

MENA1000-Materialer, energi og nanoteknologi- **Kap. 10**

Energi; kilder, konvertering, lagring

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Energikilder - reserver og bruk

Solenergi

Direkte og indirekte

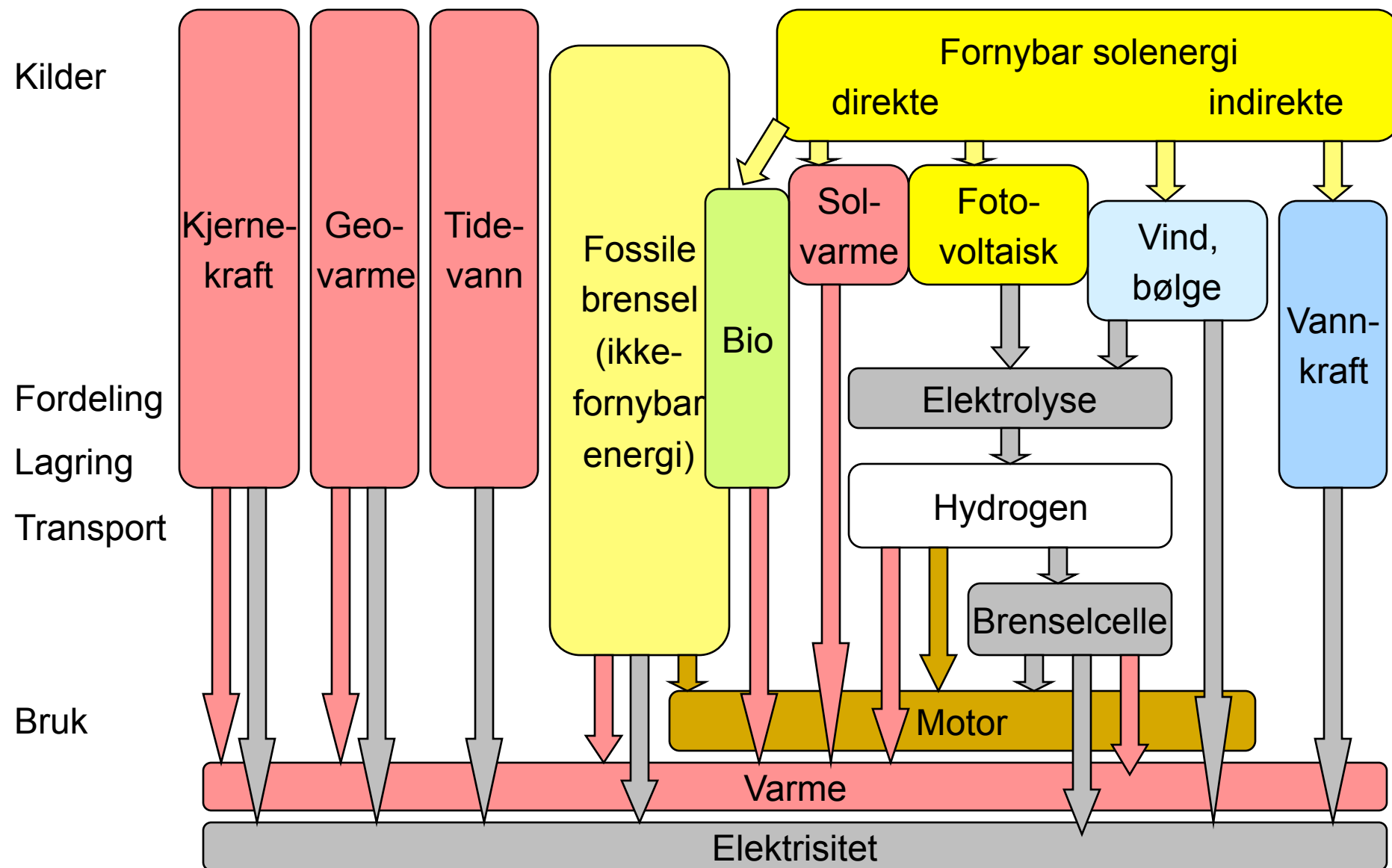
Fossile energikilder

Andre energikilder

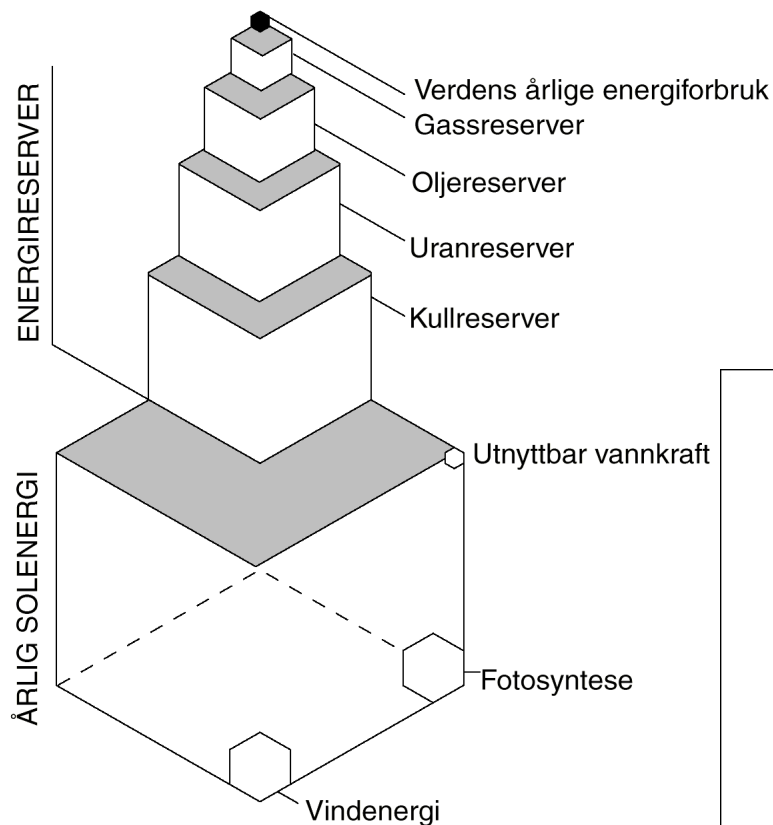
Konvertering

Lagring

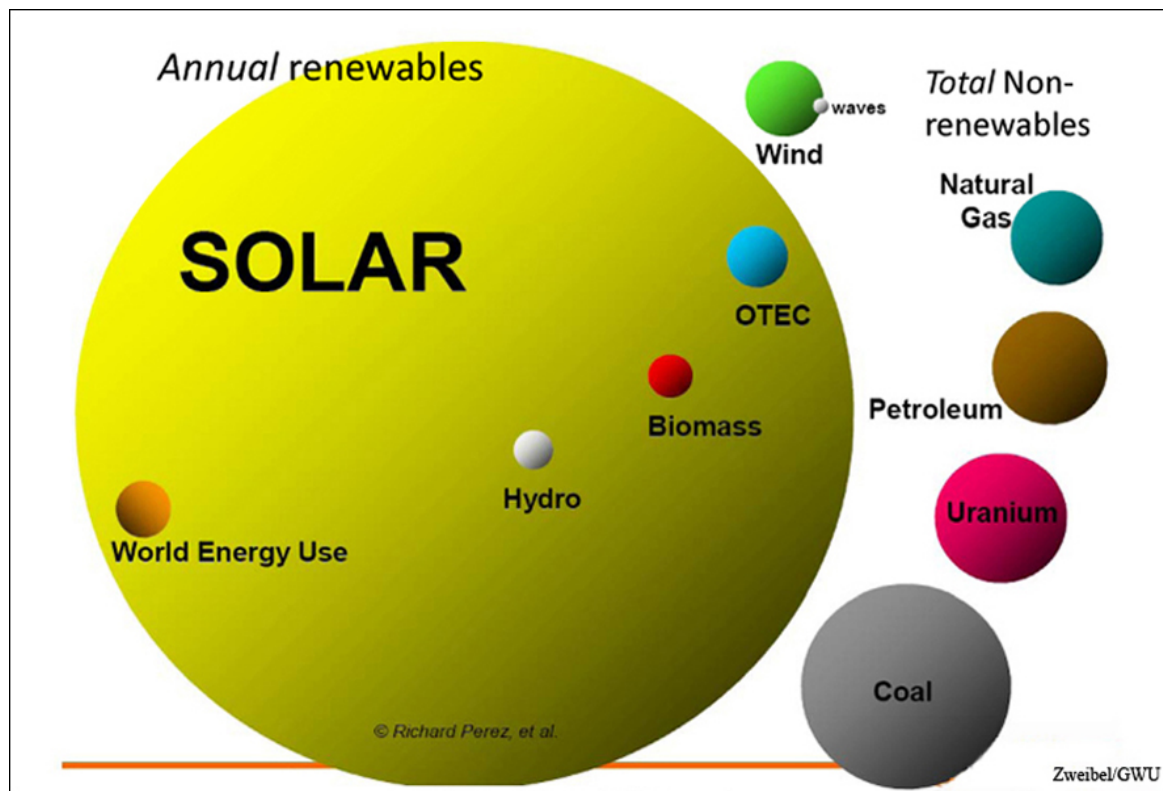
Energi; Kilder og bruk (med hydrogenlagring)



Solenergi og andre energikilder; reserver og forbruk



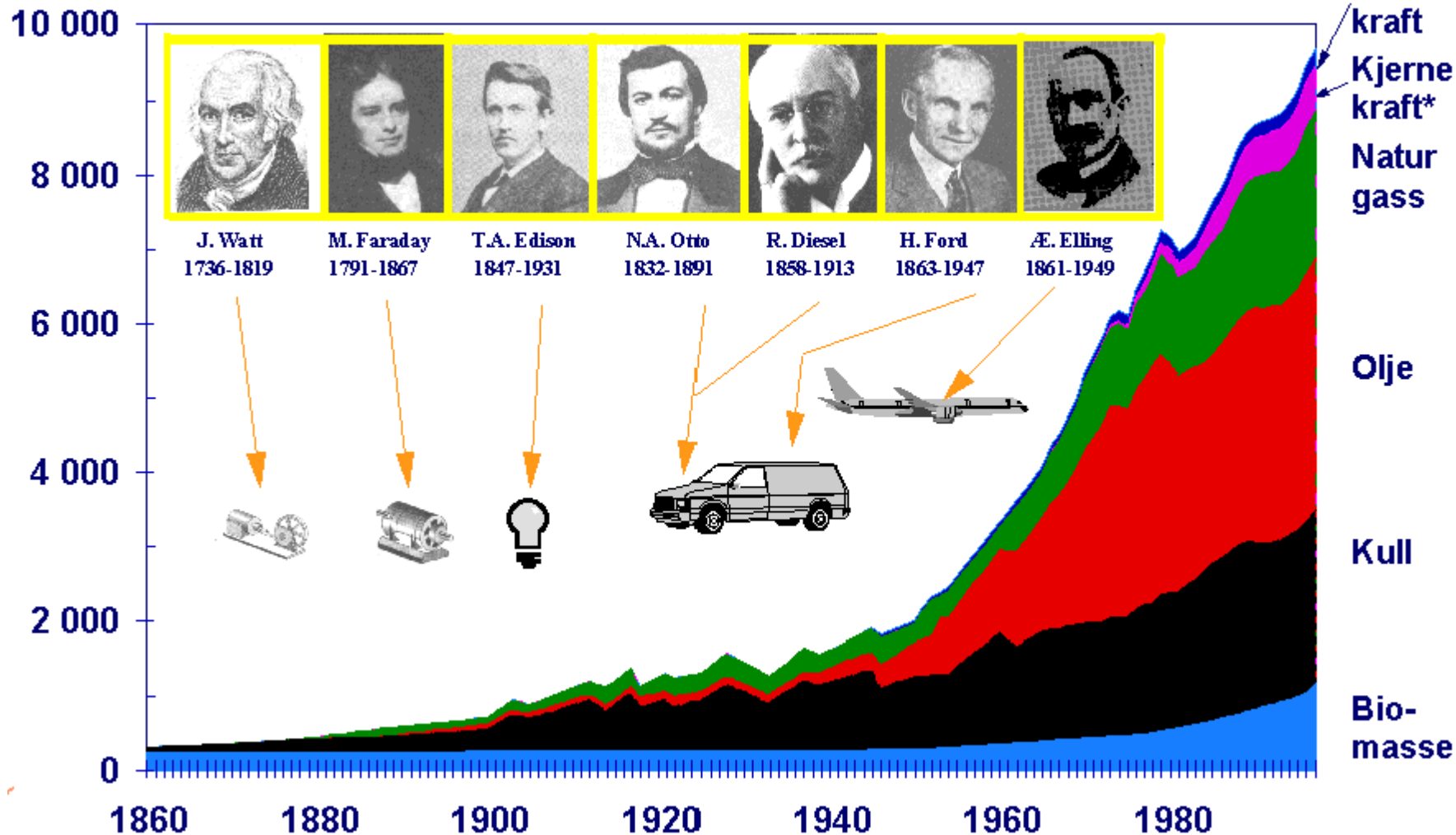
Figur: Bellona



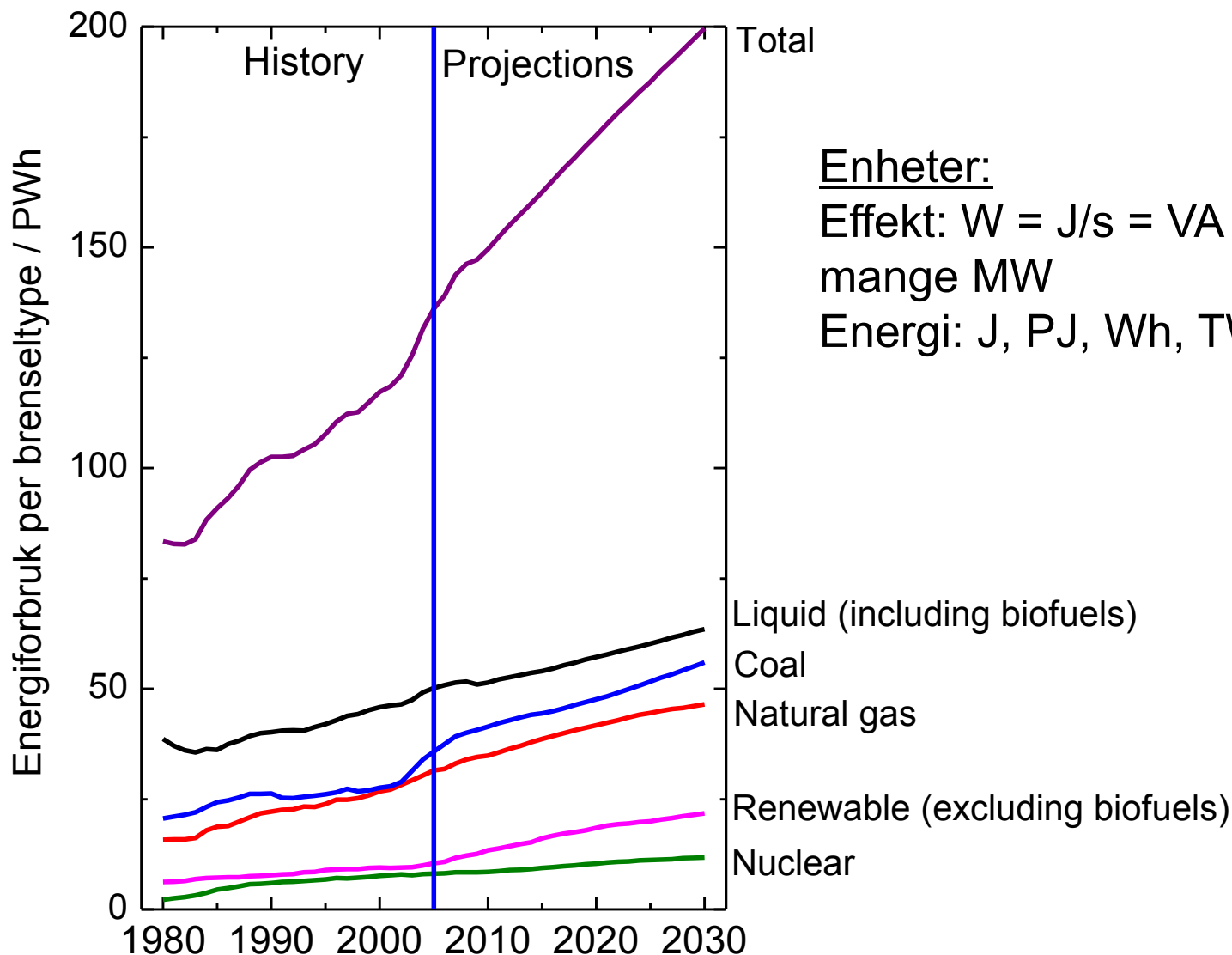
Verdens energikilder i et historisk perspektiv

2004: 11 059 MTOE = 128,3 PWh

mill. tonn oljeequivalenter pr. år



Verdens energiforbruk fordelt på brenseltyper



Enheter:

Effekt: $W = J/s = VA = VC/s$; typisk mange MW

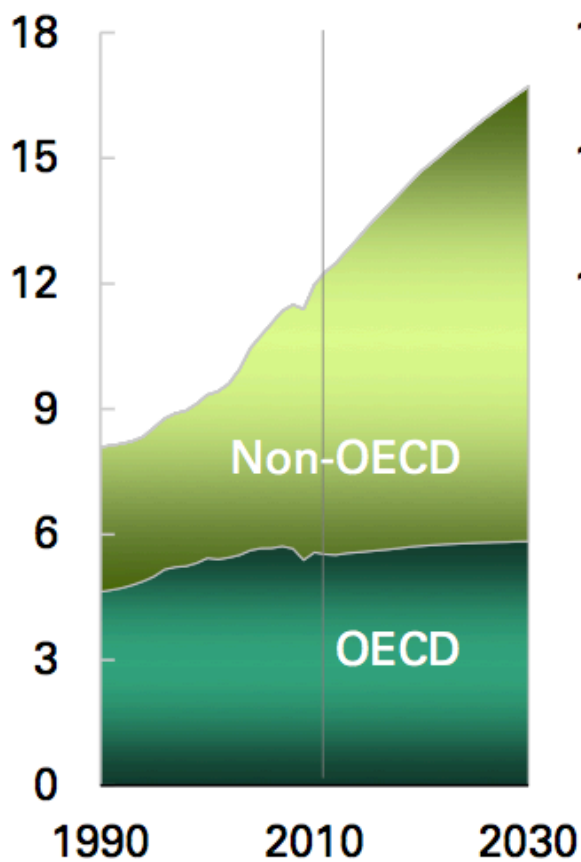
Energi: J, PJ, Wh, TWh, TOE

Kilde: Energy Information Administration, IEO 2007

Energibruk

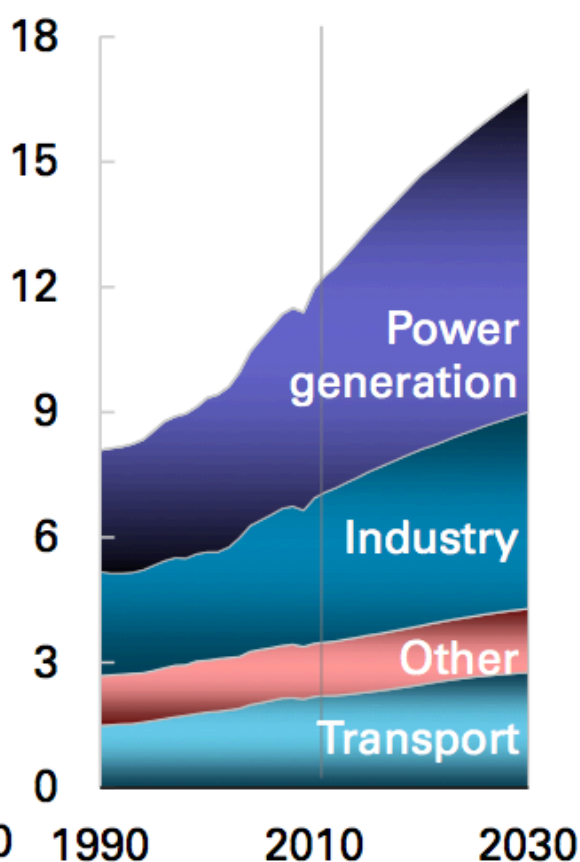
By region

Billion toe



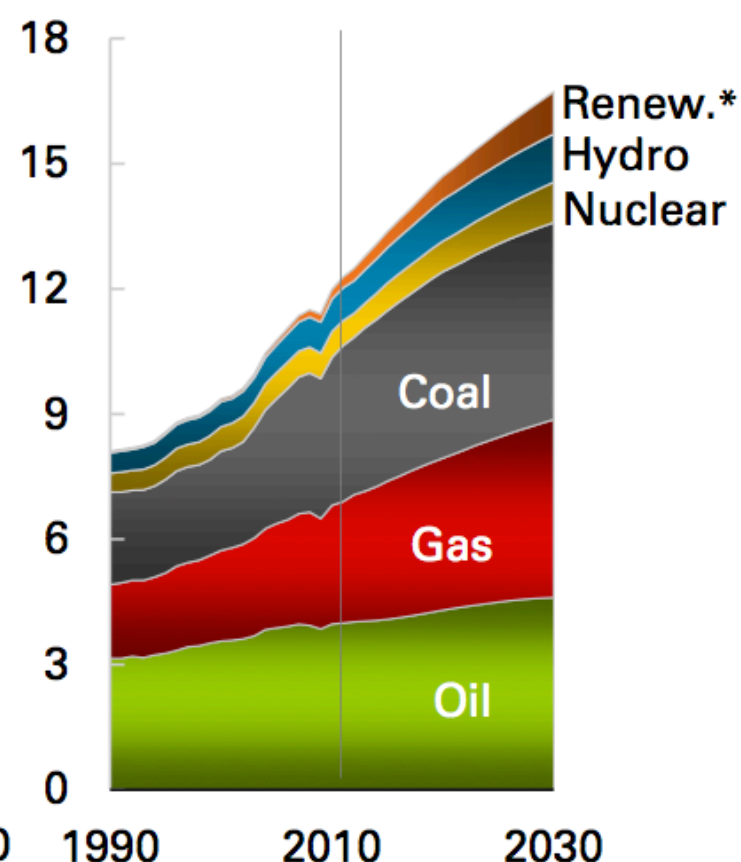
By primary use

Billion toe



By fuel

Billion toe



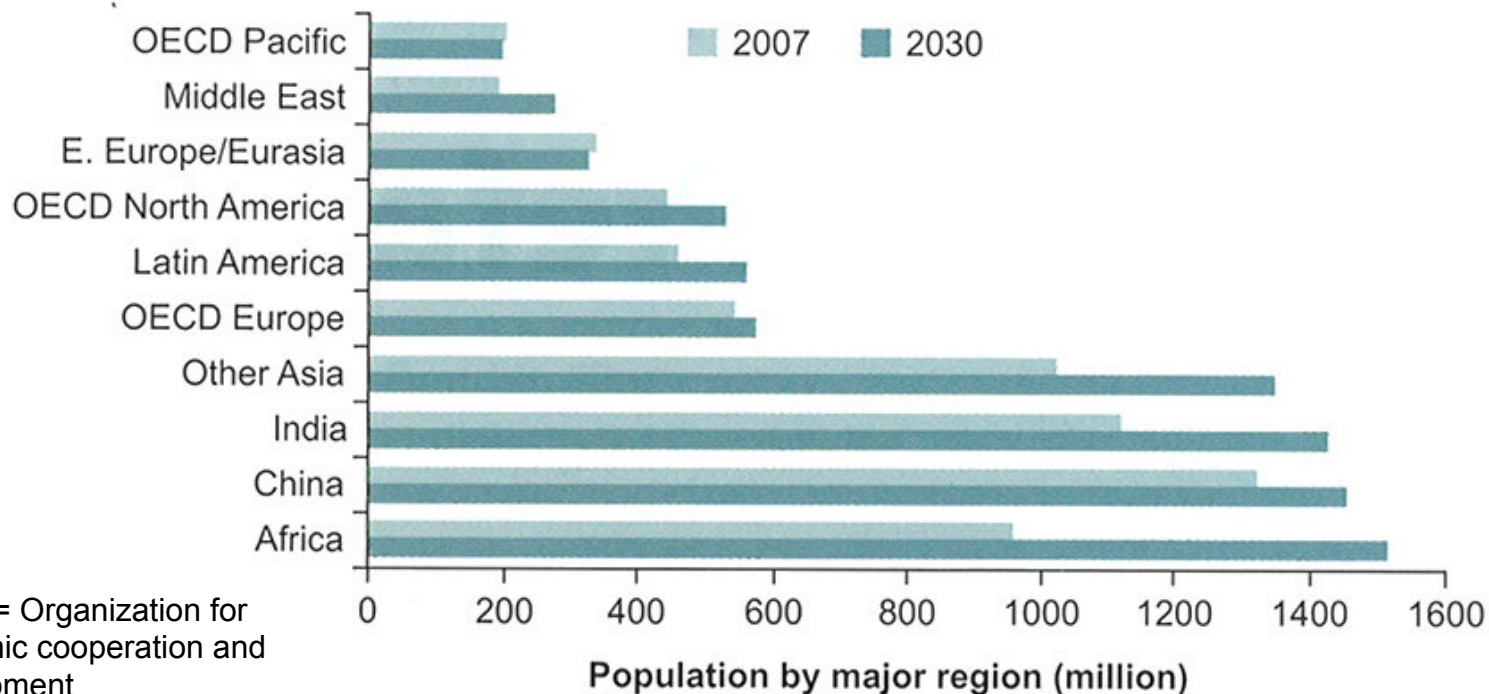
*Includes biofuels



Innovative and **creative solutions** are necessary to meet growing global energy demand and environmental concerns

Diversifying the energy sources through renewable energy is a key answer towards sustainable development

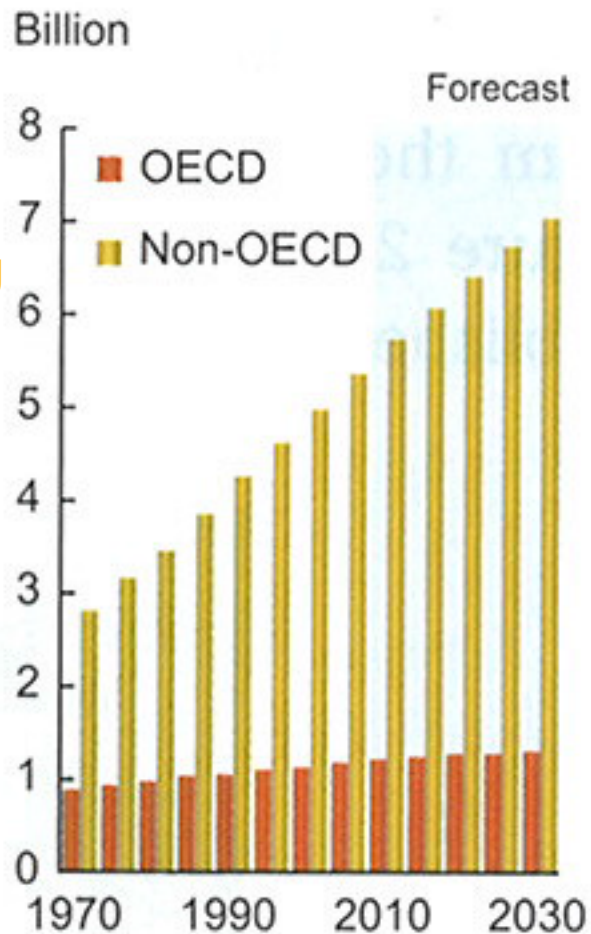
Population by major region (IEA report)



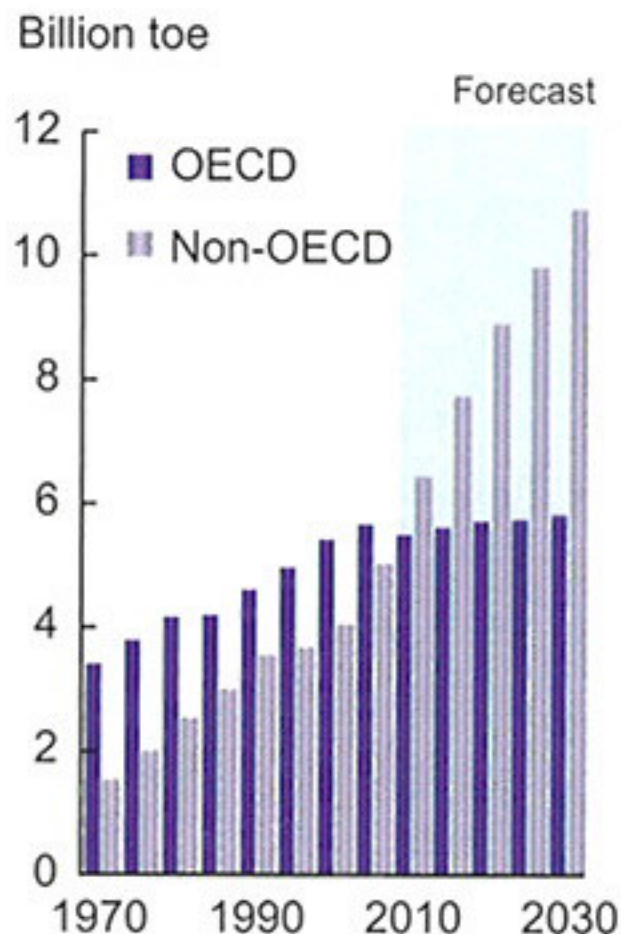
OECD = Organization for economic cooperation and development

Plots of population and energy use *versus* time current and projected

Population



Primary energy

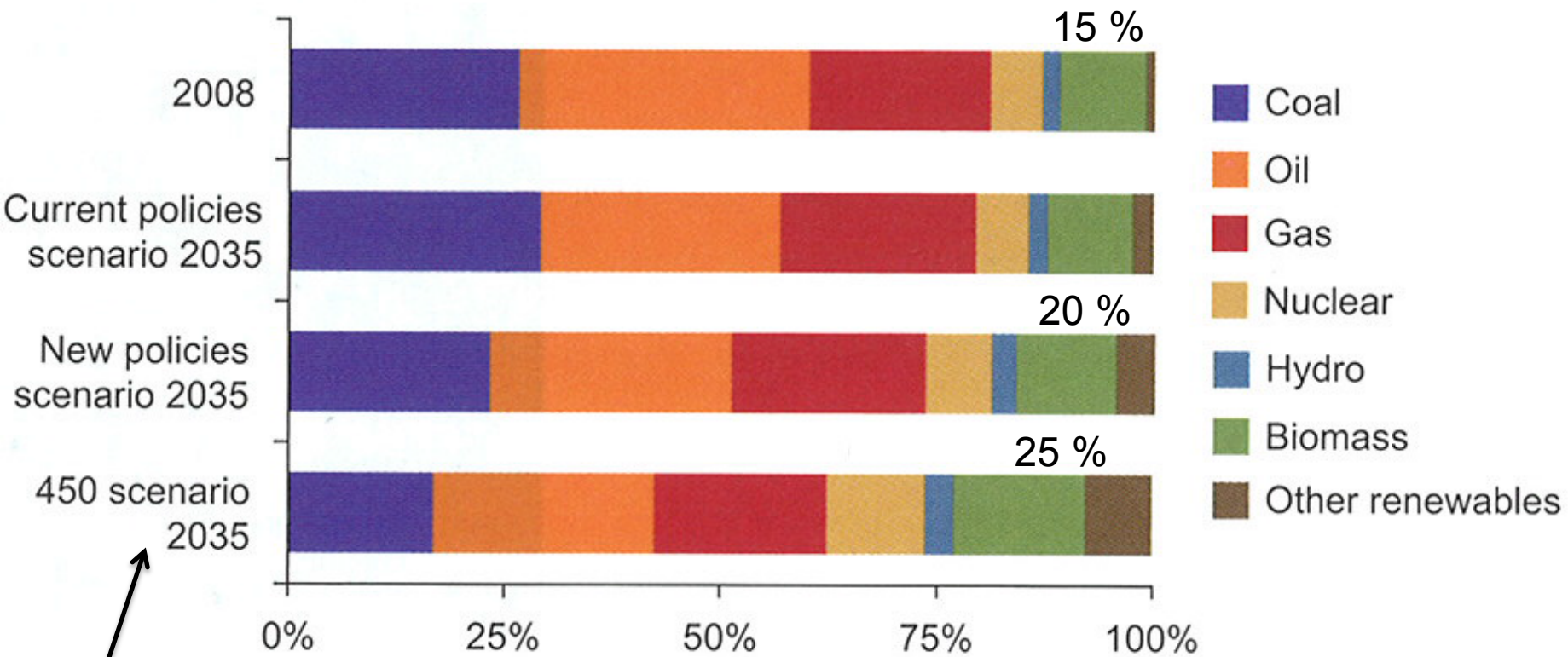


Developed

New developing

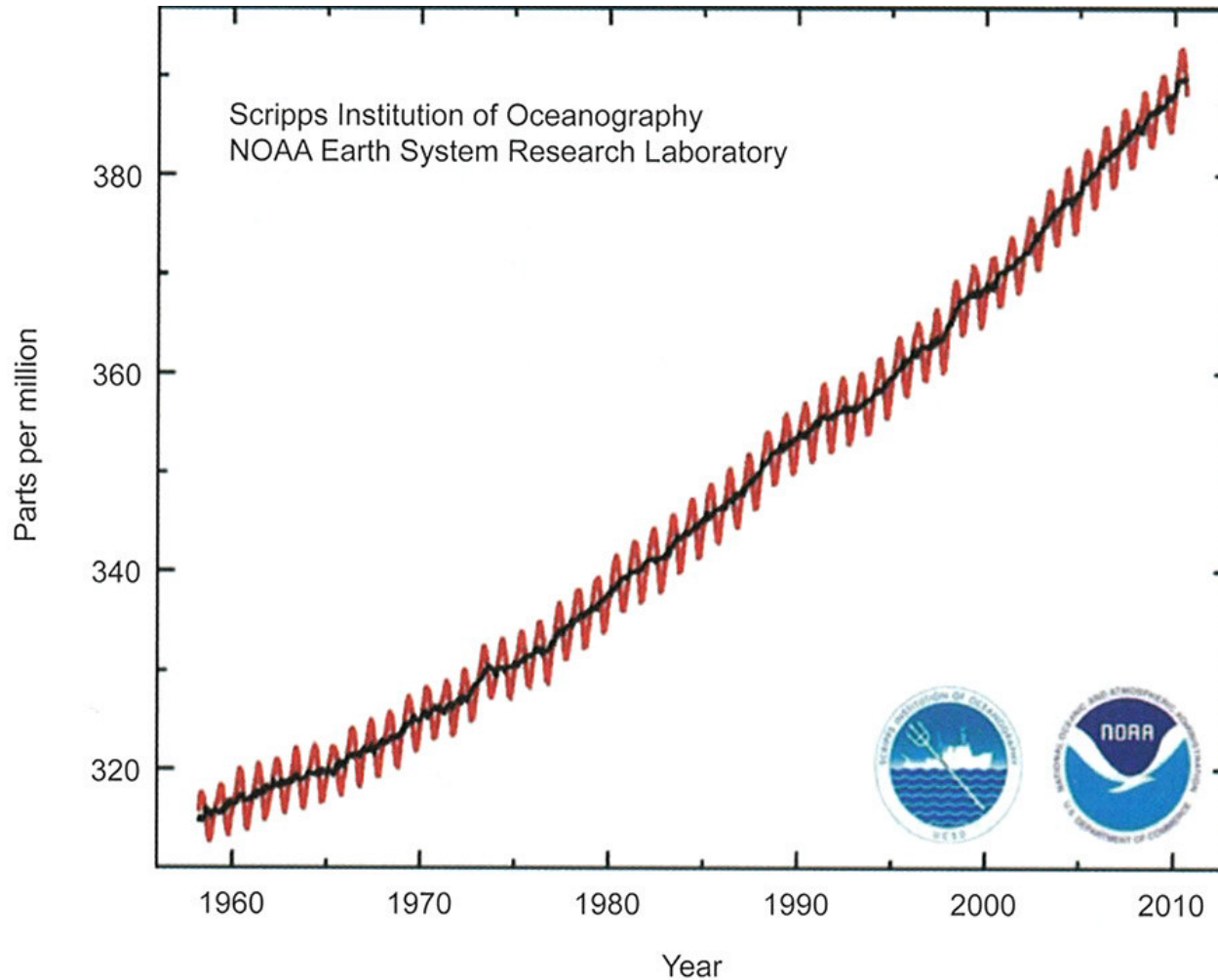
toe = tonne of oil equivalent = 11.788 kWh

Shares of energy sources in world primary demand by scenario



Policy necessary to limit CO₂ to 450 ppm

Atmospheric concentration of CO₂ at the Mauna Loa Observatory from 1958 to 2010



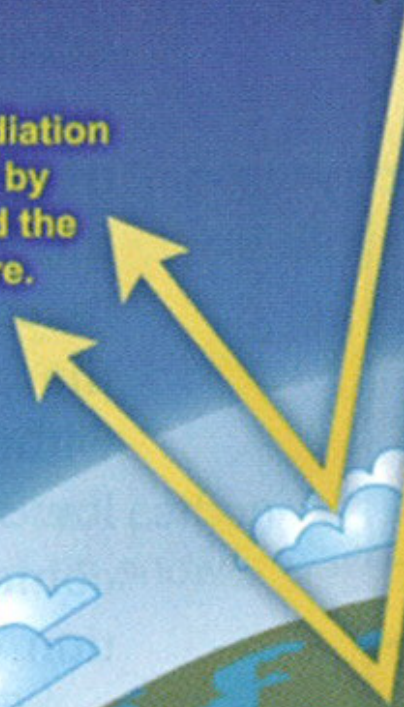
The Greenhouse Effect

Some of the infrared radiation passes through the atmosphere but most is absorbed and re-emitted in all directions by greenhouse gas molecules and clouds. The effect of this is to warm the Earth's surface and the lower atmosphere.

