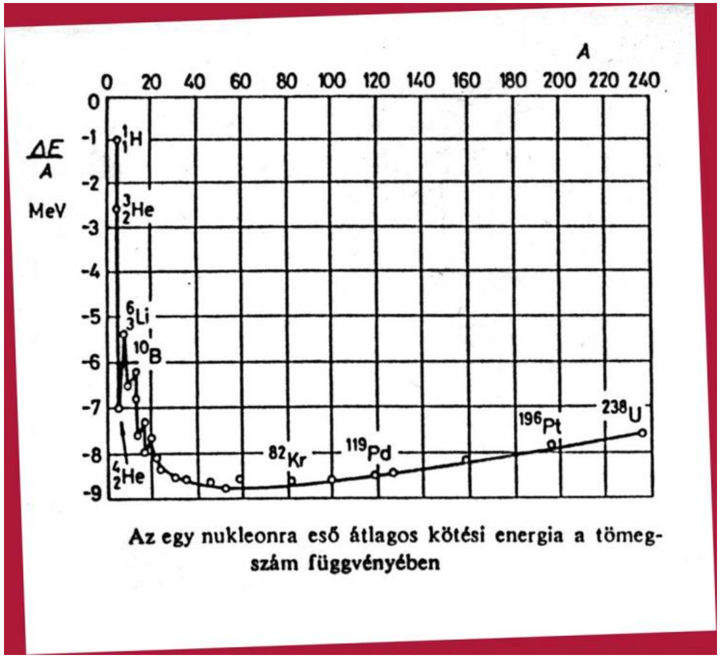
Common types of heat engines

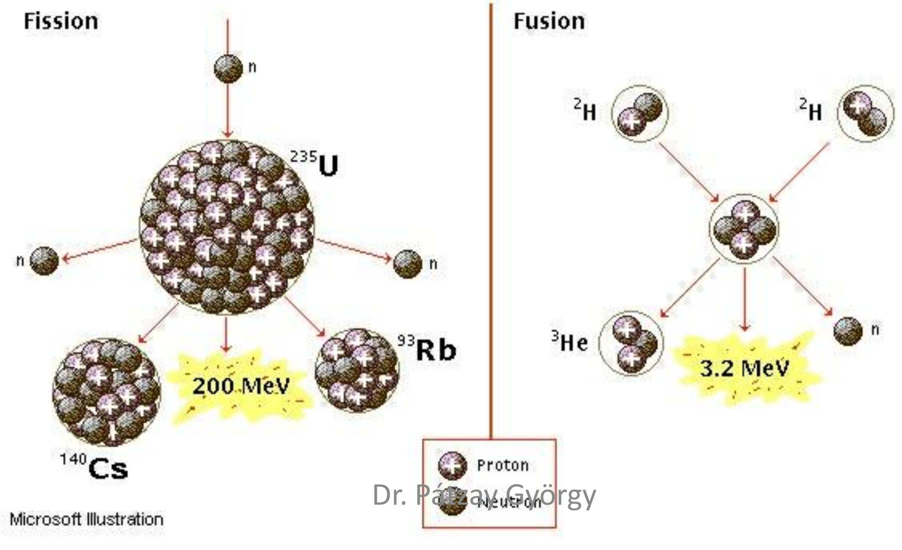
- Rankine cycle: stationary power system (power plant for generating electricity from fossil fuels or nuclear fission), efficiency around 30%
- Brayton cycle: improvement on Rankine to reduce degradation of materials at high temperature (natural gas and oil power plants), efficiencies of 28%
- Combined Rankine-Brayton cycle: for natural gas only, efficiencies of 60%!
- Otto cycle: internal combustion engine, electric spark ignition, efficiency around 30%
- Diesel cycle: internal combustion engine, compression ignition (more efficient than Otto if compression ratio is higher), efficiency around 30%



Principles of Nuclear Power Production

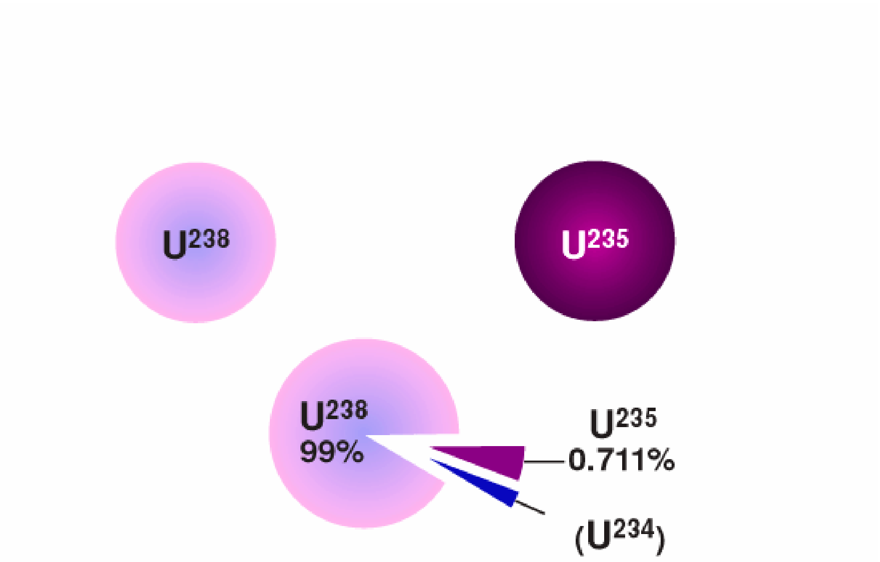






Nuclear Energy

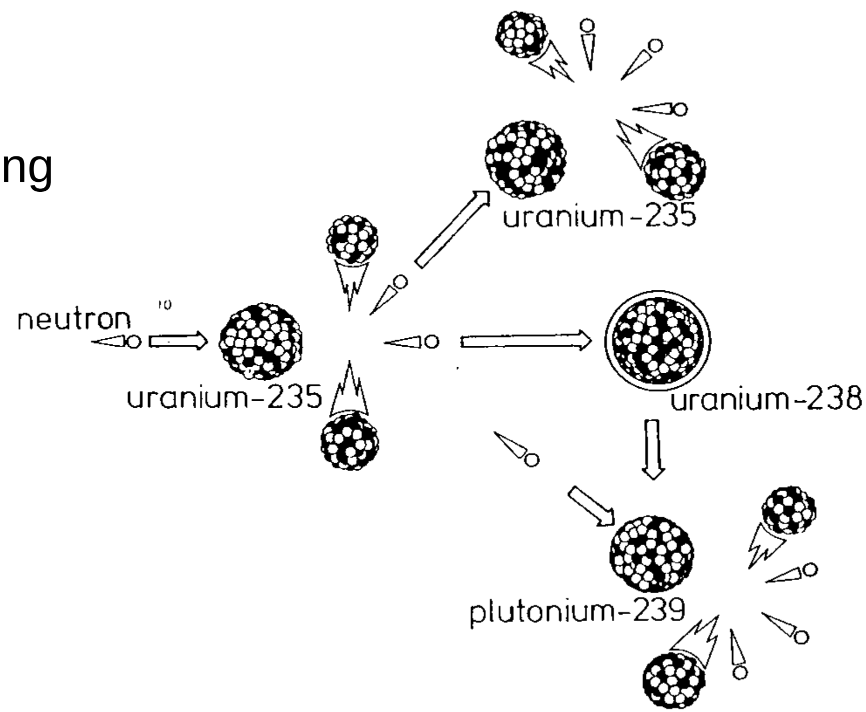
- First sustained nuclear reactor
  - Enrico Fermi
    - University of Chicago (1942)
    - 200 Watts
- Isotopes
  - naturally occurring
  - ^{238}U - 99.3%
  - ^{235}U - 0.7%



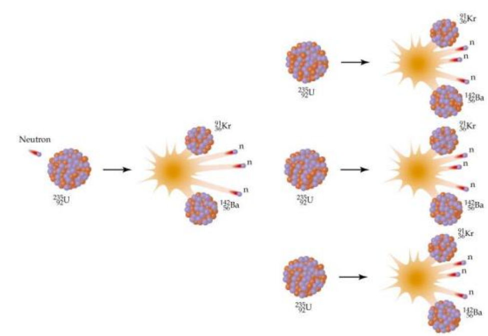
Potential fissionable-fertile nucleus

Nucleus	^{232}Th	^{233}U	^{234}U	^{235}U	^{236}U	^{238}U	^{237}Np	^{239}Pu	^{240}Pu
Temporary nucleus	^{233}Th	^{234}Th	^{235}U	^{236}U	^{237}U	^{239}U	^{238}Np	^{240}Pu	^{241}Pu
Neutron energy (MeV)	1,3	T	0,4	T	0,8	1,2	0,4	t	>0

Fission and breeding

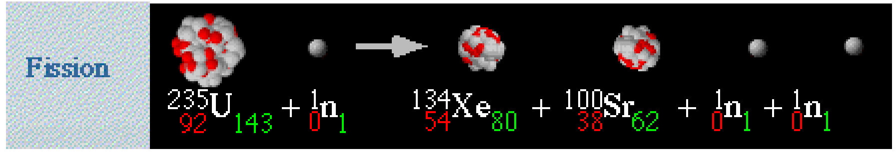


AZ U-235 LÁNCREAKCIÓ ÉS A PU-239 KÉPZŐDÉSE



Raw Materials

- Uranium Ore
  - U_3O_8
    - yellowcake
  - deposit concentration varies
    - cost of recovery varies



Raw Materials

- uranium resources classified according to cost
  - <$130/kg
    - = 1.7 x 10^6 tonnes (U.S)
    - = 5.4 x 10^6 tonnes (other)
  - $130/kg < $260/kg
    - 1.3 x 10^6 tonnes (U.S)
    - = 12.2 x 10^6 tonnes (other)

Nuclear Reactors

- produces heat energy (Carnot efficiency)
  - steam to drive turbine
  - turbine connected to generator
- fuel
  - 97% U-238
  - 3% U-235
  - Problem with this ratio

Moderators

- slow down the neutrons
  - neutrons move through some material
    - water
    - graphite
    - elastic collisions transfer energy to moderator
    - neutrons slow
  - K = 0.025 eV
  - thermal neutrons

Control Rods

- help control the fission rate
  - frequently boron compound
  - readily absorbs neutrons
  - fully inserted
    - reactor shuts down
  - fully extracted
    - maximum power level
      - potential danger

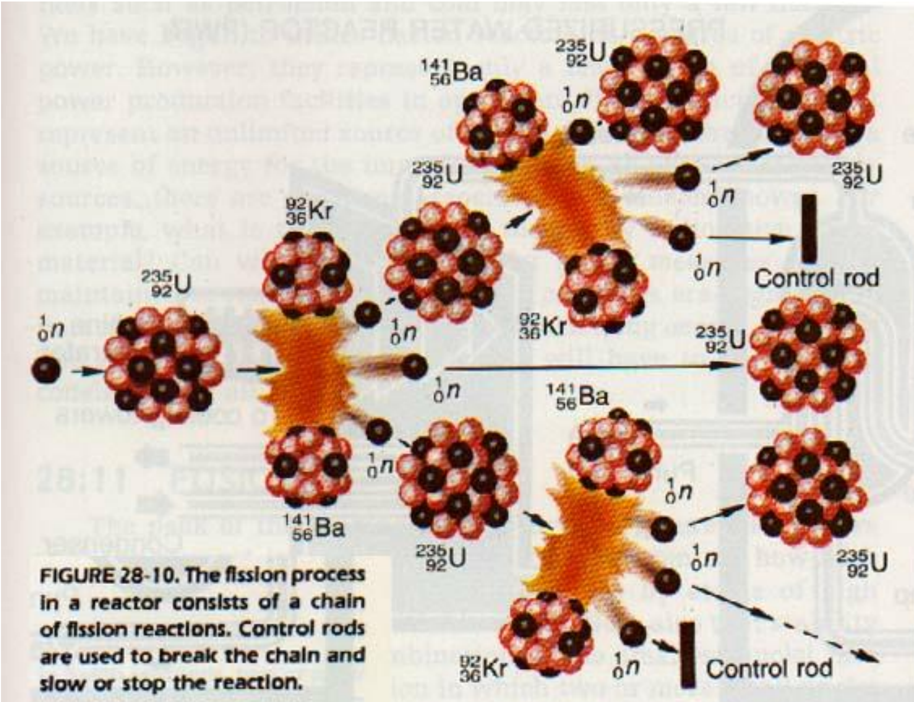
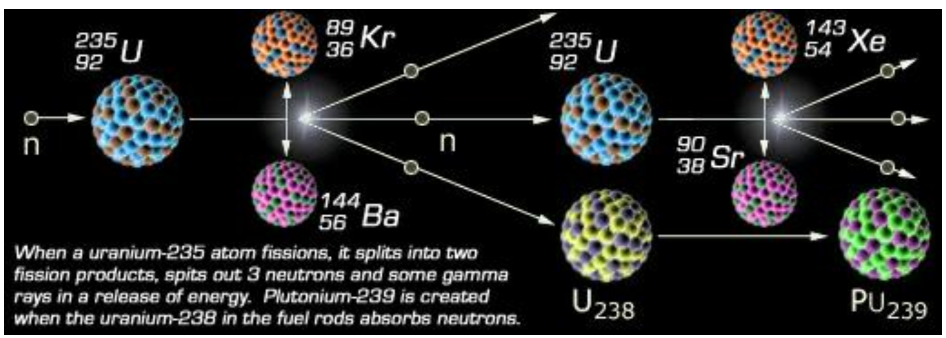
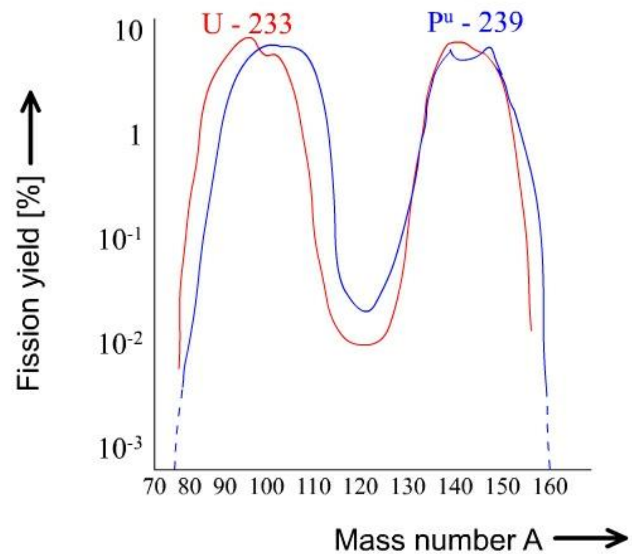
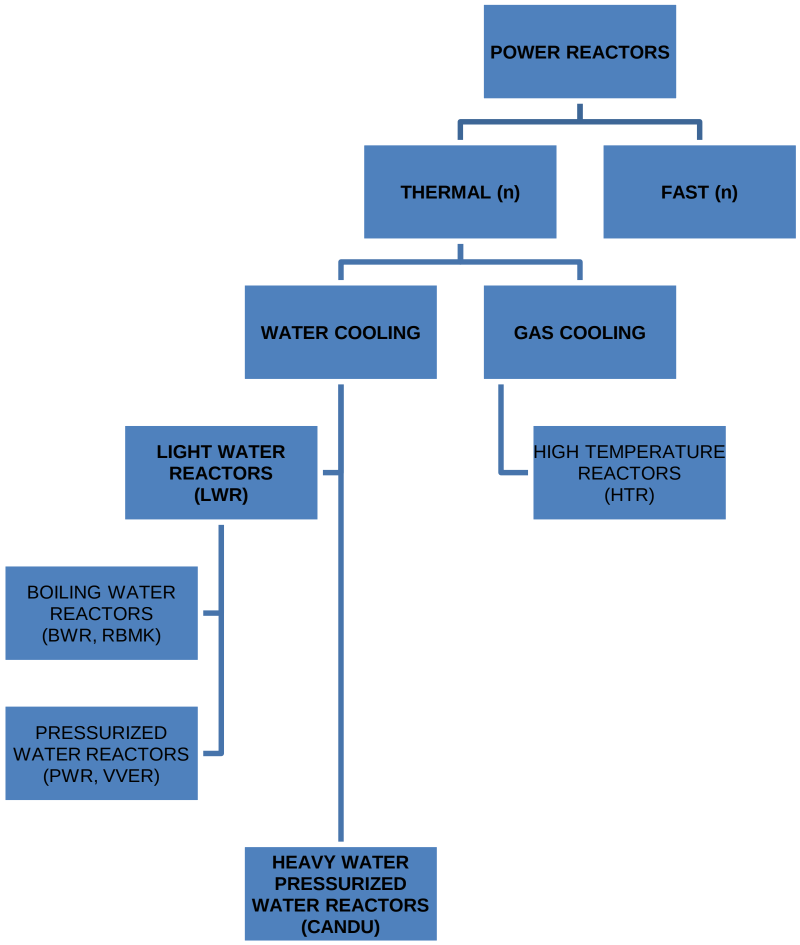


FIGURE 28-10. The fission process in a reactor consists of a chain of fission reactions. Control rods are used to break the chain and slow or stop the reaction.