Solar radiation powers the climate system.



Some solar radiation is reflected by the Earth and the atmosphere.



ATMOSPHERE

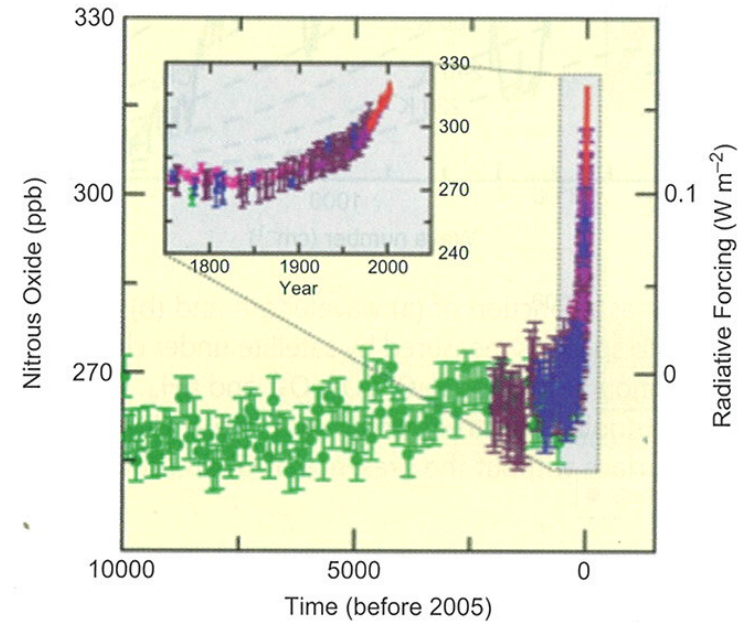
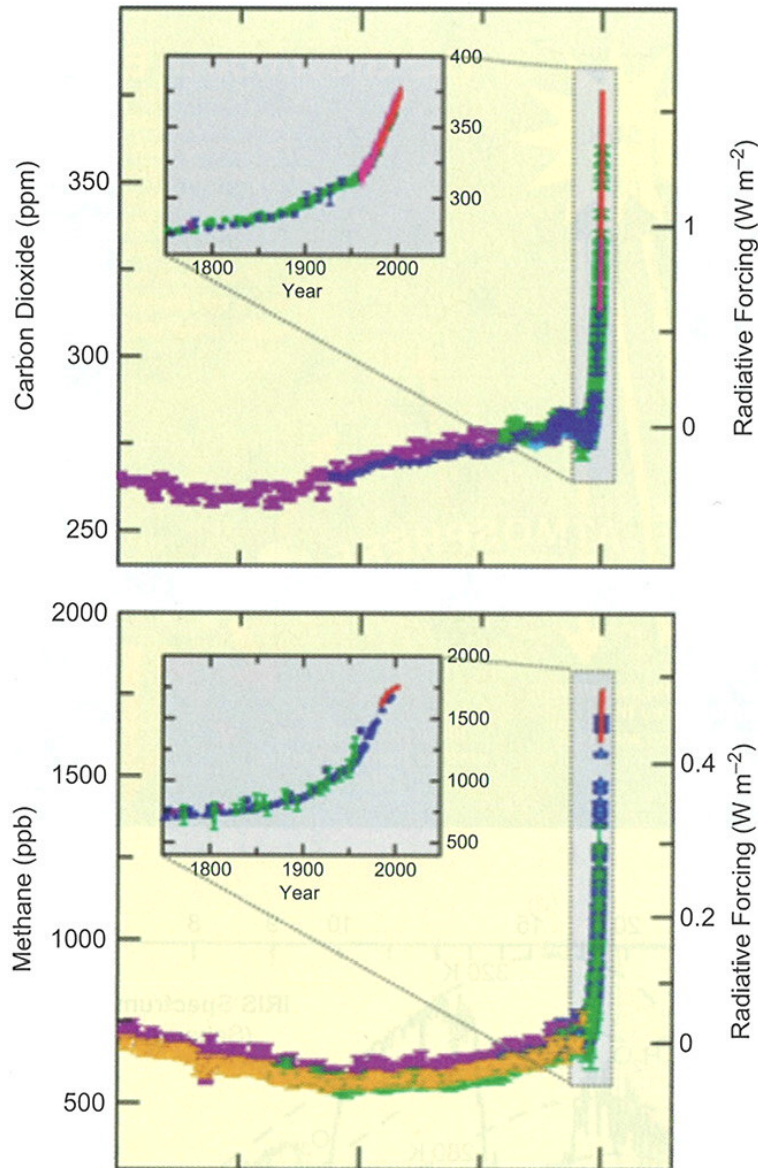
EARTH

About half the solar radiation is absorbed by the Earth's surface and warms it.

Infrared radiation is emitted from the Earth's surface.



Atmospheric concentrations of carbon dioxide, methane, and nitrous oxide (N₂O) over the last 10,000 years (large panels) and since 1750 (inset panels)



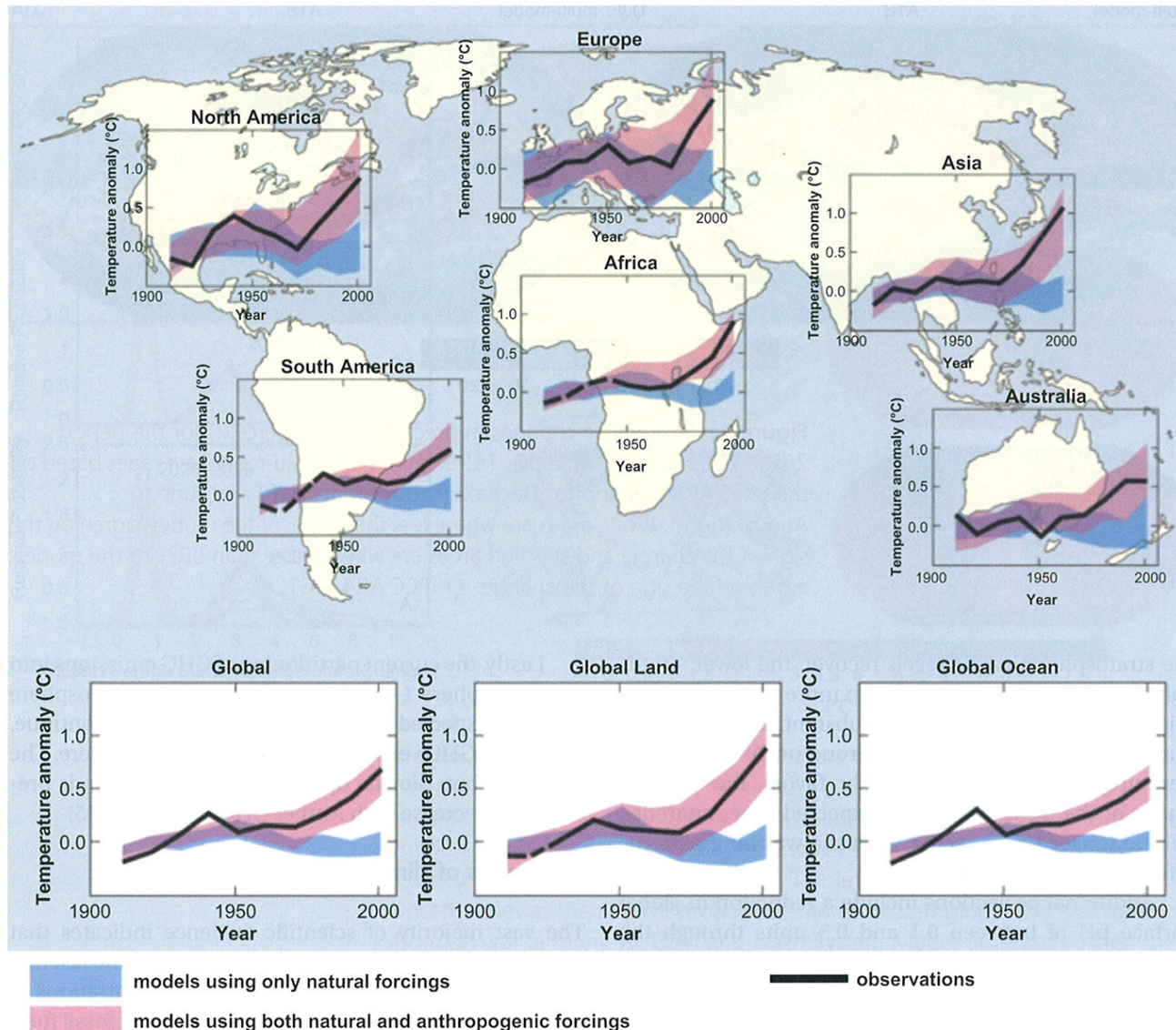
Measurements from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines)



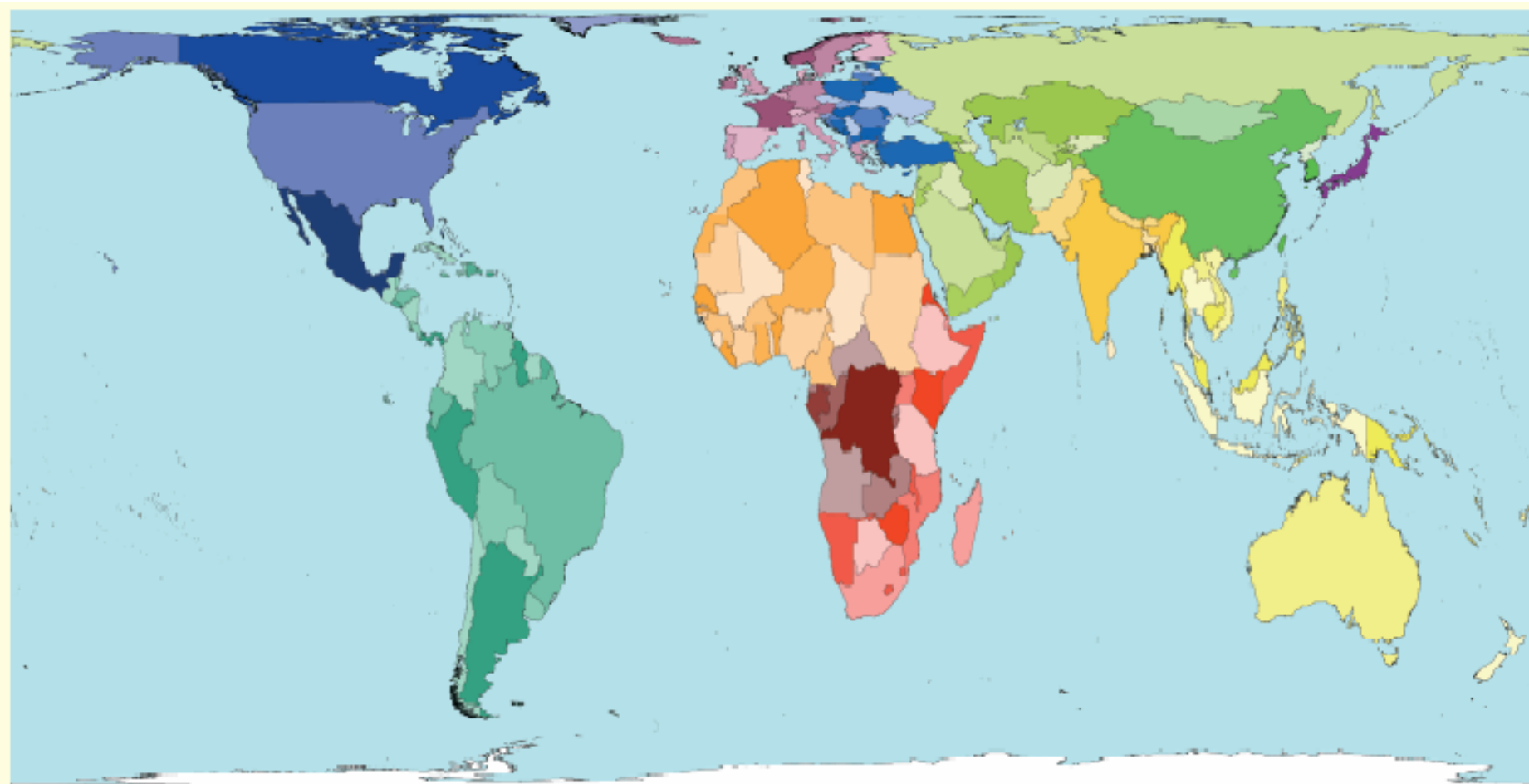
Youtube video: NASA's Analysis of 2012 Global Temperature

<https://www.youtube.com/watch?v=NnjTnUm9t-0>

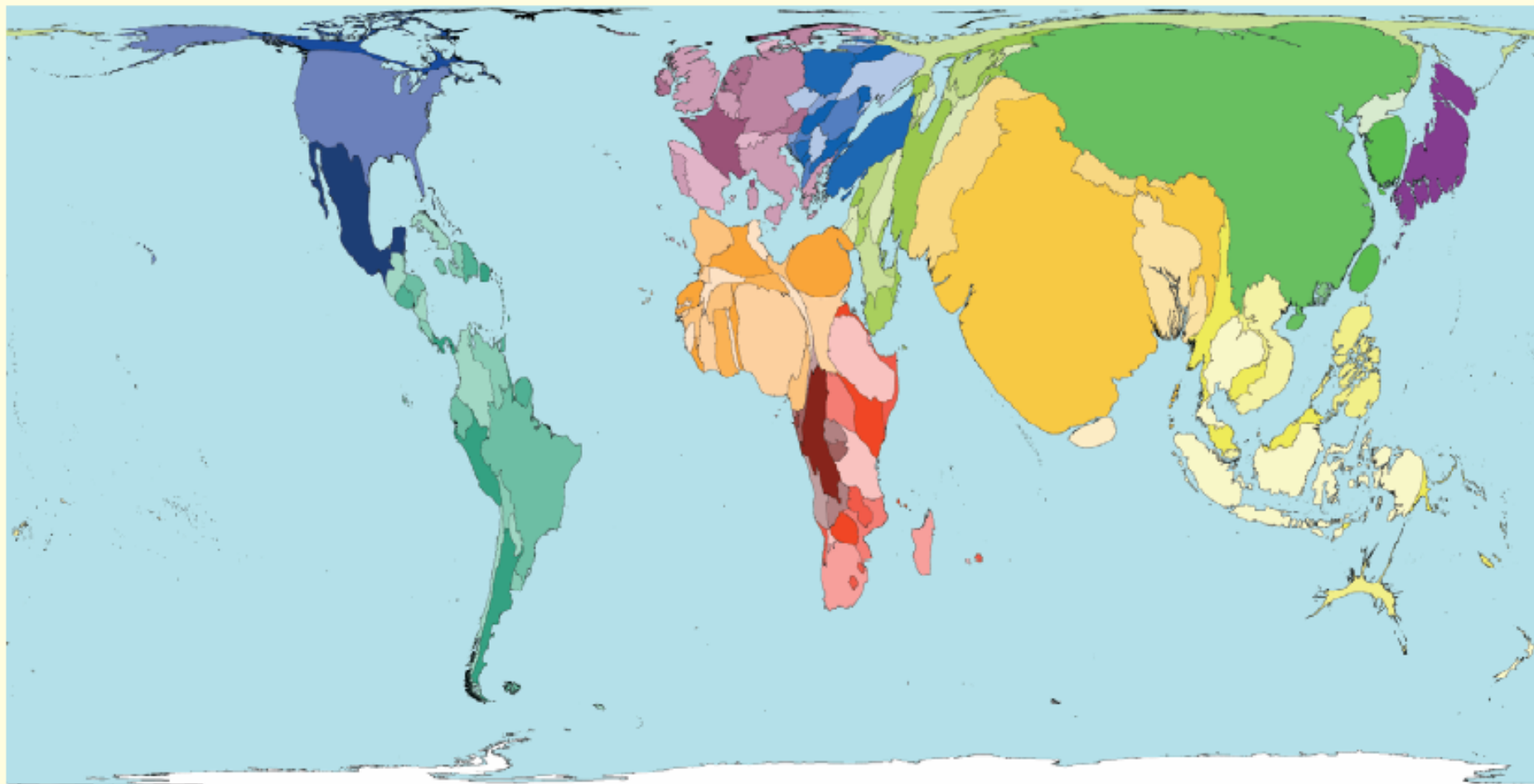
Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using natural and anthropogenic forcings



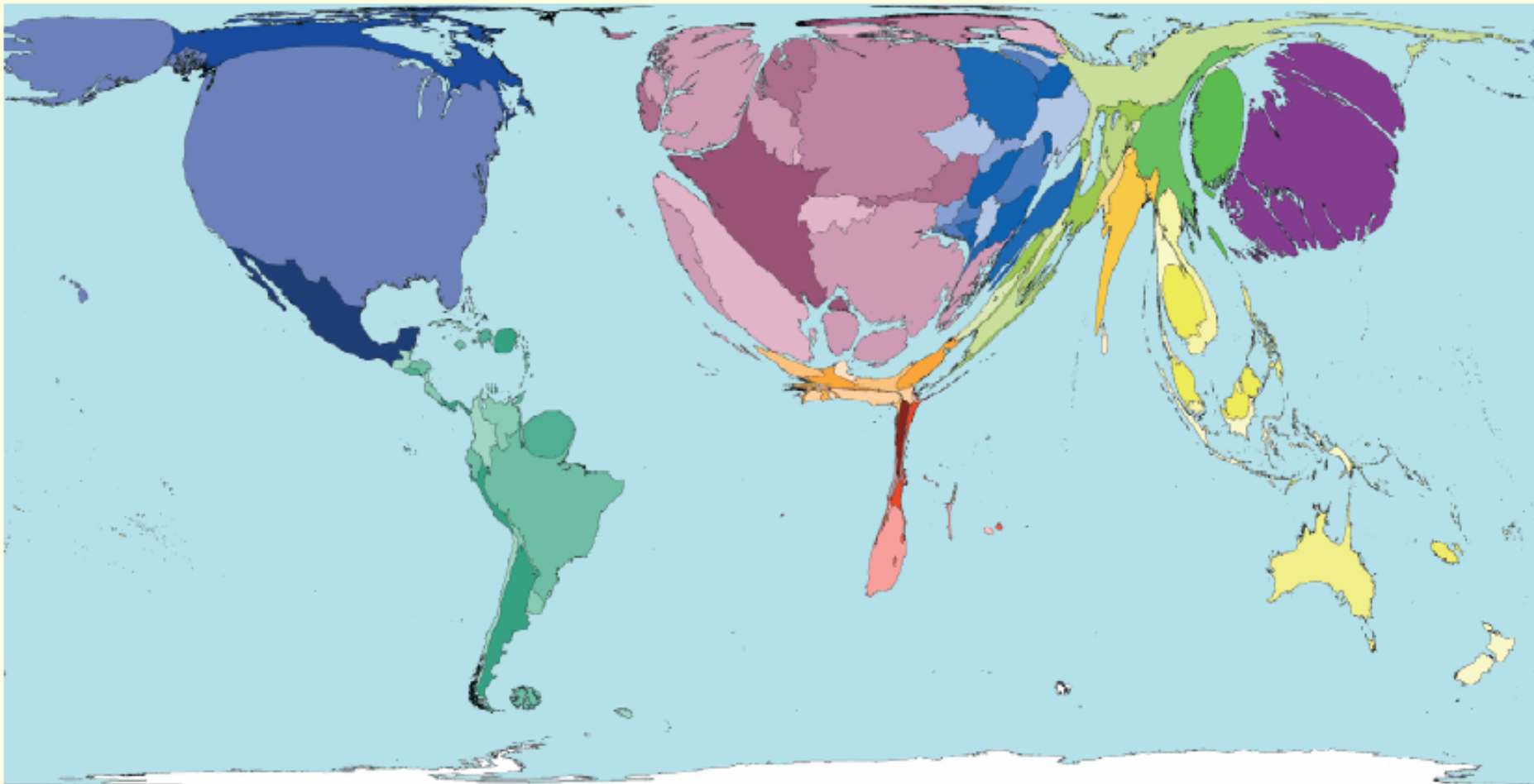
Verdens landområder



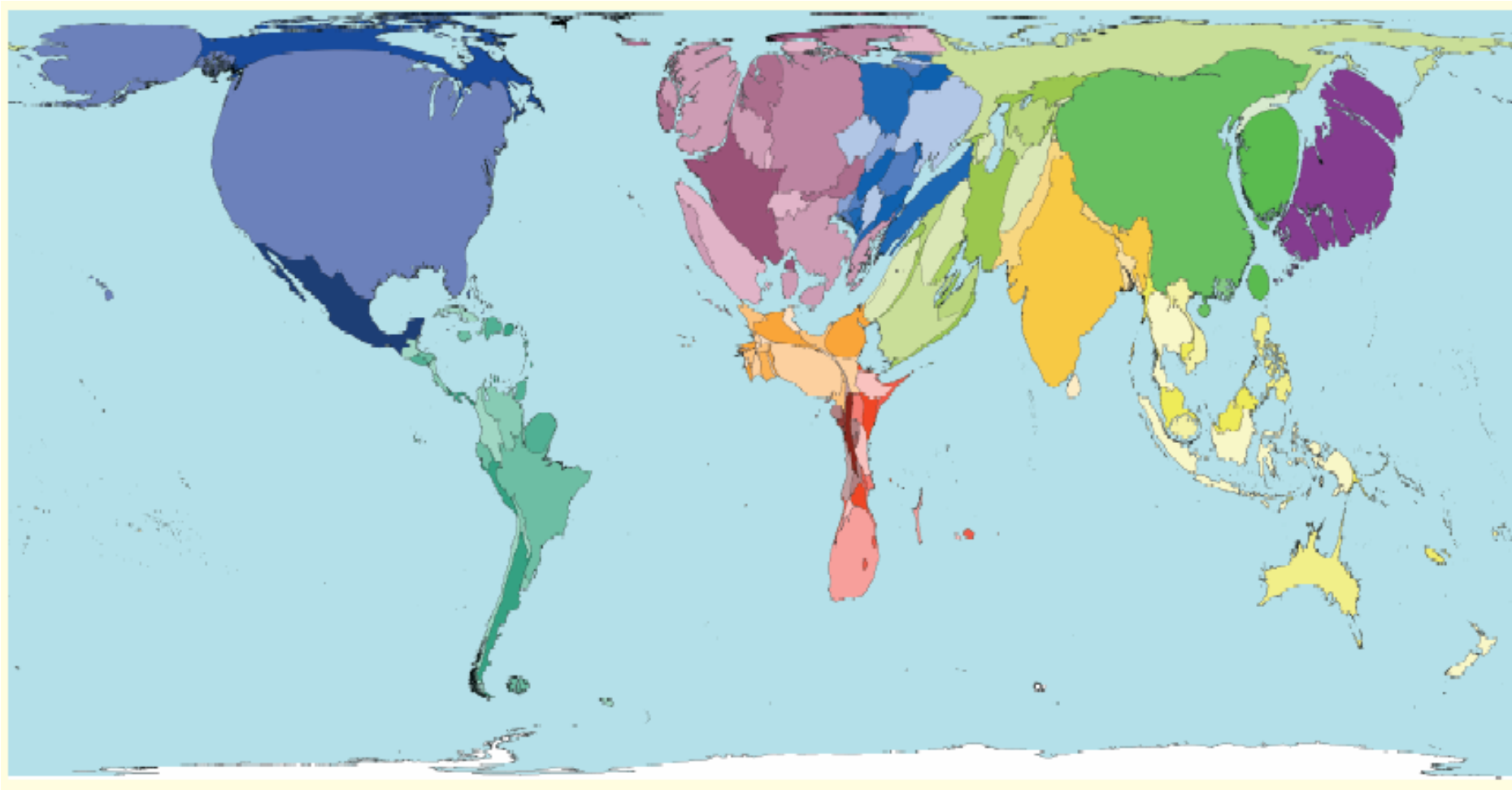
Verdens befolkning (2002)



Verdens personbiler (2002)

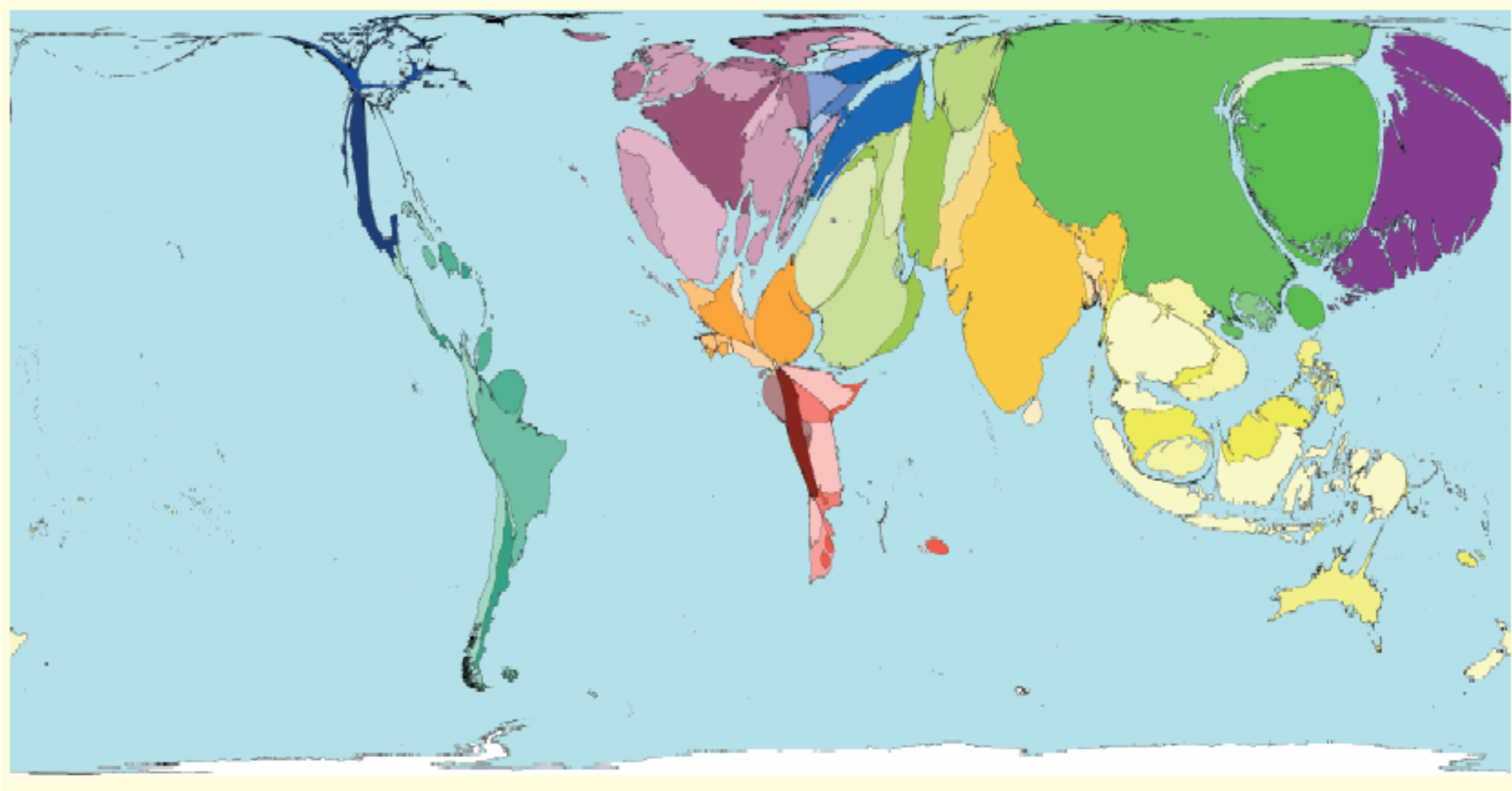


Verdens forbruk av brensel (2001)

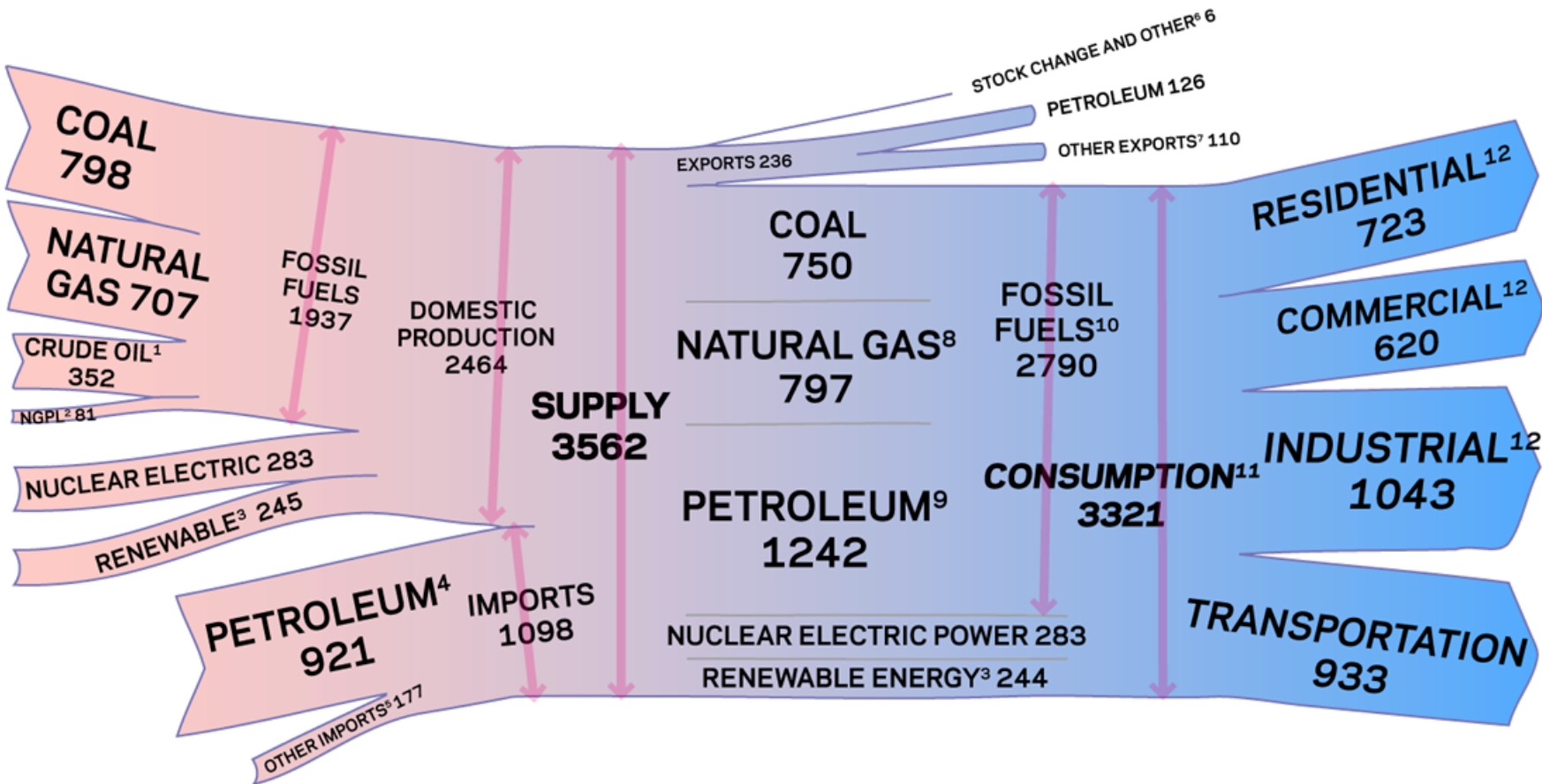


Brensel: gass, kull, olje, bio og kjernekraft

Verdens økte forbruk av brensel (1980 – 2001)



Energiflytdiagram USA 2008



¹ Includes lease condensate.

² Natural gas plant liquids.

³ Conventional hydroelectric power, biomass, geothermal, solar/photovoltaic, and wind.

⁴ Crude oil and petroleum products. Includes imports into the Strategic Petroleum Reserve.

⁵ Natural gas, coal, coal coke, fuel ethanol, and electricity.

⁶ Adjustments, losses, and unaccounted for.

⁷ Coal, natural gas, coal coke, and electricity.

⁸ Natural gas only; excludes supplemental gaseous fuels.

⁹ Petroleum products, including natural gas plant liquids, and crude oil burned as fuel.

¹⁰ Includes 0.04 quadrillion Btu of coal coke net imports.

¹¹ Includes 0.11 quadrillion Btu of electricity net imports.

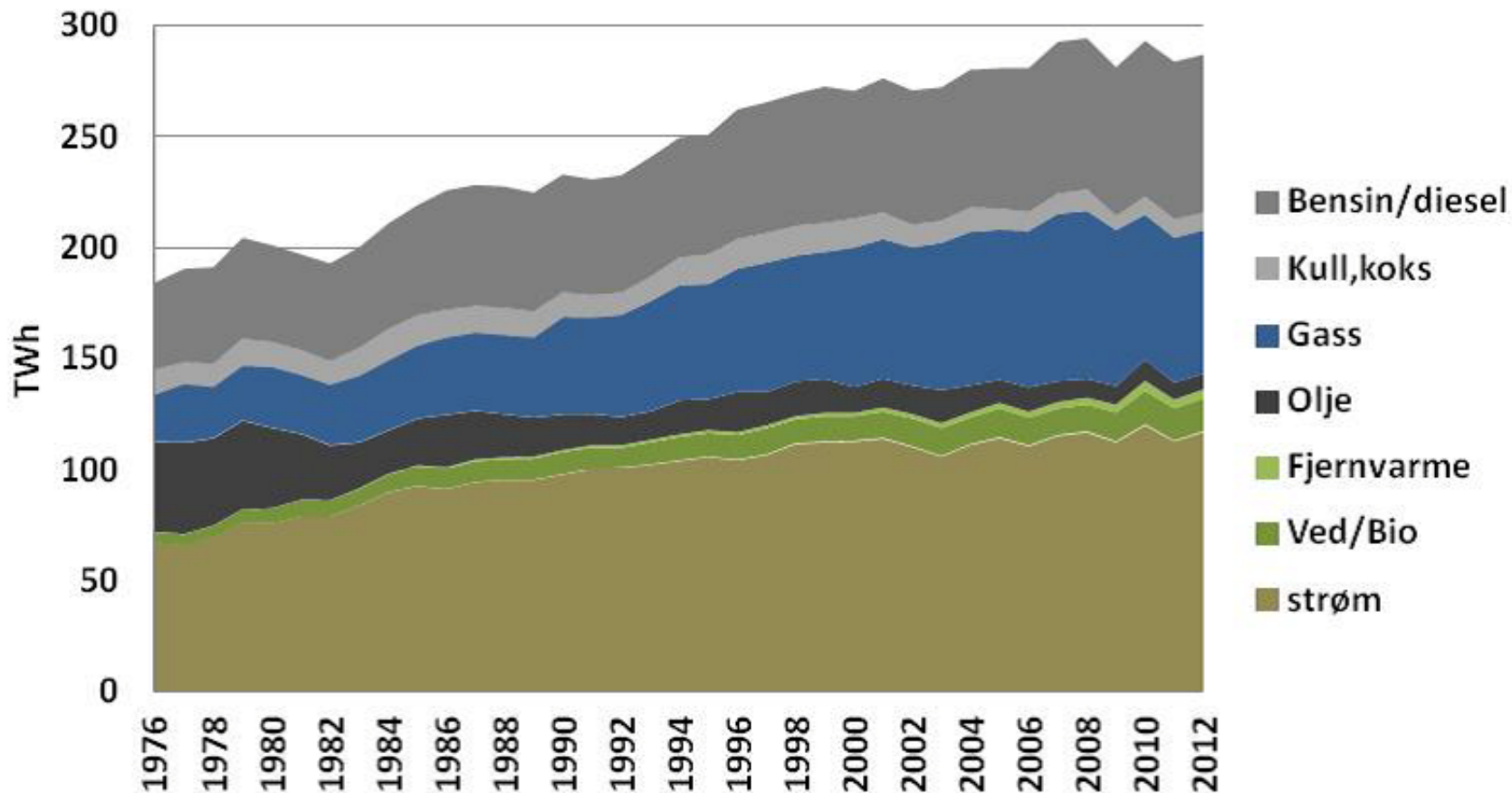
¹² Primary consumption, electricity retail sales, and electrical system energy losses, which are allocated to the end-use sectors in proportion to each sector's share of total electricity retail sales. See Note, "Electrical Systems Energy Losses," at end of Section 2.

Notes: • Data are preliminary. • Values are derived from source data prior to rounding for publication. • Totals may not equal sum of components due to independent rounding.

Sources: Tables 1.1, 1.2, 1.3, 1.4, and 2.1a.

Energiforbruk i Norge

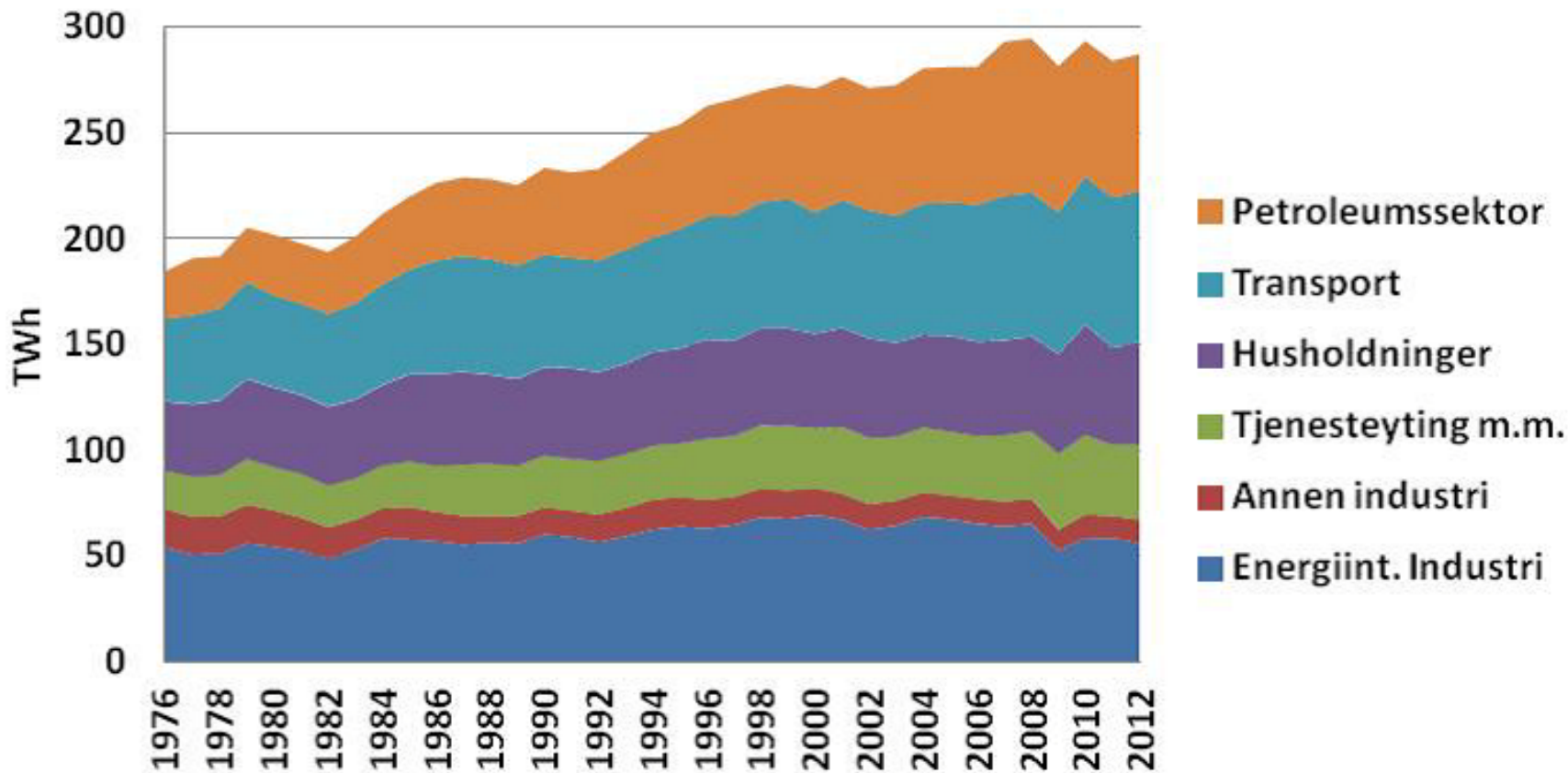
Energibruk i Norge etter energivare [TWh per år]



Figur: www.ssb.no

Energiforbruk i Norge

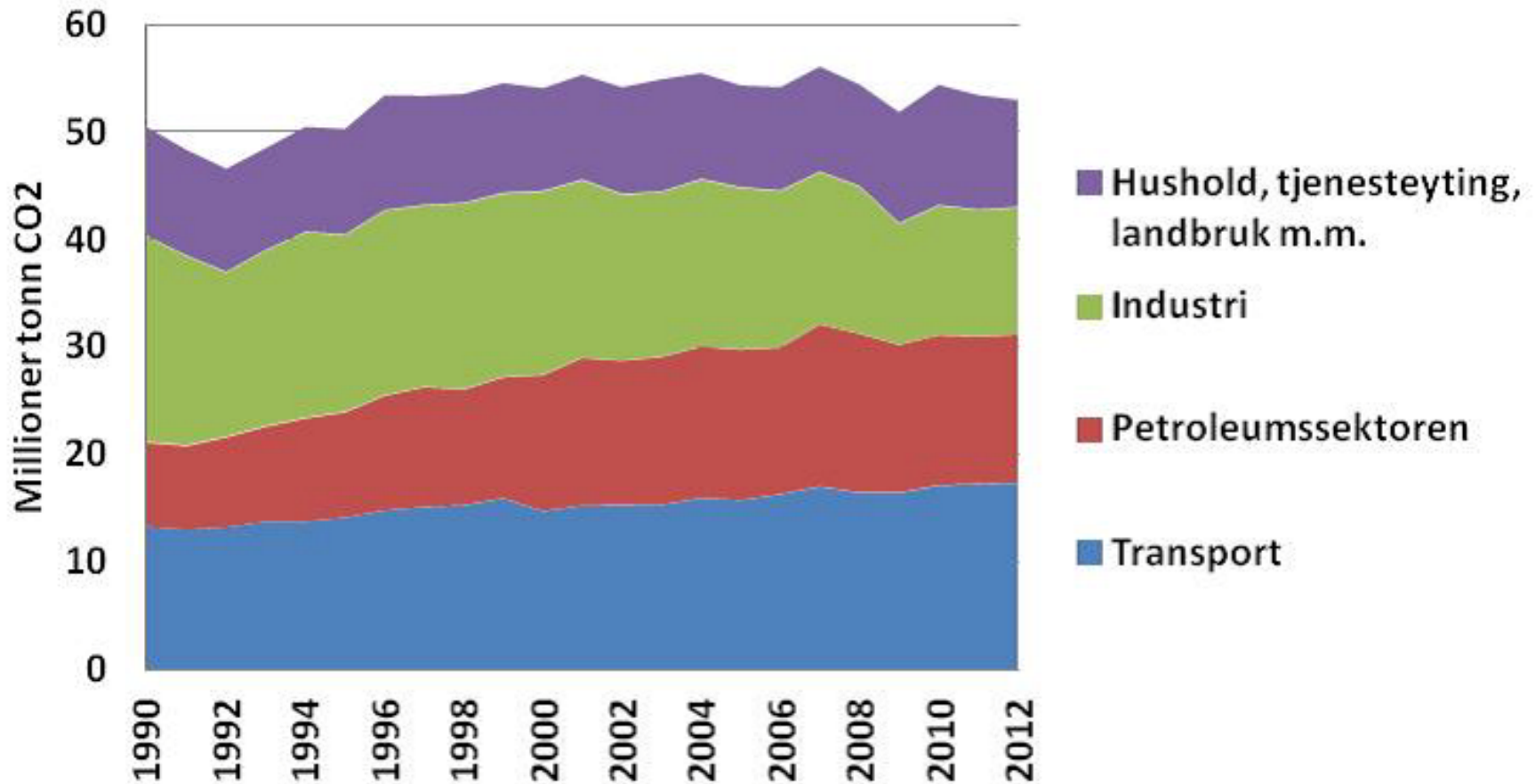
Energibruk i Norge etter sektor [TWh per år]



Figur: www.ssb.no

Energiforbruk i Norge

Klimagassutslipp etter sektor [millioner tonn CO₂]



Figur: www.ssb.no

Solen

- Solen

- Hydrogenbrenning

Totalreaksjon: 4 protoner blir til en heliumkjerne + tre typer stråling:



Solen gir fra seg energi som stråling og mister litt masse i hht. Einstein:

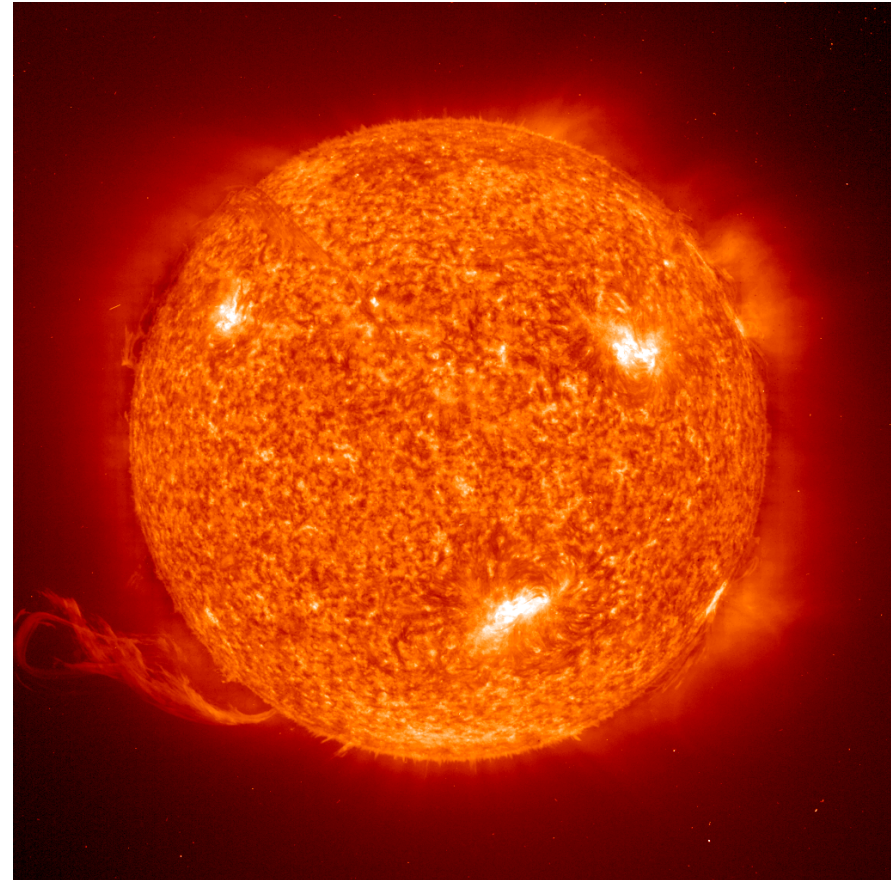
$$E = mc^2$$

Total effekt: $3,86 \cdot 10^{26}$ W

Temperaturen i kjernen: $T = 15\,600\,000$ K

Temperaturen på overflaten: $T = 5800$ K

$$\lambda_{\text{max}} = 0,1 - 1 \mu\text{m}$$



Stråling til Jorden

(Repetisjon fra Kap. 2)

$1,496 \cdot 10^{11}$ m (150 millioner km) fra Solen til Jorden

Effekten per m^2 (solarkonstanten S) avtar med kvadratet av avstanden.

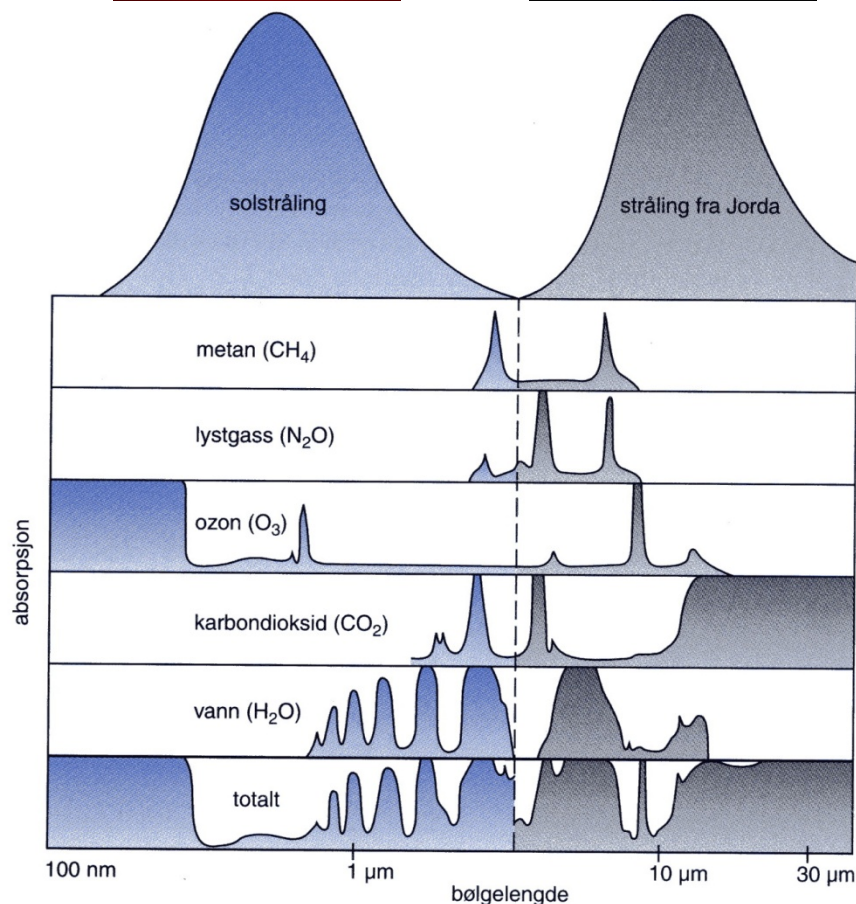
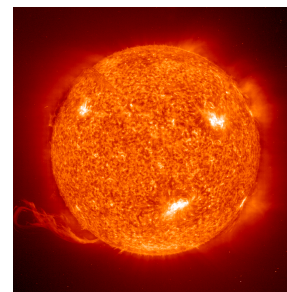
S (på jordens solside) = 1370 W/m^2

30% reflekteres direkte (albedoen), 70% absorberes (på solsiden)

Stråling fra Jorden skjer fra hele overflaten på alle sider. Derfor kan Jorden avgi all stråling den mottar, selv om temperaturen er lav. I følge Stefan-Boltzmann (kap. 2) burde temperaturen på jordoverflaten være omtrent $-20 \text{ }^\circ\text{C}$;

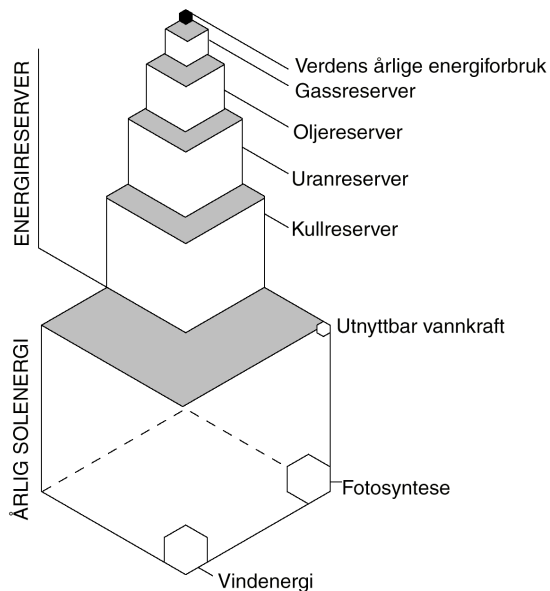
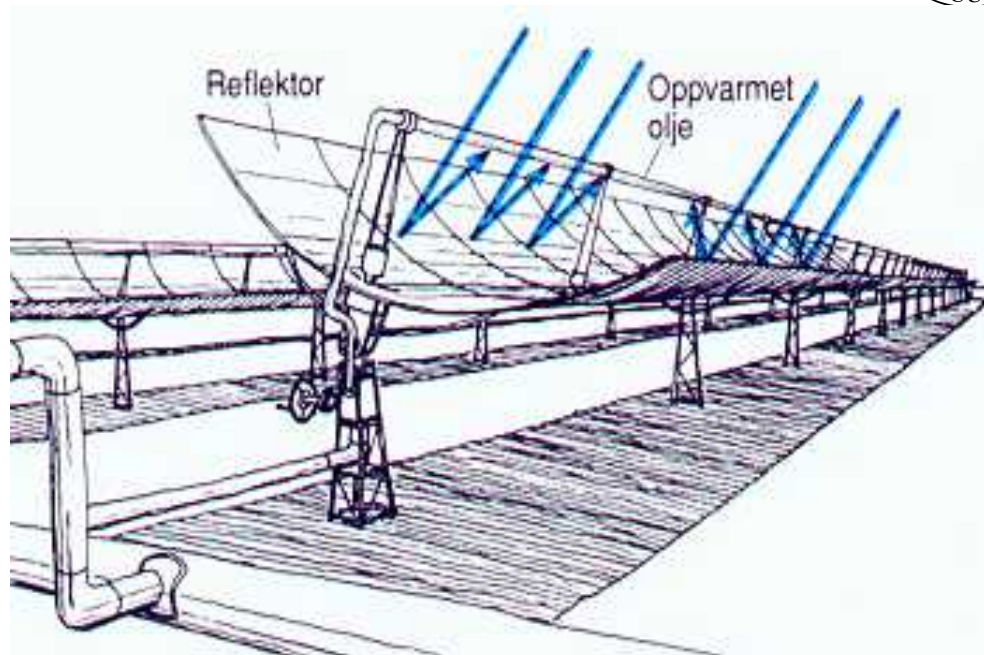
λ_{max} = ca $15 \text{ } \mu\text{m}$ (infrarødt)

Imidlertid sørger CO_2 og H_2O for mer absorpsjon i dette området enn for sollyset (synlig og ultrafiolett område; O_3 og H_2O), slik at temperaturen på overflaten er høyere for å oppnå energibalanse.



Direkte solenergi - termisk

- Absorpsjon av sort legeme
 - Fra lys til varme eller elektrisitet
 - Termisk solkraftverk
 - pasive og aktive
 - Lagring av varme mulig

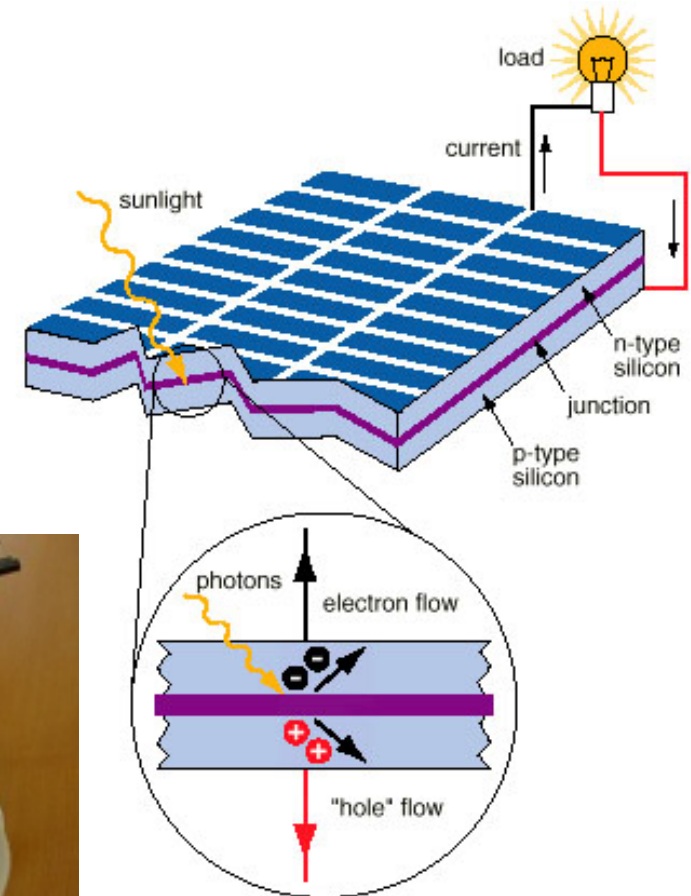


Figurer: Bellona, Høgskolen i Volda, BrightSource Energy

Fra elektromagnetisk stråling (lys) til elektrisitet

Fotovoltaiske celler - solceller

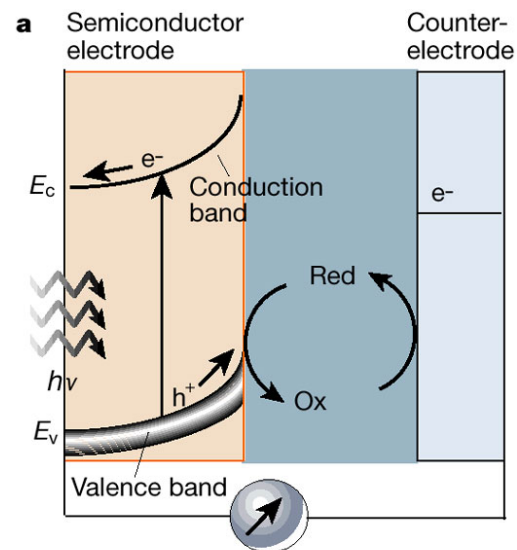
- Krystallinsk silisium (wafers)
 - 10-20% effektivitet
- Amorft silisium
 - 5-10% effektivitet
 - Mindre materialforbruk
 - Kan innbakes i polymerer; fleksible celler
- GaAs
 - Mer egnet båndgap
 - Dyrere teknologi
- Tandemceller
- Kombinasjon med solvarmefangere



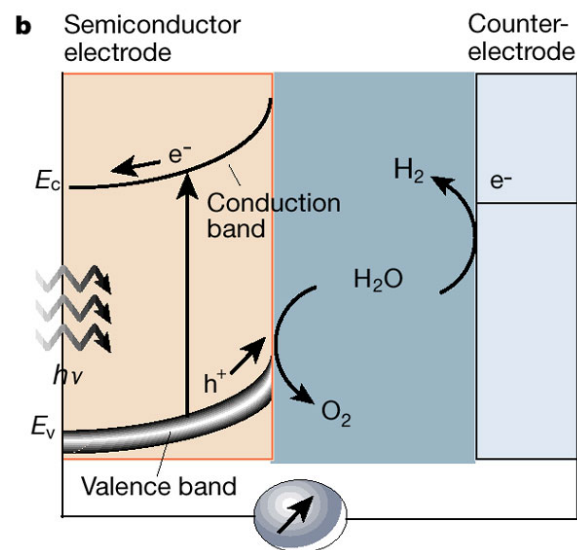
Fra lys til elektrokjemiske prosesser

Fotoelektrokjemiske celler

- Fotogalvanisk
 - Spenning ved lys på elektrode



- Fotoelektrolytisk
 - Spalter vann direkte



Fra lys til elektrokjemiske prosesser

Fotoelektrokjemiske celler – forts.



- Fotobiologisk
 - fotosyntese
 - H_2 fra bakterier, alger



- Grätzel-celler

"dye-sensitized"

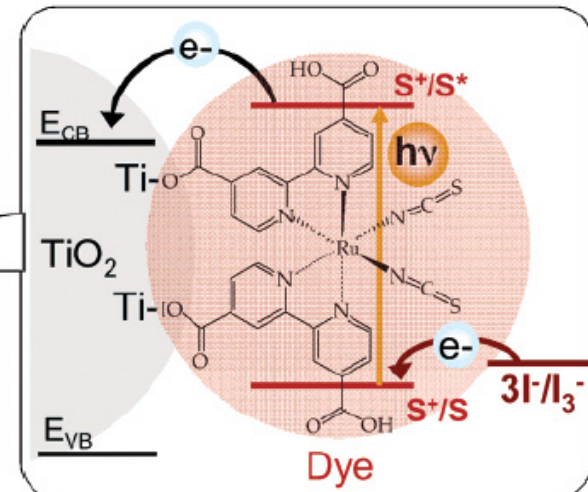
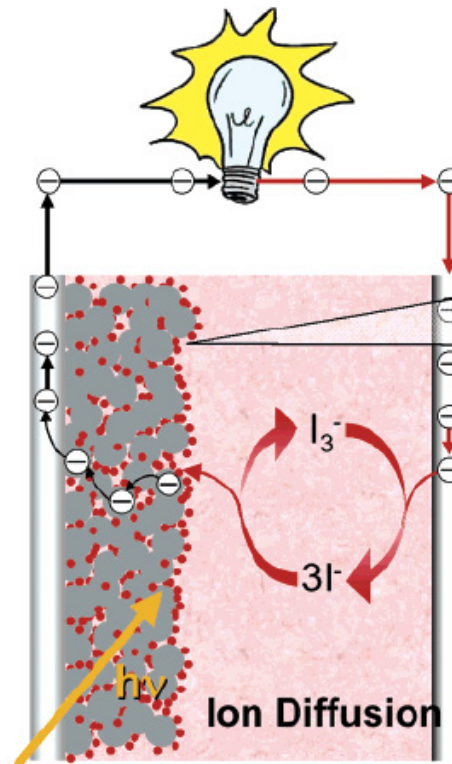
Ledende glasselektroder

Halvleder (nano-TiO₂)

Adsorbent fargestoff ("dye")

Elektrolytt

Redokspaar (I^- / I_3^-)

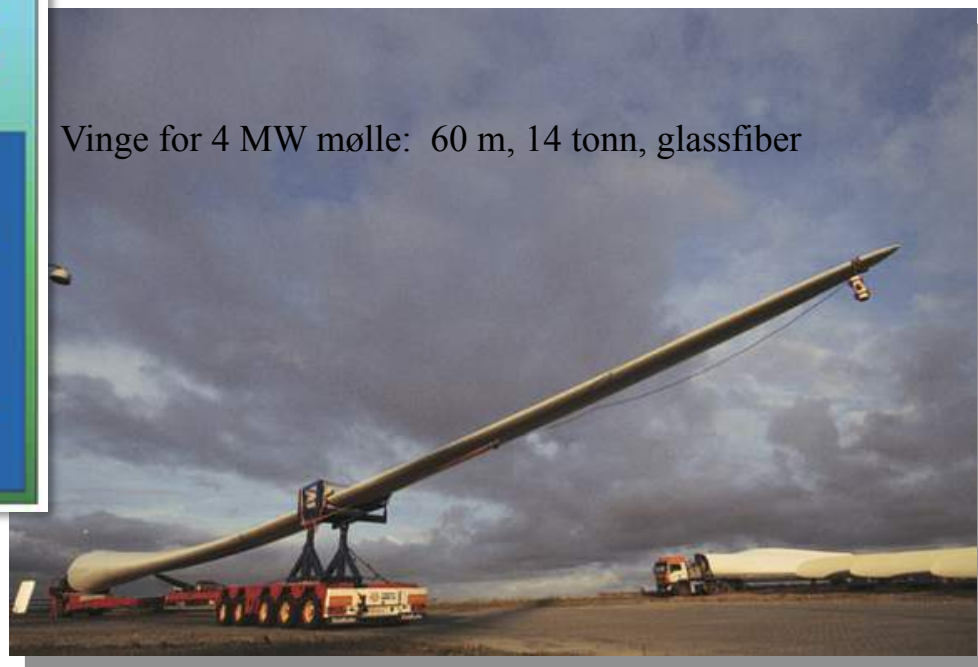




Indirekte solenergi - vind



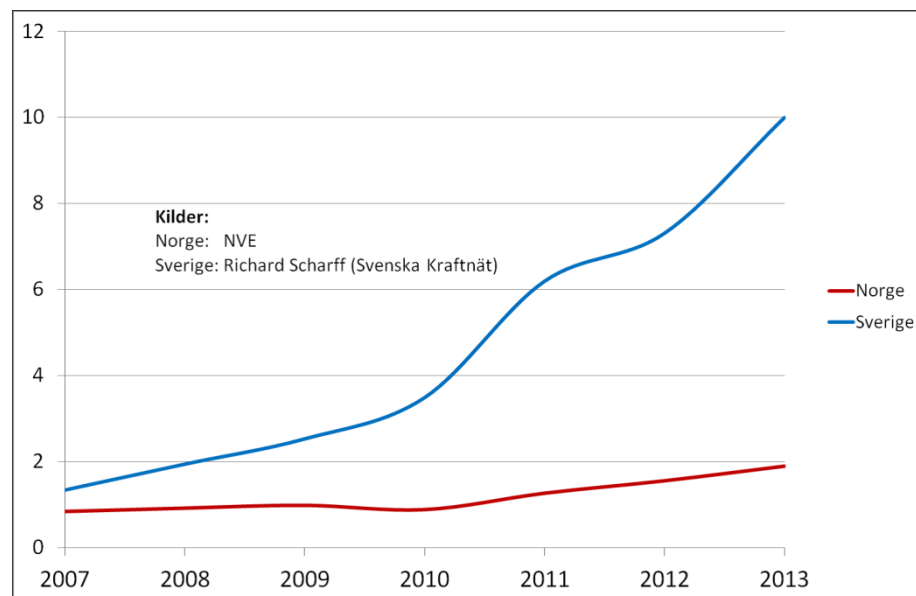
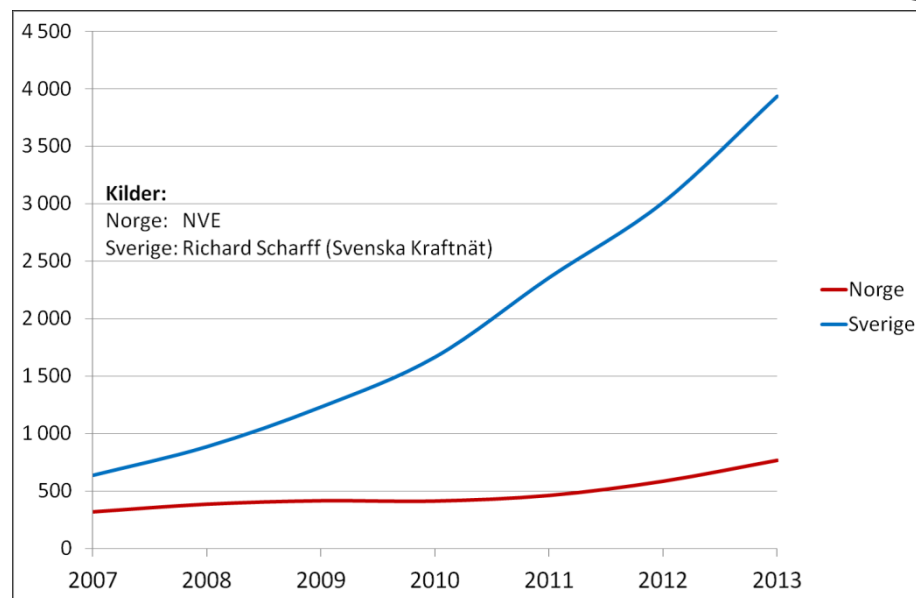
Vinge for 4 MW mølle: 60 m, 14 tonn, glassfiber



Indirekte solenergi - vind

- Moden teknologi
 - Men trenger lagring av produsert strøm i land uten vannkraft

- ”Fullt” utnyttet i enkelte land
 - eks. Danmark
 - Norge langt etter
 - Har gode vindressurser
 - Stort inngrep i landskap (?)
 - Kostbar installasjon
 - Velegnet offshore



Indirekte solenergi - bølger

- To hovedtyper

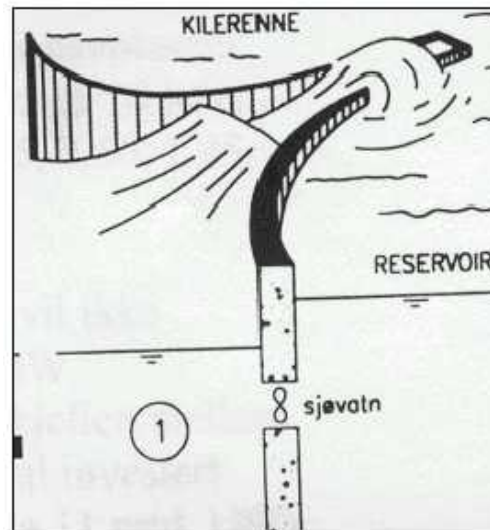
- Turbin basert på flottør eller annen bevegelse opp-ned

- Åpent hav eller i kystformasjoner
 - Kan kombineres med vindkraft?