Fission yields for the fission of ^{233}U and ^{239}Pu by Thermal Neutrons



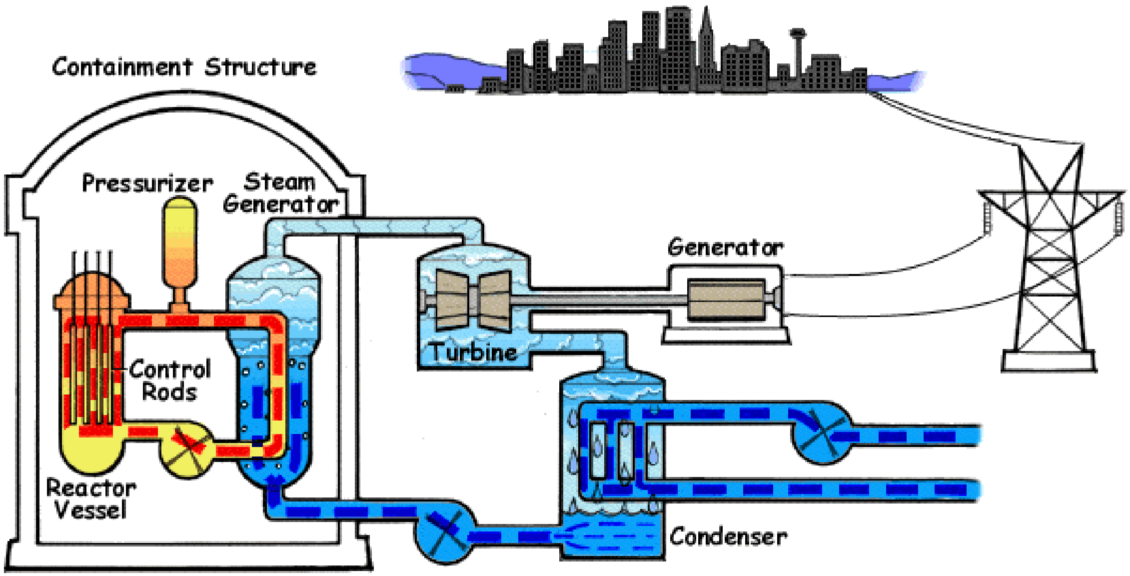


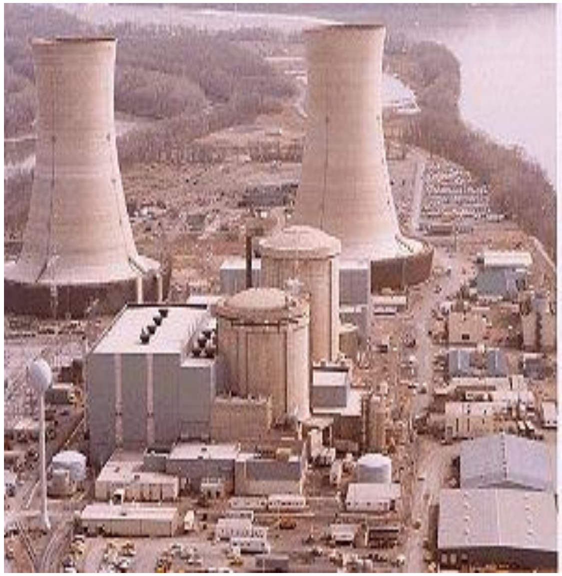
Paks NPP 440 MW_e VVER-440/213, 1 fuel rod l=2,4 m, 99%Zr 1%Nb

1 fuel element contains 126 fuel rods, in the reactor are 312 fuel elements (42 t UO_2 3,5% ^{235}U)

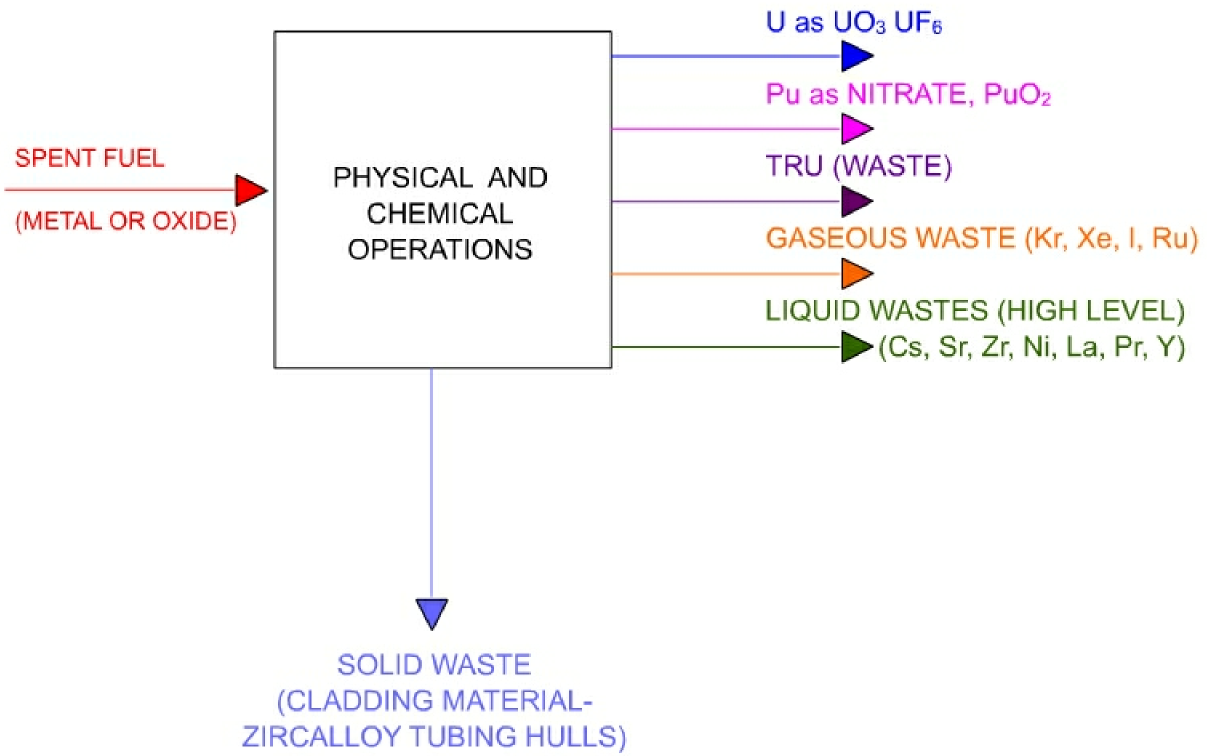
Types

- Boiling Water Reactor (BWR)
  - water flows through core
    - reactor heats water
    - water boils
    - steam piped to turbines
- Pressurized Water Reactor (PWR)
  - naval propulsion


Containment Structure
Pressurizer
Steam Generator
Generator
Turbine
Control Rods
Reactor Vessel
Condenser

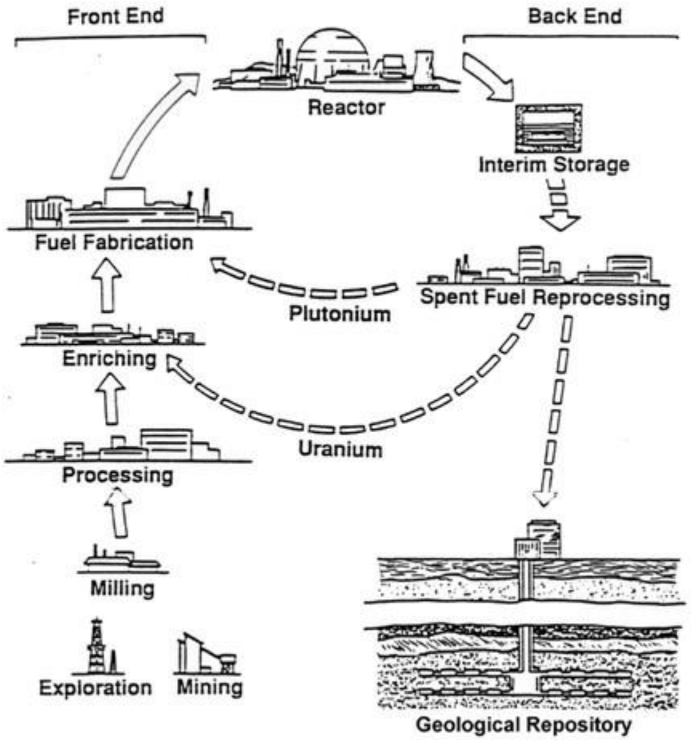


Schematic of Reprocessing Separations

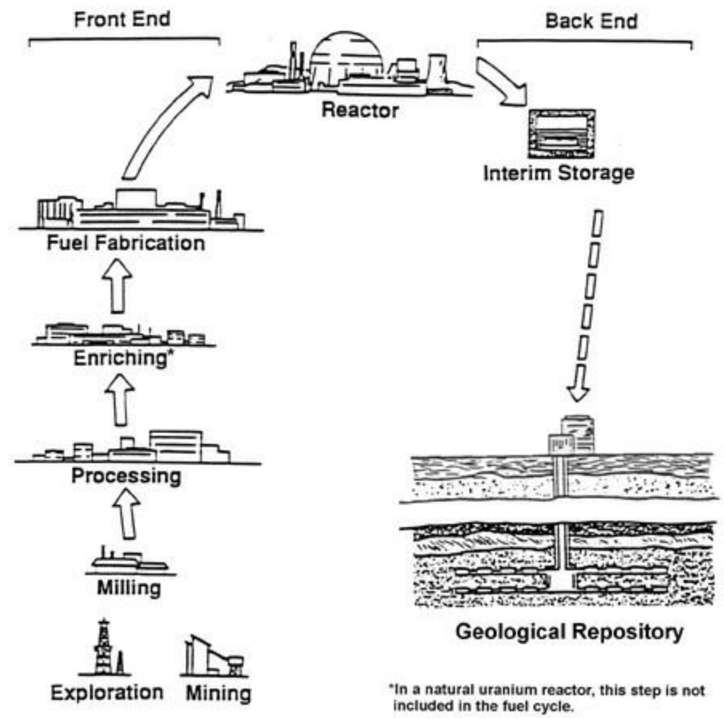


Nuclear Fuel Cycles

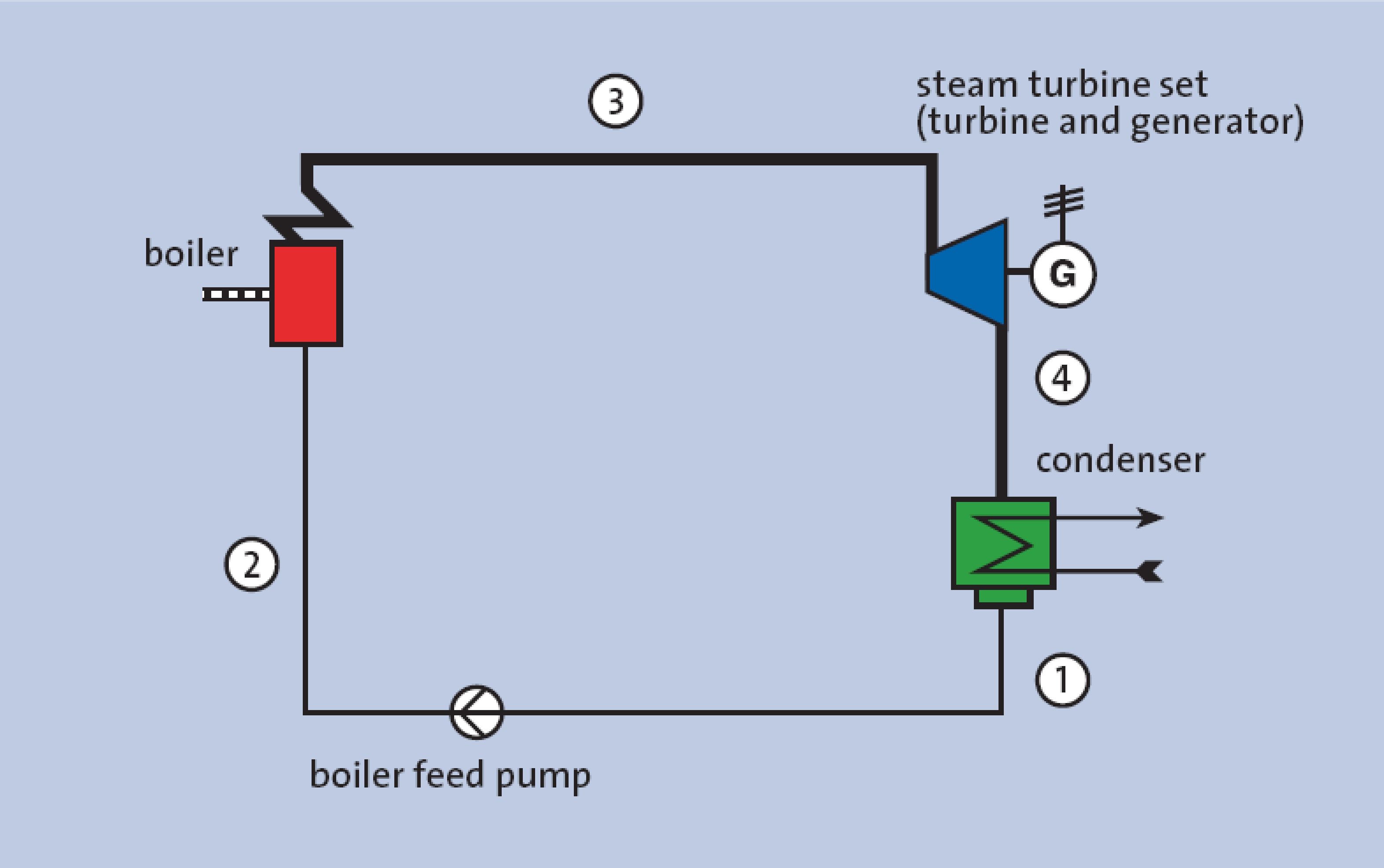
- Full recycle of plutonium and uranium



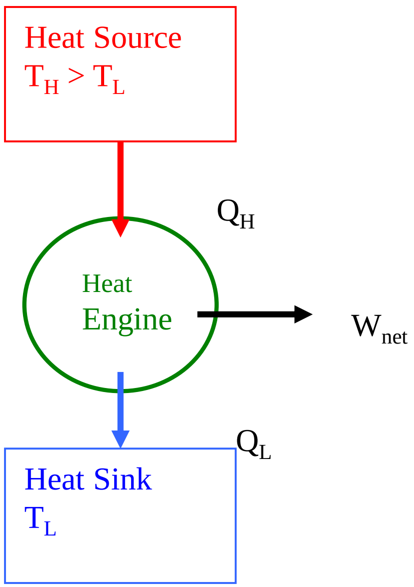
- Disposal of spent fuel
- Current policy in U.S.

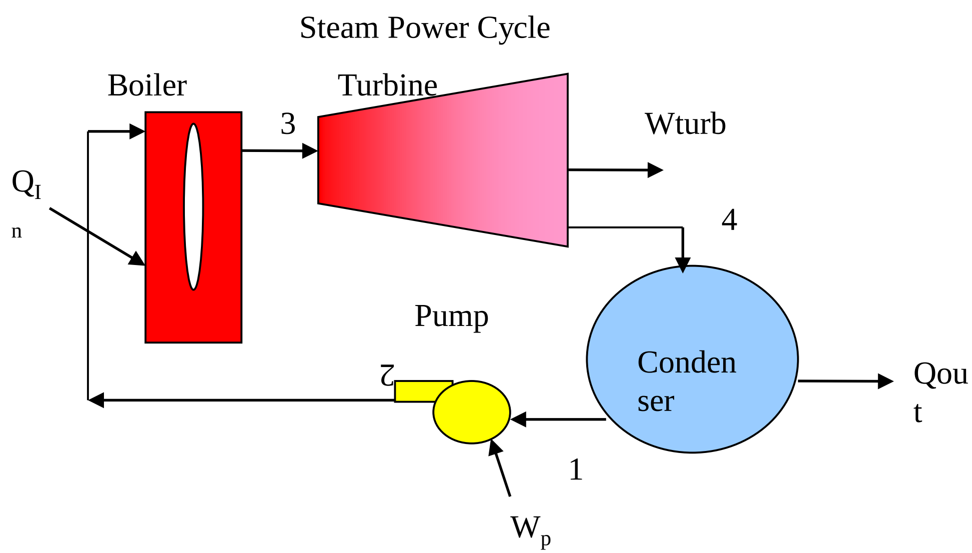


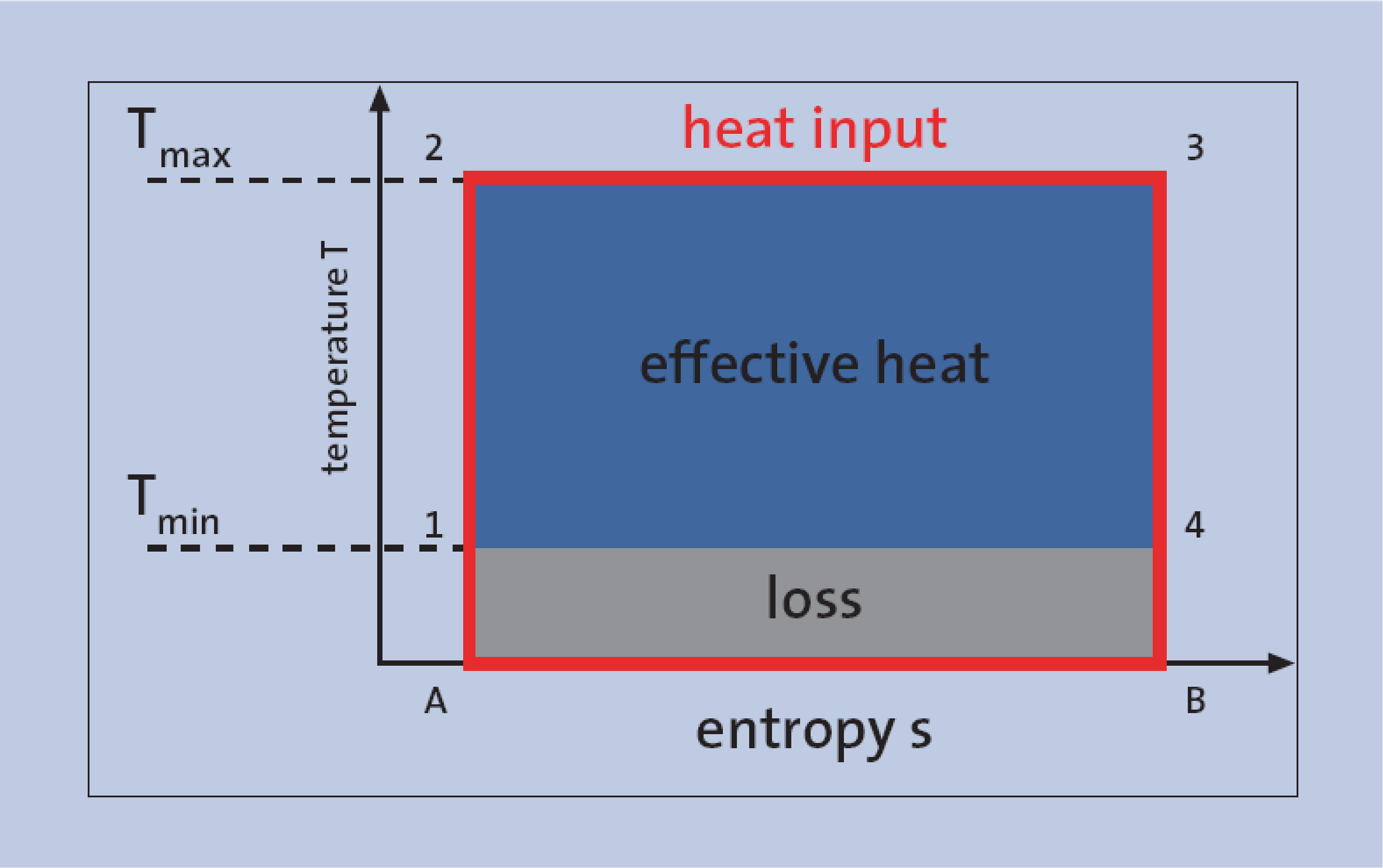
Power Plants - Thermodinamics



The Carnot Vapor Cycle

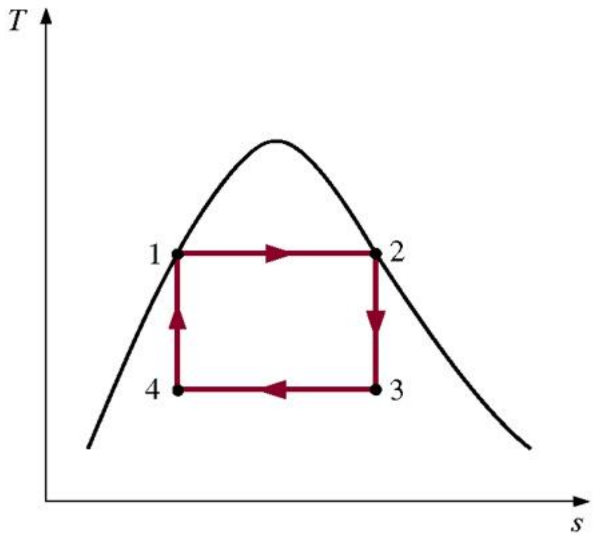






T_{max}
2
heat input
3
temperature T
effective heat
T_{min}
1
4
loss
A
B
entropy s

T-s Diagrams for a Possible Carnot Vapor Cycle



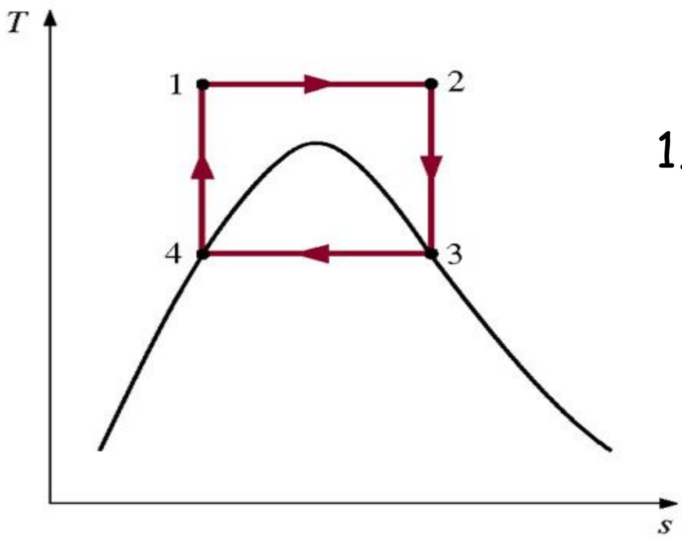
(a)

The Cycle is Not Practical because:

1. Pumping process 4-1 requires the pumping of a mixture of saturated liquid and saturated vapor at state 4 and the delivery of a saturated liquid at state 1.

2. The turbine needs to handle steam with low quality, that is, steam with a high moisture content.

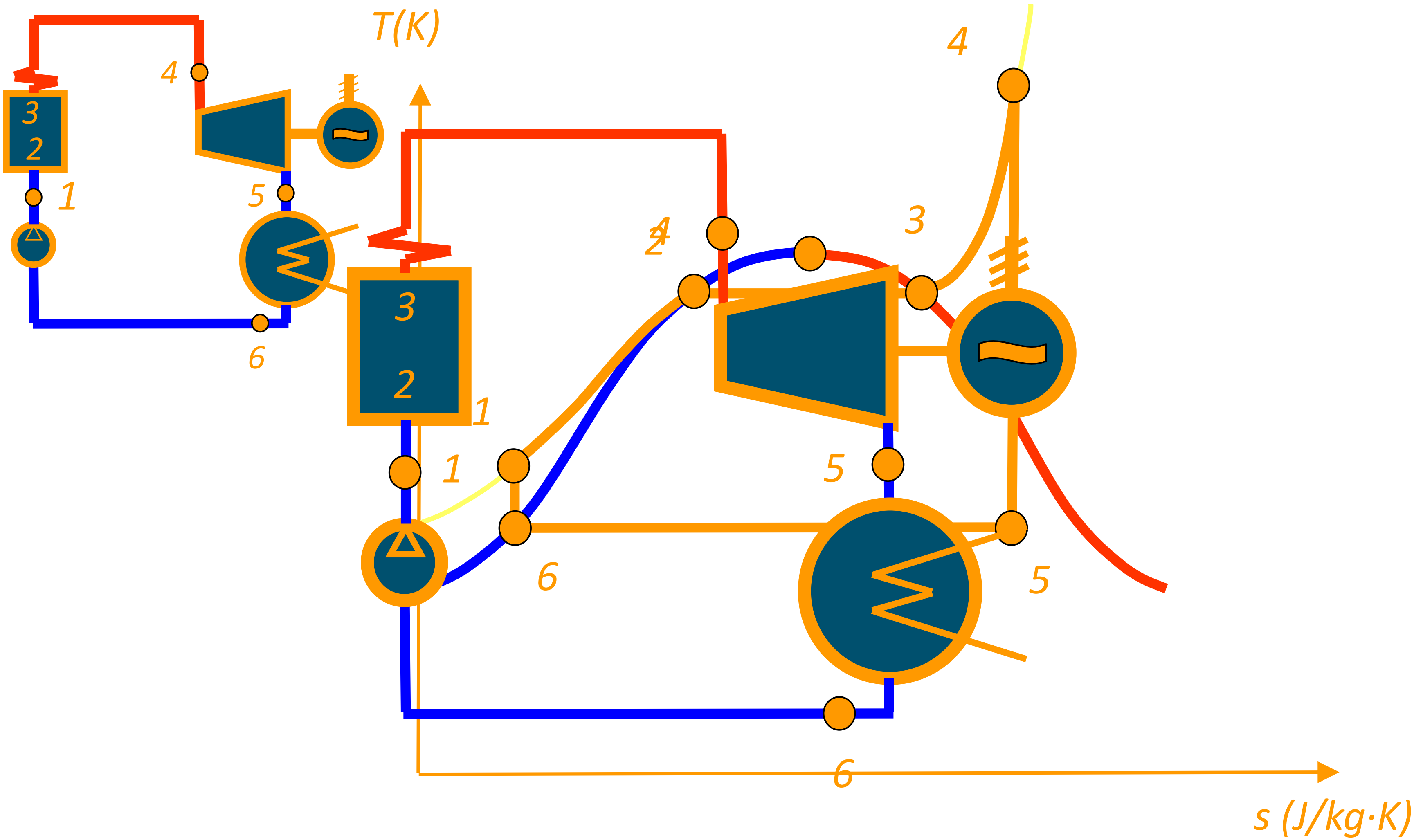
Another Possible Carnot Vapor Cycle



The Cycle is Not Practical because:

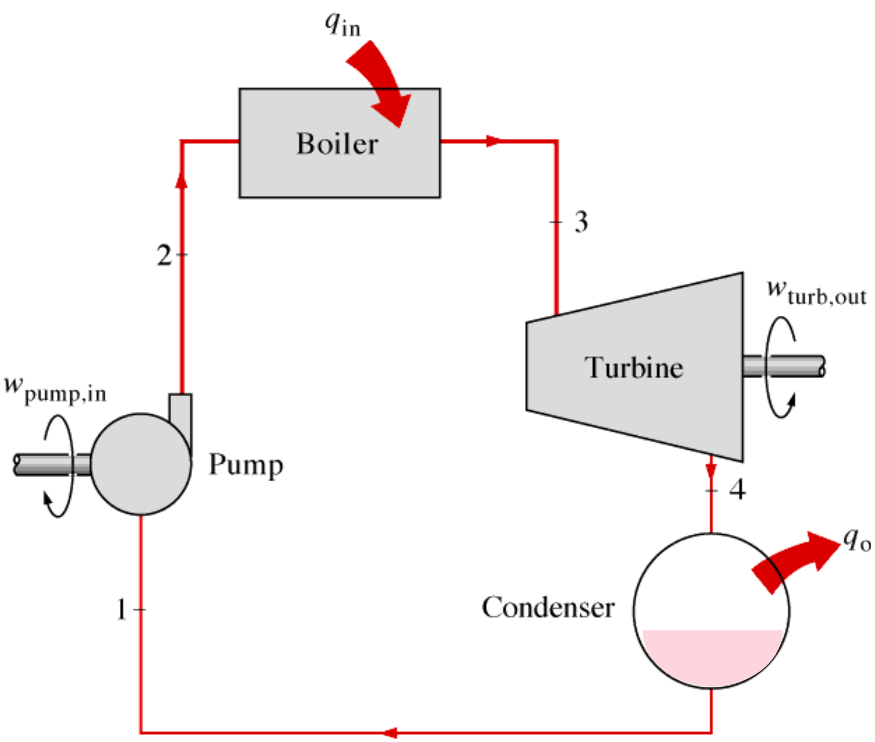
1. To superheat the steam to take advantage of higher temperature, elaborate controls are required to keep TH constant while the steam expands and does work

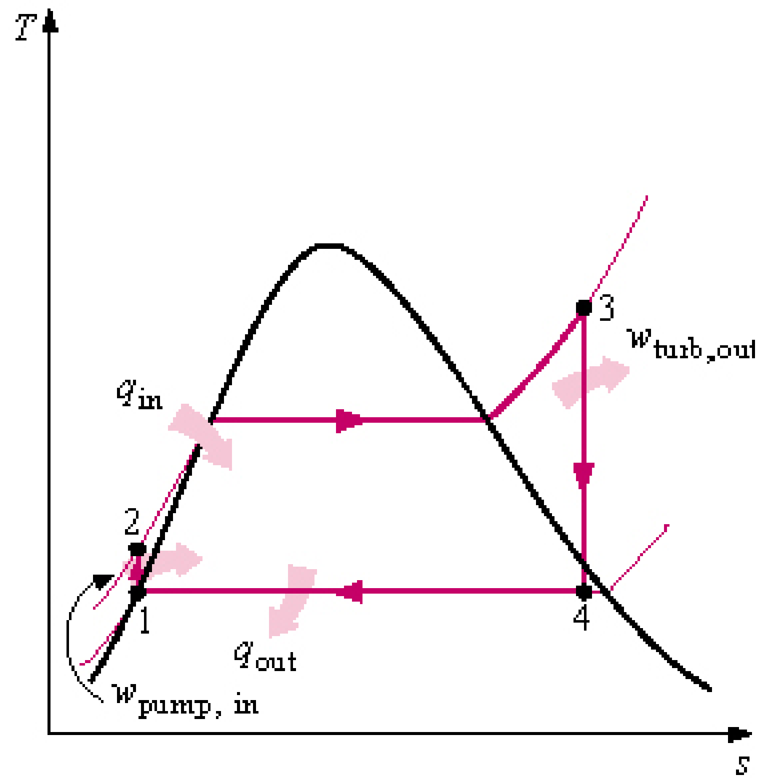
The Rankine-Clausius cycle



1-2 heating of water 2-3 evaporation 3-4 superheating

The Simple Ideal Rankine Cycle





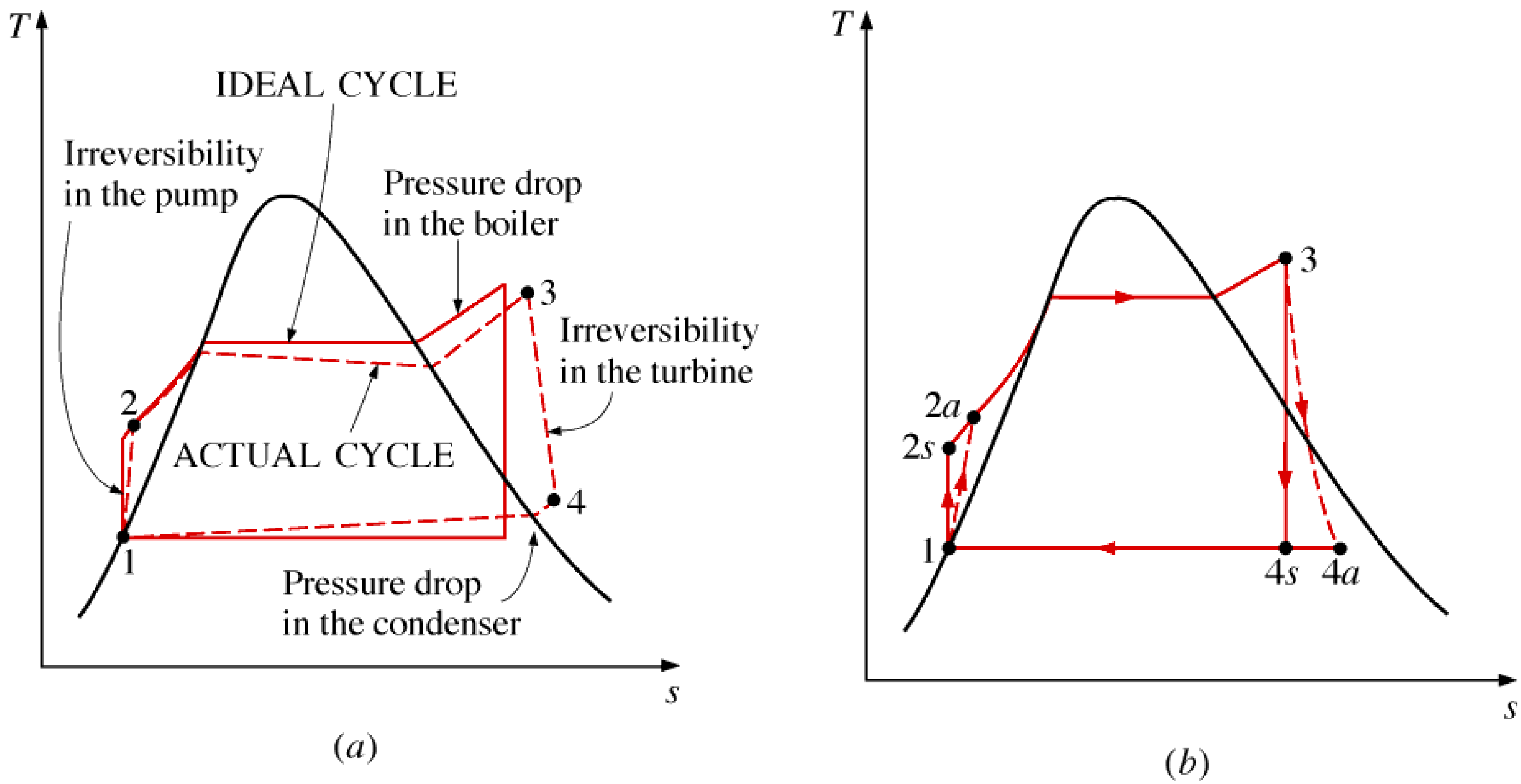
The Simple Ideal Rankine Cycle

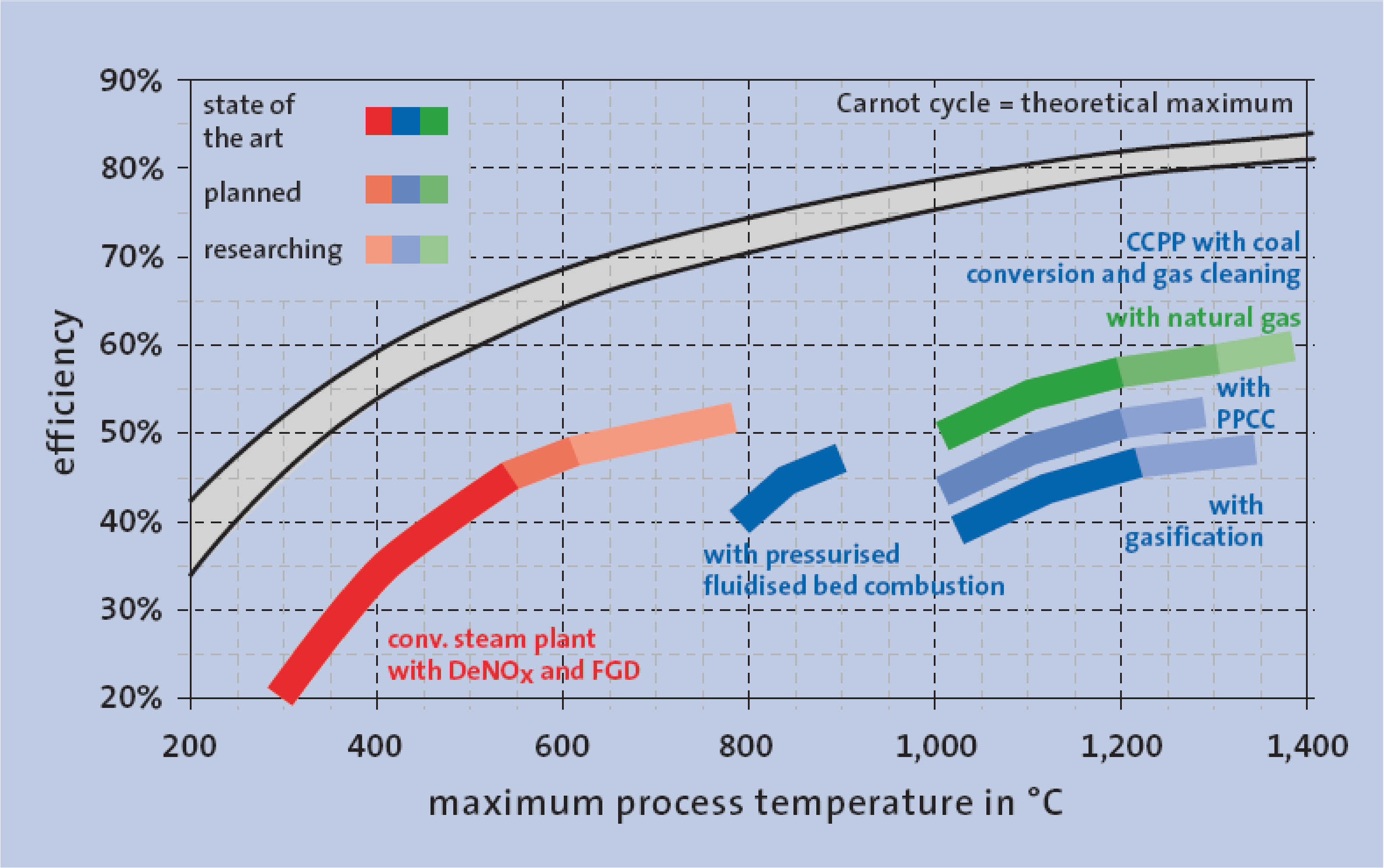
- The model cycle for vapor power cycles is the *Rankine cycle* which is composed of four internally reversible processes:

- 1. constant-pressure heat addition in a boiler
- 2. isentropic expansion in a turbine
- 3. constant-pressure heat rejection in a condenser
- 4. isentropic compression in a pump (Steam leaves the condenser as a saturated liquid at the condenser pressure)

Rankine Cycle: Actual Vapor Power Deviation and Pump and Turbine Irreversibilities

(a) Deviation of actual vapor power cycle from the ideal Rankine cycle.
(b) The effect of pump and turbine irreversibilities on the ideal Rankine cycle.