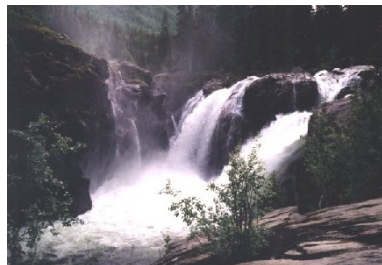
- Samling og fukusering av bølger; løftes inn i reservoar i basseng eller fjordarm

- Turbin i utløp
 - Lagring innebygget

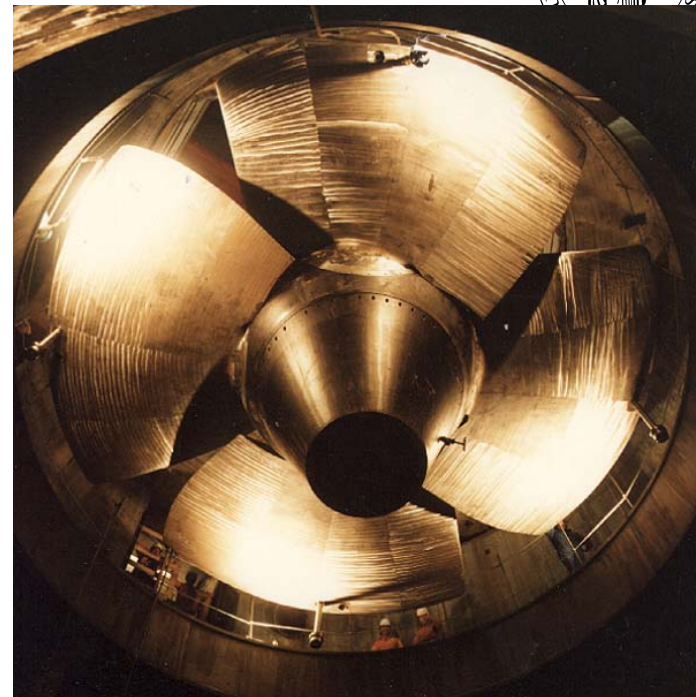


Indirekte solenergi - vannkraft

- Innebygget lagring i sjøer og demninger
- Økende interesse for mindre vannkraftverk
 - 10 MW: Småkraftverk
 - 1 MW: Minikraftverk
 - 100 kW: Mikrokraftverk
- Fra Kapittel 3:

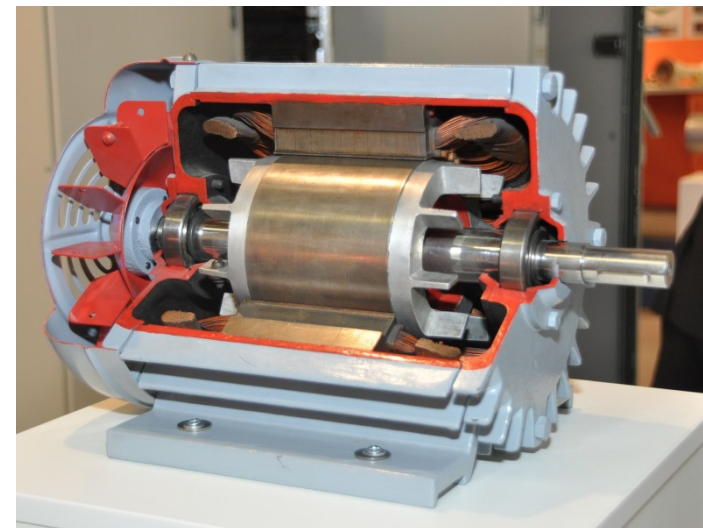
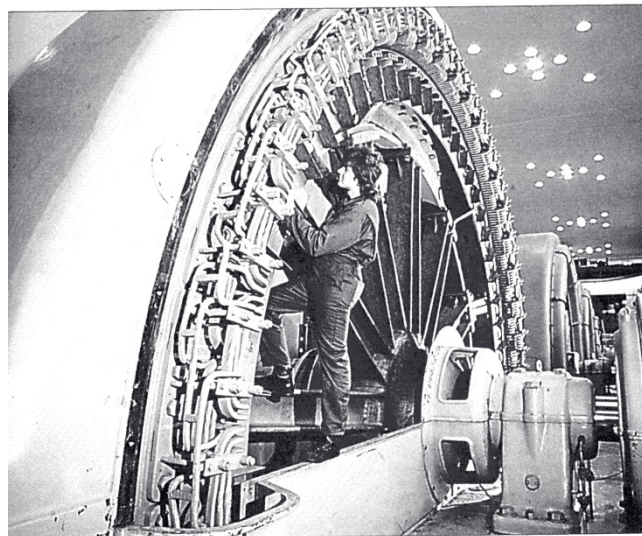


Solbergfoss 1 og 2.
Inngangspartiet til den nye stasjonen synes til venstre i bildet

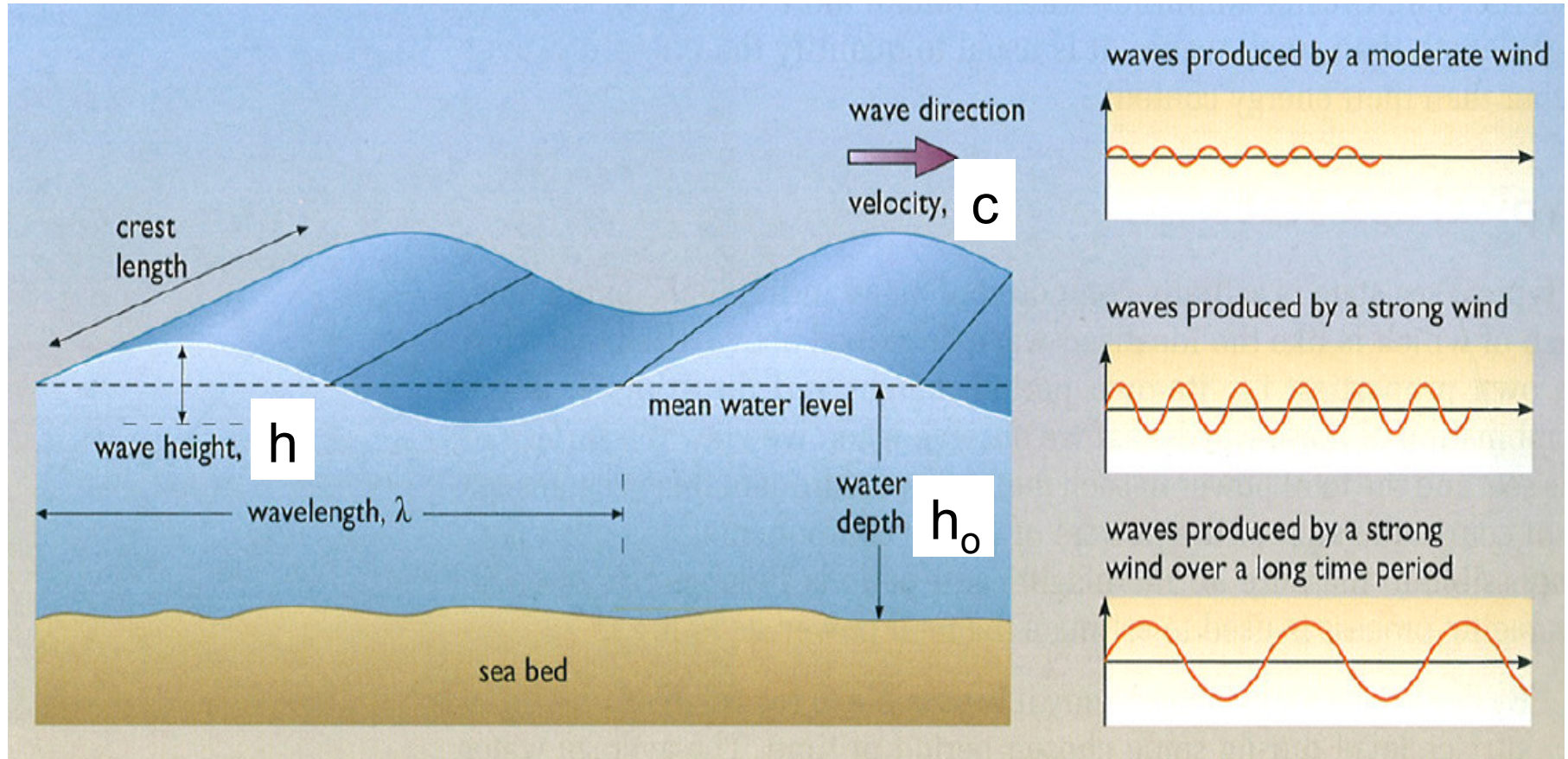


El-generator

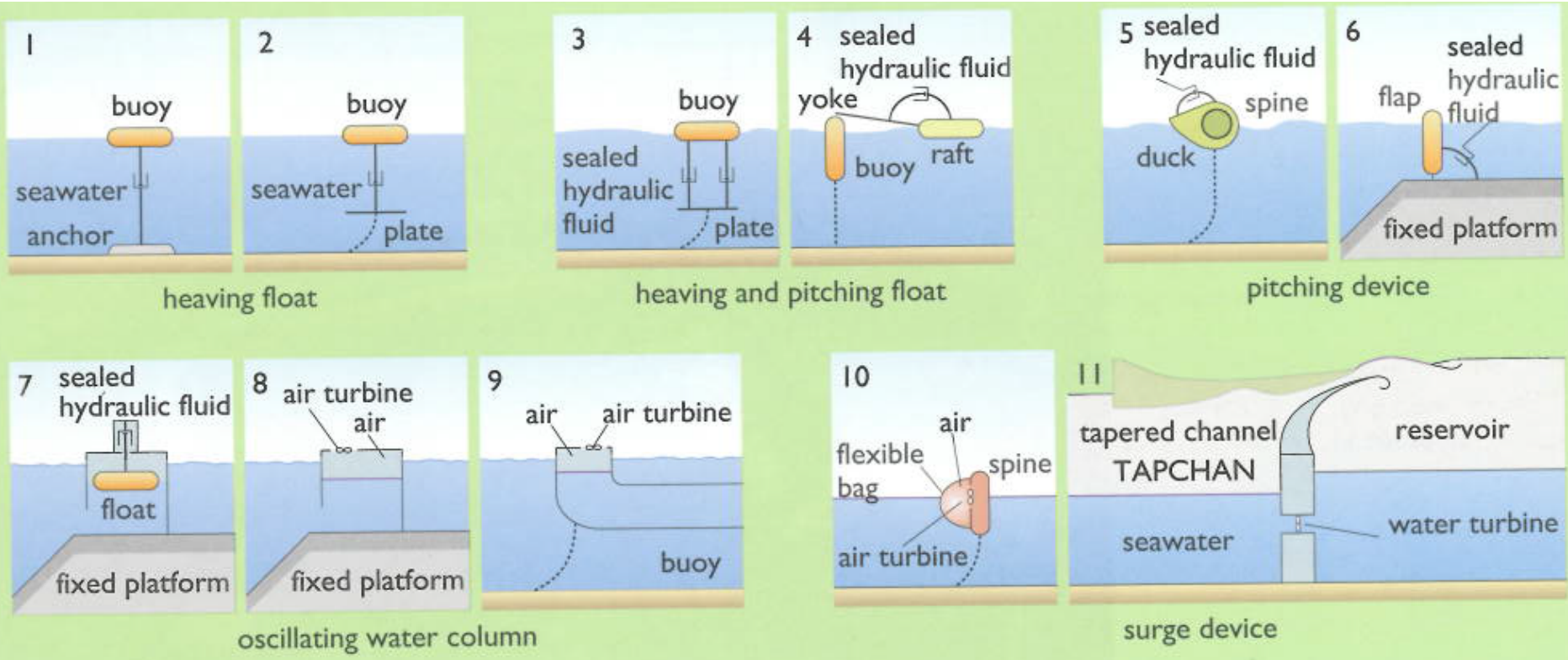
El-motor



Deep, intermediate and shallow waves

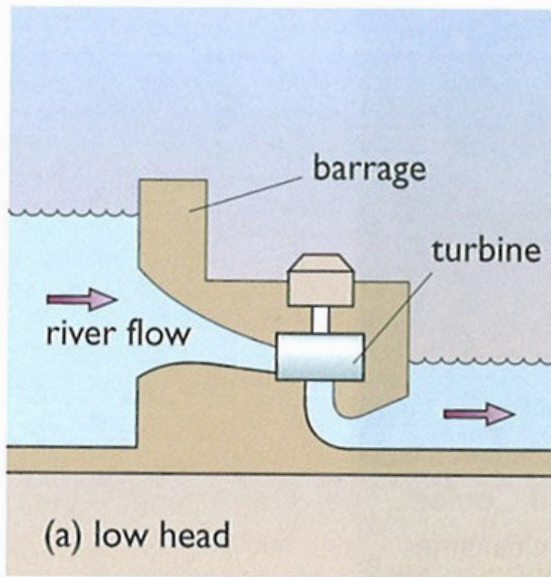


Wave energy converters



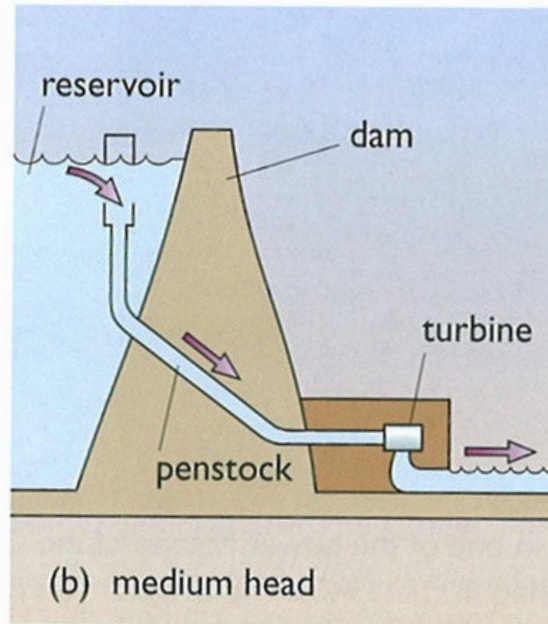
They can be classified in terms of their location: fixed to the seabed, generally in shallow water; floating offshore in deep water; tethered in intermediate depths

Types of hydroelectric plant

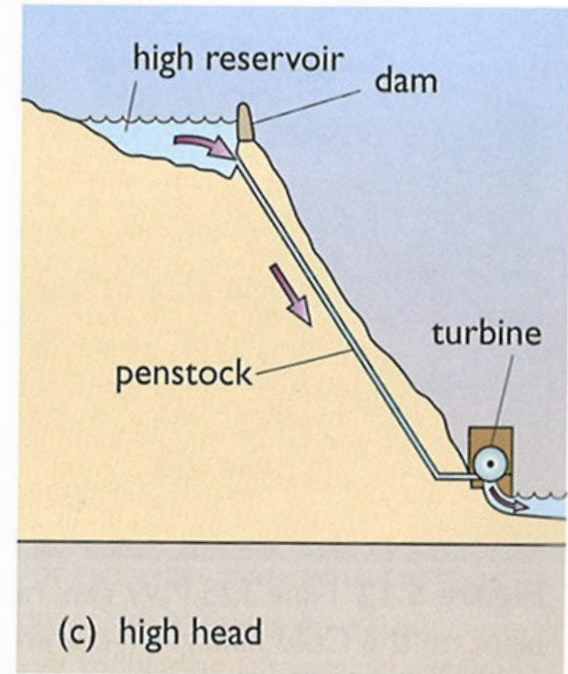


(a) low head

< 10 m



(b) medium head

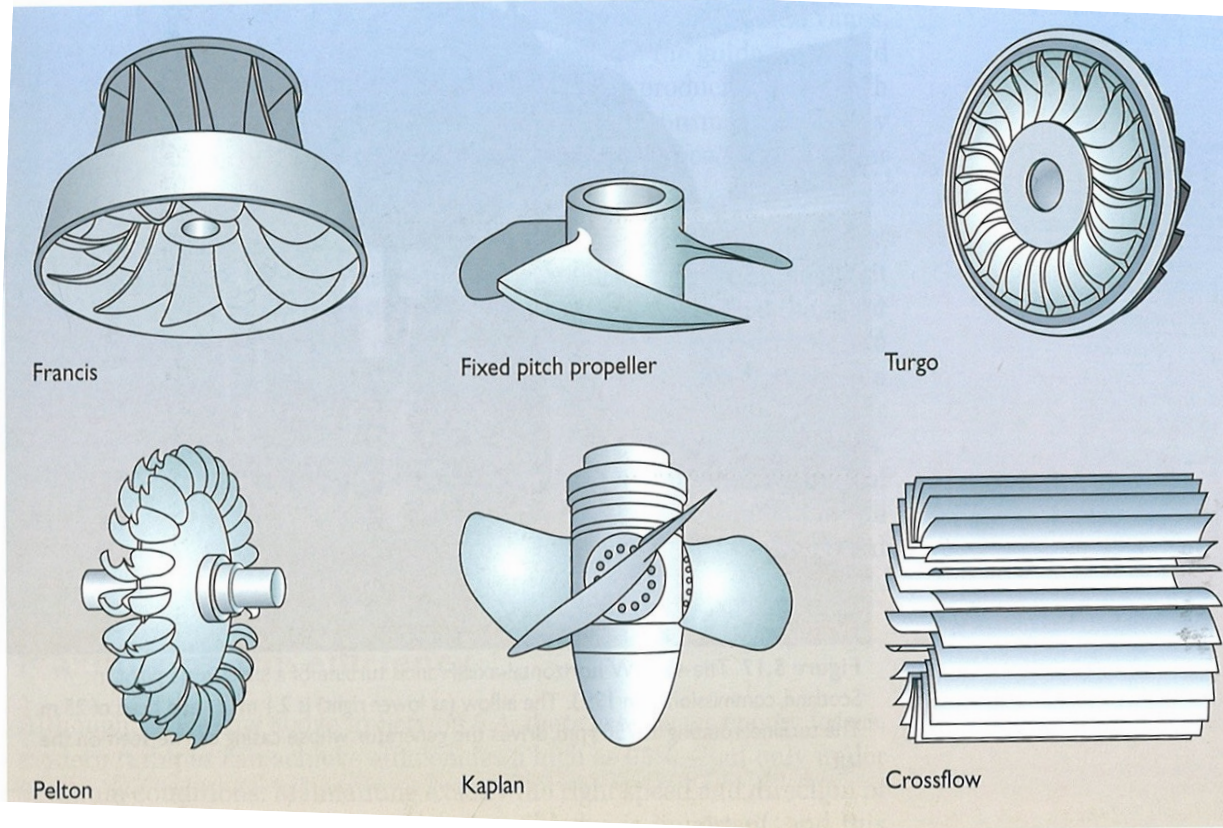


(c) high head

> 100 m

- Low dam or barrage. High capital cost because large volume flow means large mechanisms
- Typical of very large hydroelectric installations, with a dam at a narrow point in a river valley. High costs but good supply and economic return
- In “high head” plant the reservoir lies well above the outflow level. The penstock may even pass through a mountain to reach the turbine. With a high head, the flow needed for a given power is much smaller than for a low-head plant, so the turbines, generators and housing are **more compact**. The long penstock adds to the cost, and the structure must be able to withstand the extremely high pressures

Water turbines

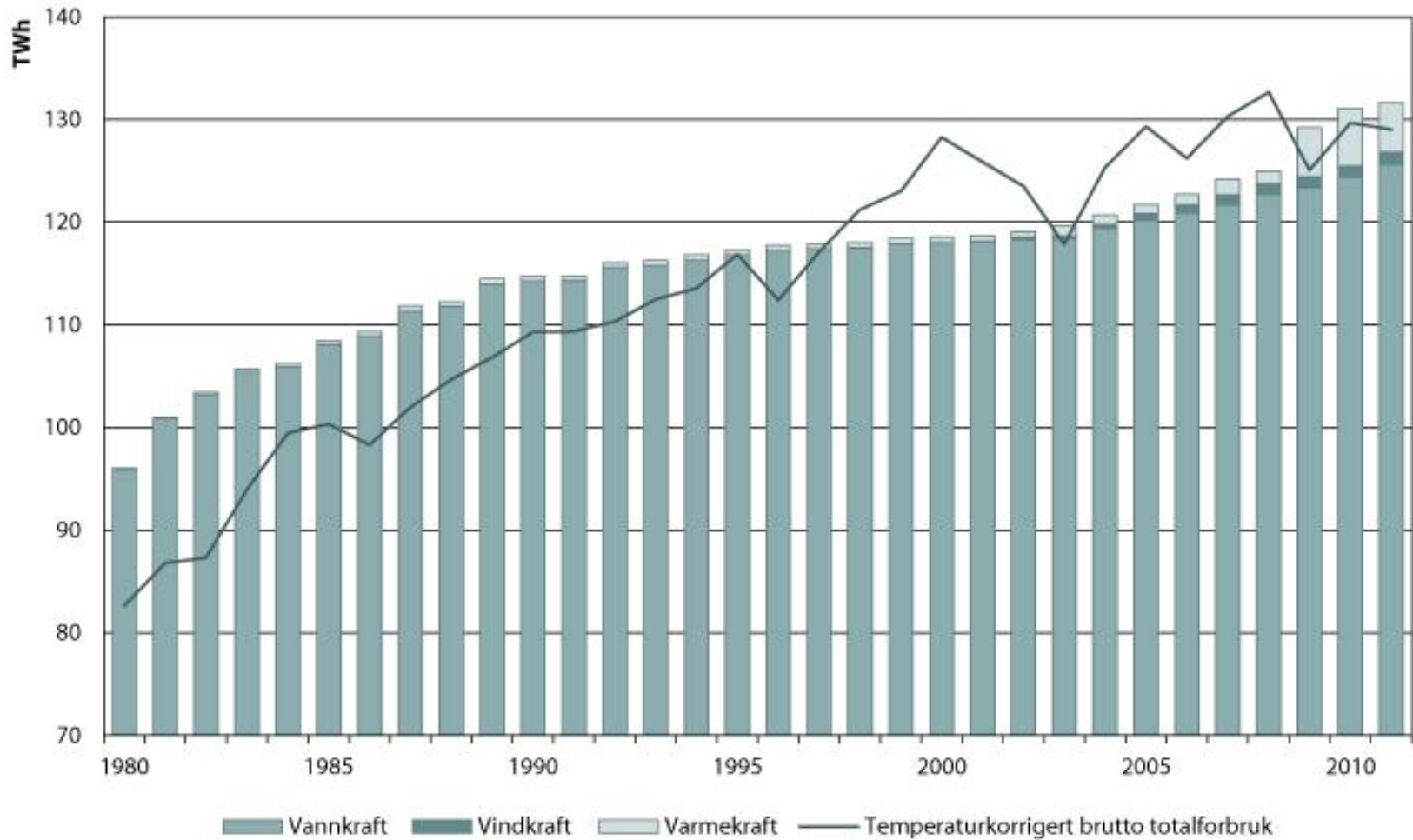


Turbines come in a variety of shapes. They also vary considerably in size, with runner diameters ranging from as little as a third of a meter to some 20 times this

Two basic designs of water turbines:

- **impulse turbine, Pelton**
- **reaction turbine, Francis** the blades are fully immersed in water

Vannkraft og annen kraftproduksjon i Norge

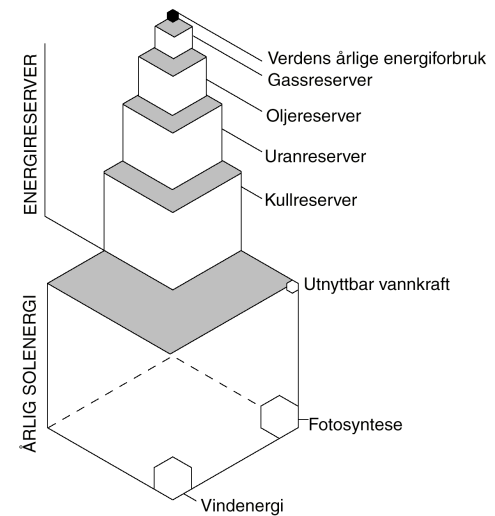


Bioenergi



- Med biomasse mener vi trevirke, kompost, avfall, flis, etc.

- Hva med mat?



Termokjemisk prosessering

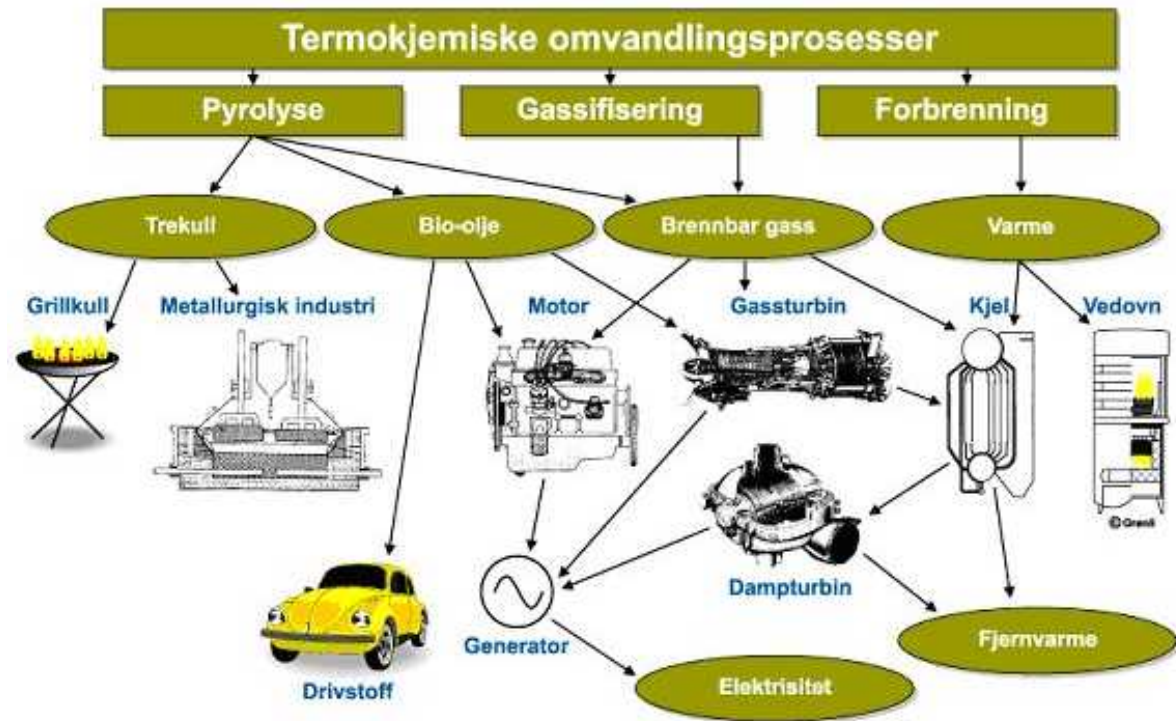
- Pyrolyse (thermochemical decomposition in the absence of O₂)
 - Produkt: Trekull, oljer

- Gassifisering

- Oksidasjon med damp, luft, O₂
- Produkt: CH₄, C₃H₈, CO, H₂

- Forbrenning

ENERGI FRA BIOMASSE



Fuels

Combustion:

- It needs oxygen
- The fuel undergoes a major change
- Energy is released



Table 4.1 Heat content and CO₂ emissions

Fuel	Heat content /GJ t ⁻¹	CO ₂ released /kg GJ ⁻¹
coal	~30	~80
oil	42	70
natural gas	55	50
air-dry wood	~15	~80 ^a

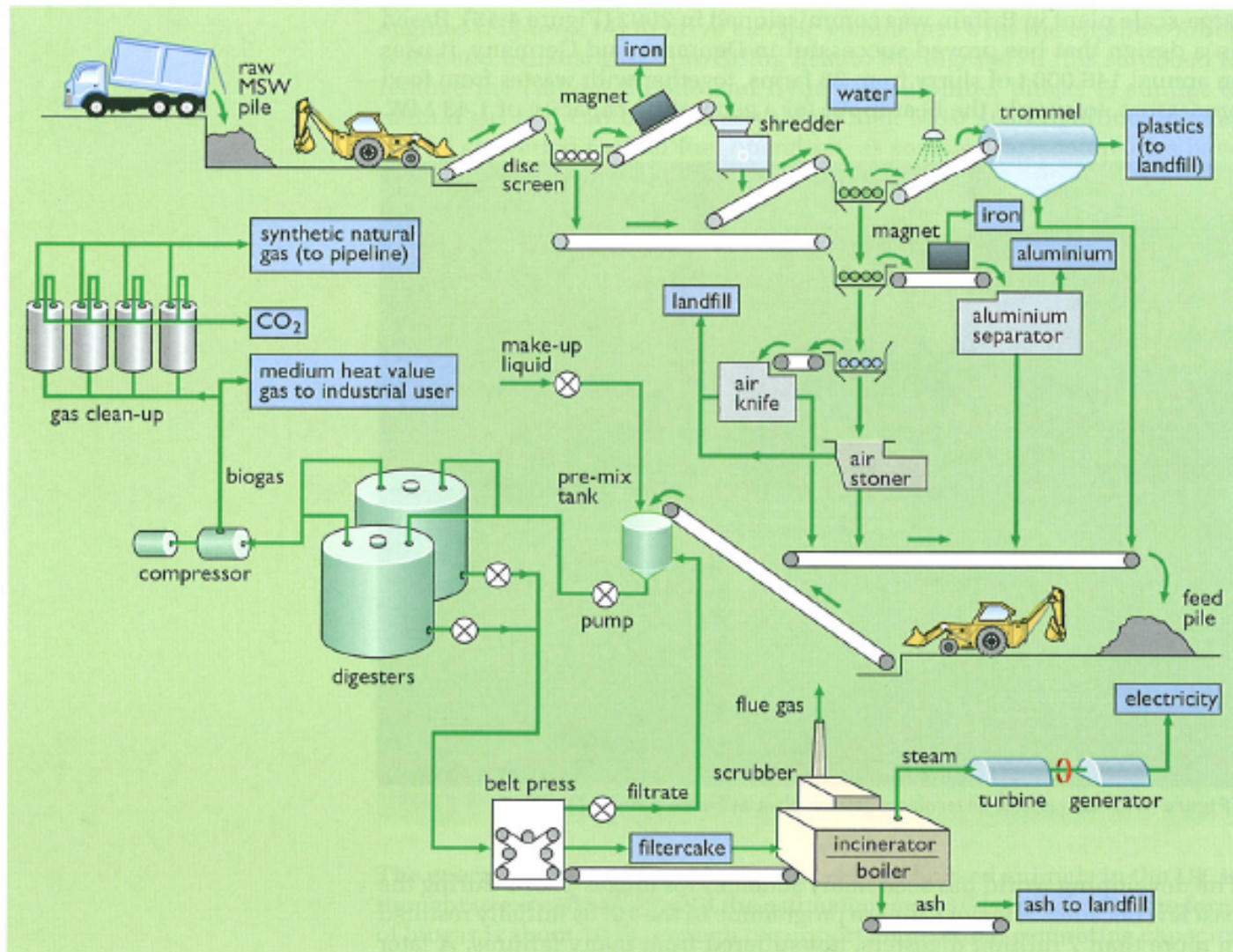
Table 4.2 Average heat energy content of fuels

Fuel	Energy content		Fuel	Energy content	
	GJ t ⁻¹	GJ m ⁻³		GJ t ⁻¹	GJ m ⁻³
Wood (green, 60% moisture)	6	7	Straw (as harvested, baled)	15	1.5
Wood (air-dried, 20% moisture)	15	9	Sugar cane residues	17	10
Wood (oven-dried, 0% moisture)	18	9	Domestic refuse (as collected)	9	1.5
Charcoal	30	*	Commercial wastes (UK average)	16	*
Paper (stacked newspapers)	17	9	Oil (petroleum)	42	34
Dung (dried)	16	4	Coal (UK average)	28	50
Grass (fresh-cut)	4	3	Natural gas (at supply pressure)	55	0.04

Production of gaseous fuels from biomass

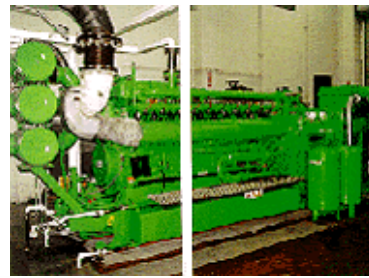
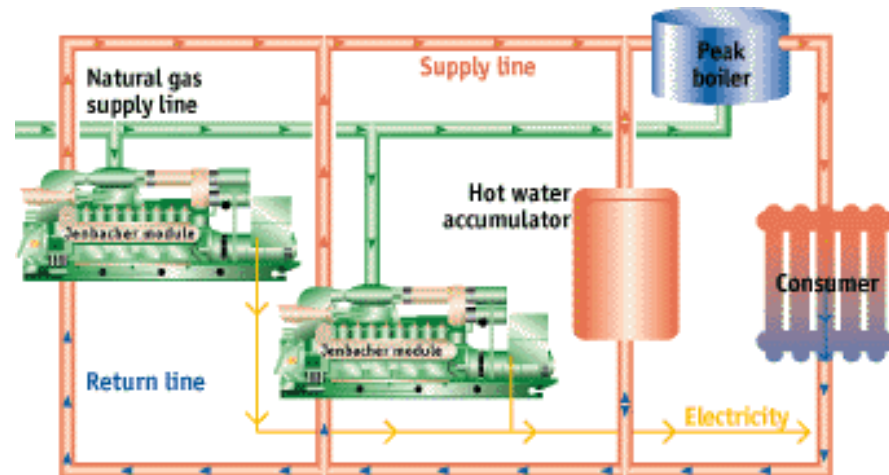
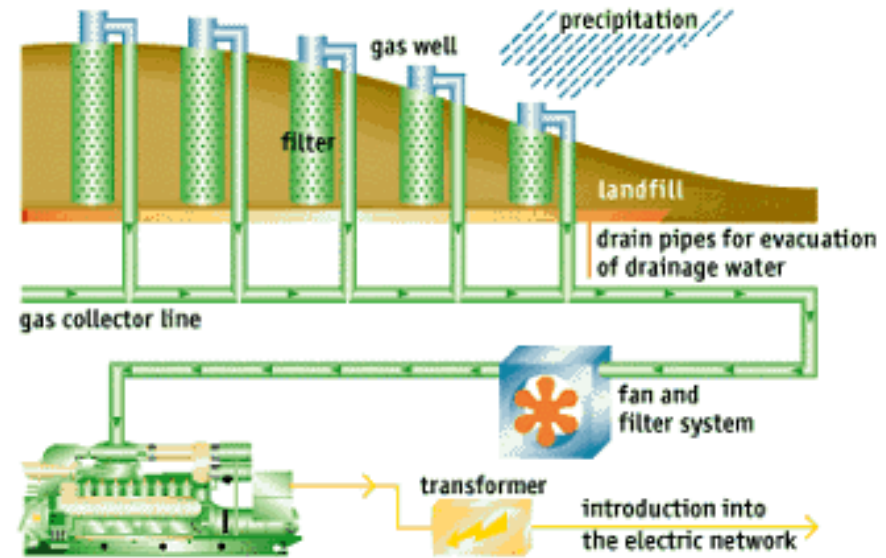


- Anaerobic digestion
- Anaerobic digesters from MSW
- Gasification



Deponigass

- Avfallsdeponier utvikler gass ved forråtnelse og gassifisering
- Kan brukes til elektrisitet og fjernvarme
- Oslo:
 - 1000 GWh/år bioenergi
 - Mest fjernvarme
 - 50 GWh elektrisk via dampturbin
- Drammen: Lager H₂ ved reformering; for hydrogenbiler ☺



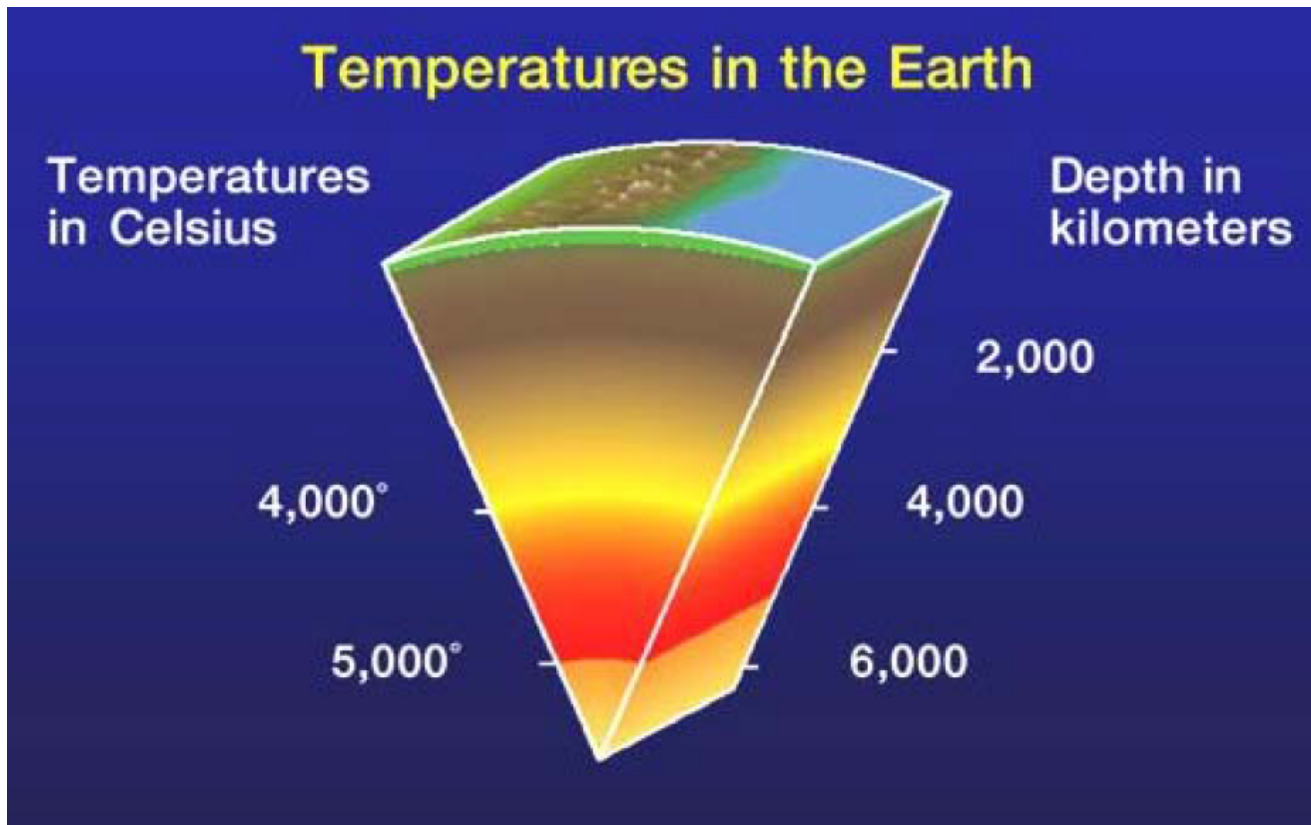
Geotermisk varme og jordvarme

- Kilder til geotermisk energi:
 - Varmestrøm fra jordens varme kjerne
 - Kjernereaksjoner i mantelen
- Strømmer til jordoverflaten
 - Gjennomsnittlig $0,063 \text{ W/m}^2$
 - Totalt 32 TW for hele kloden
- Virker sammen med oppvarming fra sola; jordvarme
- Vi kan ta ut geotermisk varme fra store dyp eller der varme når opp gjennom sprekker i skorpen
 - > 40°C : Oppvarming
 - > 150°C : Damp turbin for elektrisitet



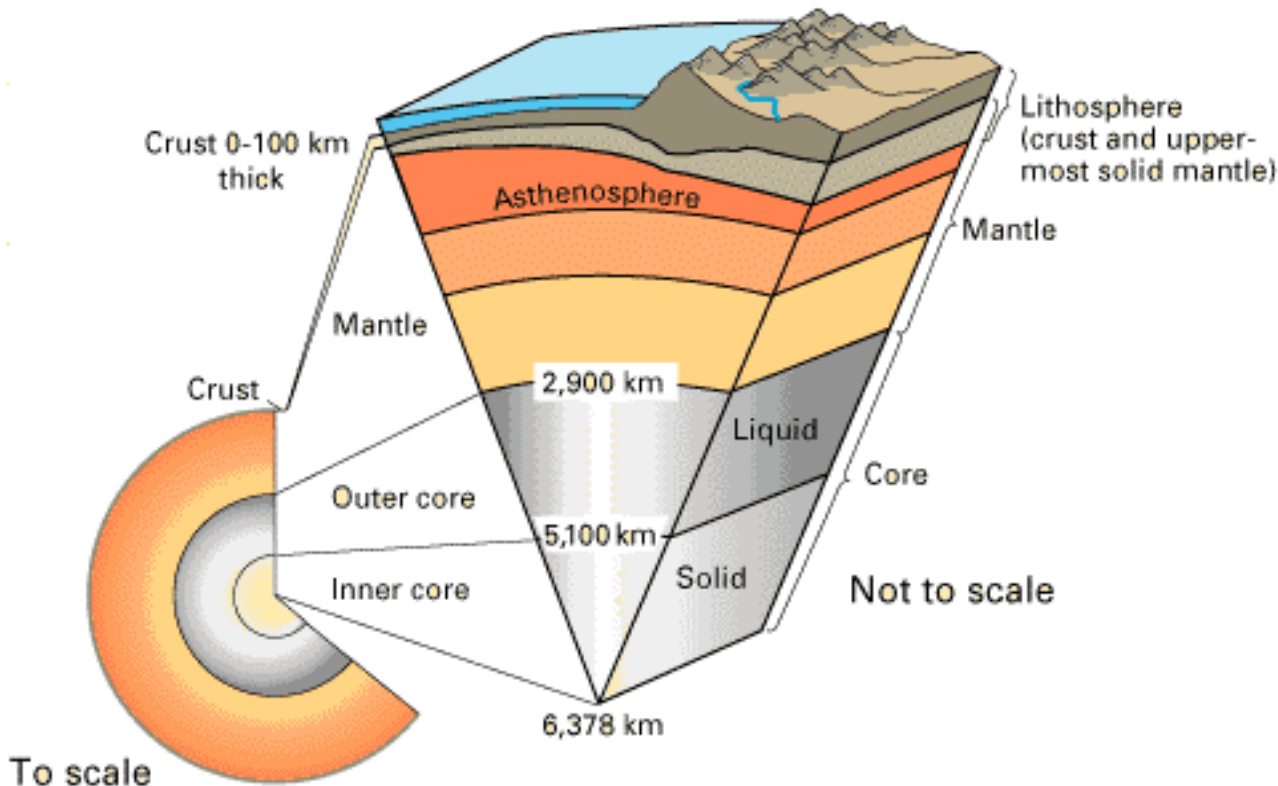
Geothermal Energy

Geothermal Energy is energy stored in the form of heat beneath the surface of the solid earth



Structure of the Earth

The Earth, about 12.750 km in diameter, is made up of **crust**, **mantle**, and **core**. **Crust** is rigid and very thin compared with the other two. Beneath the oceans, extending about 5-6 km, beneath continents averages about 30 - 40 km



Mantle, a dense, hot layer of semi-solid **rock** about 2.900 km thick, contains more iron, magnesium, and calcium, and is hotter and denser because temperature and pressure inside the Earth increase with depth.