- 



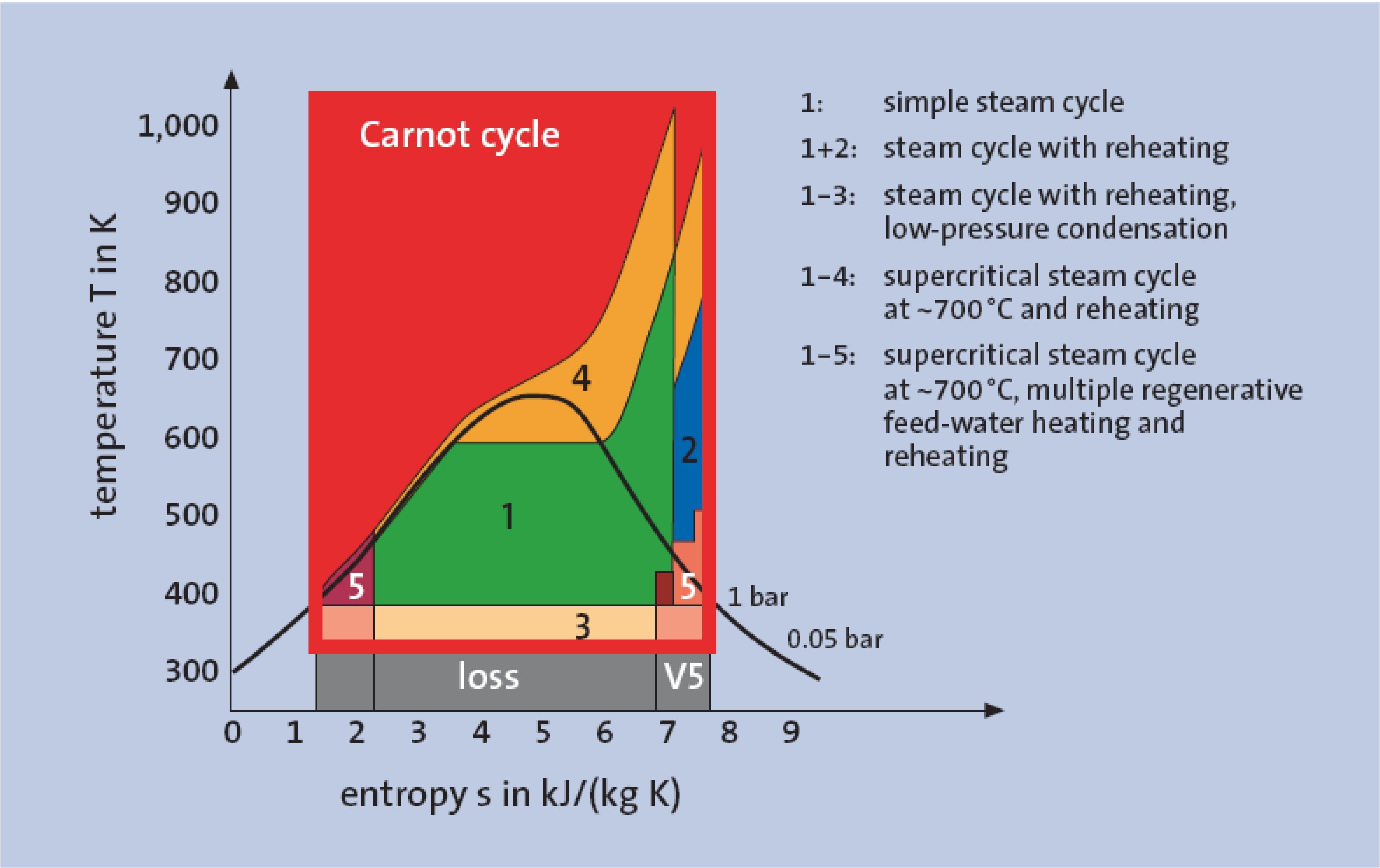
90%
80%
70%
60%
50%
40%
30%
20%
efficiency
state of the art
planned
researching
Carnot cycle = theoretical maximum
CCPP with coal conversion and gas cleaning
with natural gas
with PPCC
with gasification
with pressurised fluidised bed combustion
conv. steam plant with DeNOx and FGD
200
400
600
800
1,000
1,200
1,400
maximum process temperature in °C

Ways to Improve the Efficiency of a Simple Rankine Cycle

- Superheat the vapor
  - Higher average temperature during heat addition
  - Reduces moisture at turbine exit (we want x_4 in the above example > 85%)

- Increase boiler pressure (for fixed maximum temperature)
  - Availability of steam is higher at higher pressures
  - Increases the moisture at turbine exit

- Lower condenser pressure
  - Less energy is lost to surroundings
  - Increases the moisture at turbine exit

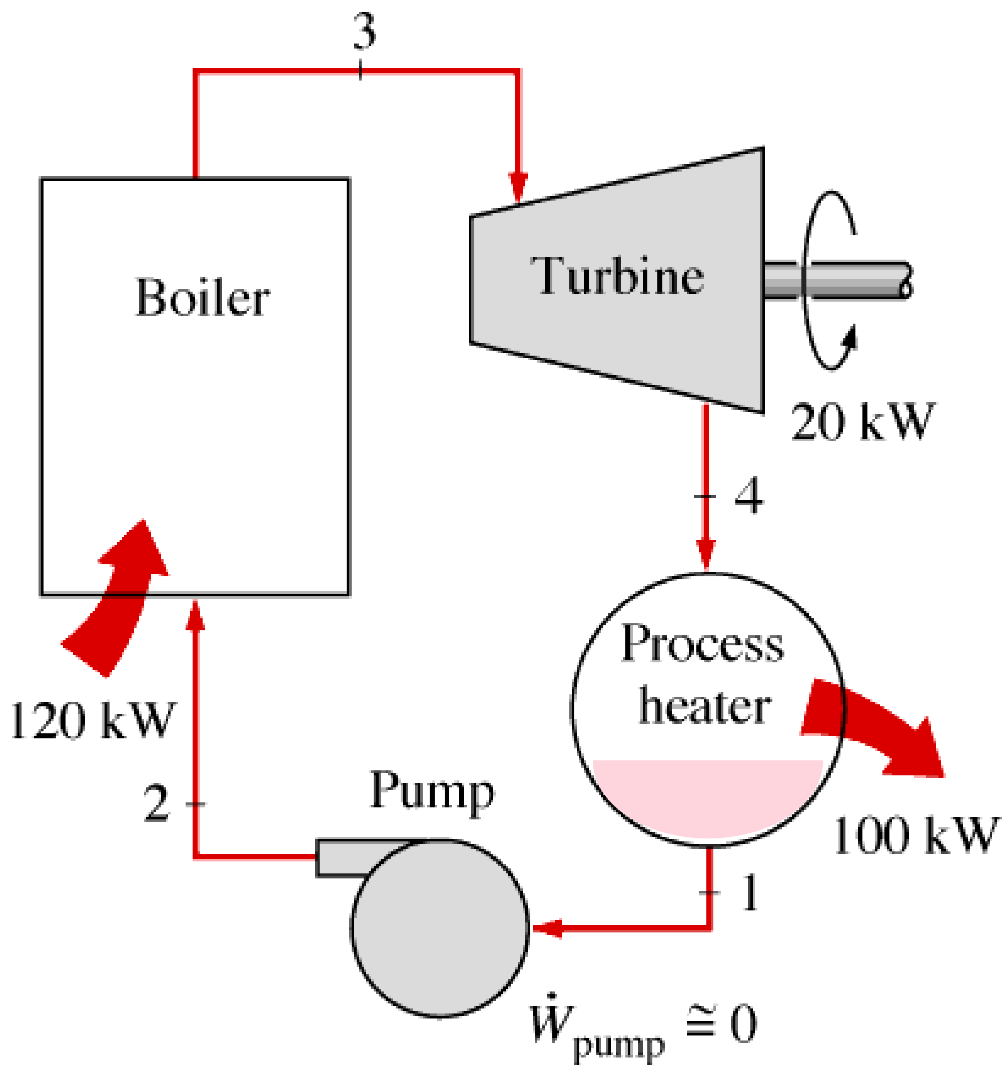

temperature T in K
1,000
900
800
700
600
500
400
300
Carnot cycle
4
1
2
5
5
3
1 bar
0.05 bar
loss
V5
0
1
2
3
4
5
6
7
8
9
entropy s in kJ/(kg K)
1: simple steam cycle
1+2: steam cycle with reheating
1–3: steam cycle with reheating, low-pressure condensation
1–4: supercritical steam cycle at ~700 °C and reheating
1–5: supercritical steam cycle at ~700 °C, multiple regenerative feed-water heating and reheating

The Concept of Cogeneration

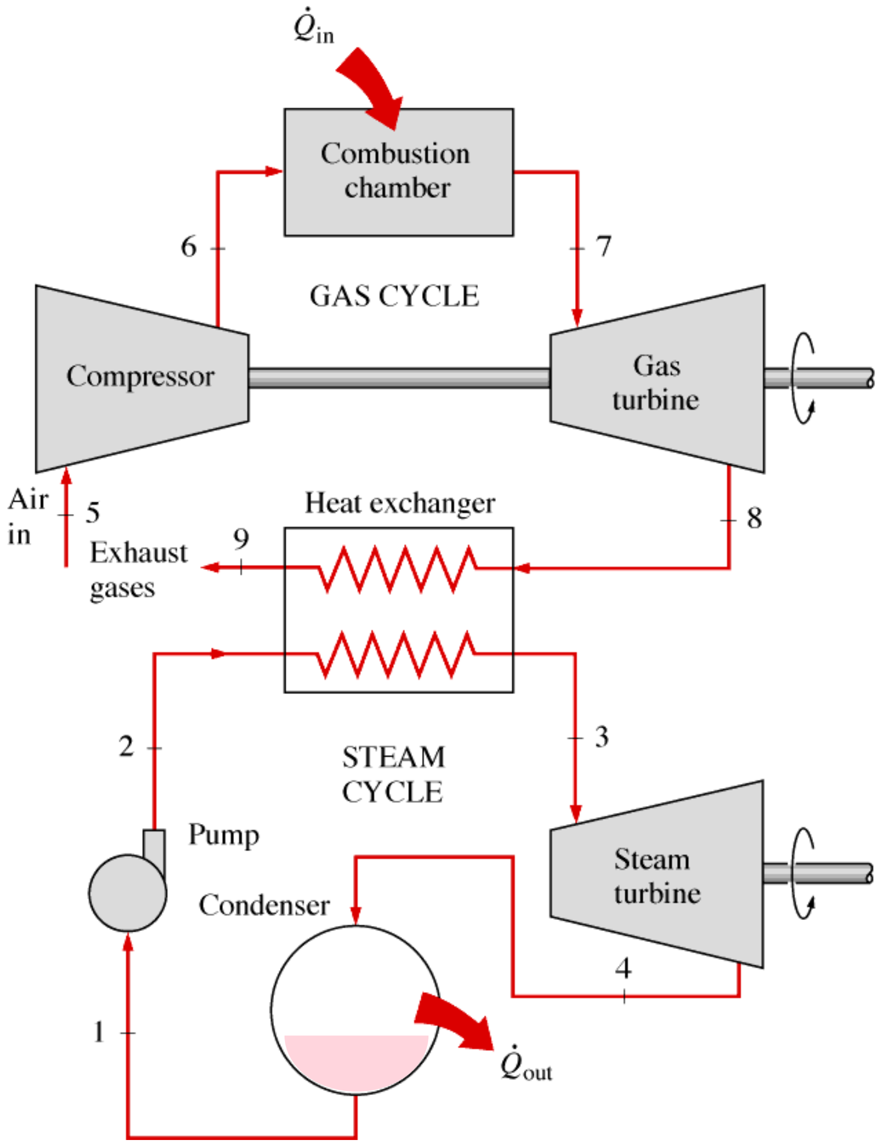
- The production of more than one useful form of energy (such as process heat and electric power) from the same energy source is called *cogeneration*. Cogeneration plants produce electric power while meeting the process heat requirements of certain industrial processes. This way, more of the energy transferred to the fluid in the boiler is utilized for a useful purpose. The faction of energy that is used for either process heat or power generation is called the *utilization factor* of the cogeneration plant.

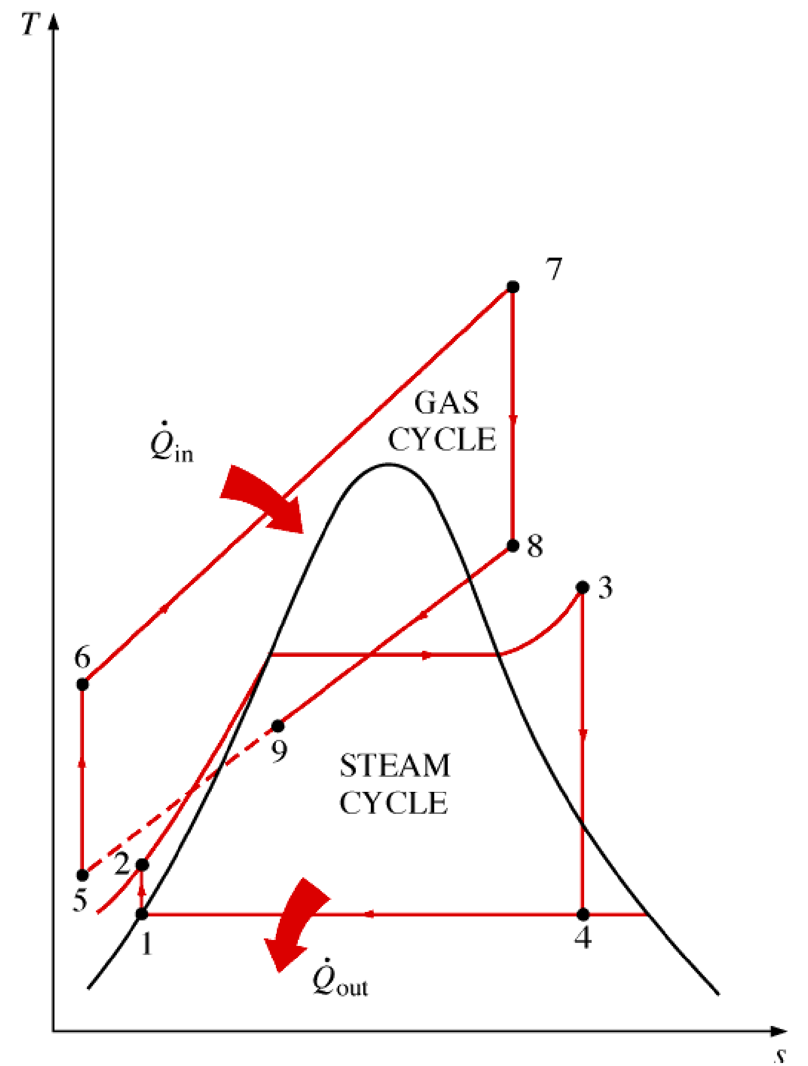
An Ideal Cogeneration Plant

(Fig. 9-21)



Combined Gas-Steam Power Plant

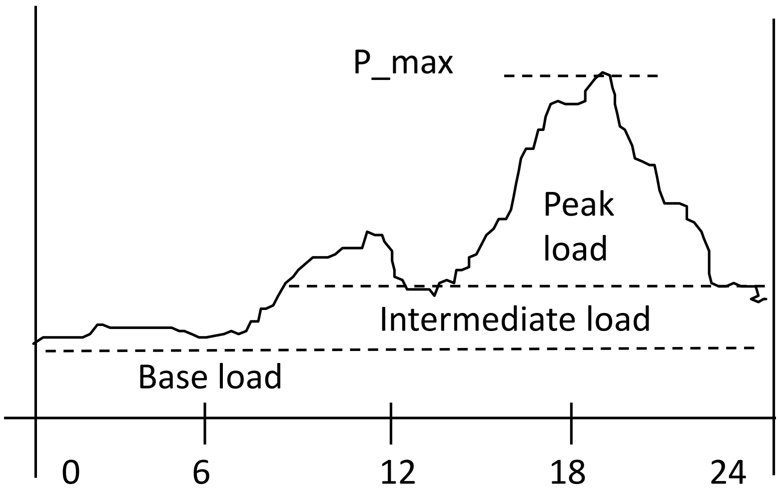




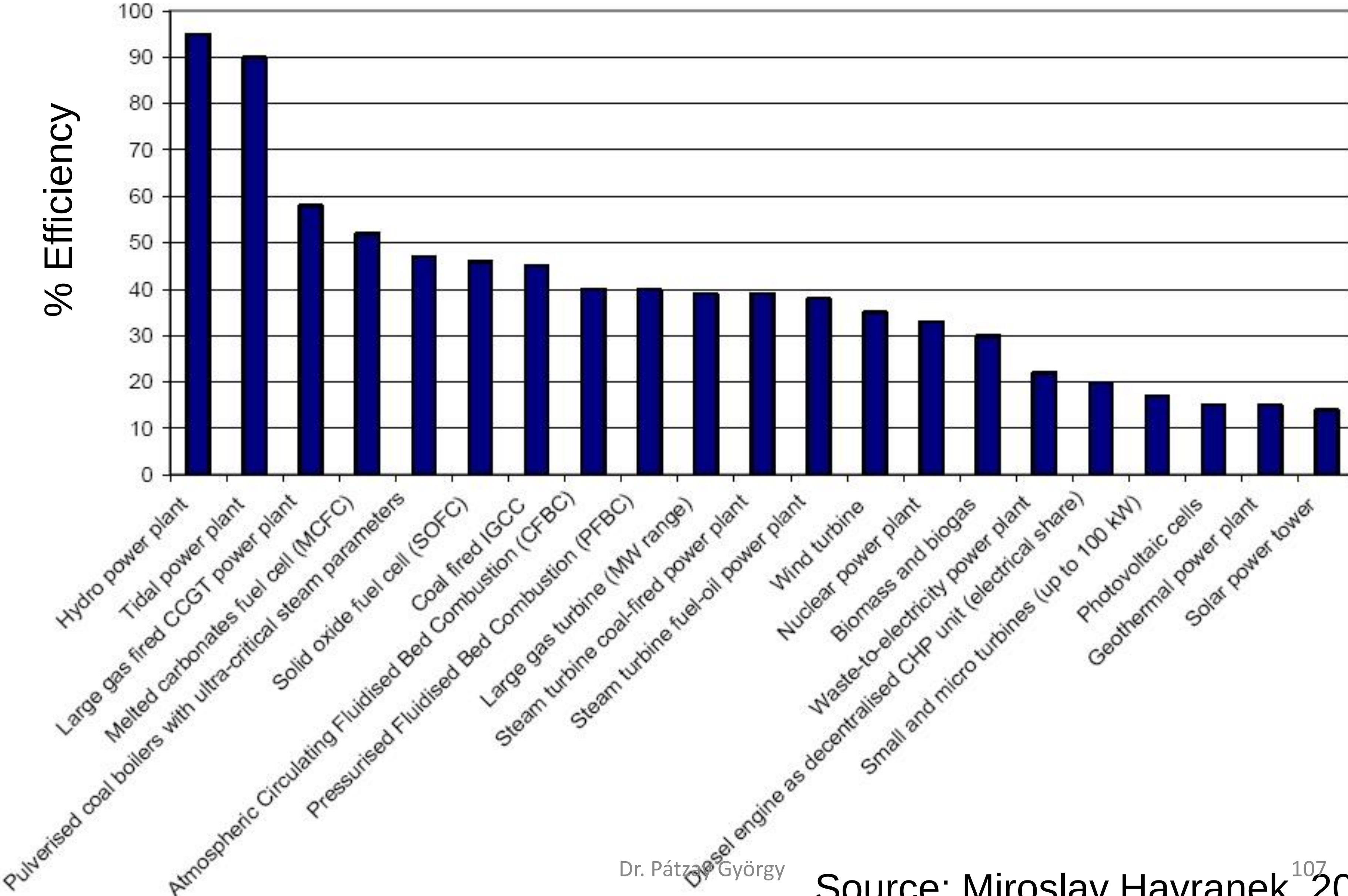
Electric Load

- The load changes continuously
  - Daily
  - Seasonal
- The daily maximum occurs around 4-6 PM , the minimum at night.
- The load or demand is defined as the average load (MW) for 15 minutes
- Seasonal changes: Summer load is higher than the winter load in AZ.

- **Base load (large thermal and nuclear plants)**
- **Intermediate loads (medium steam and hydro)**
- **Peak load (gas turbine and combined cycle plants)**



Power plant & fuel cell efficiencies



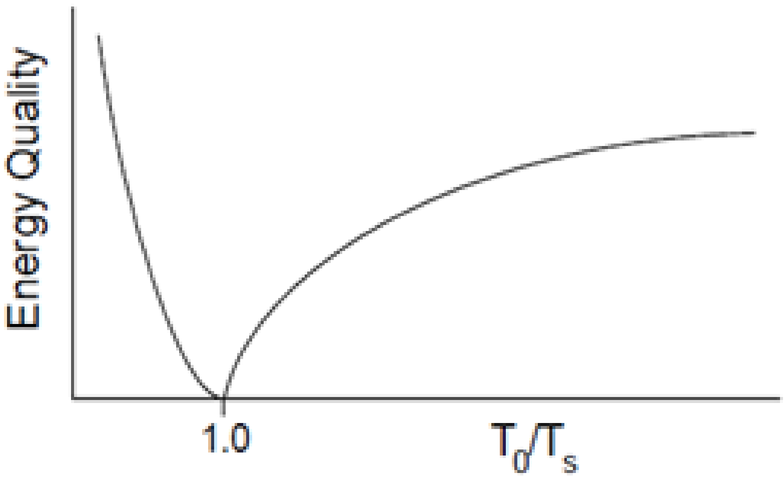
Source: Miroslav Havranek, 2007

Energy – Quality - Exergy

Exergy = Energy * Quality

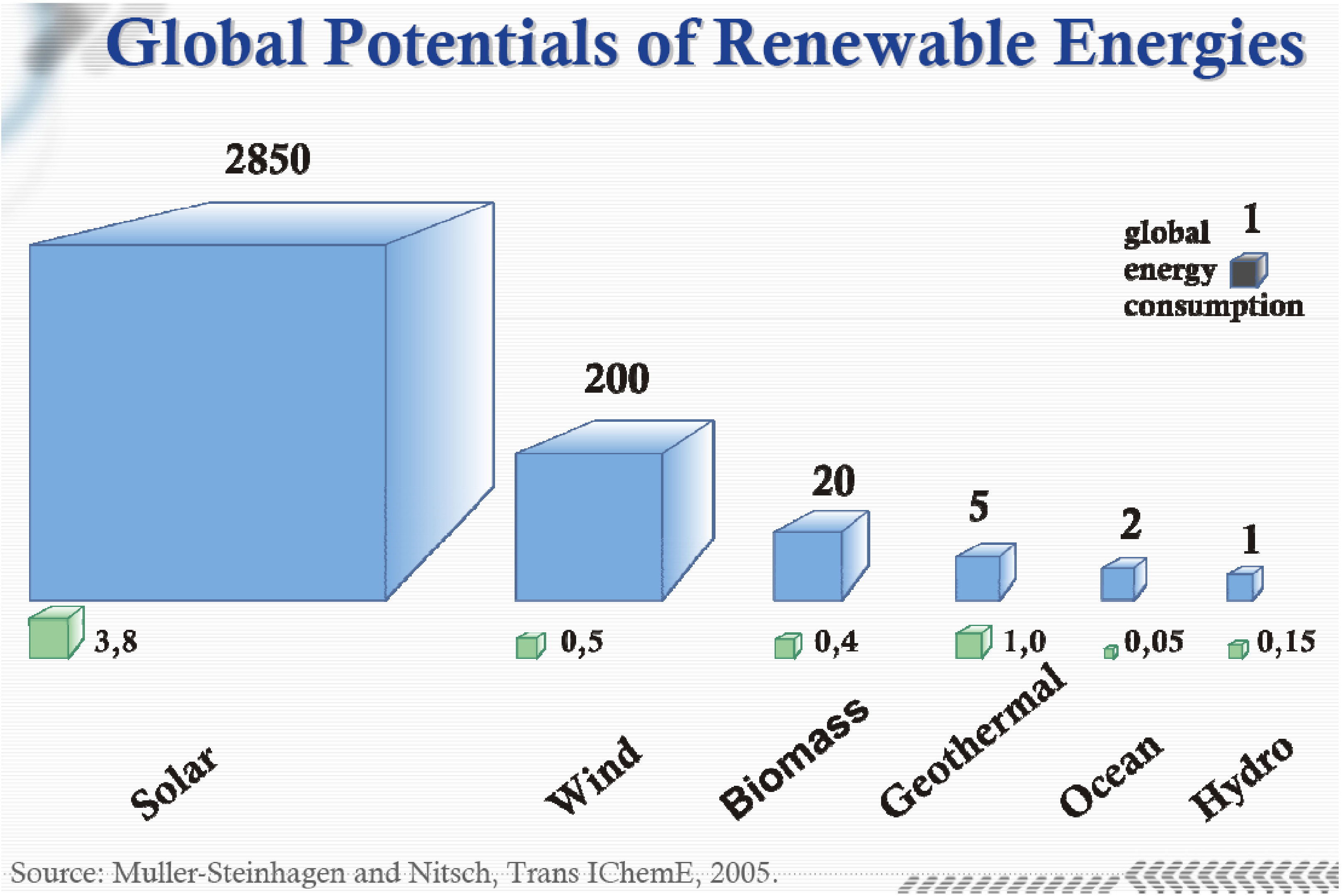
where the quality is given by

$$Quality = \left|1 - \frac{T_0}{T_s}\right|$$

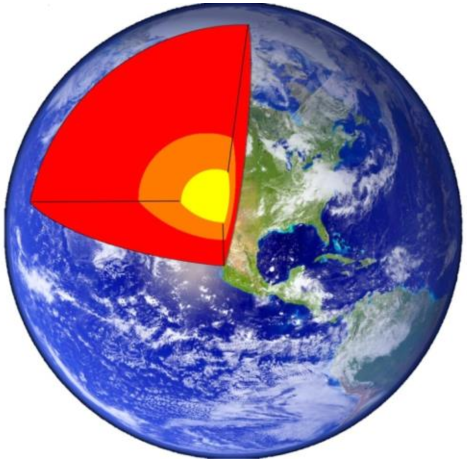


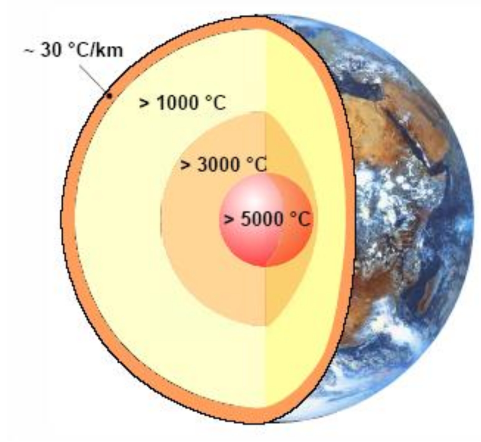
Source	Energy (J)	Exergy (J)	Quality (%)
Water at 0 °C	100	9	9
Water at 25 °C	100	0	0
Water at 80 °C	100	16	16
Natural Gas	100	99	99
Electricity or Work	100	100	100

Renewable energy sources

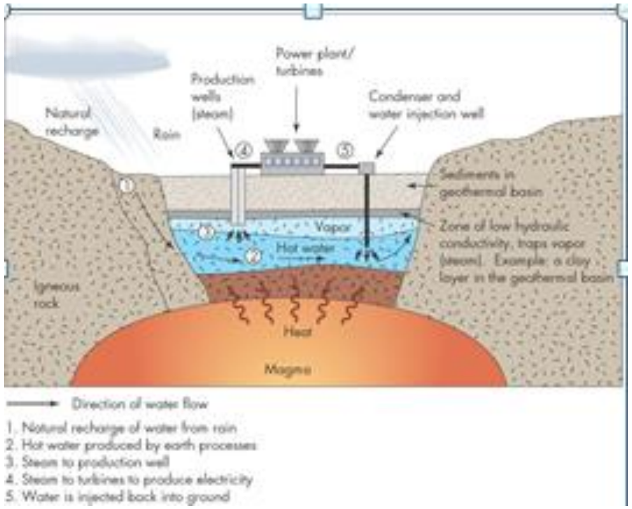


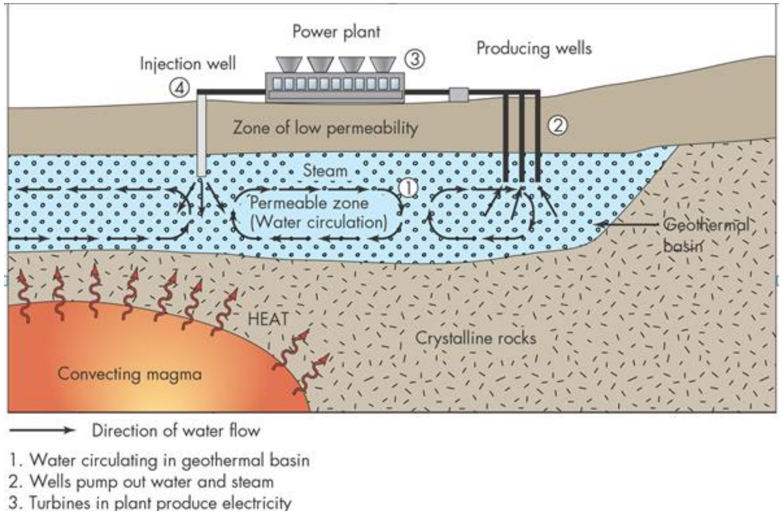
Geothermal energy

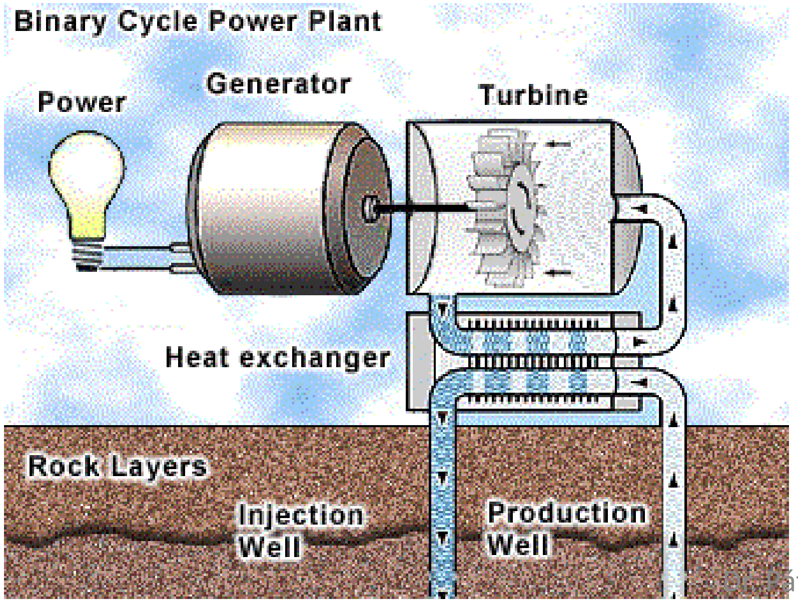


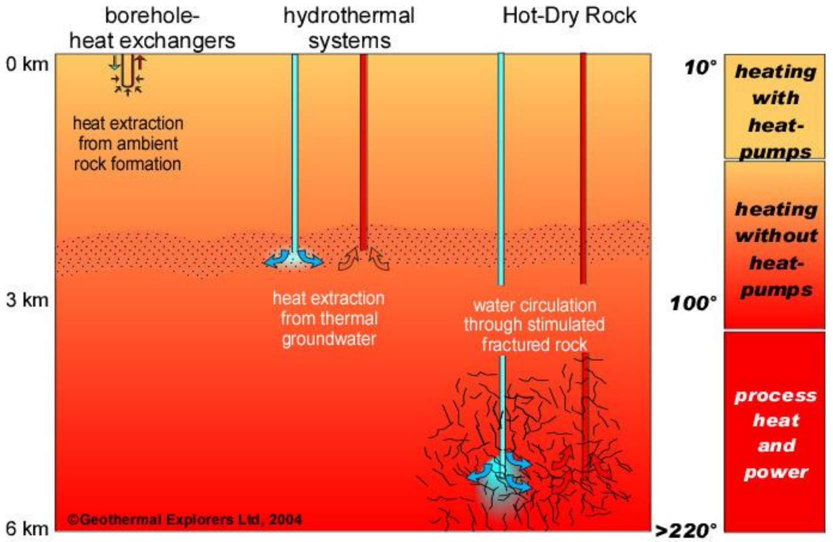


Geothermal energy

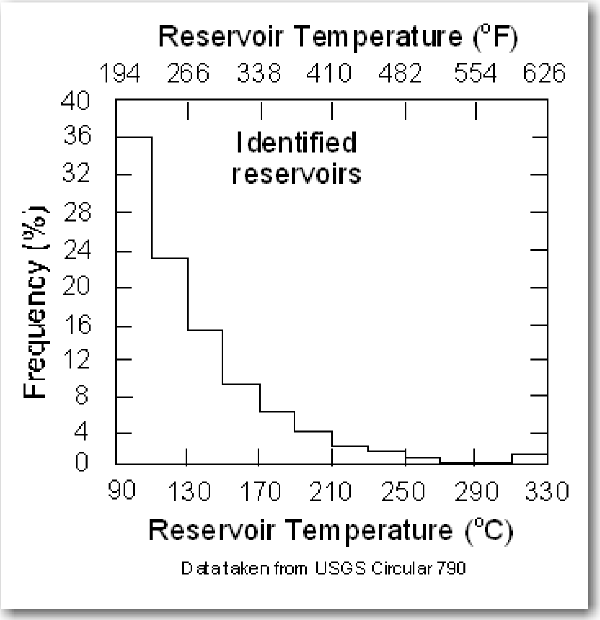


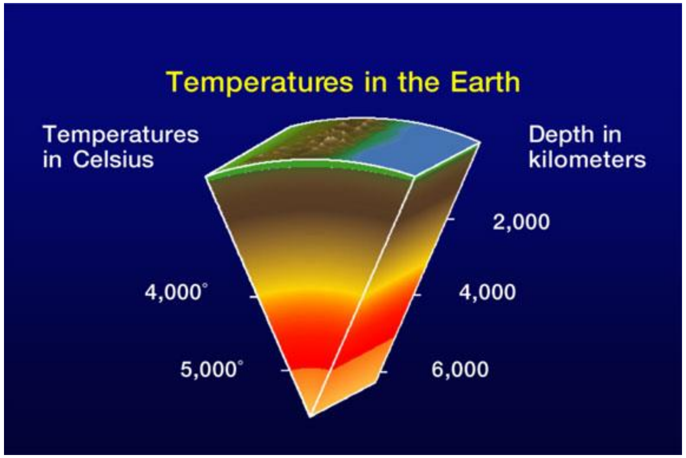


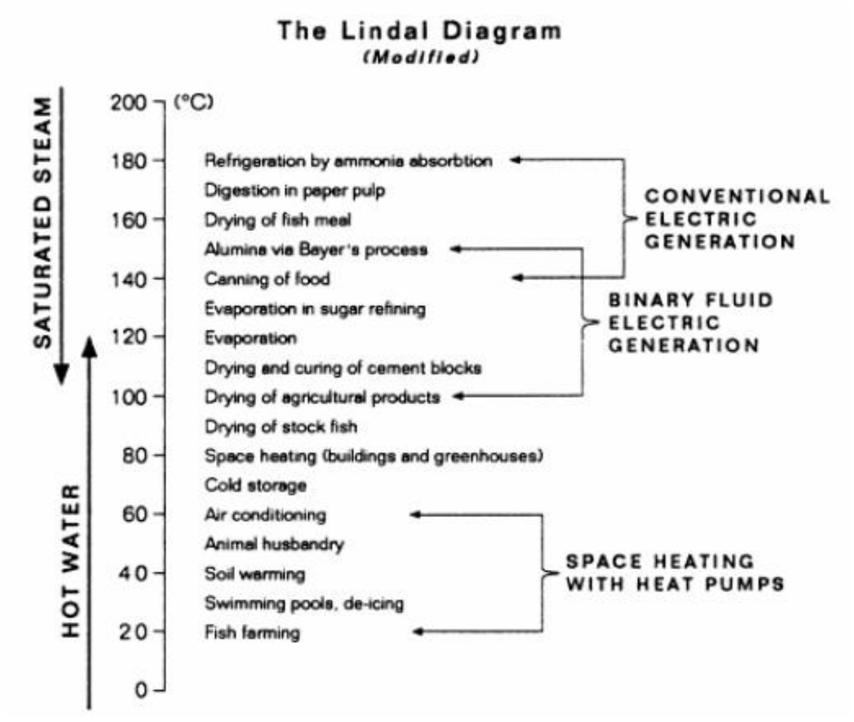




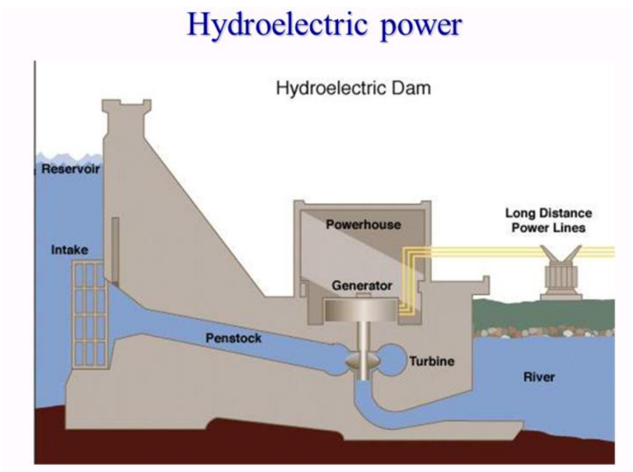
Geothermal energy

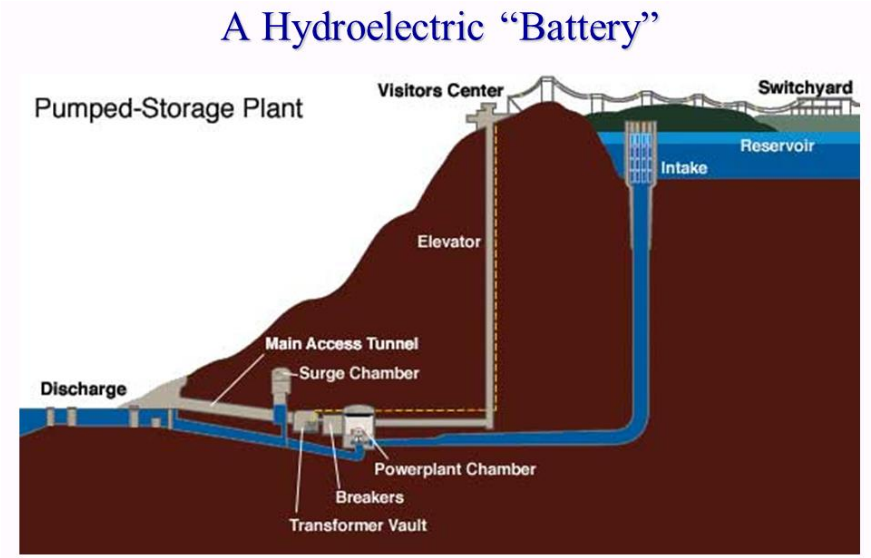






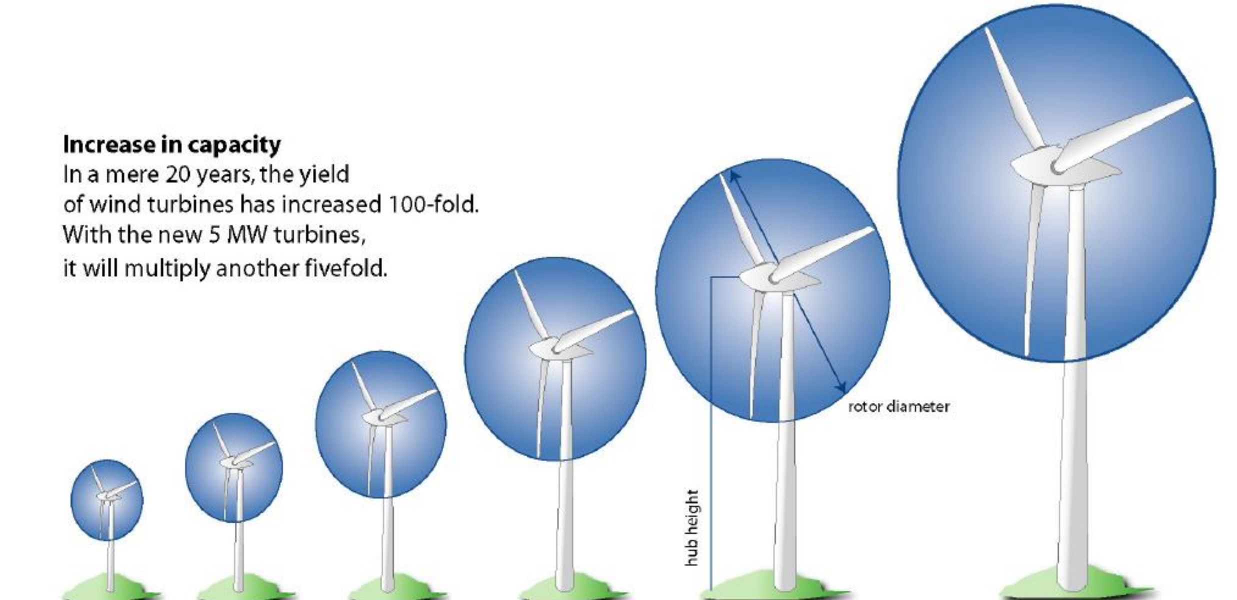
Water energy





Wind energy in Germany

Increase in capacity
In a mere 20 years, the yield
of wind turbines has increased 100-fold.
With the new 5 MW turbines,
it will multiply another fivefold.