Core, nearly twice dense of **Mantle**, composition is metallic (iron-nickel alloy), contain two parts: a 2.200 km-thick **liquid outer core** and a 1.250 km-thick **solid inner core**.

As the Earth rotates, the liquid outer core spins, creating the Earth's magnetic field.



The source of heat

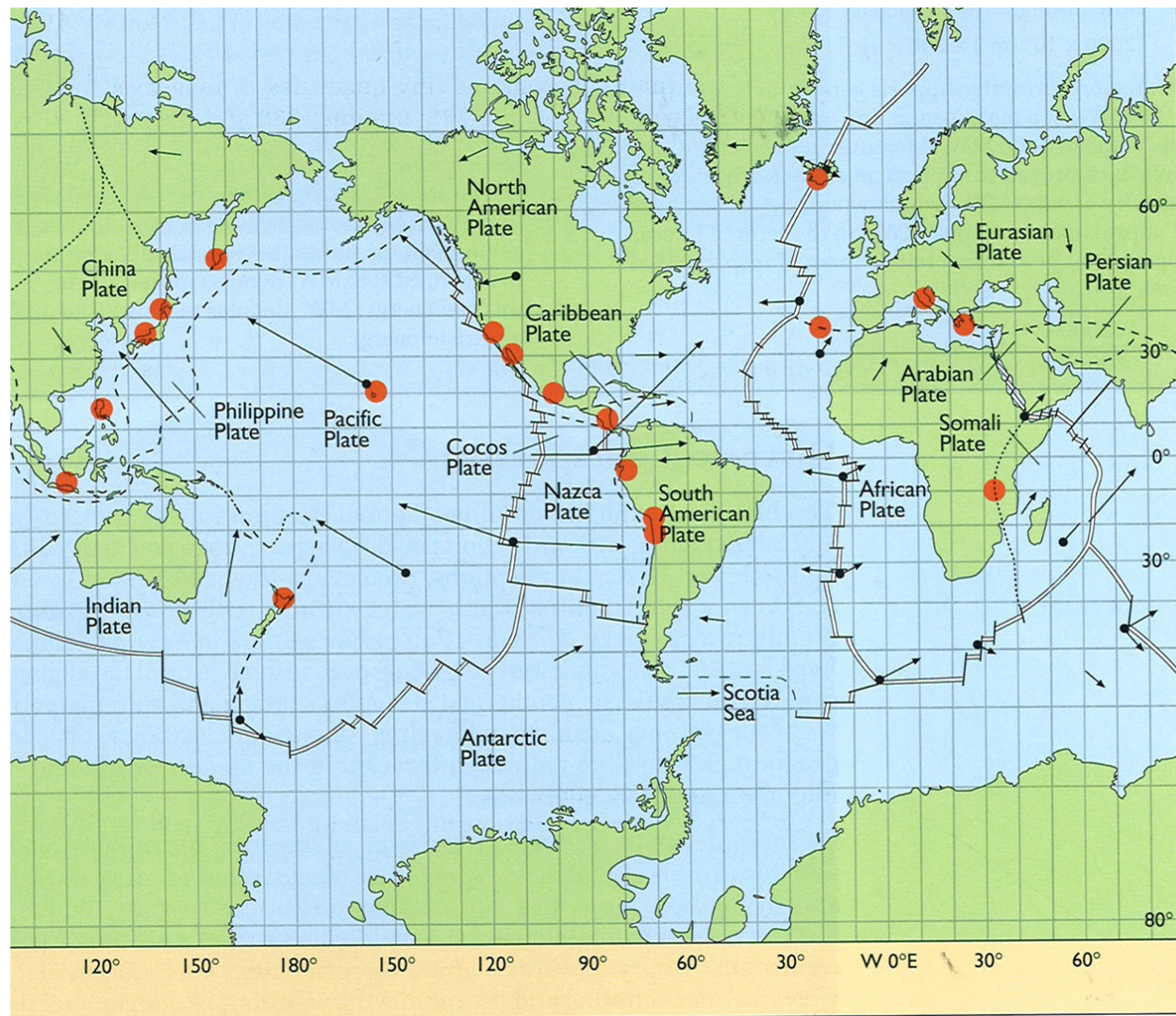
The heat stored within the earth results firstly from the gravitation energy at the time of the formation of the earth about 4.5 billion years ago due to contractions of gas, dust and rocks.

The Earth contains tiny quantities of long-lived radioactive isotopes, *thorium 232*, *uranium 238* and *potassium 40*, all of them liberate heat as they decay. These radiogenic elements are concentrated in the upper crustal rocks.

Geothermal energy----- the energy stored and flowing as heat beneath the surface of the earth

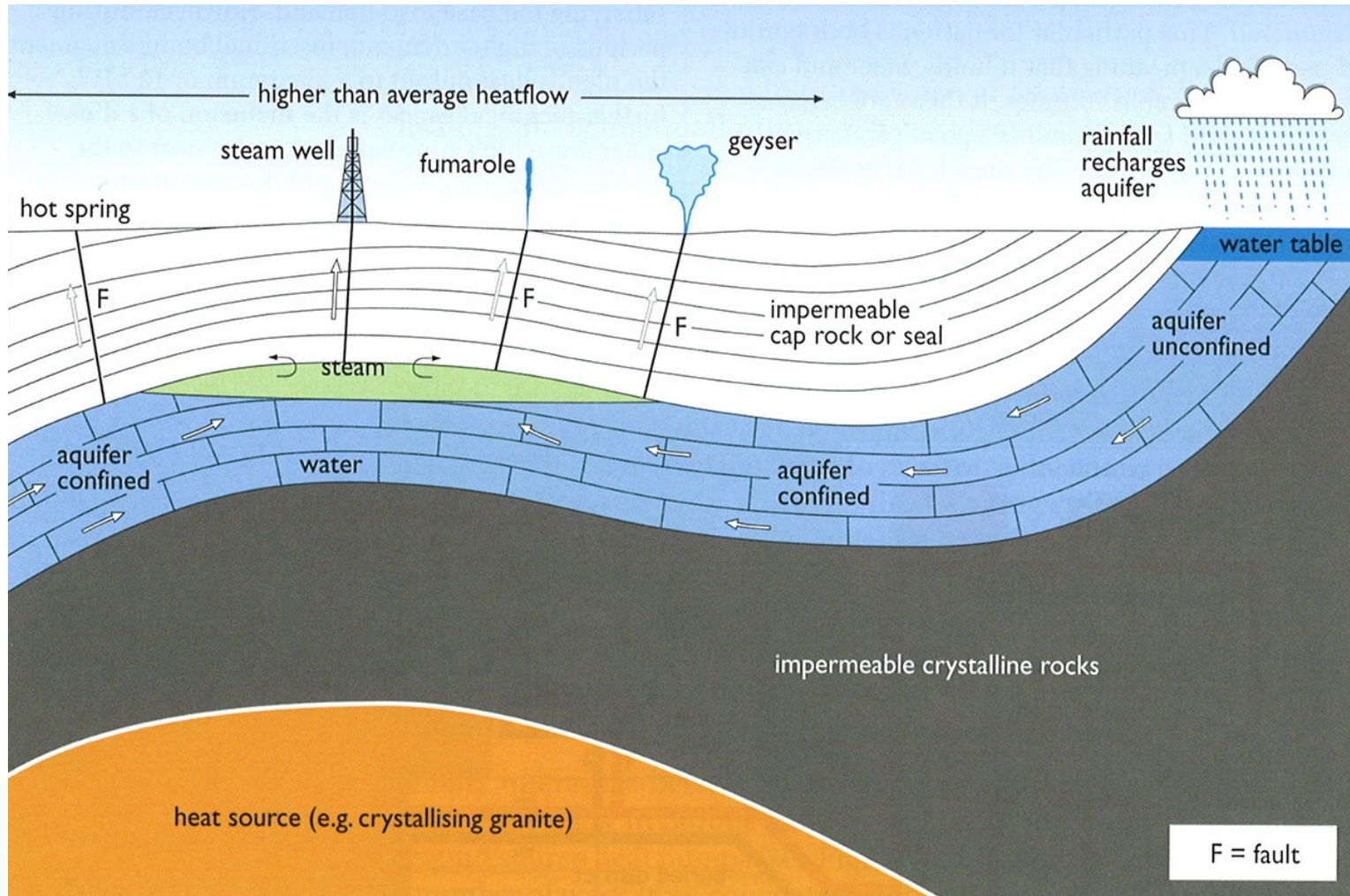
The *average* 'heat flow' through the earth's crust is about 60 mW/m², the global heat flow, in the form of steam and hot water, is ~44 TW

Map of the earth's lithospheric plates



- incipient plate boundaries
- divergent boundaries
- major high-enthalpy geothermal energy producing areas
- convergent boundaries
- strike-slip boundaries (sideways motion)

The physics of Geothermal resources



Three essential characteristics of geothermal site:

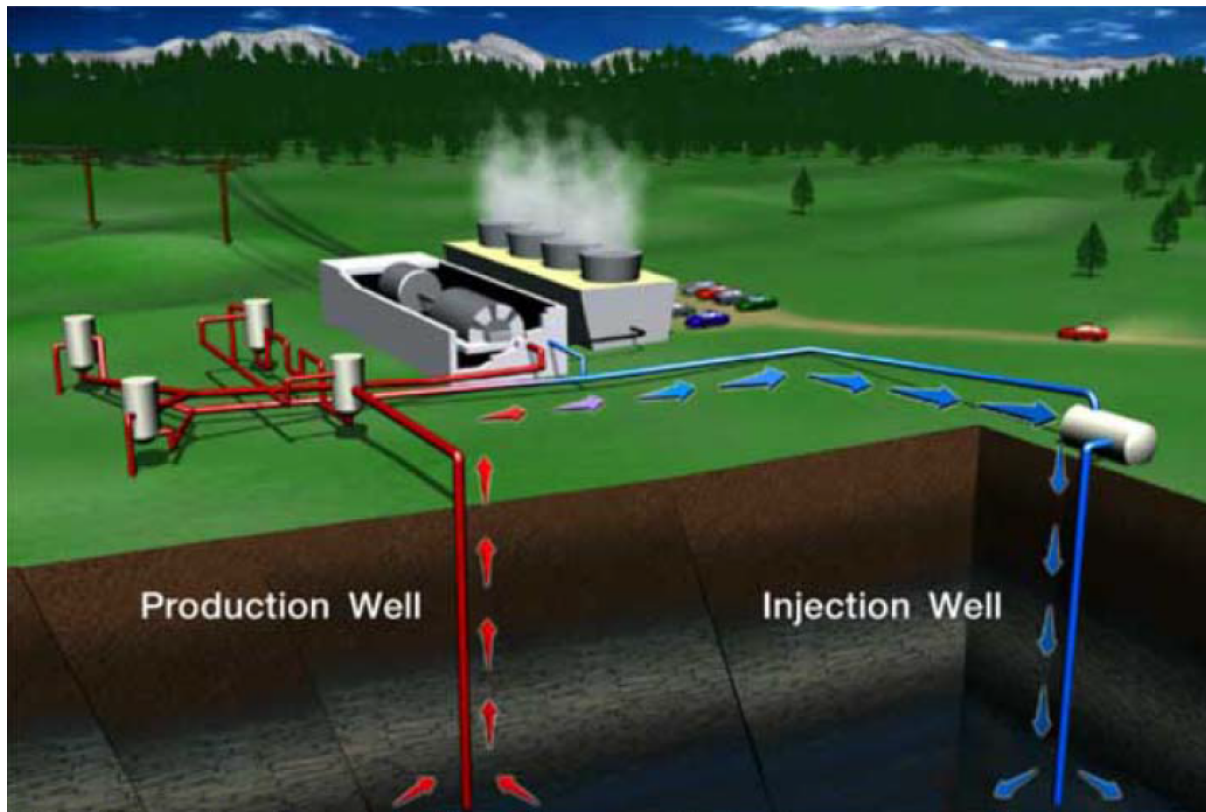
- An **aquifer** containing water that can be accessed by drilling
- A **cap rock** to retain the geothermal fluid
- A **heat source**

Geothermal power plants

From steam or hot water to electricity

(thermal energy to mechanical energy to electricity)

(Available around the clock, carbon-free)



Fluid temperature, pressure, salinity, content of other gases all affect plant efficiency and design

A typical unit gives 30-50 MW_e

<http://www.youtube.com/watch?v=kjpp2MQffnw>

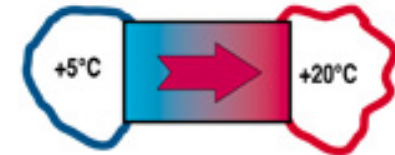
Varme og varmepumper

- Varm luft ($T > 0\text{ K}$) kan deles i en varmere del og en kaldere del, med konstant totalenergi.
- Det koster litt energi (typisk 25%) å kjøre prosessen i endelig hastighet.
- Dvs: 1 kW elektrisitet inn kan typisk gi 3 kW varme ut.
- Vi varmer huset og kjøler uteluften (eller hav/sjø). Solen varmer omgivelsene opp igjen over tid, dvs. dette er i lengden solenergi.

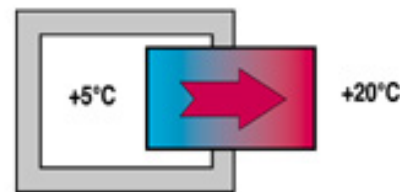
1) Naturlig varmetransport - fra varm til kald side



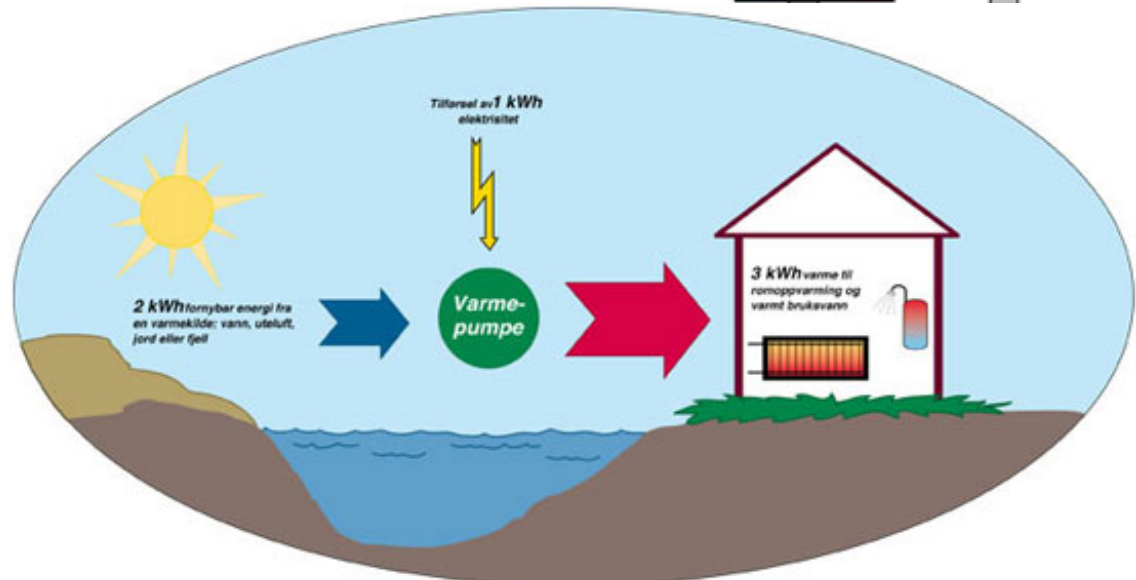
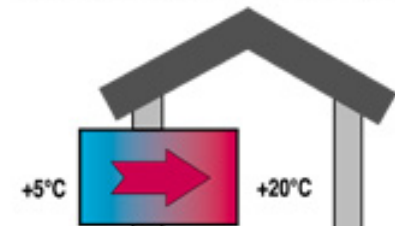
2) Varmepumpe - fra kald til varm side



3) Kjøleskap med varmepumpe



4) Hus med varmepumpe



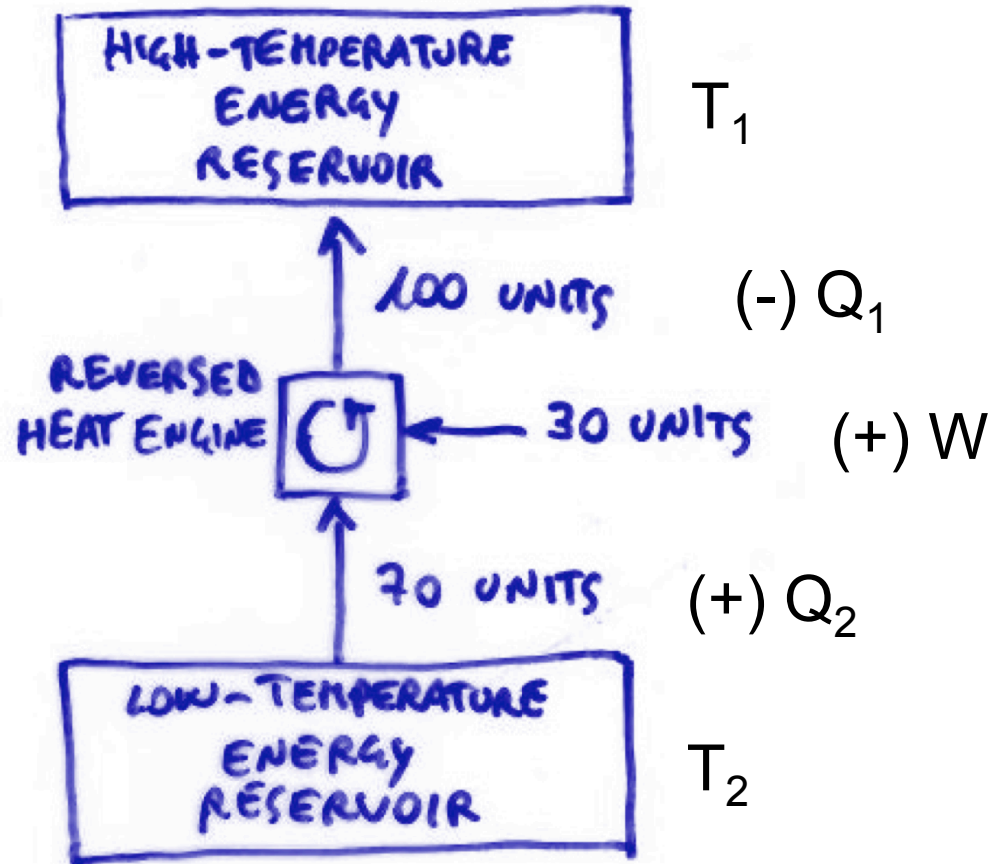


The effectiveness of a reversed heat engine is defined in terms of a coefficient of performance, COP. When the reversed engine is used mainly as a refrigerator the coefficient of performance is defined as:

$$\text{COP}_{\text{ref}} = \frac{Q_2}{W}$$

When the reversed heat engine is used as a heat pump the heat transferred to the high temperature reservoir is the useful energy:

$$\text{COP}_{\text{hp}} = \frac{-Q_1}{W}$$

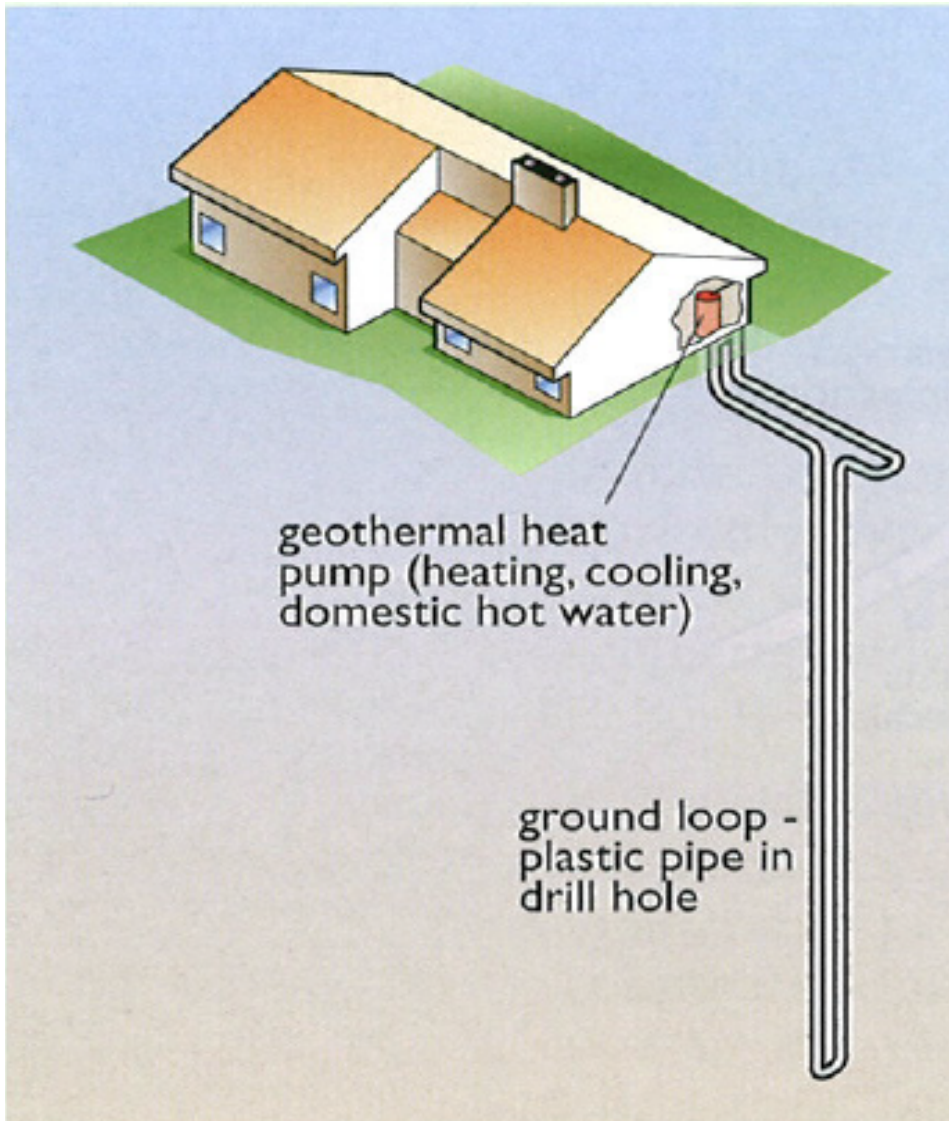


$$\text{COP}_{\text{ref}} = 70/30 = 2.333$$

$$\text{COP}_{\text{hp}} = 100/30 = 3.333$$

Reversed heat engine

Ground source heat pump (GSHP)



Heat Q_2 is extracted at a temperature T_2 , heat Q_1 is expelled at a hotter temperature T_1 (near room temperature), and work W is done by the compressor

For an ideal heat pump heating a building:

$$\text{COP} = \frac{T_2}{(T_1 - T_2)}$$

If ground temperature of $T_2 = 6 \text{ }^\circ\text{C} = 279 \text{ K}$ and $T_1 = 37 \text{ }^\circ\text{C}$, what is COP?

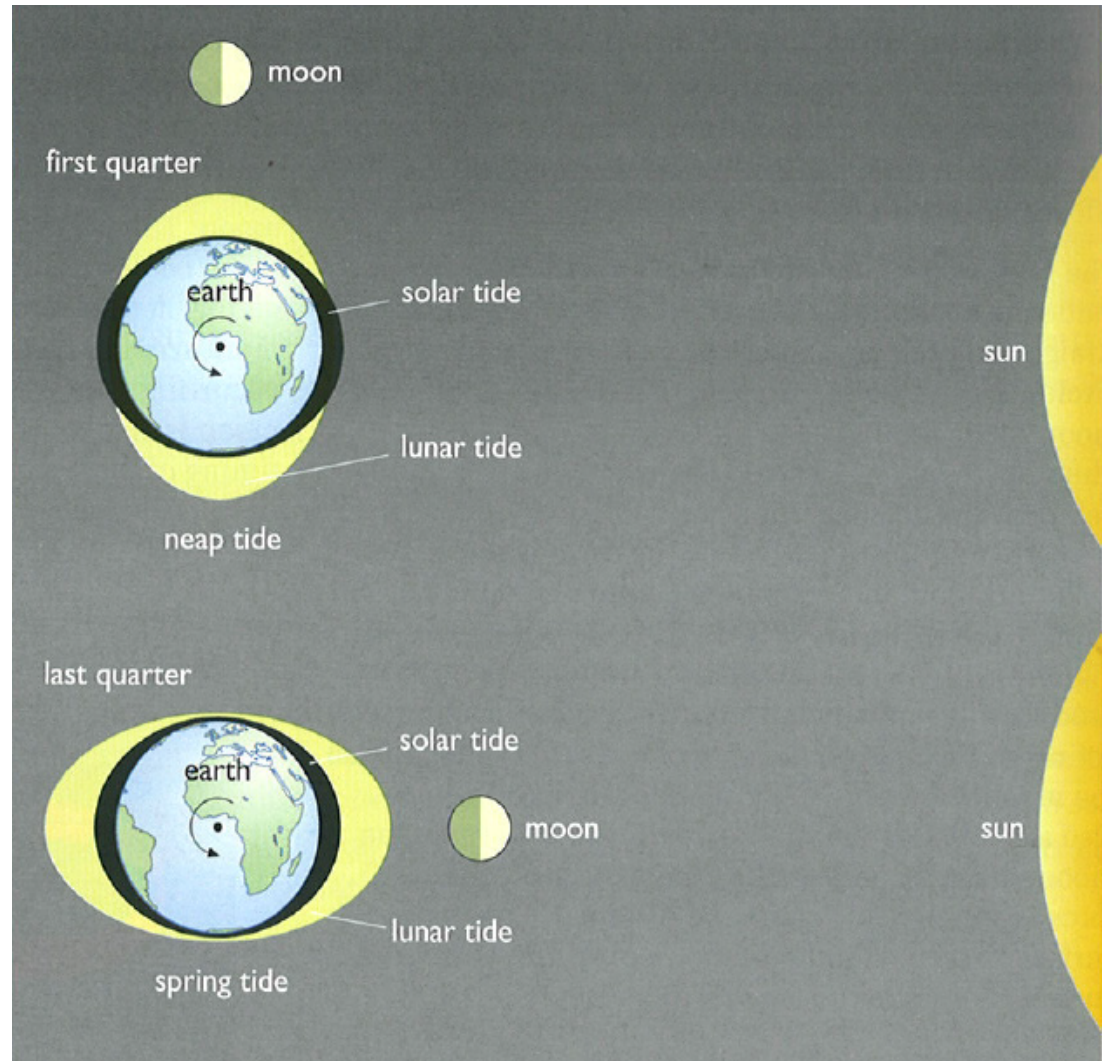
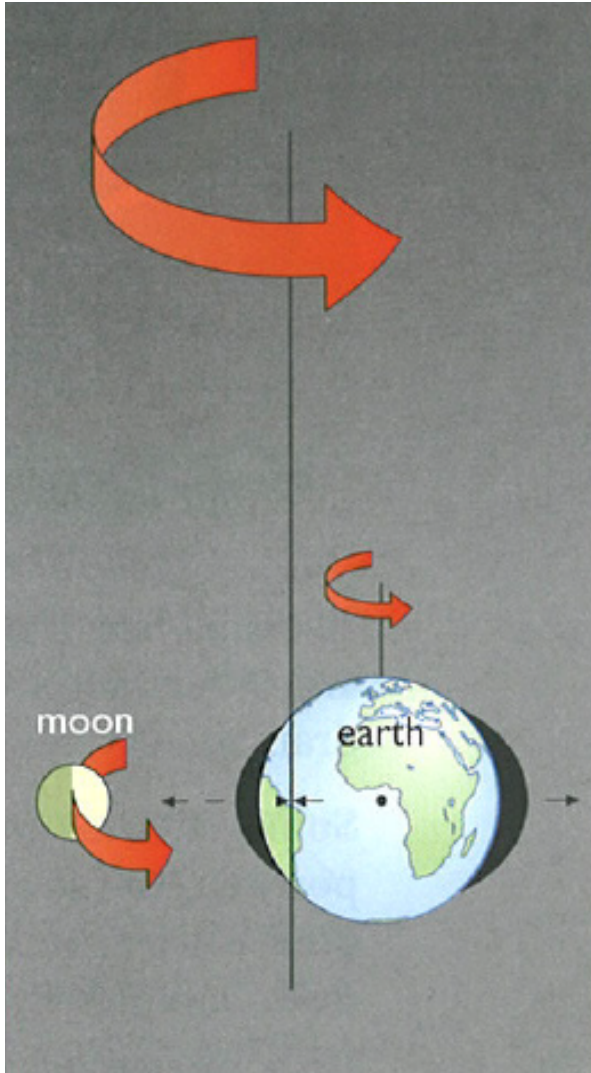
For a $T_1 - T_2 = 31 \text{ }^\circ\text{C}$, we have $\text{COP} = 10$
The actual COPs for heating or cooling units for buildings typically lie between 3 and 4.5

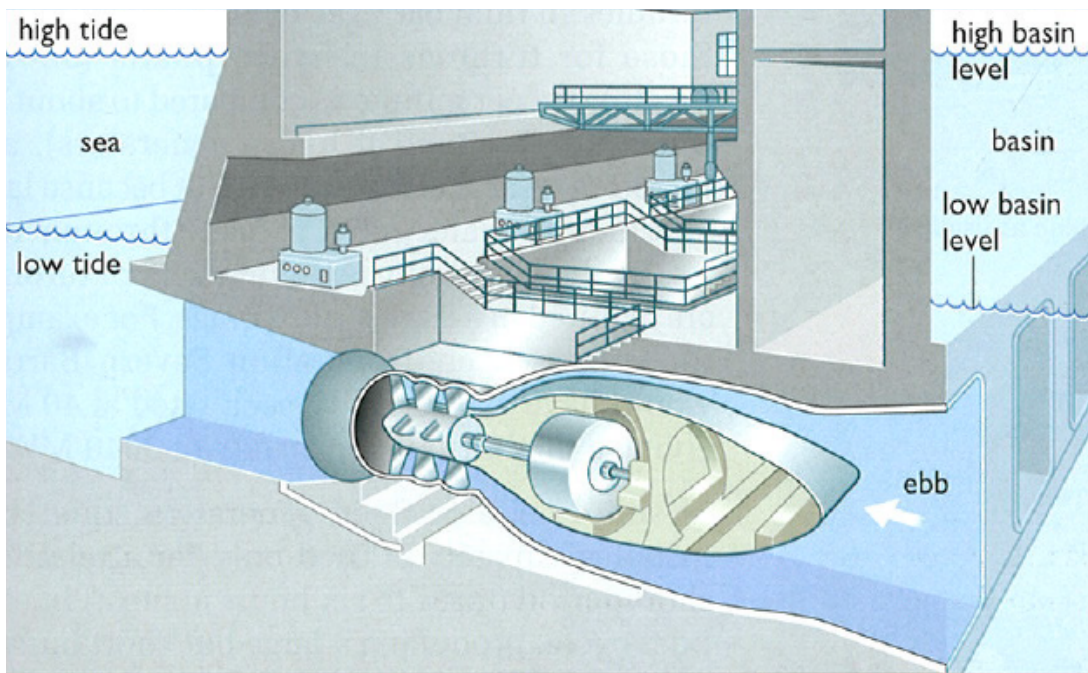
Tidevannskraft

- Månens (og Solens) gravitasjon trekker på havvannet i regelmessige svingninger
- To prinsipper:
 - Mølle som utnytter strømmen gjennom sund begge retninger
 - Oppfylling av åpnet basseng eller fjordarm – stengning – utløp gjennom turbin
- Norges første anlegg i Kvalsundet ved Hammerfest