	1980	1985	1990	1995	2000	2005
rated power :	30 kW	80 kW	250 kW	600 kW	1,500 kW	5,000 kW
rotor diameter :	15 m	20 m	30 m	46 m	70 m	115 m
hub height :	30 m	40 m	50 m	78 m	100 m	120 m
annual energy yield :	35,000 kWh	95,000 kWh	400,000 kWh	1,250,000 kWh	3,500,000 kWh	appr. 17,000,000 kWh

Dinner Debate May 8th, 2007 - W. Hoffmann, Director of EREC, President of EPIA 17

Biomass

What is biomass?

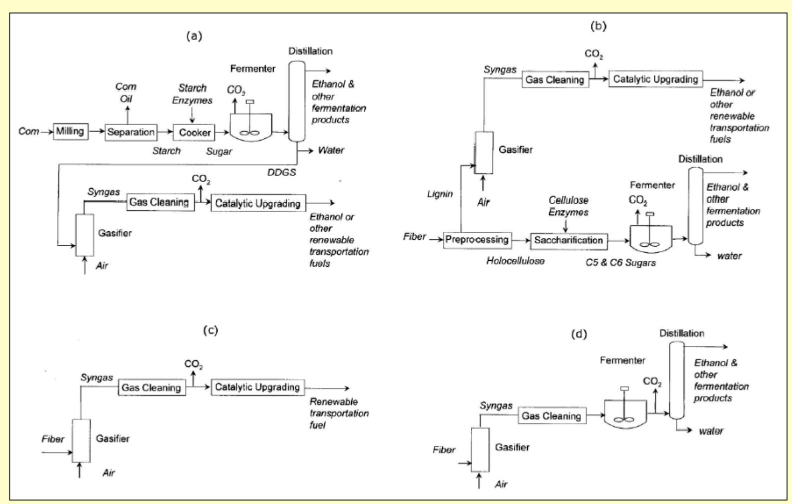
Biomass (in our case more correctly phytomass) as very diverse material has no exact chemical formula. For average biomass the mole ratio formula of main elements – C, H, and O (S and N are minor) is:

Biomass = $CH_{1.4}O_{0.6}$

This formula is workable for a large number of tree and plant species in case when the water and ash are eliminated from biomass. On the basis of this formula is possible to write approximate chemical equations for different biomass chemical conversion processes. For instance, gasification of biomass would be presented:

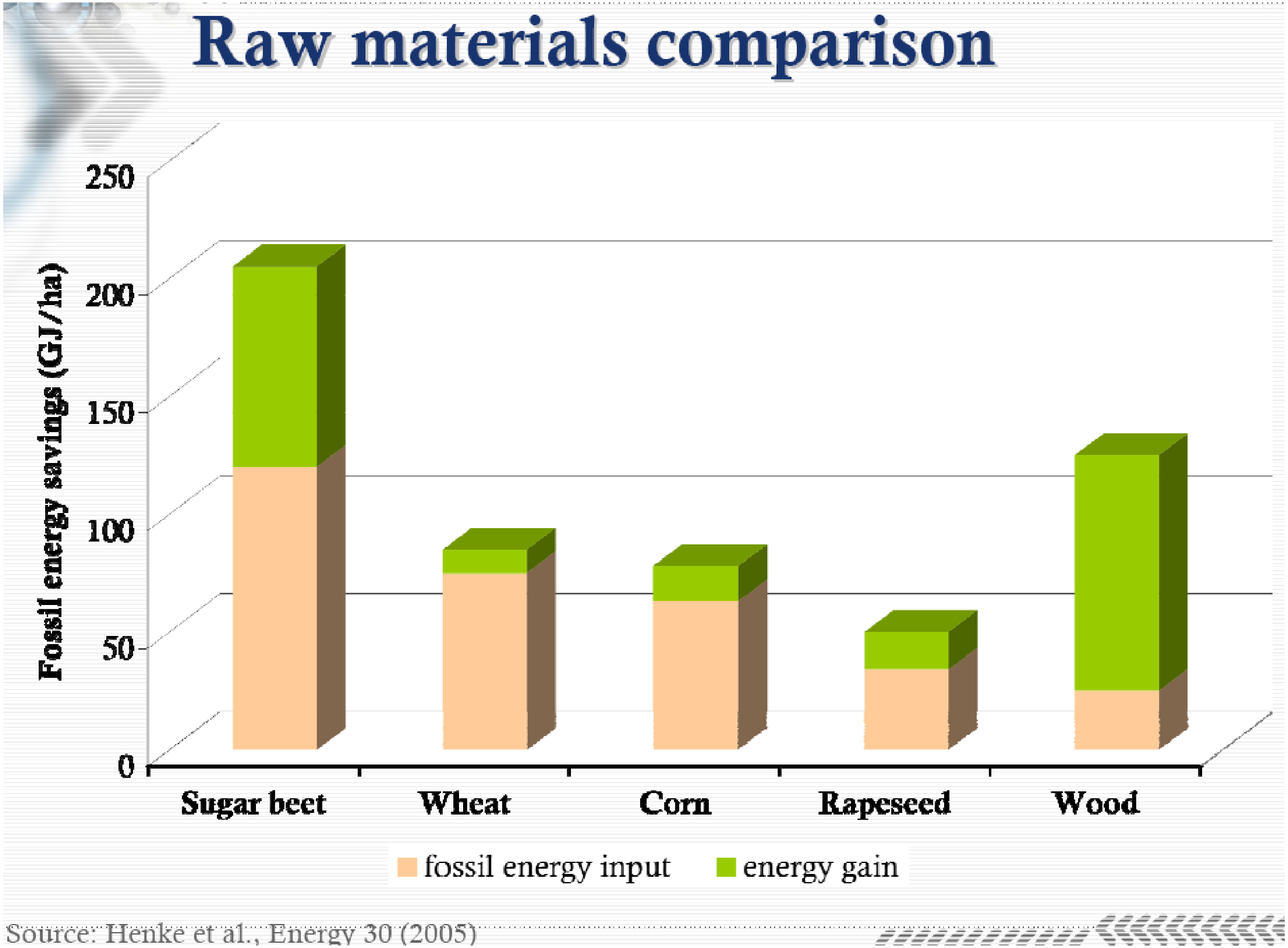
$$CH_{1.4}O_{0.6} + 0.35O_2 \rightarrow 0.4CO + 0.6H_2 + 0.4CO_2 + 0.1H_2O + 0.2C$$

A biorefinery is a technologies cluster, which integrates biomass conversion into transportation fuels, power, chemicals and advanced materials within zero emissions framework.



Main potential biorefineries

Biomass



Raw materials comparison
Fossil energy savings (GJ/ha)
0
50
100
150
200
250
Sugar beet
Wheat
Corn
Rapeseed
Wood
fossil energy input
energy gain
Source: Henke et al., Energy 30 (2005)

Biomass

Producing 1 kg of biodiesel

Requires

- 3,8 kg abiotic material
- 4,4 t di water
- 0,56 kg fertilizers
- 0,34 kg oil equivalent
- 14,2 m^2 productive surface

Releases

- 1071 g CO_2
- 18 g NOx
- 3 g VOC
- 7 g CO
- 0,96 kg topsoil used up
- 3,19 kg industrial residues

Energy Output/Input = 2,30

Basic disadvantages of biofuels production

> **Not enough biomass** for replacement of fossil fuels

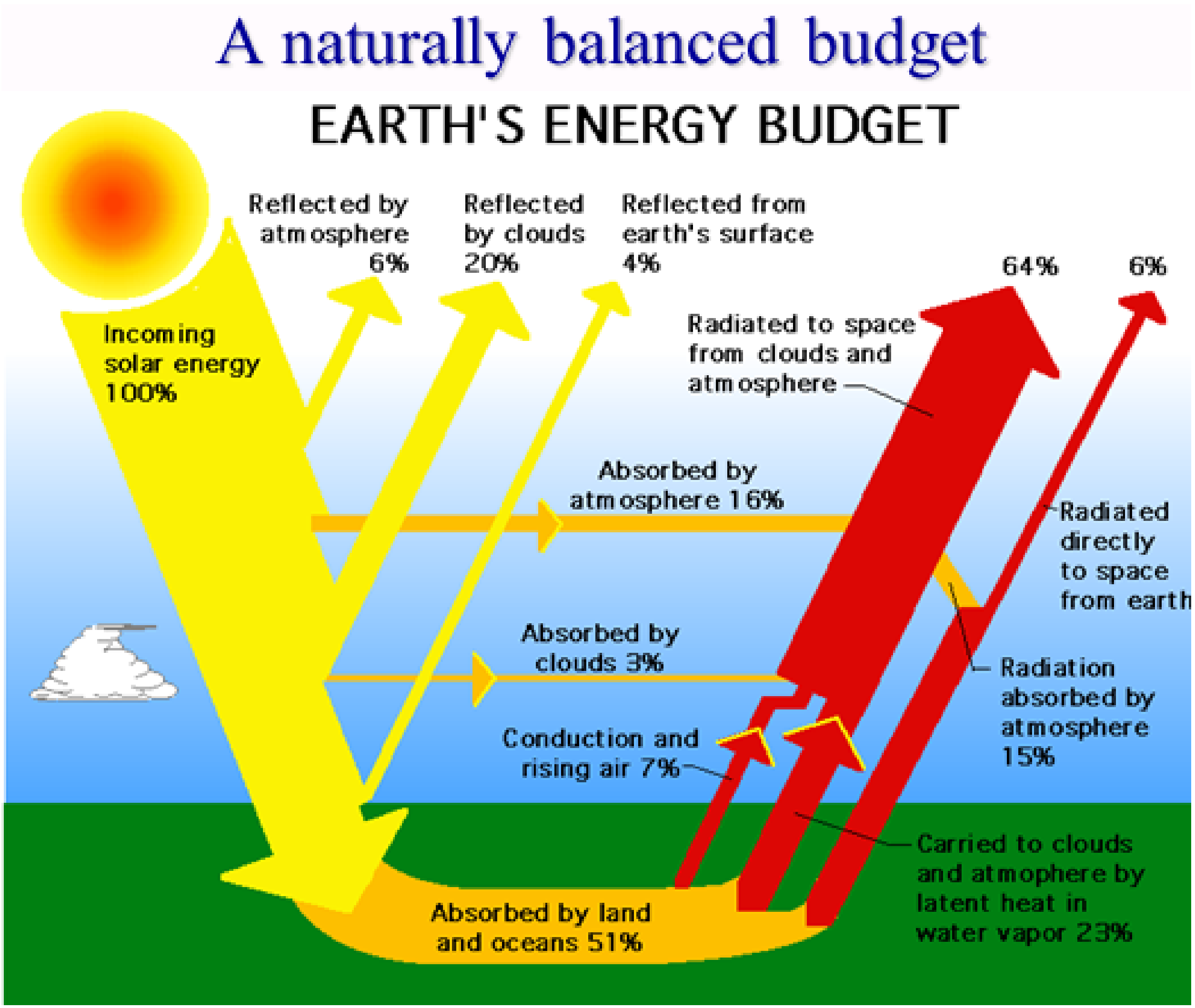
> **Transportation and storage off-season** is costly

> **Fraction of renewable energy** in bio fuel is small and diluted

> **Recycling of minerals** and energy (humus) needed

> Replacing fuel oil for energy by burning wood seems to be more energy efficient as using bio ethanol

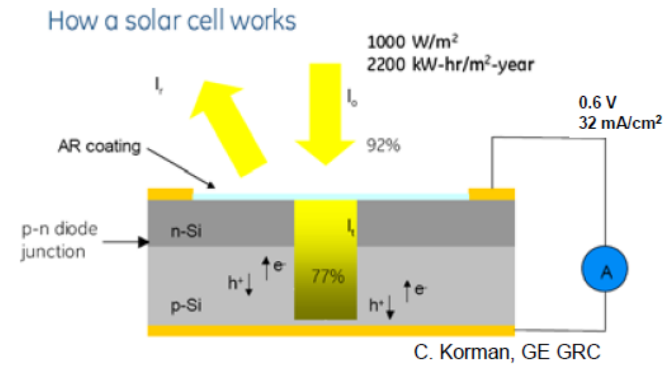
Sun energy


A naturally balanced budget
EARTH'S ENERGY BUDGET
Reflected by atmosphere 6%
Reflected by clouds 20%
Reflected from earth's surface 4%
64%
6%
Incoming solar energy 100%
Radiated to space from clouds and atmosphere
Absorbed by atmosphere 16%
Radiated directly to space from earth
Absorbed by clouds 3%
Radiation absorbed by atmosphere 15%
Conduction and rising air 7%
Carried to clouds and atmophere by latent heat in water vapor 23%
Absorbed by land and oceans 51%

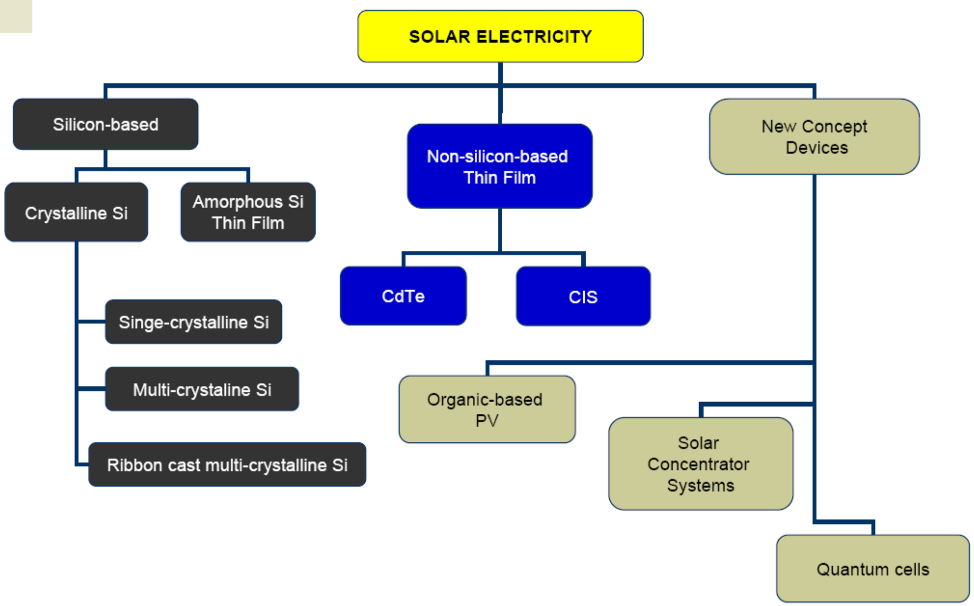
Sun energy

Solar PV

- Grid-connected centralized *(power plants)*
- Grid-connected distributed *(rooftop)*
- Off-grid non-domestic *(power plants)*
- Off-grid domestic *(rooftop)*



Maximum theoretical efficiency of single-junction silicon solar cell: ~29%.
R.M. Swanson, Proc. 31st IEEE Photovoltaic Specialists Conference (Lake Buena Vista, FL, 2005) p. 889



How does a photovoltaic device (solar cell) work?

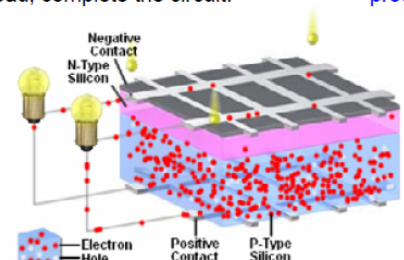
(1) Charge Generation: Light excites electrons, freeing them from atomic bonds and allowing them to move around the crystal.

(2) Charge Separation: An electric field engineered into the material (pn junction) sweeps out electrons.

(3) Charge Collection: Electrons deposit their energy in an external load, complete the circuit.

Advantages: There are no moving parts and no pollution created at the site of use (during solar cell production, that's another story).

Disadvantages: No output at night; lower output when weather unfavorable.