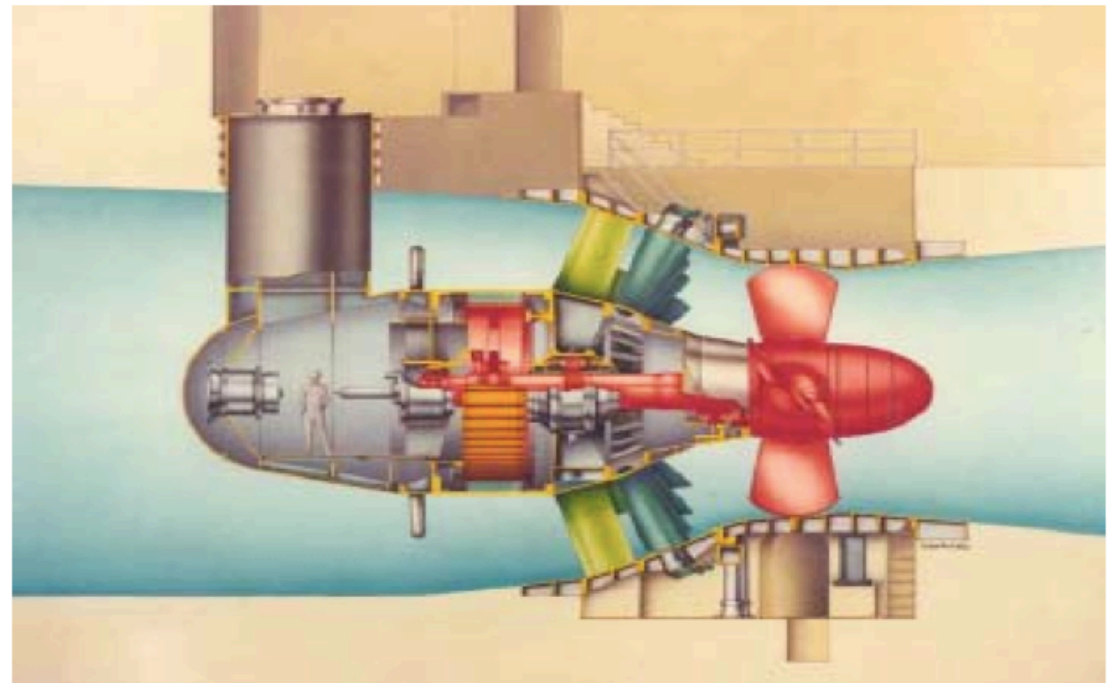
Tidal power





Typical layout of a power generation scheme

Bulb turbine used at La Rance



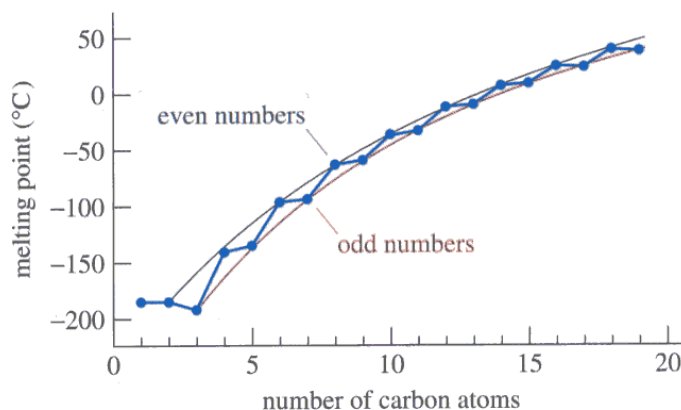
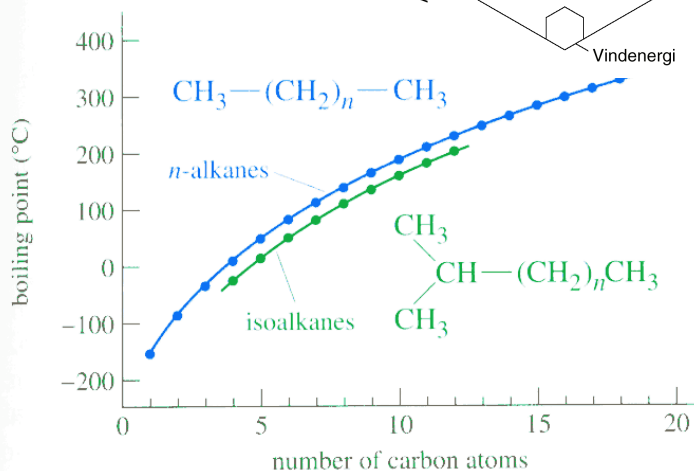
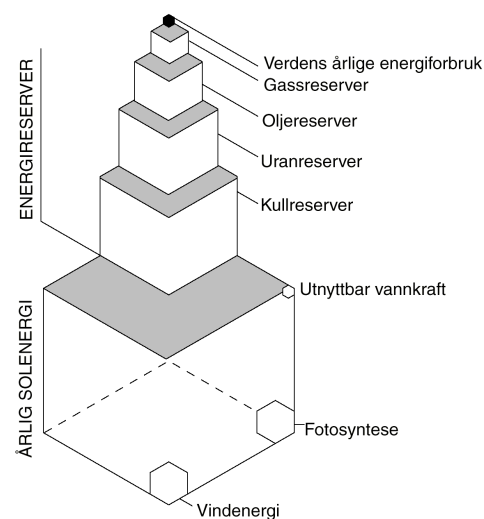
Fossile energikilder

- Kull

- Komplekst
 - organisk
 - C,H,O,S,N
 - uorganiske mineraler

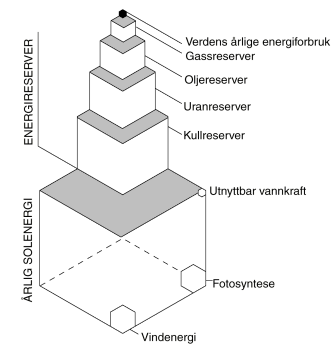
- Hydrokarboner

- Alkaner; mettede
 - C_nH_{2n+2}
 - Metan, etan, propan, butan...
- Alkener og alkyner (umettede)
 - eks. eten C_2H_4 og etyn (C_2H_2)
- Uforgrenede/forgrenede
- Uaromatiske/aromatiske (ringformede)
- Gass: $n = 1..3$
- Råolje: $n = 2....$
- Forbrenner til CO_2 og H_2O , eks.:
 $CH_4 + 2O_2 = CO_2 + 2H_2O$



Kull

- Største reserve av energi på jorden
 - Mange kvaliteter
 - Mange bruksområder
 - Forbrenning
 - Foredling som brensel
 - Råstoff
 - Karbotermisk reduksjon – fremstilling av metaller
- Behandling som for biomasse:
 - Forbrenning
 - Pyrolyse
 - koks
 - Forgassing
 - Med damp til vanngass:
$$\text{C} + \text{H}_2\text{O} = \text{CO} + \text{H}_2$$
- Høye innhold av svovel
 - SO_x ; sur nedbør
- Tungmetaller
- Sot



Kina: 3 215 døde under produksjon av kull i 2008
(offisielle tall, i følge www.china.org.cn)

Olje

- Råolje:
 - Gass, flytende, fast
 - Varierende svovelinnhold
- Fraksjonert destillasjon, bl.a.:
 - Gass ($n=1..2$)
 - LPG (Liquefied Petroleum Gas) ($n=3..4$)
 - Bensin ($n=5..8$)
 - Flybensin og diesel ($n=9..16$)
 - Oljer (fyring, smøring) ($n=16..30$)
 - Paraffinvoks ($n>25$)
 - Asfalt ($n>35$)
- Cracking
 - Deling i mindre komponenter
 - Øker andelen lettere råstoffer, for bensin og polymerer
- Prosessering
 - Hydrogenering/dehydrogenering
 - Oksidasjon, aromatisering, polymerisering



Destillasjonstårn og cracker

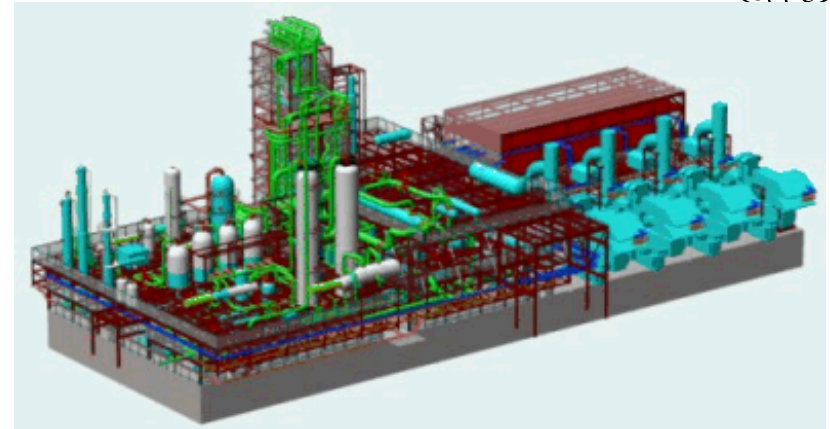
Petroleumsindustri: olje og gass

Petrokjemisk industri: avledede produkter

Naturgass

Kårstø: 3,5 TWh

- Typisk sammensetning:
 - 70% CH₄
 - 10% C₂H₆
 - 15% C₃H₈
 - 5% andre
- LNG (Liquefied Natural Gas)
- Lave svovelinnhold
- Viktige reaksjoner:



Snøhvitfeltets ilandførings- og LNG-anlegg på Melkøya ved Hammerfest

- Partiell oksidasjon til syntesegass

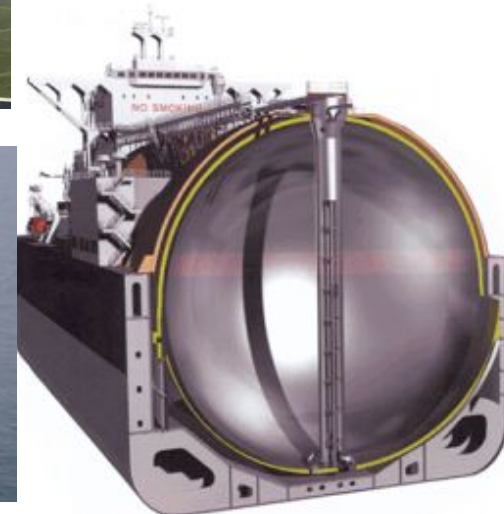
$$\text{CH}_4 + \frac{1}{2}\text{O}_2 = \text{CO} + 2\text{H}_2$$
- Dampreformering til syntesegass

$$\text{CH}_4 + \text{H}_2\text{O} = \text{CO} + 3\text{H}_2$$
- Vann-skift

$$\text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2$$
- Metanolsyntese

$$\text{CO} + 2\text{H}_2 = \text{CH}_3\text{OH}$$
- Dimerisering, eks.

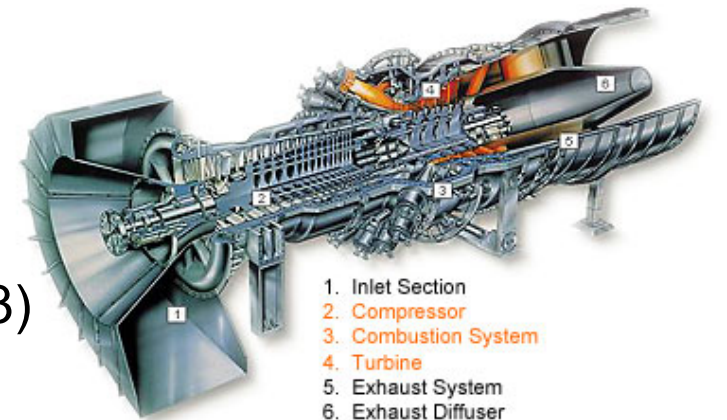
$$2\text{CH}_4 = \text{C}_2\text{H}_6 + \text{H}_2$$



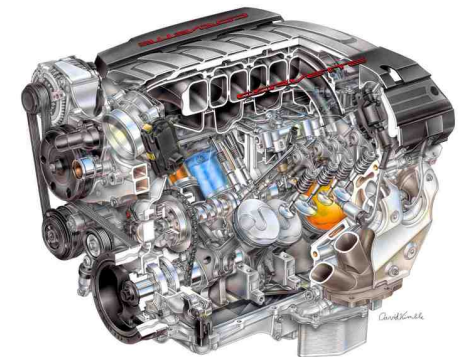
Dagens LNG-skip, utviklet av Kværner

Varmemaskiner

- Fossile brensel konverteres i all hovedsak til varme ved forbrenning, og videre til bevegelse ved varmemaskiner.
- Varmemaskiner er godt utviklet og moden teknolog.
- Begrenset effektivitet – Carnot-syklus (Kap. 3)
- Roterende maskiner - turbiner
- Reverserende maskiner - motorer

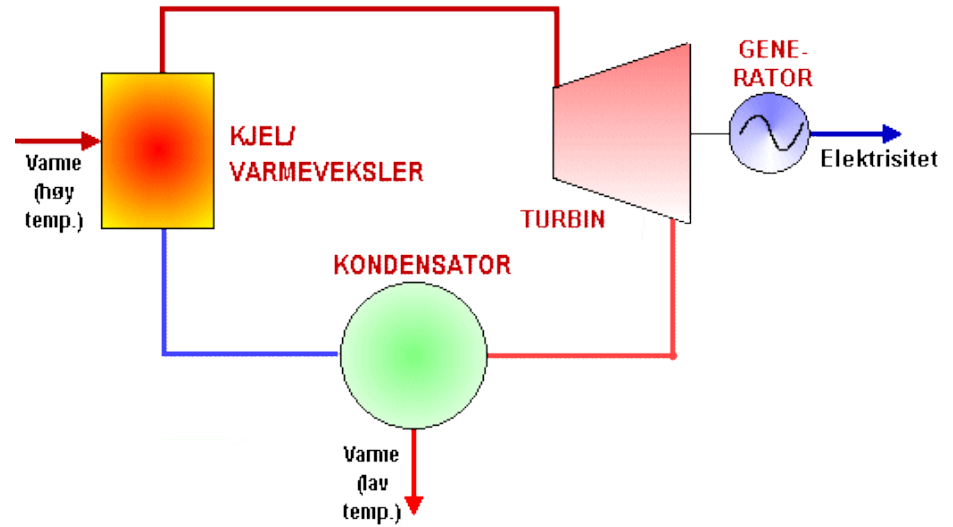


Courtesy of Siemens Westinghouse

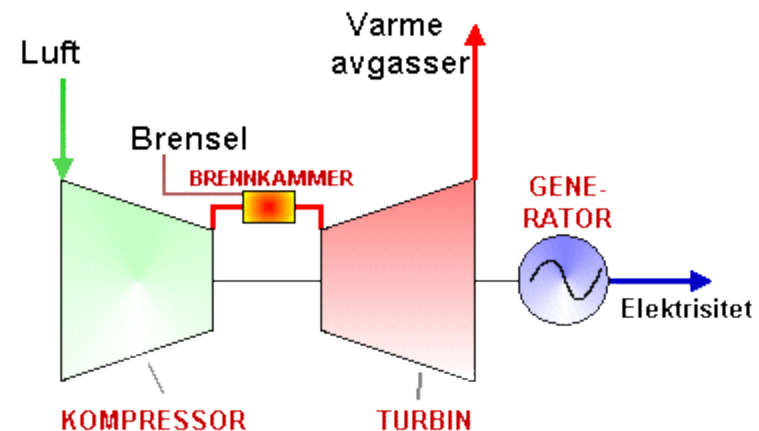


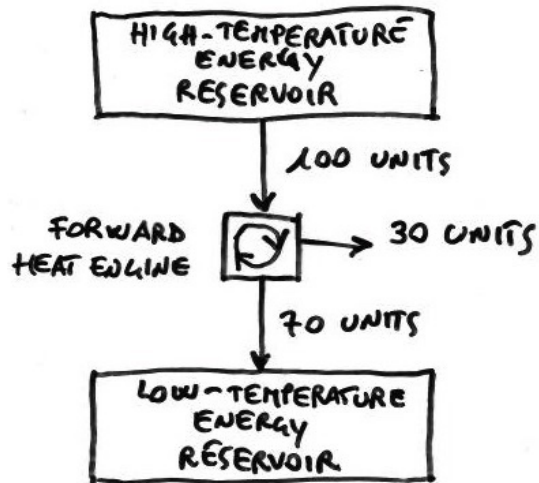
Varmemaskiner: Turbiner for ekspanderende gasser

- Dampturbin
 - Kjel



- Gassturbin
 - Brennkammer
 - Turbin
 - Kompressor



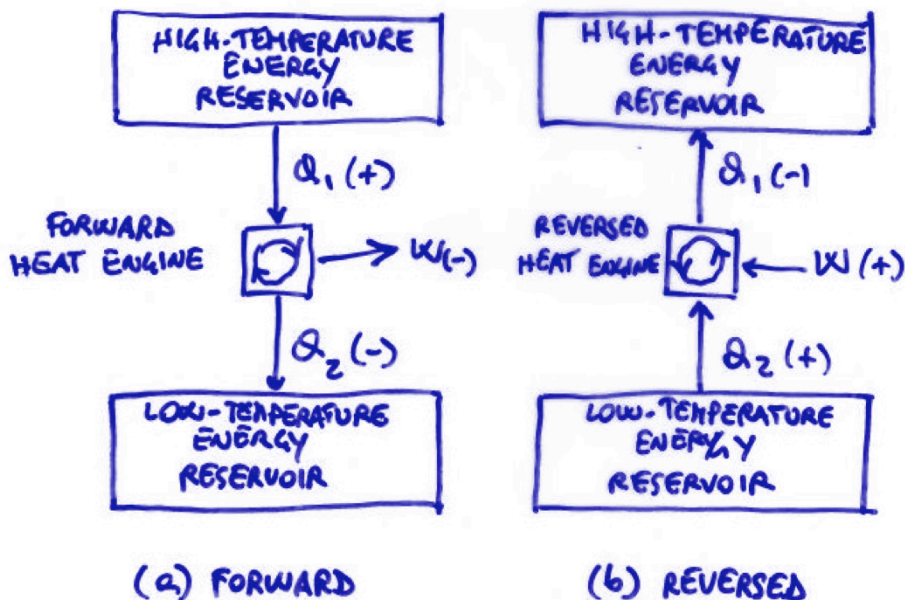


The heat supplied of 100 units (e.g. from the boiler which convert cold water into steam) equates to the work output of 30 units (e.g. by the steam on the turbine blades) plus the heat rejected of 70 units (e.g. in the condenser where steam is converted back to cold water)

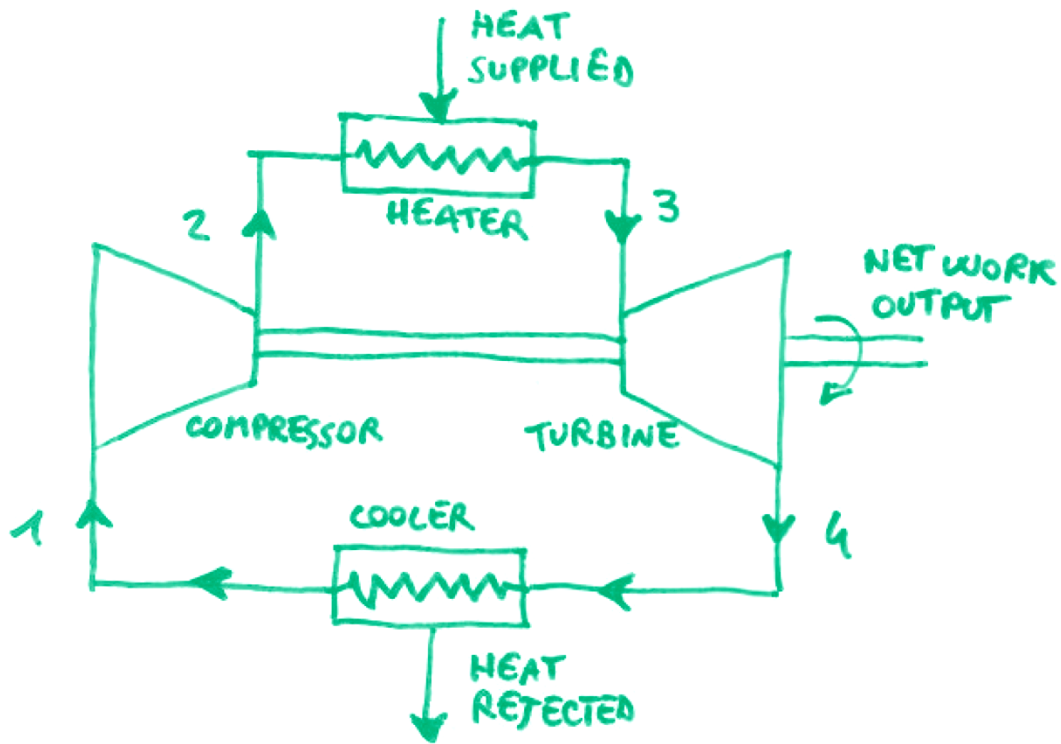
It is impossible to construct a forward heat engine in which 100 units of heat are supplied and 100 unit of work output are produced

First Law of Thermodynamics: when a system undergoes a complete cycle the net heat supplied plus the net work input is zero (based on the conservation of energy principle)

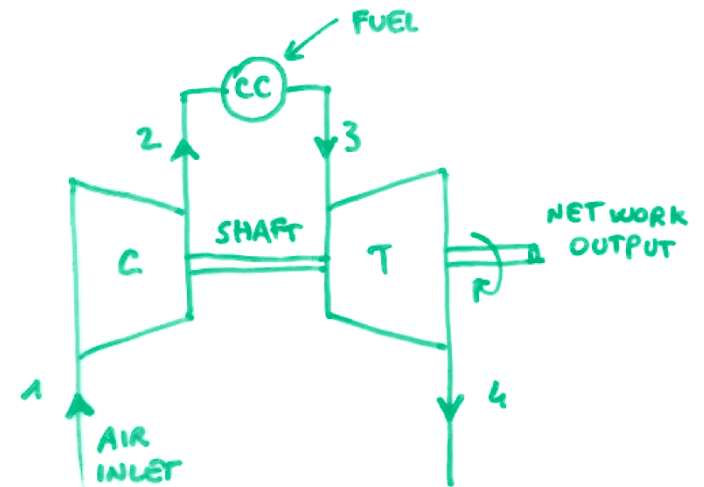
The Second Law of Thermodynamics: in any complete cycle the *gross* heat supplied plus the net work input must be greater than zero. Thus for any cycle in which there is a net work output (i.e. $W > 0$), heat must always be rejected



Heat engines



Gas turbine unit

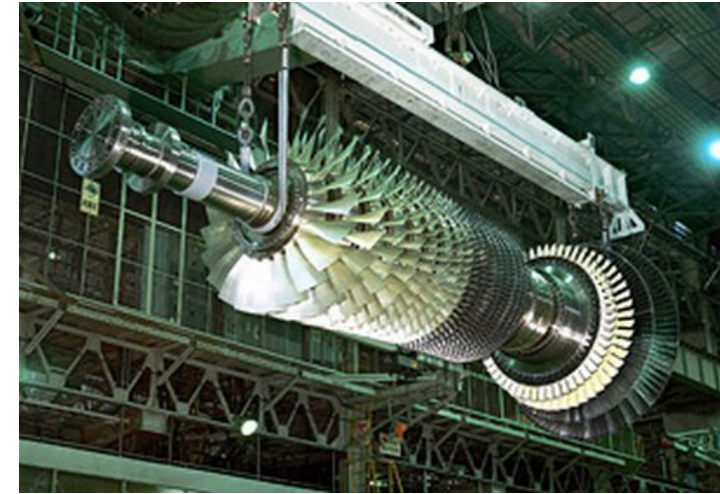
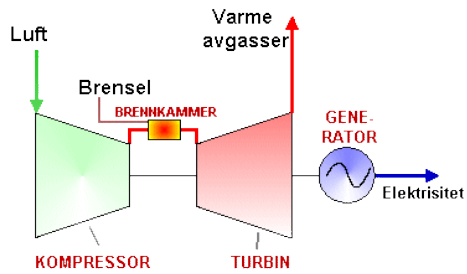


Practical Gas turbine with combustion chamber

Fra kjemisk til mekanisk energi; roterende motorer

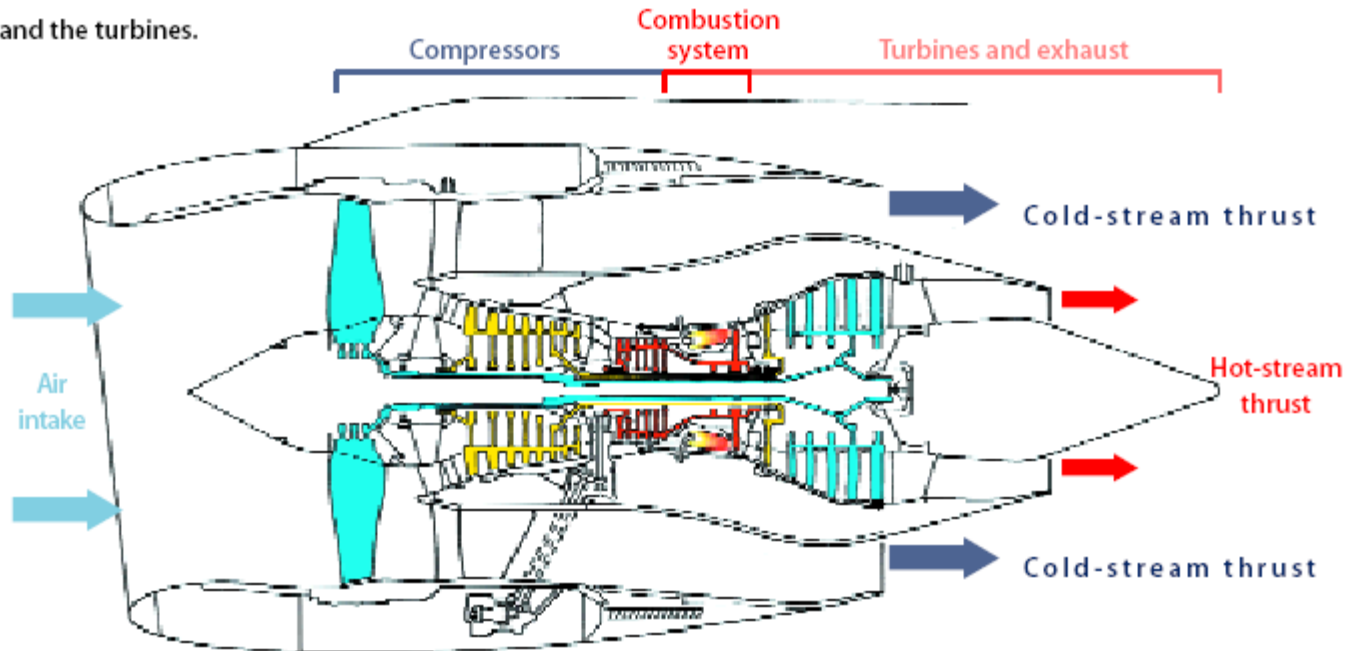
Gassturbin

Jetmotor



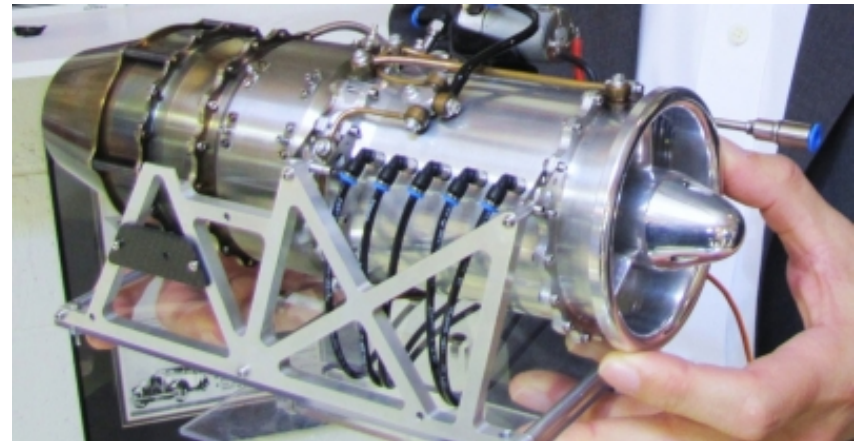
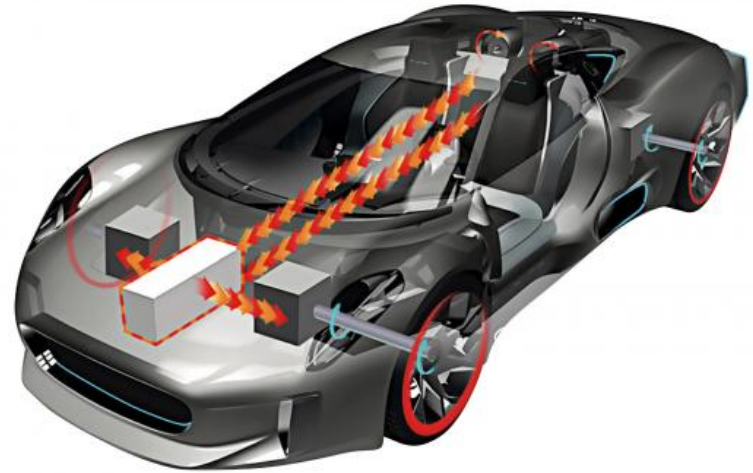
Layout of the gas turbine

The gas turbine has three main sections:
the compressors, the combustion system, and the turbines.



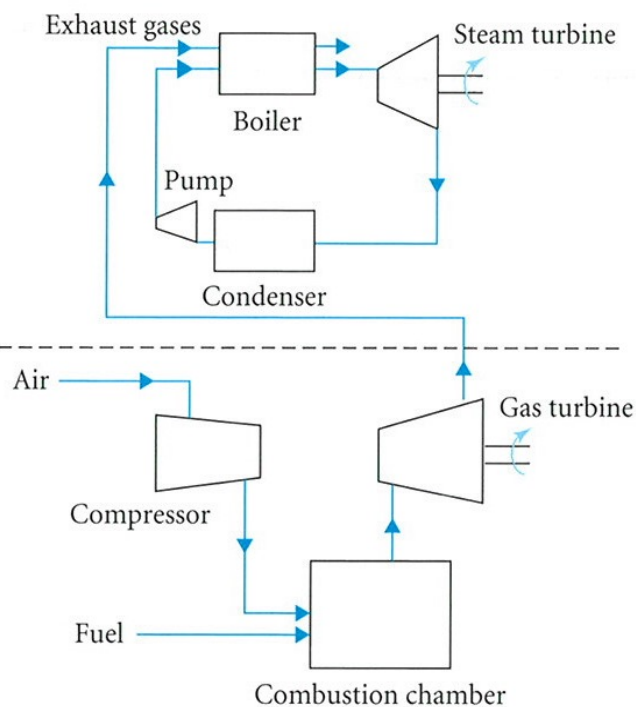
Jetmotor i biler?

- Jaguar CX 75 konsept
- Elbil med mikrogassturbin
“range-extender”

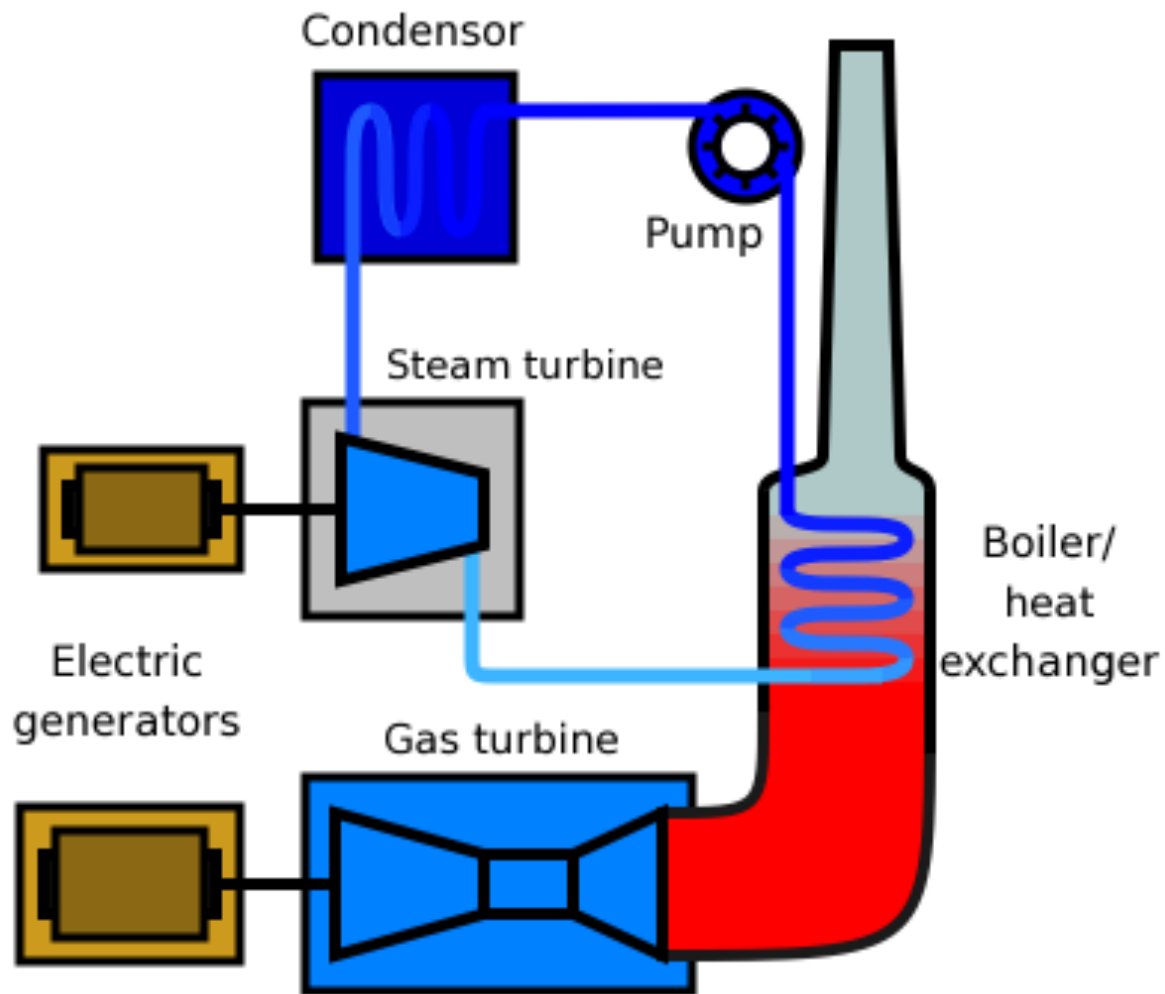


"Combined cycle" kraftverk

- Gassturbin
- Dampsturbin

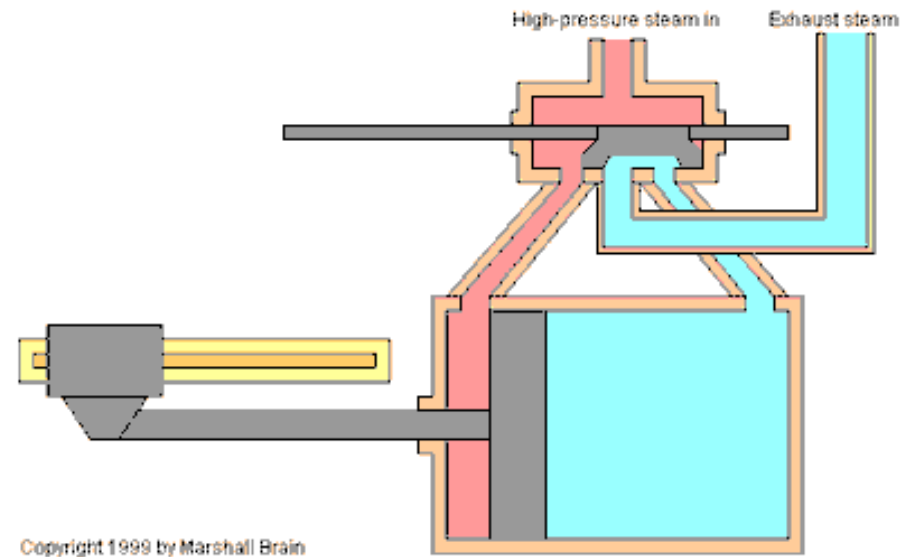
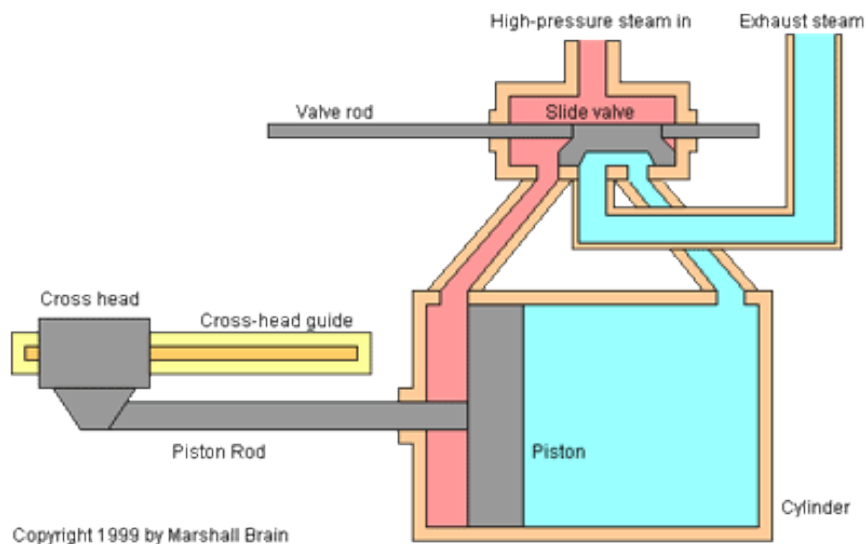


Combined cycle gas turbine (CCGT) generation



Fra kjemisk til mekanisk energi; reverserende motorer

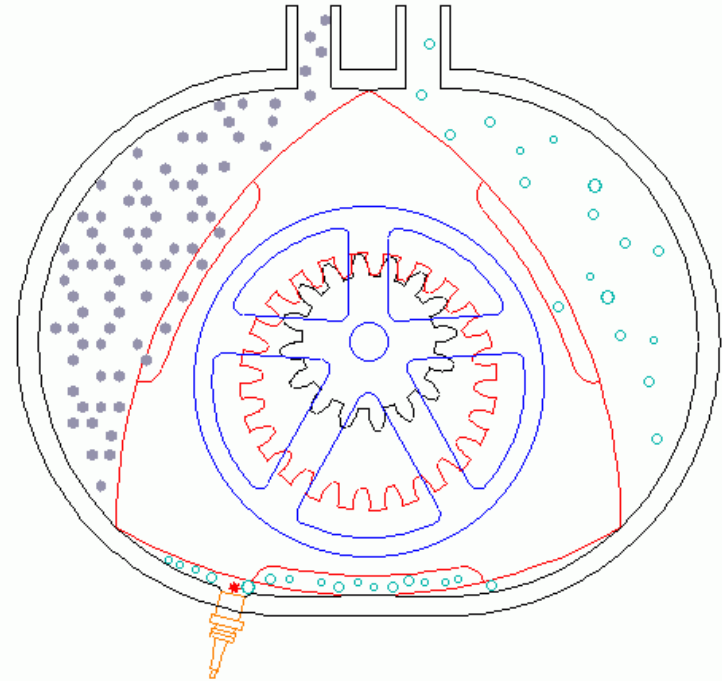
Dampmaskinen



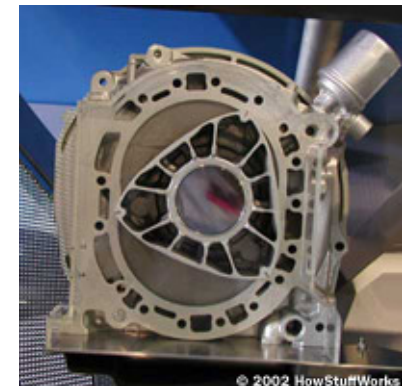
Fra kjemisk til mekanisk energi

Forbrenningsmotorer

- Reverserende
 - Velkjent
 - 1...n sylindre, 2- eller 4-takter
 - Otto
 - Eksplosjon tennes med gnist
 - Diesel
 - Eksplosjon skjer ved tilstrekkelig kompresjon
- Roterende
 - Wankel
 - Morsomt og i prinsippet effektivt design, men nå ute av produksjon



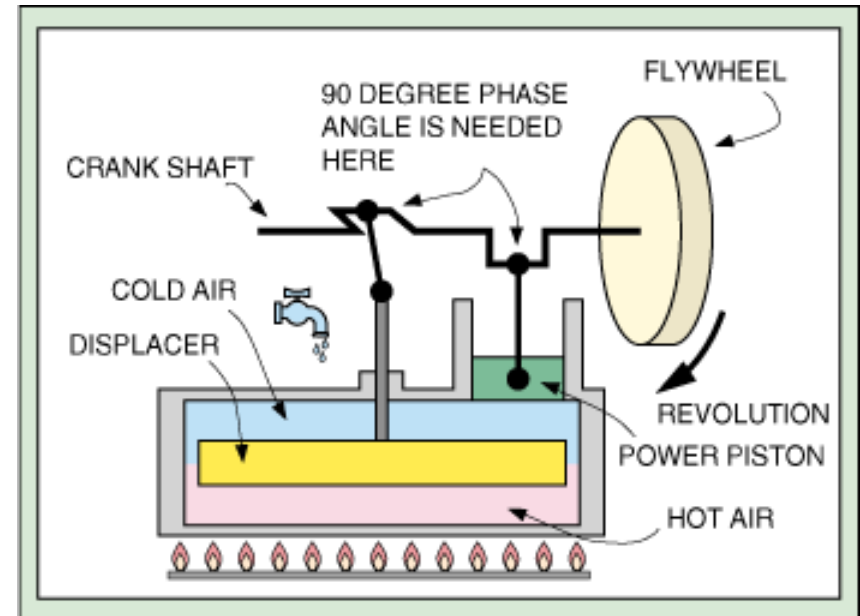
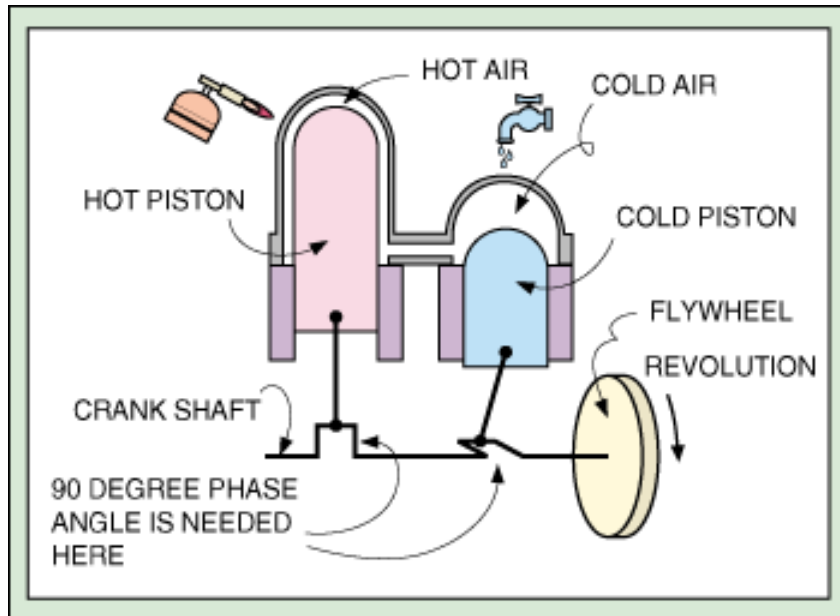
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Sterlingmotoren

- Lukket gassmengde
- Ekstern oppvarming og avkjøling
 - Kan bruke mange energityper; alt som avgir varme: brensel, elektrisitet, solvarme...
- I prinsipp effektiv og stillegående



Solvarme og stirlingmotorer

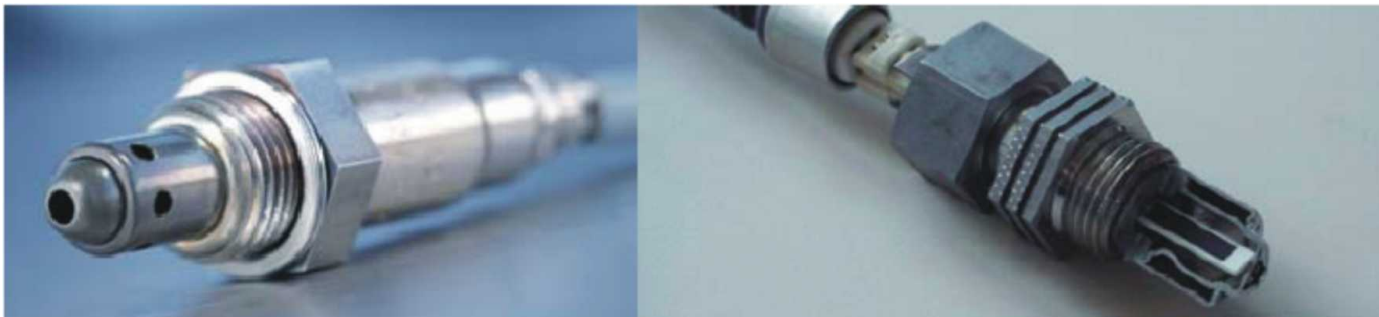
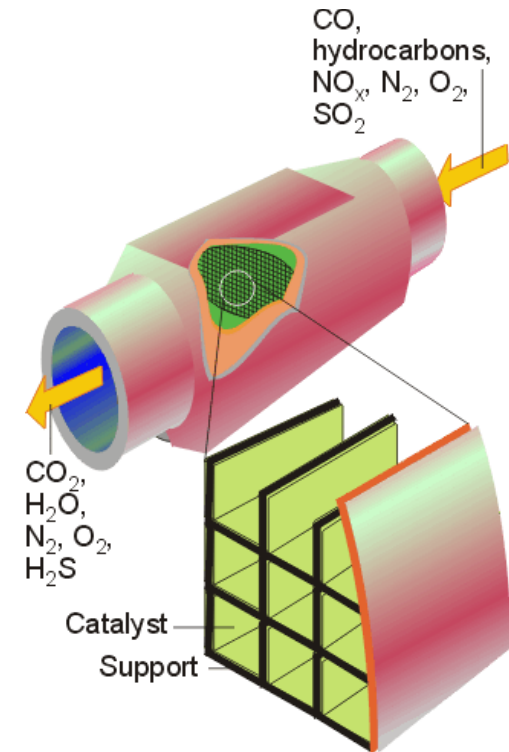


Virkningsgrad (effektivitet)

- = avgitt effekt dividert på tilført energi per tidsenhet
 - tilført energi oftest lik varmeinnholdet (reaksjonsentalpi) for brenselet
 - Virkningsgrad typisk 20% (bil) til 50% (gassturbin)
- Tap:
 - Irreversibel termodynamikk, Carnotsyklus
 - Varmetap
 - Ufullstendig brenselutnyttelse
 - Friksjon
 - Tomgang
 - Tapene blir til varme; kan utnyttes og øke total effektivitet
 - Dampturbin og generator
 - Termoelektrisk restvarmegenerator
 - Oppvarming av bil
 - Fjernvarme til hus

Avgassrensning og -kontroll

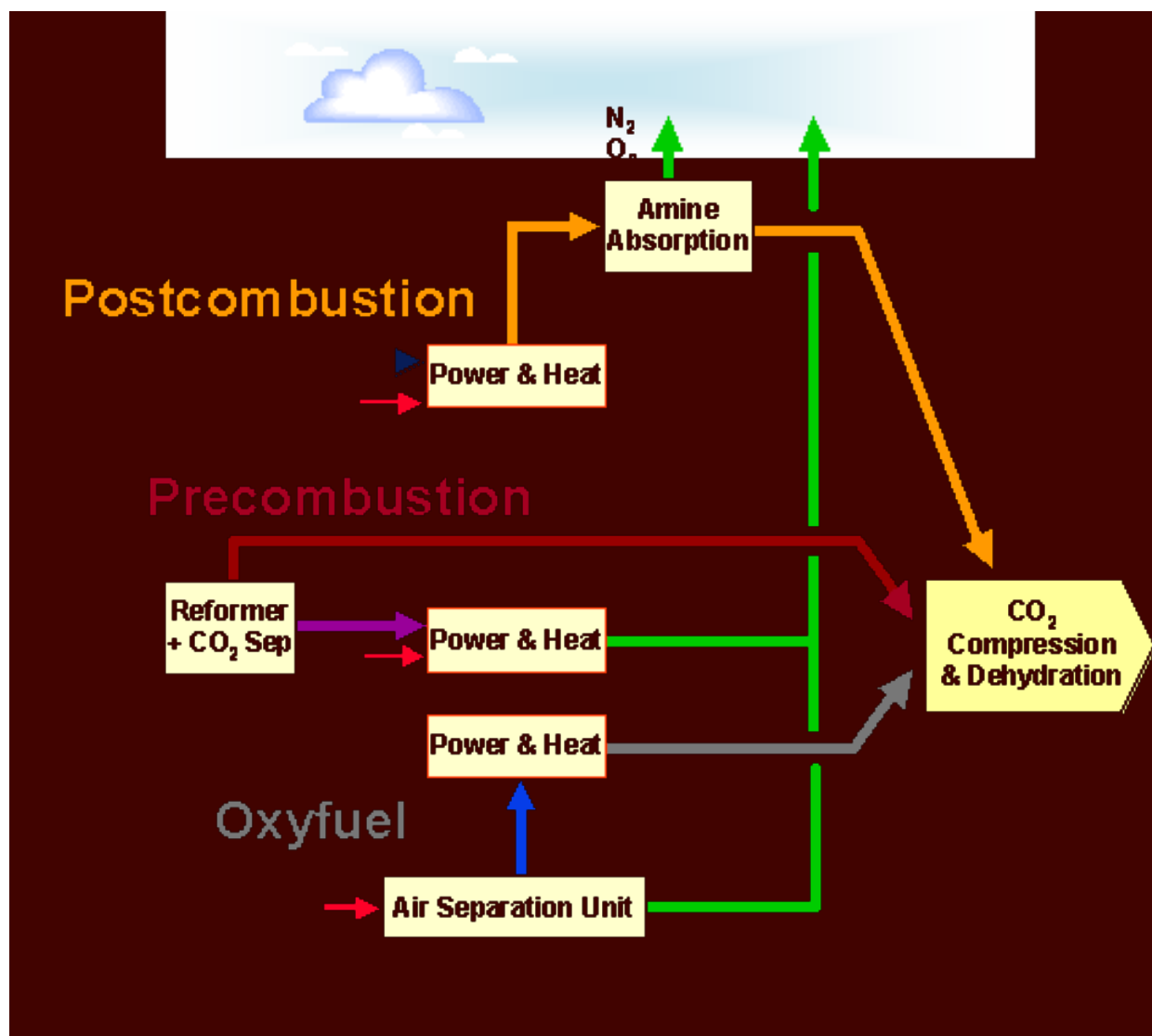
- For mye luft: NO_x
- For lite luft: Hydrokarboner og sot
- Feedback til motor og forgasser fra
 - Lambdasensor (pO_2)
 - NO_x -sensor



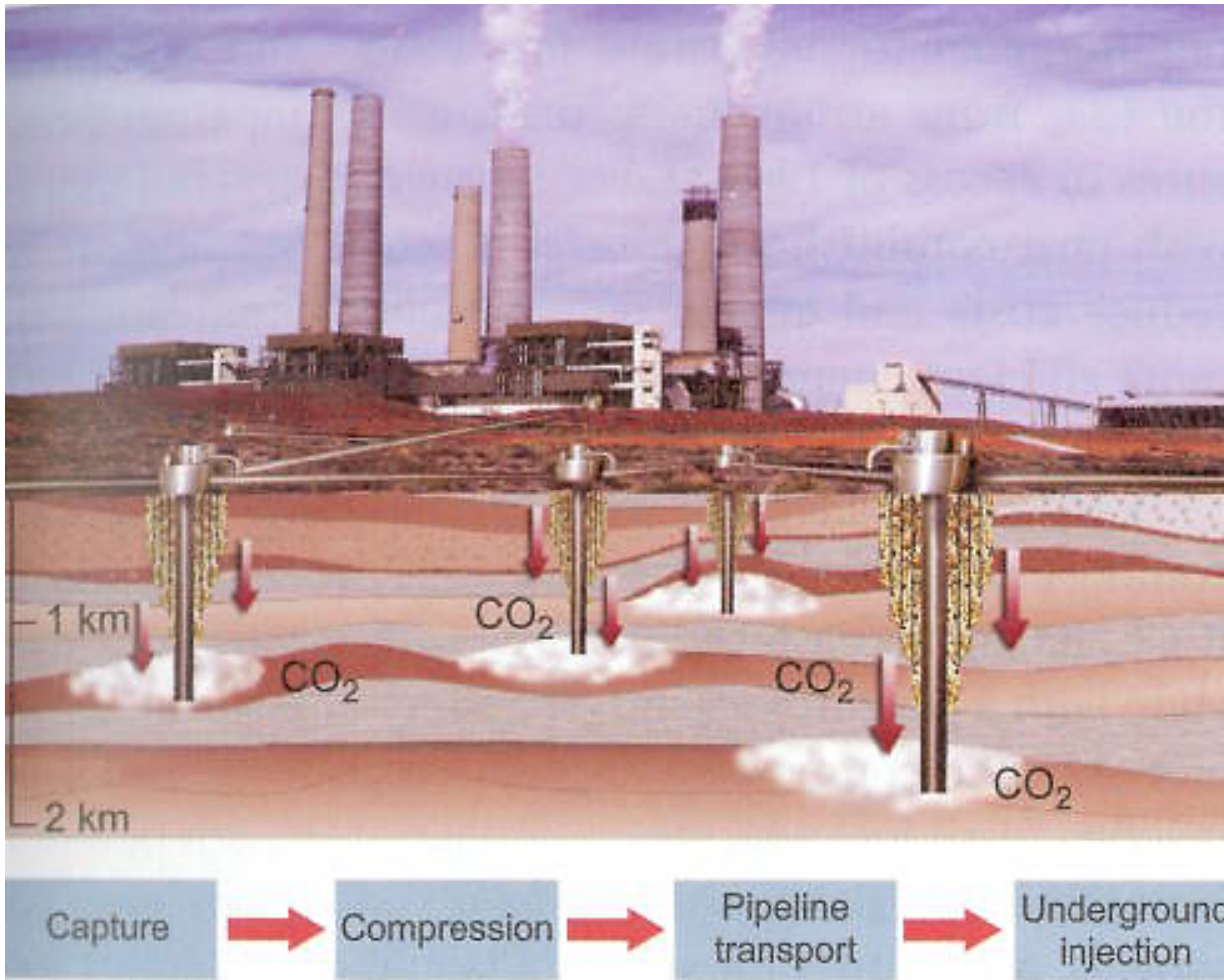
CO₂-separasjon – ”CO₂-fritt kraftverk”

- C eller CO₂ må mest mulig fjernes fra fossile brensel, og deponeres, slik at vi i praksis brenner bare hydrogenet

1. Separasjon av CO₂ før forbrenning (skille CO₂ fra H₂)
2. Separasjon av CO₂ etter forbrenning (skille CO₂ fra N₂ og H₂O)
 1. Amin-absorbsjon
 2. Alternative metoder
3. Separasjon av O₂ og N₂ i luft før forbrenning (skille CO₂ fra H₂O)
 1. Luftdestillasjon
 2. Membraner



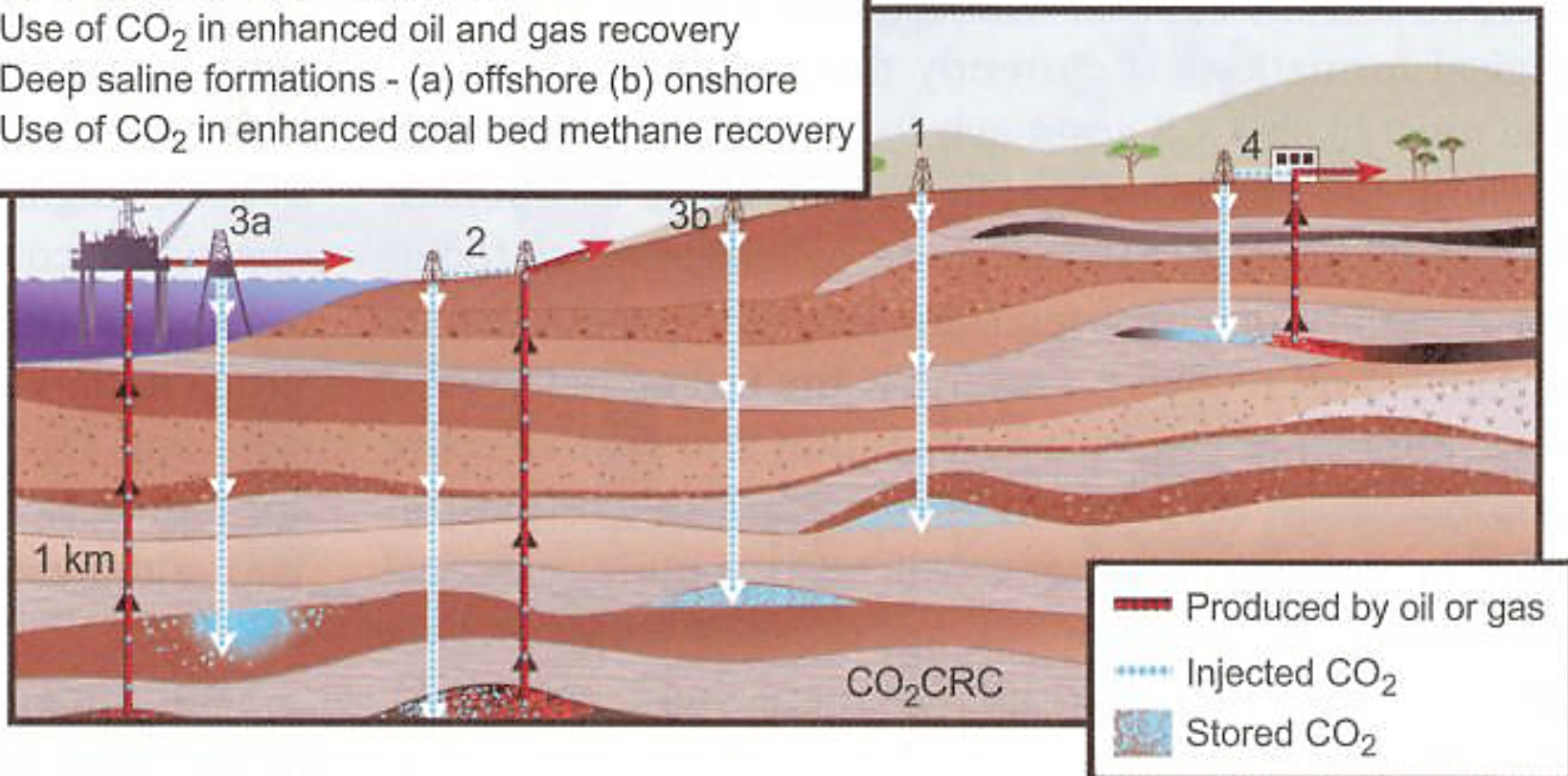
Four steps involved in CO₂ capture and sequestration



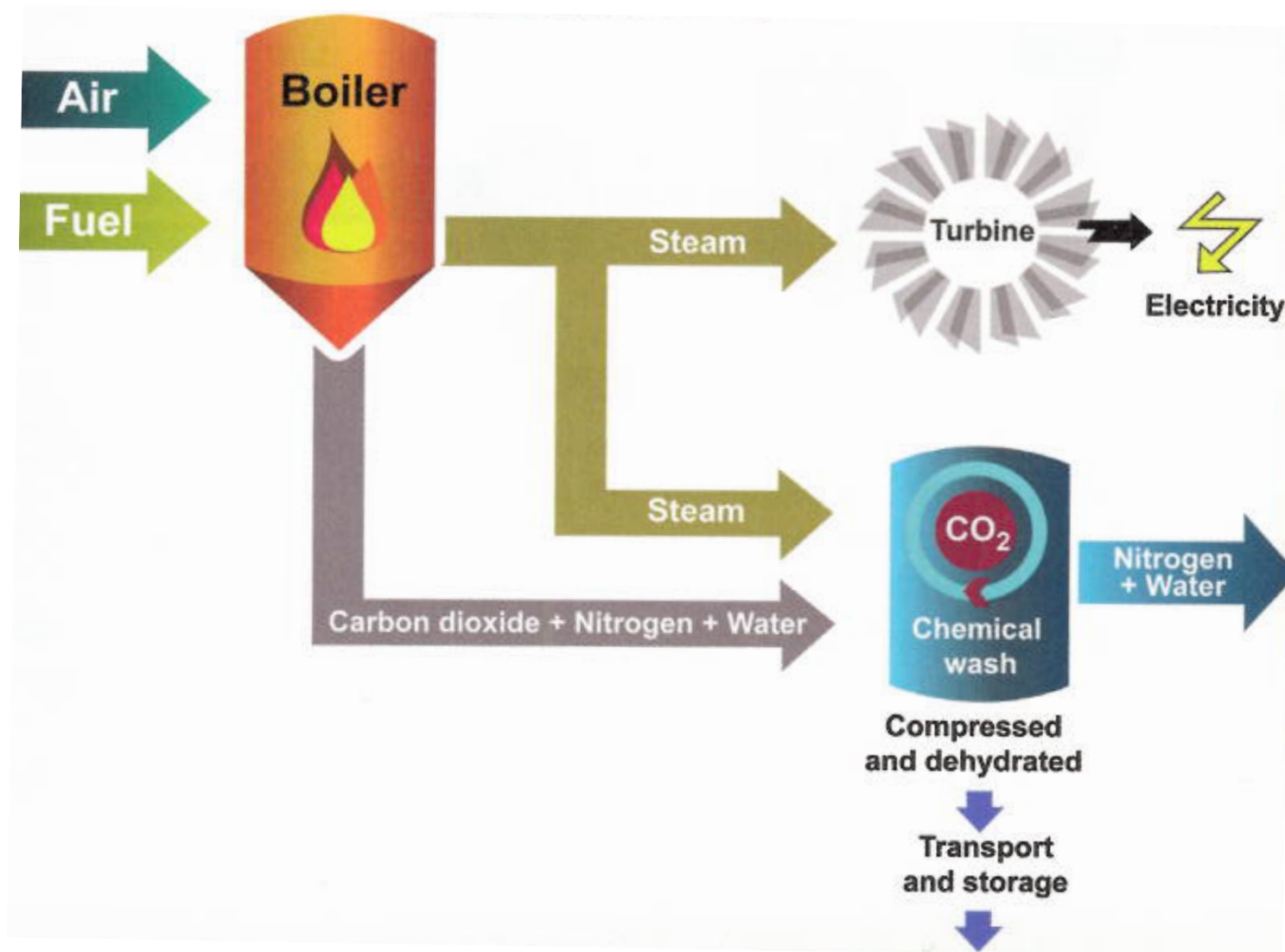
Options for geological storage of CO₂

Overview of geological storage options

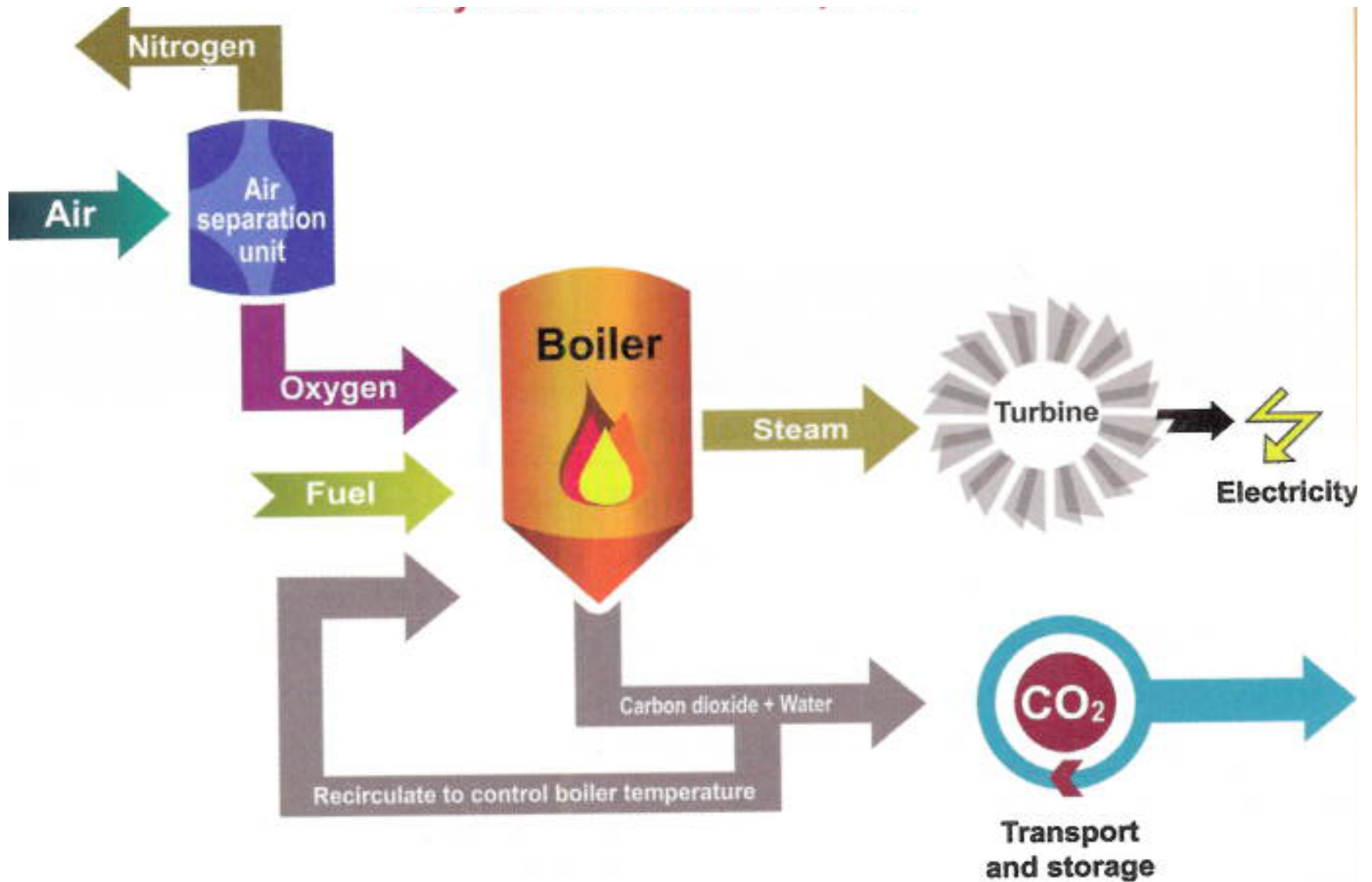
1. Depleted oil and gas reservoirs
2. Use of CO₂ in enhanced oil and gas recovery
3. Deep saline formations - (a) offshore (b) onshore
4. Use of CO₂ in enhanced coal bed methane recovery



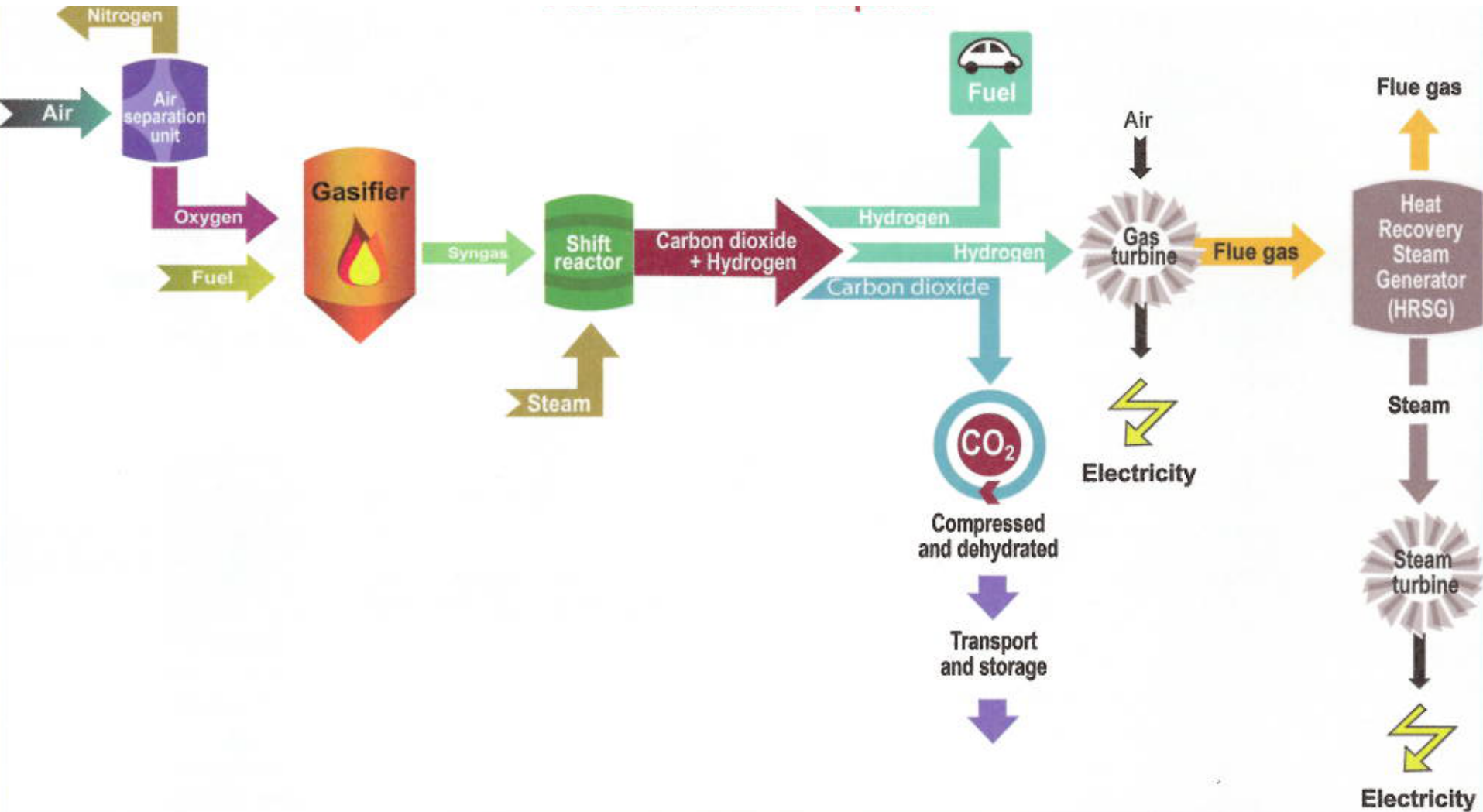
Post-Combustion Capture



Oxyfuel-Combustion Capture



Pre-Combustion Capture



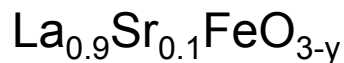
CO₂- og H₂-håndtering med blandede ledere for gasseparasjonsmembraner

Fra naturgass til syntesegass uten nitrogen

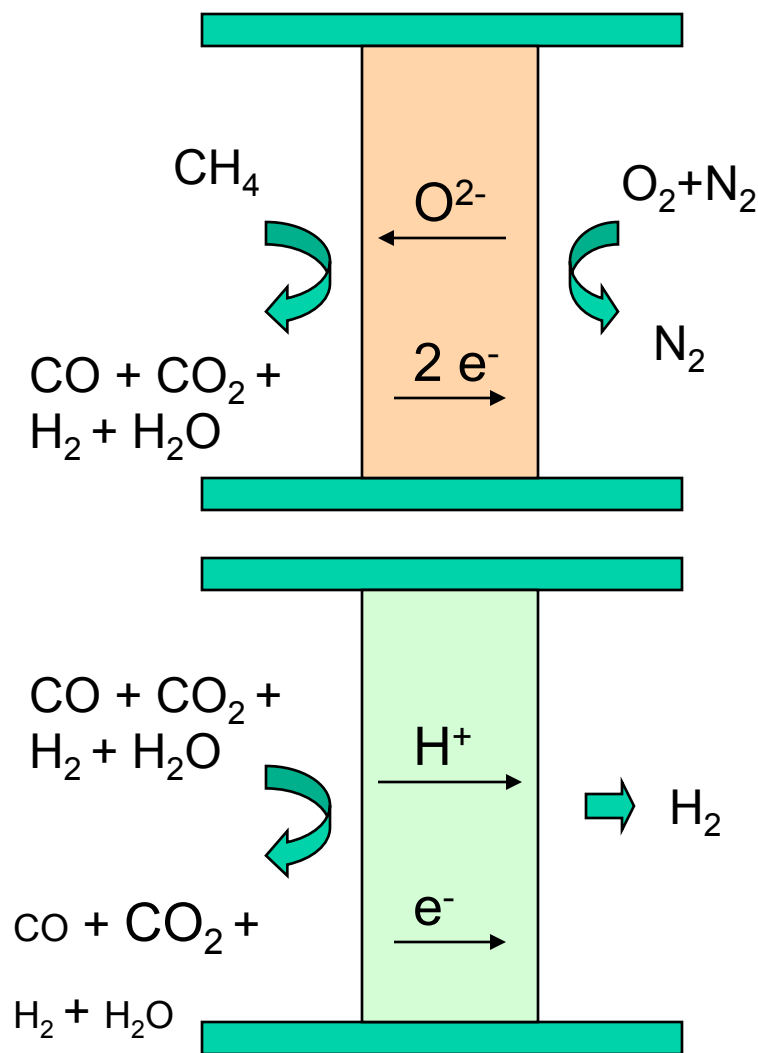
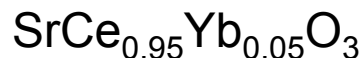
Ekstraksjon av hydrogen (med nitrogenet som sveipgass)