For full animation, see: http://micro.magnet.fsu.edu/primer/java/solarcell/

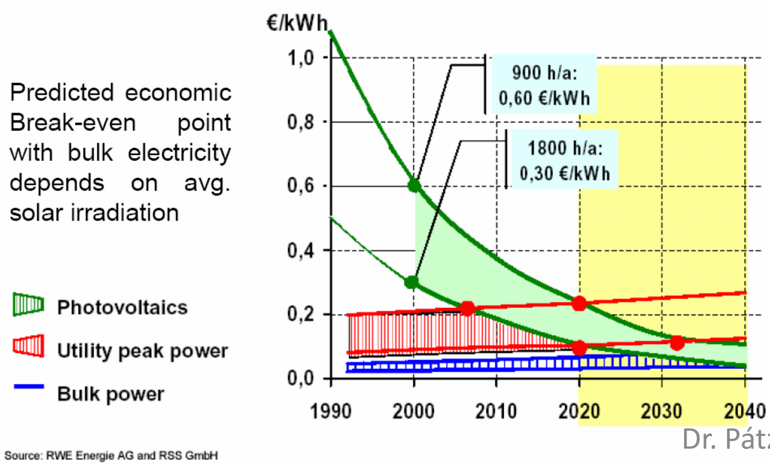
Sun energy

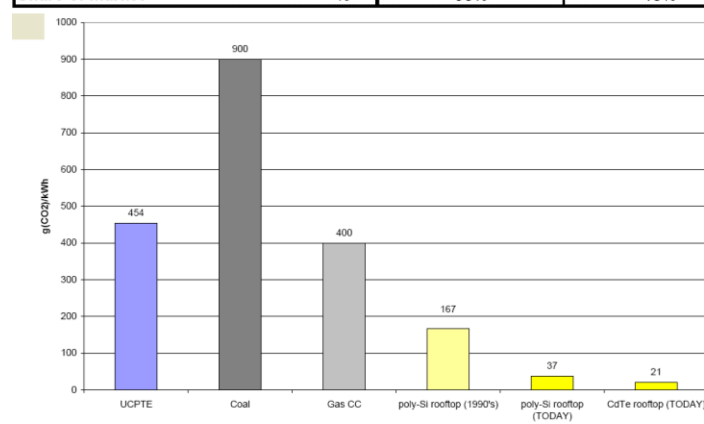
Crystalline Silicon modules can be produced in three ways:

1. Re-melting of scraps of high-purity "Electronic Grade" Silicon (EGSi) and wafer cutting (**sc-Si / mc-Si**)
2. Direct production of medium-purity "Solar Grade" Silicon (SoG-Si) and wafer cutting (**mc-Si**)
3. Direct production of medium-purity "Solar Grade" Silicon (SoG-Si) and ribbon casting (**mc-Si**)

Amorphous Silicon (a-Si) modules makes use of a thin layer of hydrogenated silicon deposited on glass

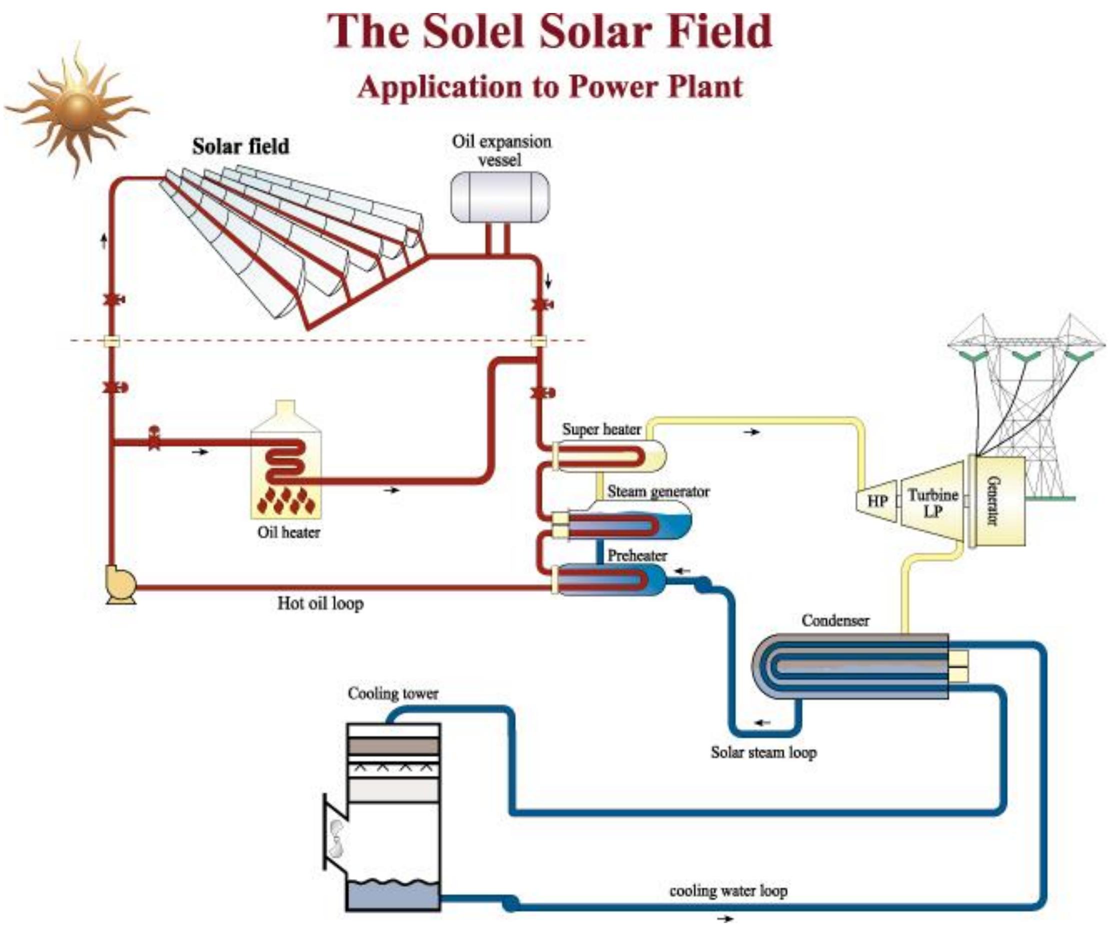
		Present					
Cumulative Inst. Capacity	GWp	3					
Technology		crystalline-Si			thin films		
		sc-Si	mc-Si	ribbon	a-Si	CIS	CdTe
crystalline Si layer thickness	um	250	250	300	N/A		
Module efficiency		14%	13%	11%	10%	10%	9%
Module technical life	years	25			25		
Installed capacity	GWp	2.7			0.3		
Share of market	%	90%			10%		

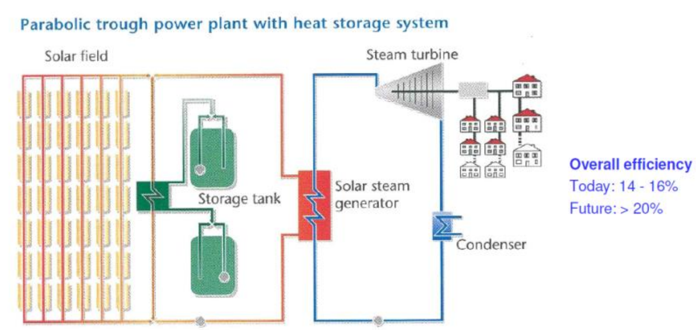




Sources: ETH, 1996; ExternE, 2003; Fthenakis and Alsema, 2006; Raugei et al., 2007

Sun energy


The Solel Solar Field
Application to Power Plant
Solar field
Oil expansion vessel
Super heater
Steam generator
Preheater
Oil heater
Hot oil loop
HP
Turbine LP
Generator
Condenser
Cooling tower
Solar steam loop
cooling water loop


Parabolic trough power plant with heat storage system
Solar field
Steam turbine
Storage tank
Solar steam generator
Condenser
Overall efficiency :
Today: 14 - 16%
Future: > 20%

Why Hydrogen?

- **Hydrogen must be produced like electricity!**
- **Today hydrogen is produced for the industry from fossil fuels (98 % in Germany) and electrolysis (2 % in Germany)**
- **Hydrogen can be produced in large central plants or in smaller distributed units**
- **Low carbon hydrogen can be produced from fossil resources (in future with carbon capture and storage, CCS), nuclear, renewables**
- **Hydrogen can be produced by photo-biological and photoelectrolysis**
- **processes, thermochemical water splitting, ...**
- **Hydrogen can be transported and stored**
- **Hydrogen can be used in fuel cells (some fuel cells can use hydrogen-containing fuel directly), in internal combustion engines, in gas turbines**
- **Hydrogen can replace oil and gas and contribute to energy security and independence from imports**

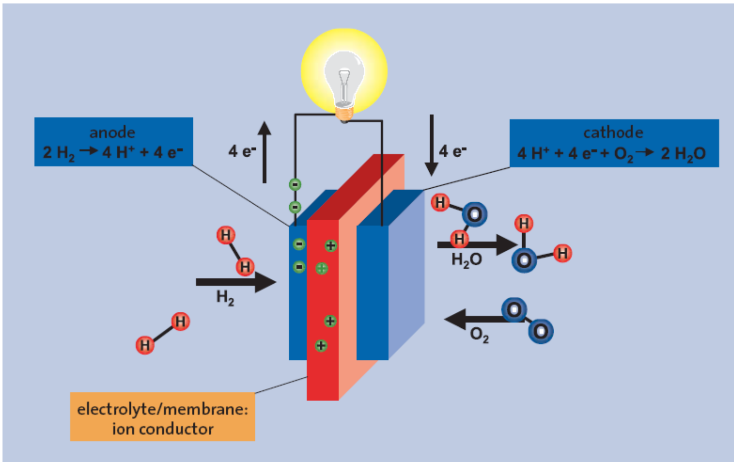
Why Fuel Cells?

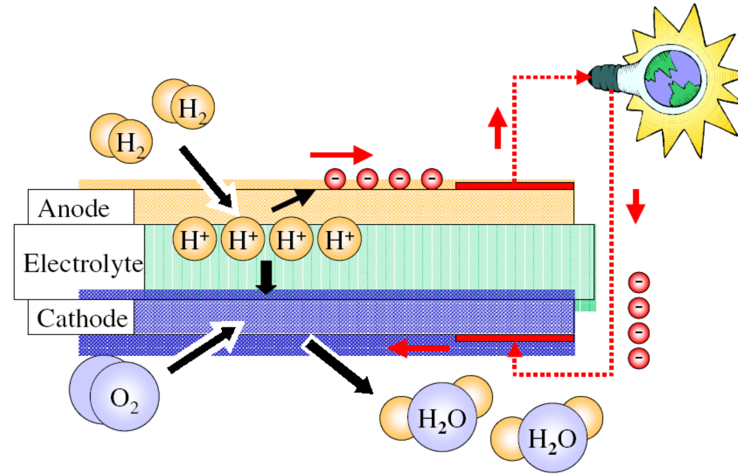
- The use of fuel cells contributes to energy efficiency (and: electricity is produced and the right amount of heat at the right temperature regime)
- Residential: fuel cells replace oil/gas central heating systems and reduce amount of electricity taken from the grid
- Stationary: fuel cells replace CHP with fossil fuels
- Transport: fuel cells replace internal combustion Why Fuel Cells?
- engines running on gasoline and diesel

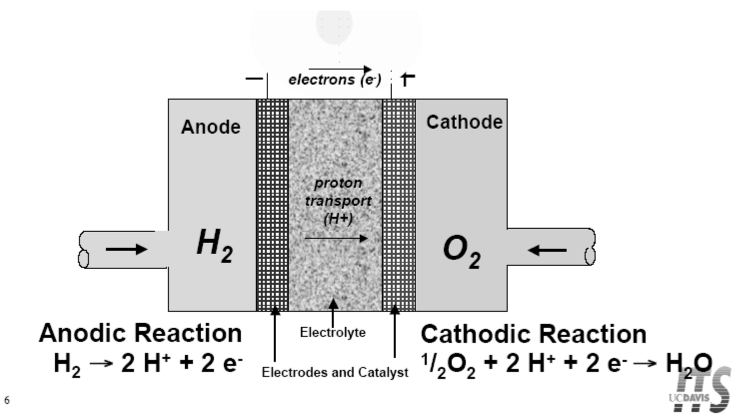
Why Hydrogen and Fuel Cells?

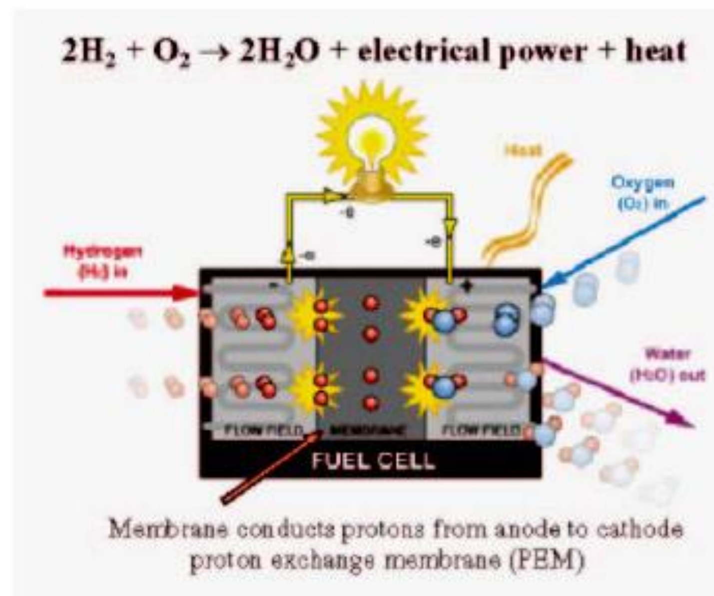
- Reducing the impact on local and global environment
- Energy security
- Diversification of energy supply
- Creation of new jobs
- Industry opportunities

Fuel cells


anode
2 H₂ → 4 H⁺ + 4 e⁻
4 e⁻
4 e⁻
cathode
4 H⁺ + 4 e⁻ + O₂ → 2 H₂O
H₂
H₂O
O₂
electrolyte/membrane:
ion conductor


H₂
H₂
Anode
Electrolyte
Cathode
H⁺ H⁺ H⁺ H⁺
O₂
H₂O
H₂O


electrons (e⁻)
Anode
Cathode
proton
transport
(H+)
H₂
O₂
Anodic Reaction
H₂ → 2 H⁺ + 2 e⁻
Electrolyte
Electrodes and Catalyst
Cathodic Reaction
¹/₂O₂ + 2 H⁺ + 2 e⁻ → H₂O
6

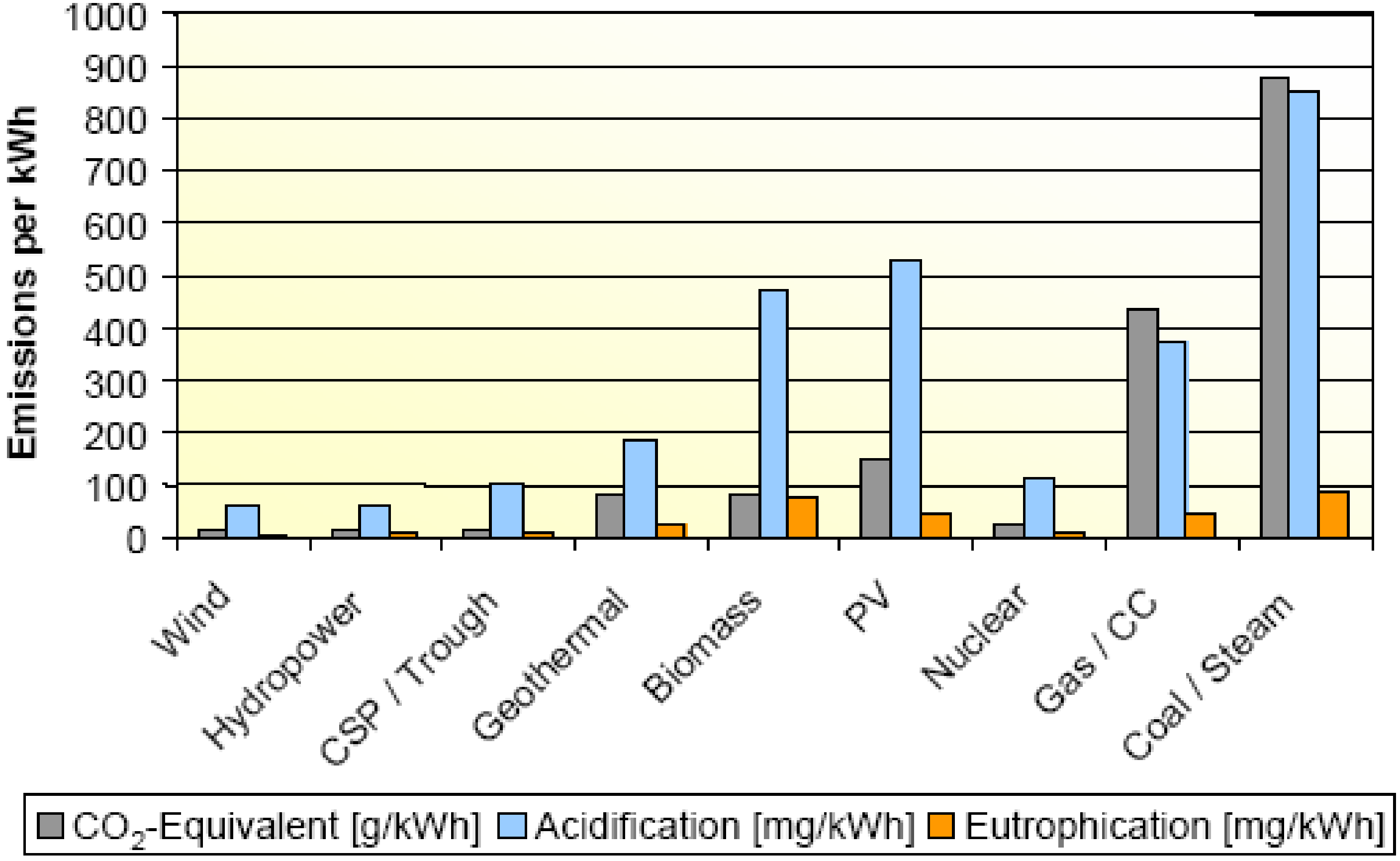

2H₂ + O₂ → 2H₂O + electrical power + heat
Heat
Oxygen (O₂) in
Hydrogen (H₂) in
Water (H₂O) out
FLOW FIELD
MEMBRANE
FLOW FIELD
FUEL CELL
Membrane conducts protons from anode to cathode
proton exchange membrane (PEM)

- Improving efficiency of final energy use:
  - Solar passive buildings, 190 → 15 kW h/m^2
  - Industry – low energy (bio)processes, process integration, CHP, poly-generation, heat pumping
  - Transport efficiency – cars, light trucks, high speed trains
  - New materials, recycling, reuse, substitution
- Energy conversion (increased efficiency), e.g.:
  - Cogeneration engine + heat pump
  - gas turbine / steam turbine comb. cycle + heat pump
  - gas turbine / steam turbine cogeneration + heat pump
- Human behaviour, marketing, R&D planning

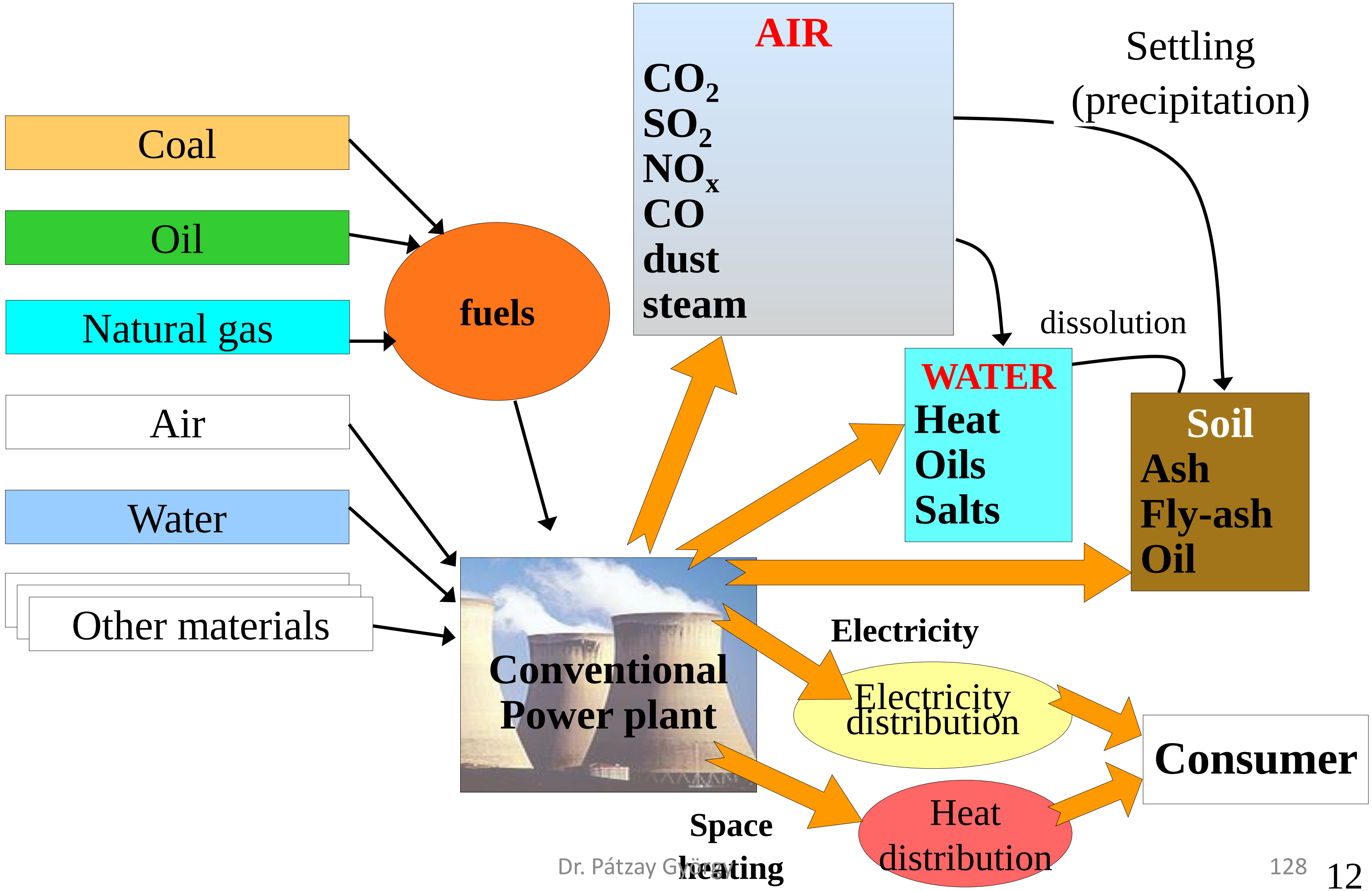
Source: Spreng D, Energy Policy 33 (2005)

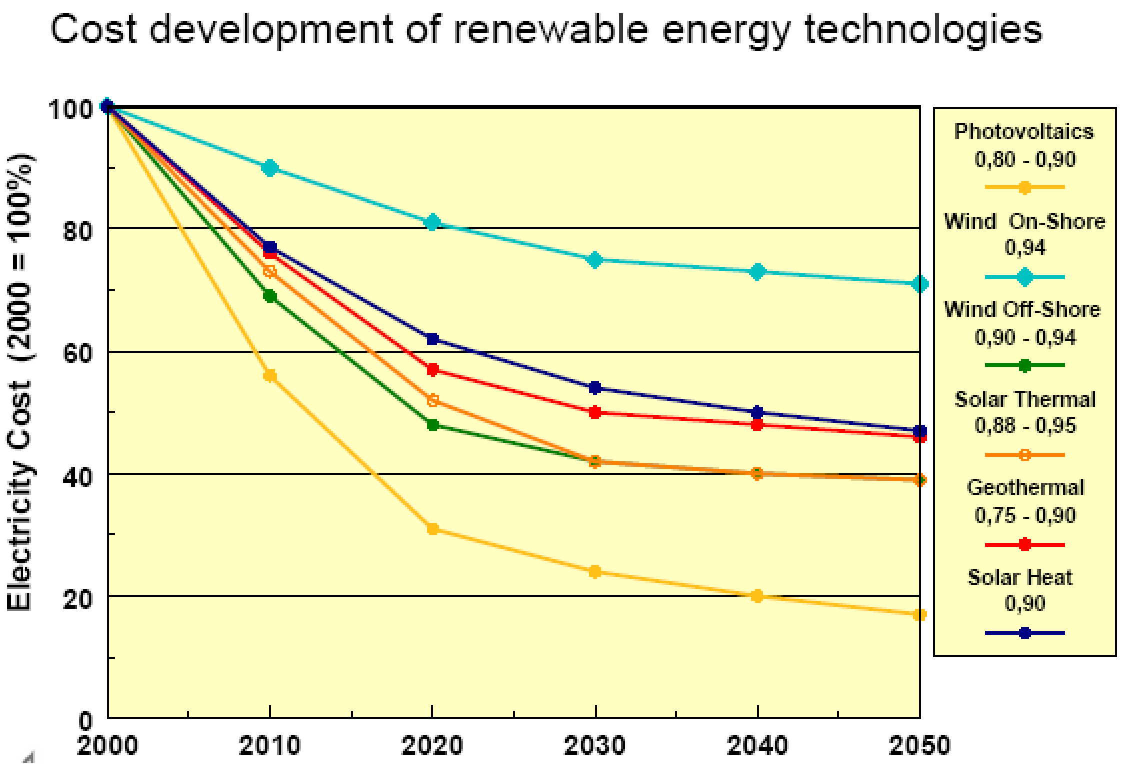
ENVIRONMENTAL EFFECTS OF POWER PLANTS

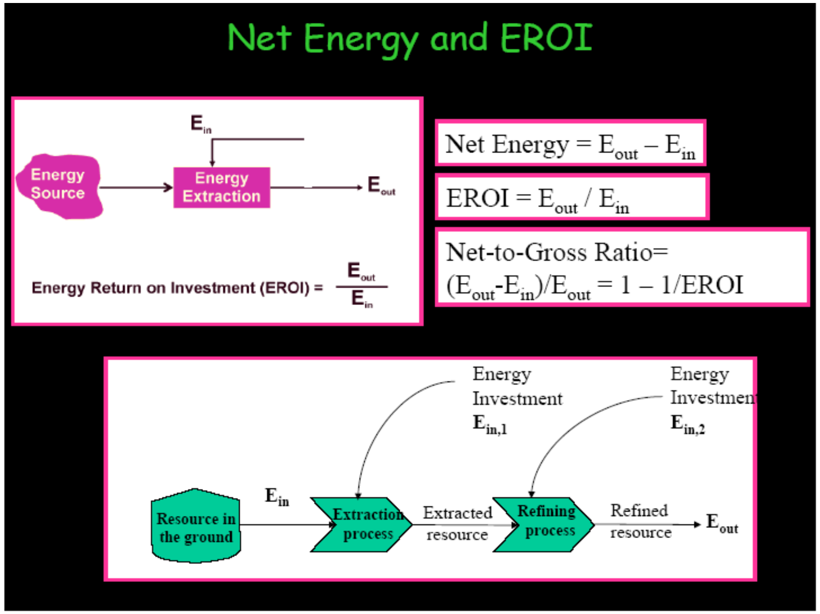
Life cycle emissions from different electricity generation technologies

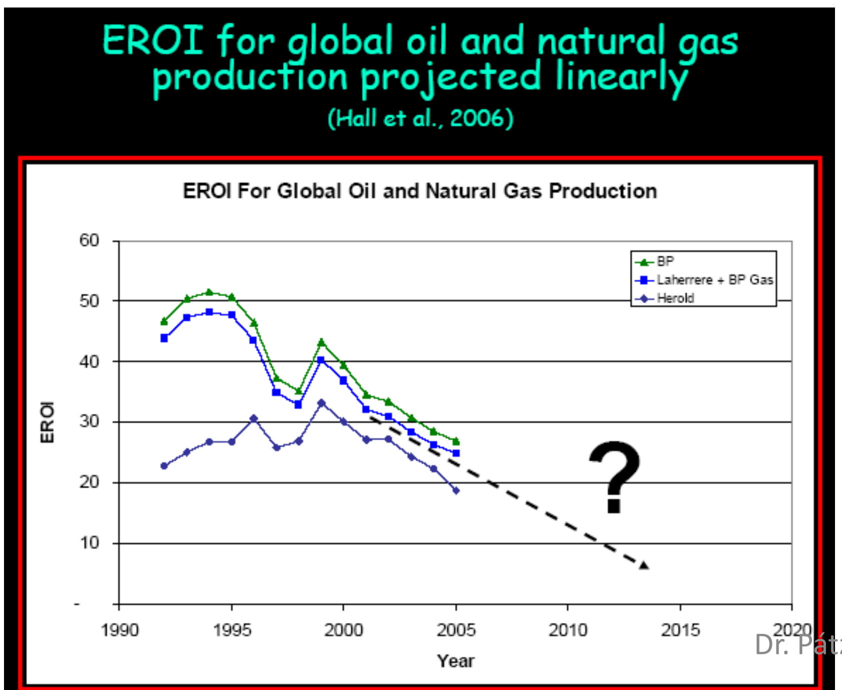


ENVIRONMENTAL EFFECTS OF CONVENTIONAL POWER PLANTS




Cost development of renewable energy technologies
Electricity Cost (2000 = 100%)
100
80
60
40
20
0
2000
2010
2020
2030
2040
2050
Photovoltaics
0,80 - 0,90
Wind On-Shore
0,94
Wind Off-Shore
0,90 - 0,94
Solar Thermal
0,88 - 0,95
Geothermal
0,75 - 0,90
Solar Heat
0,90

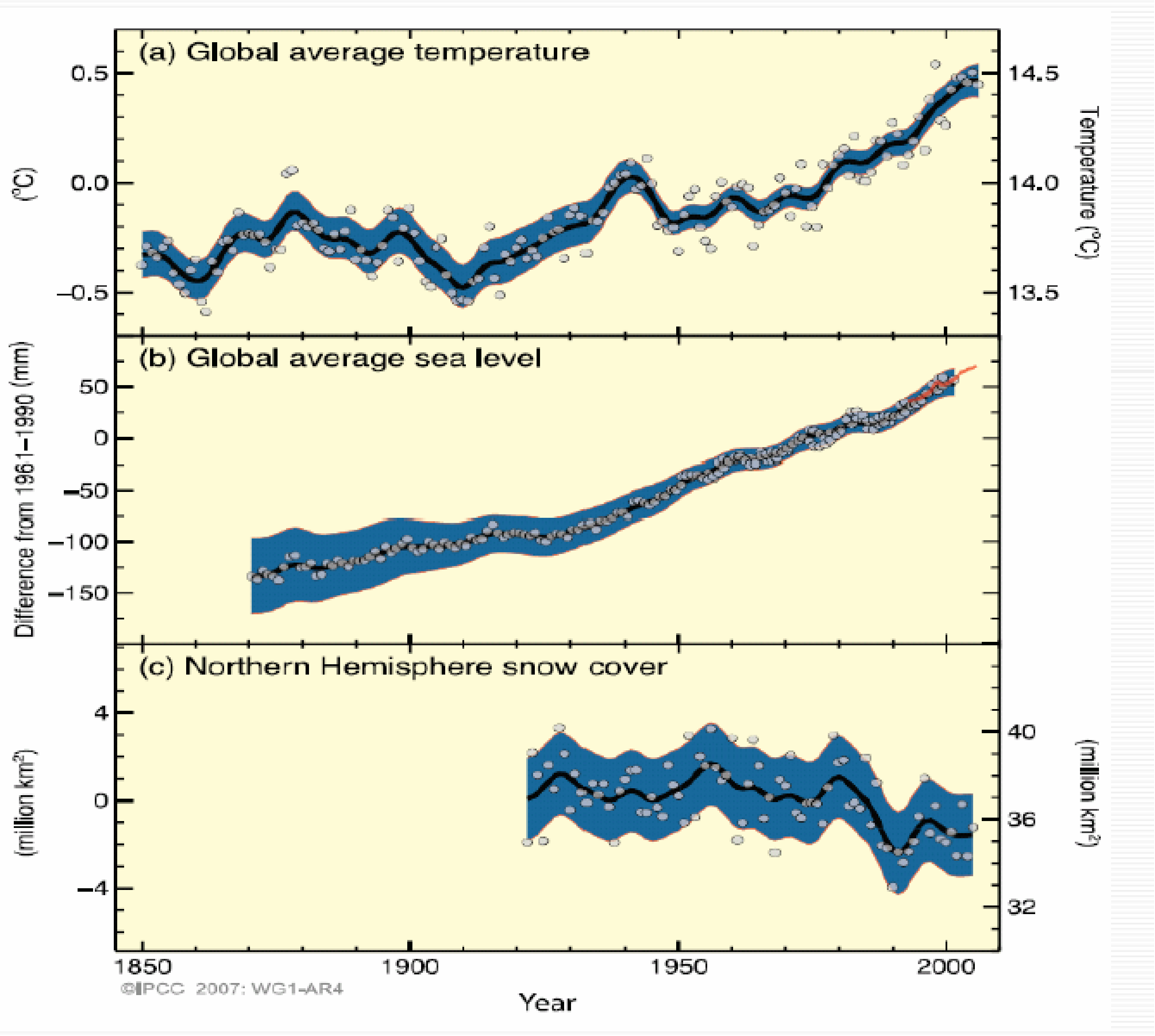


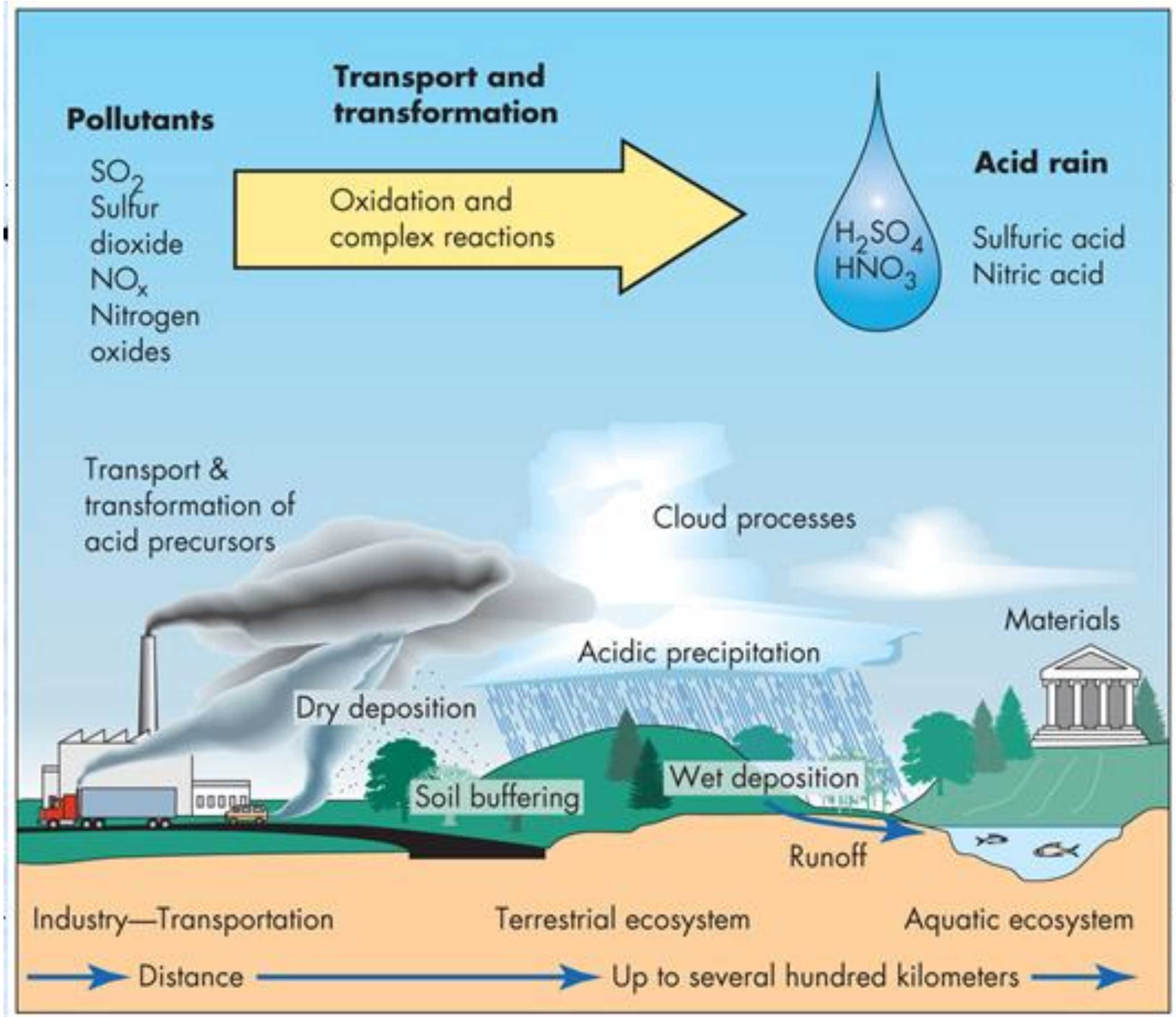


EROI of selected fossil fuels and energy carriers			
	Energy content (MJ/unit)	Energy investment (MJ/unit)	EROI
Mined			
Coal (kg)	28.01	1.39	20.15
Natural gas (kg)	57.00	3.35	17.01
Refined			
Natural gas (kg)	57.00	8.14	7.00
Coke (kg)	25.42	3.93	6.47
LPG (propane) (kg)	50.00	8.89	5.62
LPG (butane) (kg)	49.30	8.89	5.55
Gasoline (kg)	46.12	8.89	5.19
Gas oil (oil distillate) (kg)	45.21	8.89	5.09
Gas oil (oil distillate) (kg)	45.21	8.89	5.09
Diesel (kg)	44.84	8.89	5.04
Light fuel oil (kg)	43.20	8.89	4.86
Medium Fuel oil (kg)	42.85	8.89	4.82
Heavy fuel oil (kg)	42.60	8.89	4.79
Manufactured gas (kg)	57.00	22.27	2.56
Converted *(energy conversion losses accounted for as investment)*			
Electricity (kwh)	3.60	11.40	0.32

biofuels

EROI = 1.5÷2.5
Net Energy= 0.5 ÷ 1.5
Net-to-Gross ratio= 0.30 ÷ 0.60


(a) Global average temperature
(°C)
Temperature (°C)
0.5
0.0
−0.5
14.5
14.0
13.5
(b) Global average sea level
Difference from 1961–1990 (mm)
50
0
−50
−100
−150
(c) Northern Hemisphere snow cover
(million km²)
4
0
−4
40
36
32
1850
1900
1950
2000
©IPCC 2007: WG1-AR4
Year


Pollutants
SO_2
Sulfur
dioxide
NO_x
Nitrogen
oxides
Transport and
transformation
Oxidation and
complex reactions
H_2SO_4
HNO_3
Acid rain
Sulfuric acid
Nitric acid
Transport &
transformation of
acid precursors
Cloud processes
Materials
Acidic precipitation
Dry deposition
Soil buffering
Wet deposition
Runoff
Industry—Transportation
Terrestrial ecosystem
Aquatic ecosystem
Distance
Up to several hundred kilometers

Basic question → Energy storage

Energy storage in general

Mode	Primary Energy Type	Characteristic Energy Density kJ/kg	Application Sector
Pumped Hydropower	Potential	1 (100m head)	Electric
Compressed Air Energy Storage	Potential	15,000 in kJ/m^3	Electric
Flywheels	Kinchi	30-360	Transport
Thermal	Enthalpy (sensible + latent)	Water (100-40ºC) – 250 Rock (250-50ºC) – 180 Salt (latent) – 300	Buildings
Fossil Fuels	Reaction Enthalpy	Oil – 42,000 Coal – 32,000	Transport, Electric, Industrial, Buildings
Biomass	Reaction Enthalpy	Drywood – 15,000	Transport, Electric, Industrial, Building
Batteries	Electrochemical	Lead acid – 60-180 Nickel Metal hydride – 370 Li-ion – 400-600 Li-pdgmer ~ 1,400	Transport, Buildings
Superconducting Magnetic Energy Storage (SMES)	Electromagnetic	100 – 10,000	Electric
Supercapacitors	Electrostatic	18 – 36	Transport

→ Energy storage

Ragone Plot for comparing storage technologies