Deponering av CO₂

Eksempler på materialer:

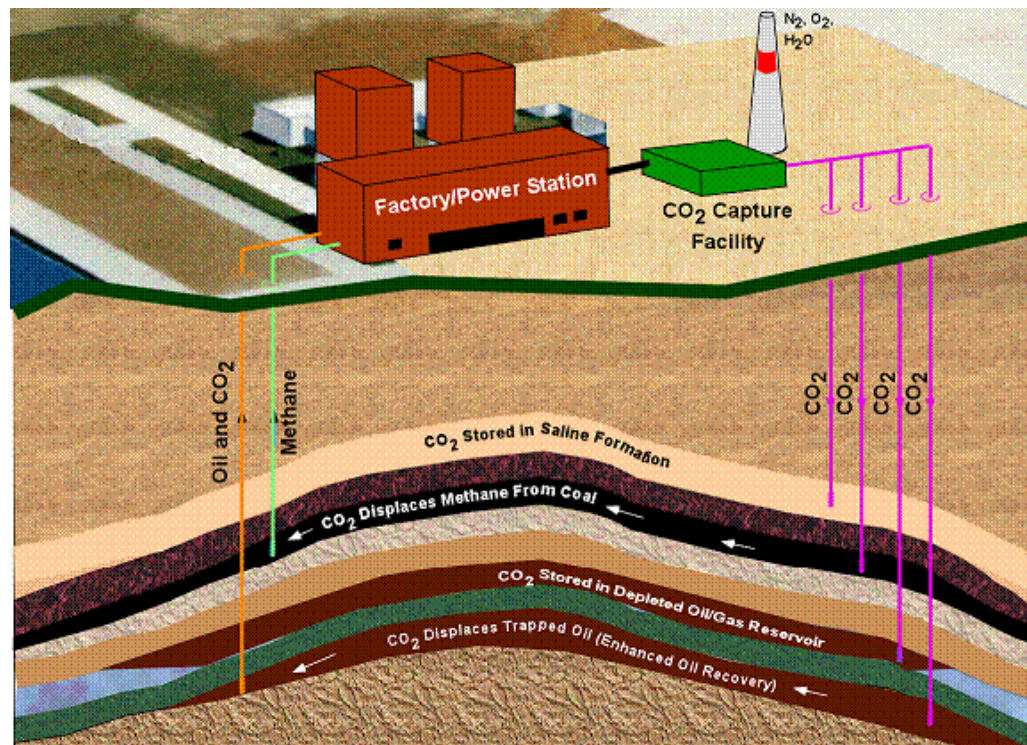
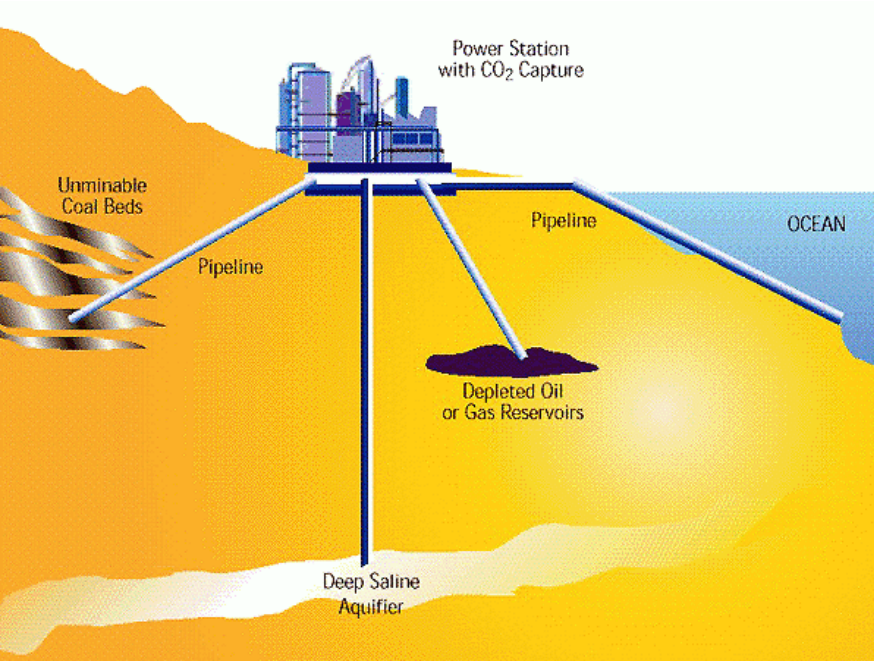


Pd



CO₂-deponering

Mange muligheter: mer et spørsmål om pris



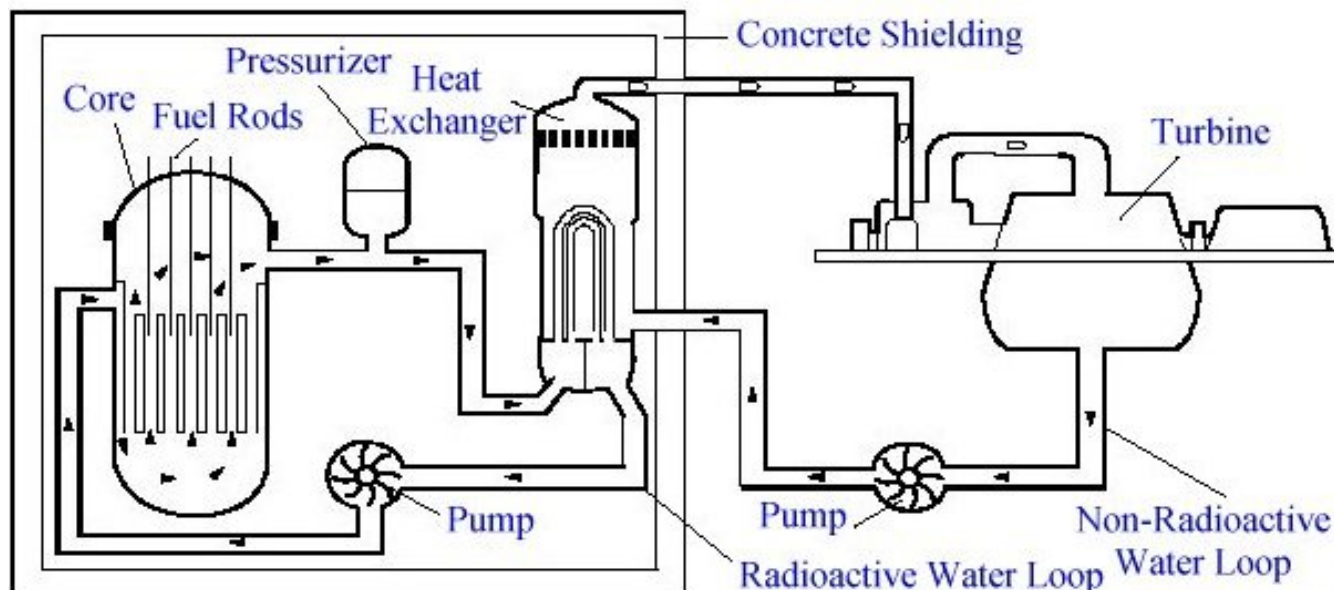
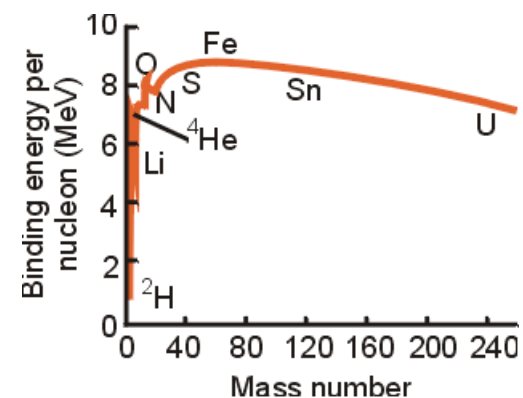
Figur: http://script3.ftech.net/~ieagreen/what_is_co2.htm

Fra fossil til fornybar energi

- Reservene av hydrokarboner varer ikke evig
 - CO₂ endrer trolig klimaet dramatisk
 - Overgang til ikke-fossil, fornybar energi er derfor nødvendig
 - Dette vil måtte gjøres over tid, fordi
 - fornybar energi er dyrere enn fossil
 - hydrogen fra fossile kilder er billigere enn fra fornybare
 - fornybar energi er oftest vanskeligere å transportere og lagre
 - overgangen krever tid og mye ekstra energi (materialer, anlegg...)
- Redskaper:
 - Bedre bruk av fossil energi
 - Utbygging av fornybar energi
 - Energieffektivisering
 - + kombinasjoner
 - Krever nye og bedre prosesser og materialer (derfor MENA1000!)

Kjernekraft - fisjon

- Uran; flere isotoper; ^{238}U (stabil) og ^{235}U
- Anriker uran på ^{235}U ved filtrering av $\text{UF}_6(\text{g})$
- $^{235}\text{U} + \text{n}$ ("kaldt") = $^{236}\text{U} = ^{92}\text{Kr} + ^{142}\text{Ba} + 2\text{n} + \text{energi}$
- En fisjonsreaktor har
 - brenselstaver med ^{235}U
 - absorptorstaver (eks. Cd)
 - moderatorstaver (eks. grafitt, H_2O)
 - kjølemiddel (H_2O , D_2O)




Problemer med kjernekraft

- Kjernefysiske våpen
 - Atombomben (fisjon)
 - Hydrogenbomben (fusjon)
- Ulykker, terrorhandlinger
- Lagring av avfall
 - Nedbrytning og korrosjon av innkapslingsmaterialer
- Hvem bestemmer hvem som får lov til å ha kjernekraftverk?





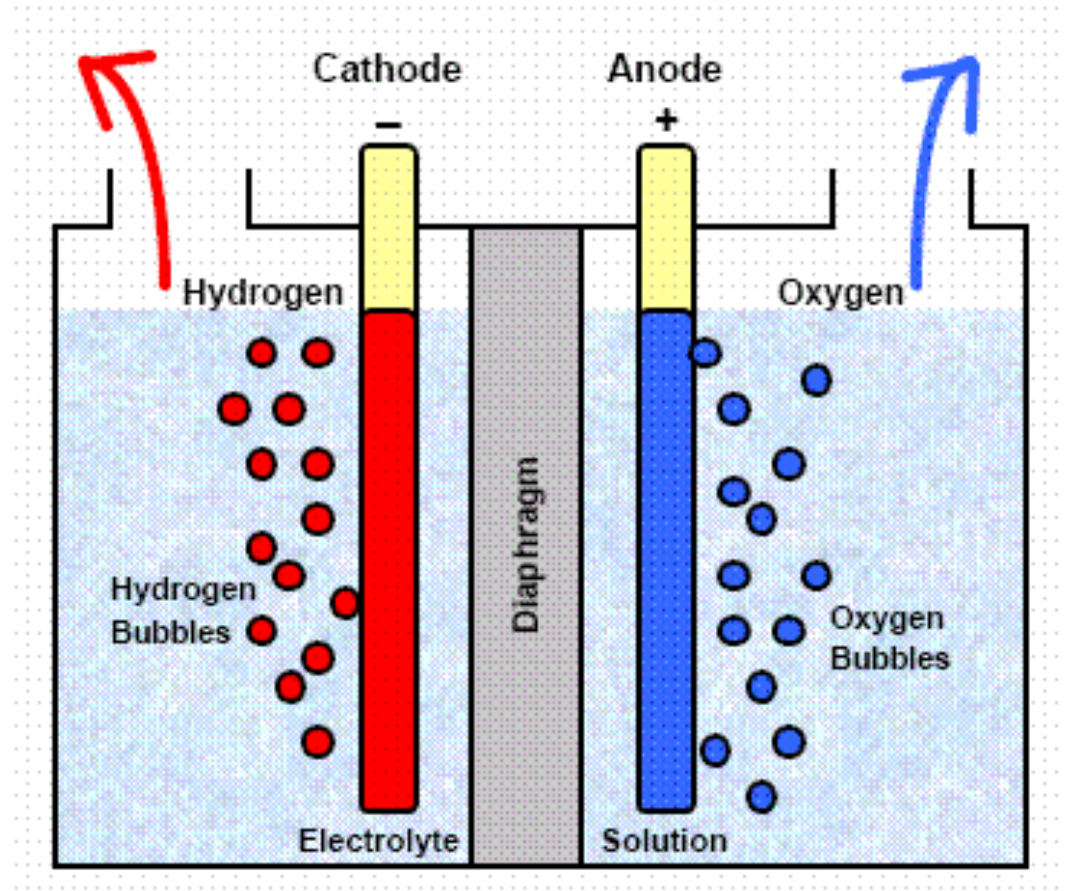


HYDROGEN IS
ABUNDANT — FOUND
IN THE WATER THAT
ENVELOPS 70% OF THE
EARTH.

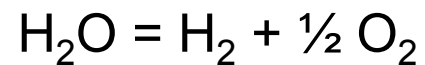
But H is combined with other elements:
we need to produce H₂!

- From water (H₂O: electrolysis)
- From methane (natural gas reformation with steam $\text{CH}_4 + 2\text{H}_2\text{O} = 4\text{H}_2 + \text{CO}_2$)
- From biomass (reach in C and H, to produce liquid and gaseous fuel which could be reformed into H₂)

Electrolysis to produce H₂



We consume electricity for the reaction



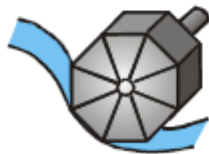
Hydrogen cycle



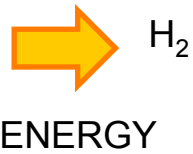
Solar power



Wind energy

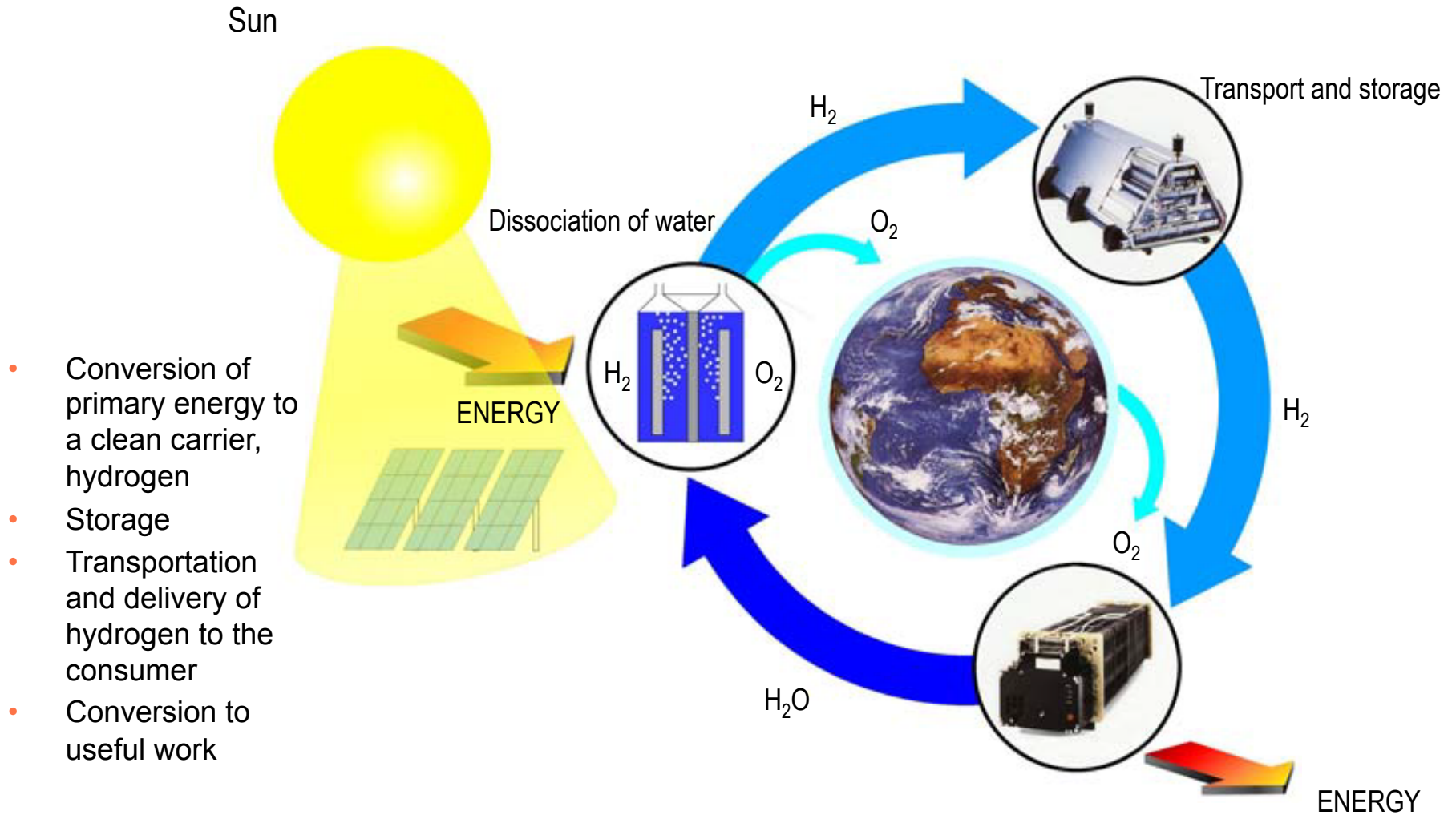


Water

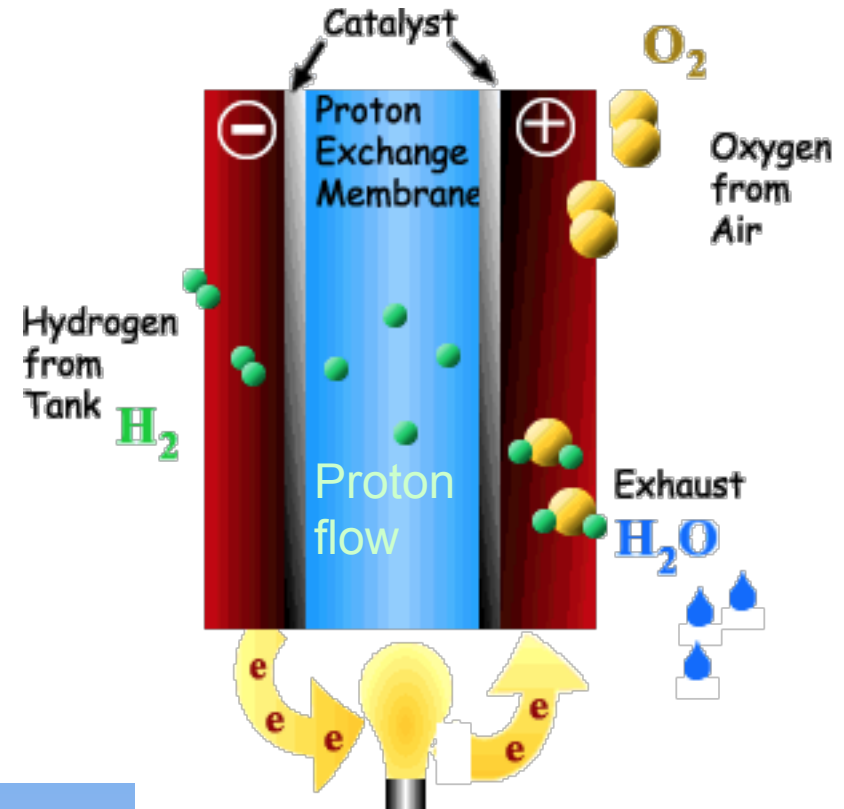
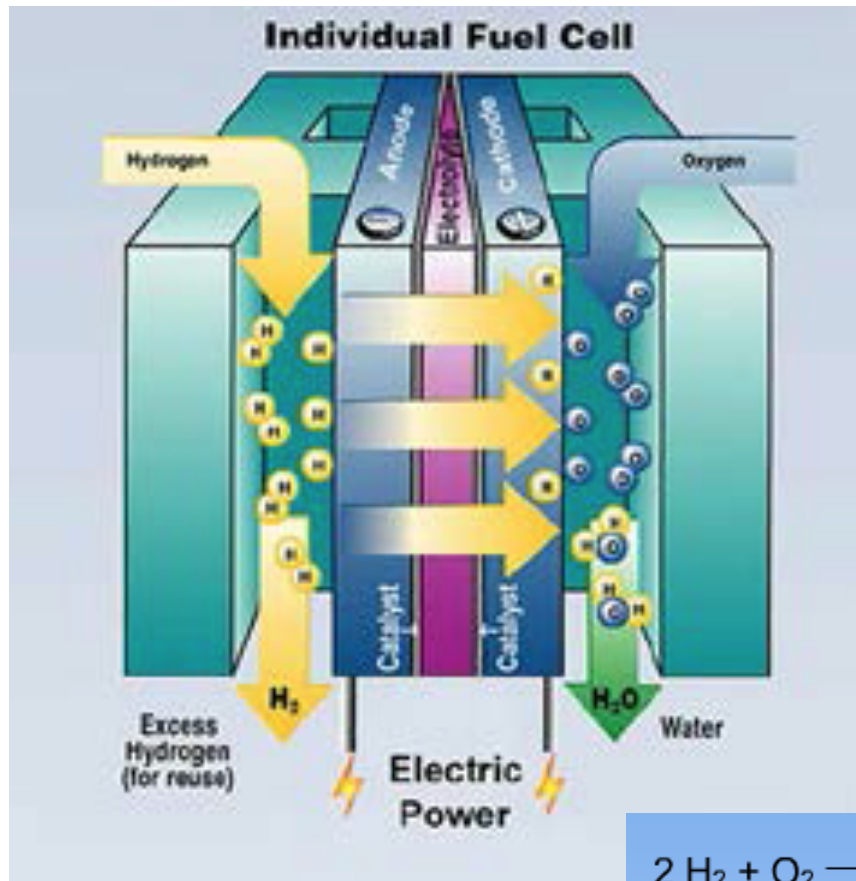


Conversion of primary energy to a clean carrier, hydrogen

Hydrogen cycle



Opposite process: fuel cell as source of electrical power



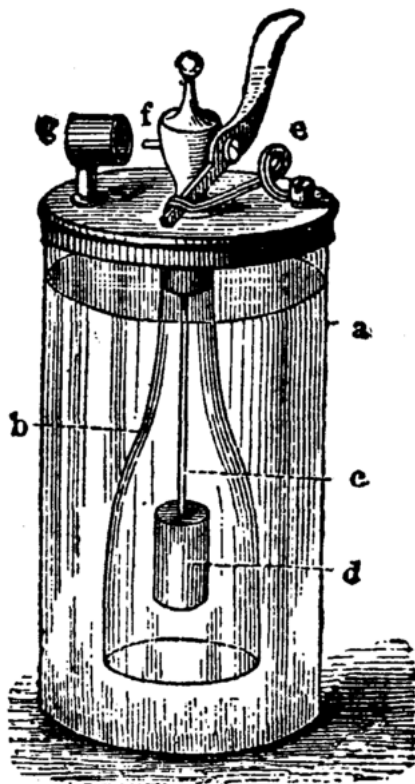
We produce electricity

Where it all started

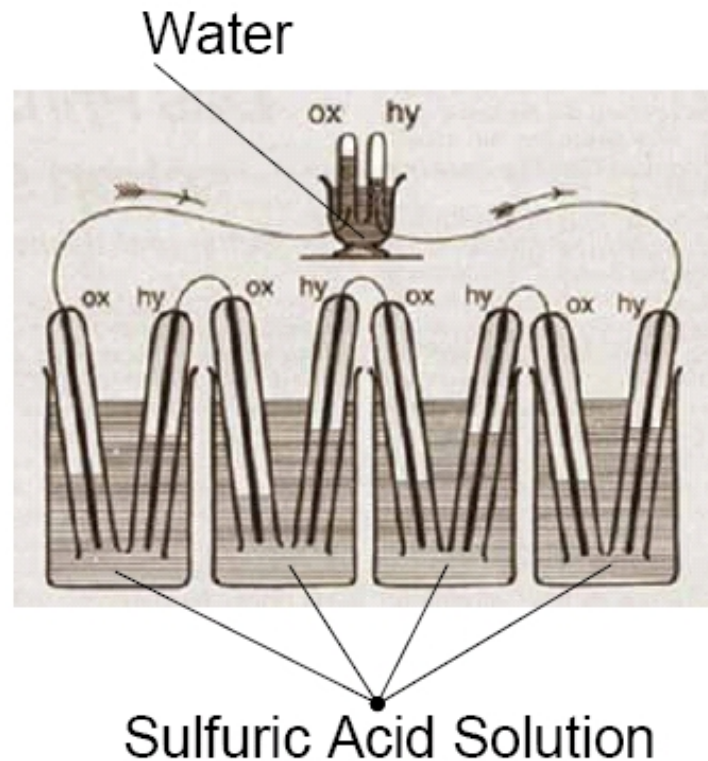


Antoine Lavoisier (1743-1794)

In 1787, Academy of Science in Paris: "for inflammable air I propose the world *hydrogene*" based on the Greek word *hydor*, meaning water forming



The Doebereiner Platinum "pocket" lighter to light cigars. H_2 by $Zn + \text{acid}$. Over 20.000 sold!!!



Sir William Robert Grove demonstrated in 1839 the **first fuel cell** with four galvanic elements in series. H_2 and O_2 combined to produce electricity and water. But with the discovering of dynamoelectric conversion of mechanical energy, fuel cells lost importance

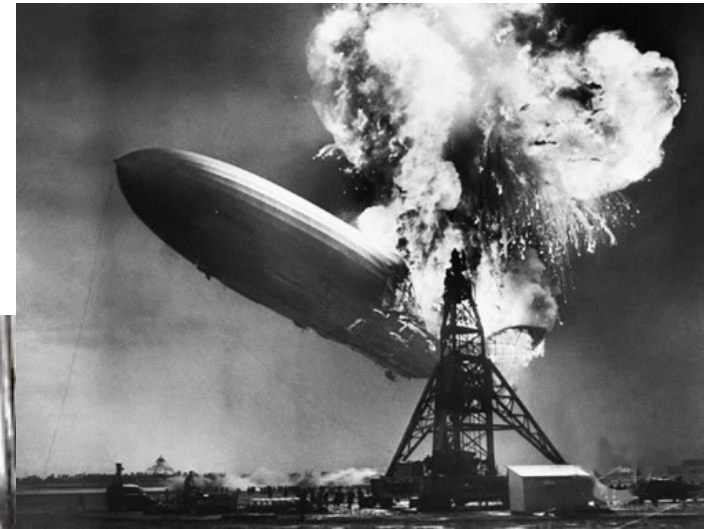
Hydrogen in transportation



1807, Swiss inventor Francois Isaac de Rivaz. Working on hydrogen (contained in a balloon) and oxygen gas



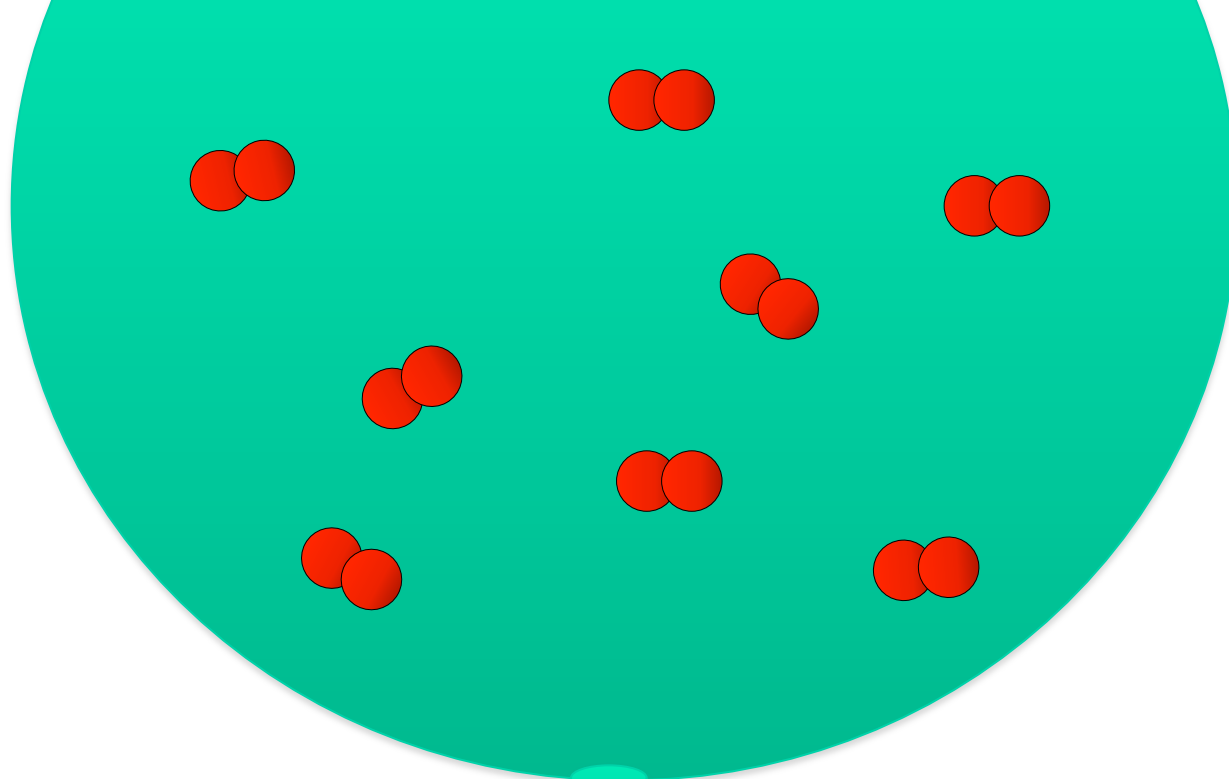
1860, 3-wheel Hippomobile by Etienne Lenoir
Hydrogen by electrolyzing water

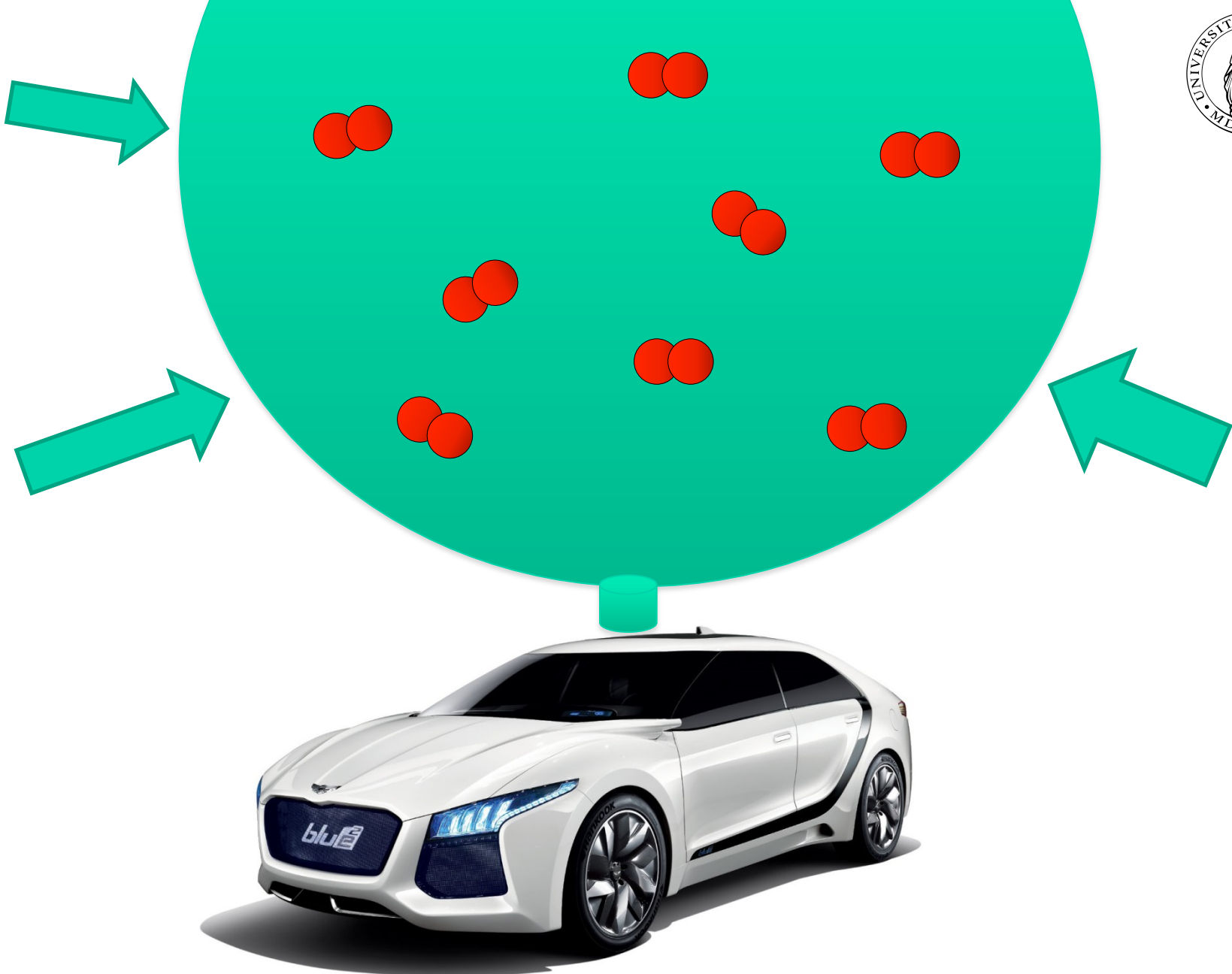


May 6, 1937, at 19:25
German zeppelin
Hindenburg

How big is a balloon full of 4 kg hydrogen gas at room temperature?







Methods for storage



Powders



-253° C

Liquid



Compressed gas

Potential applications for hydrogen & fuel cells



Fuel Cell Forklifts



HydroStik cartridge



Mobile Lighting



Fuel Cell Baggage Tug



Lilliputian charger



Backup Power



Power Trekk charger



Fuel Cell Extended Range Vehicles



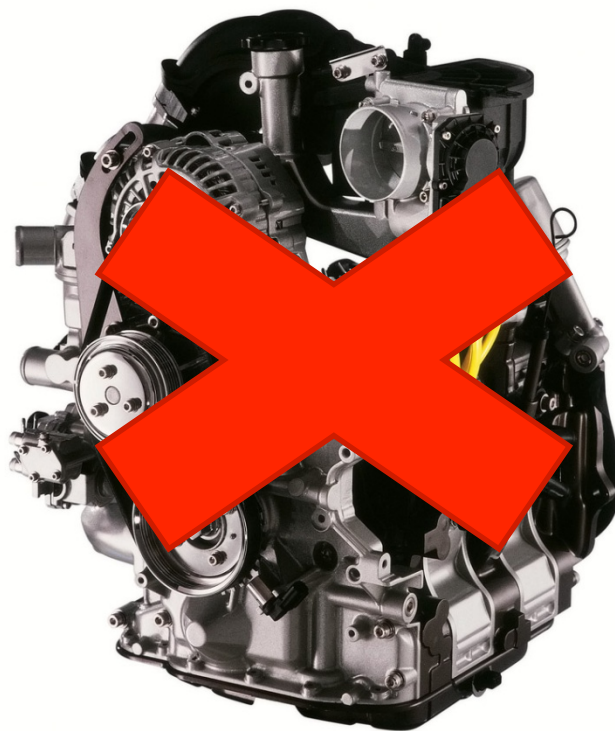
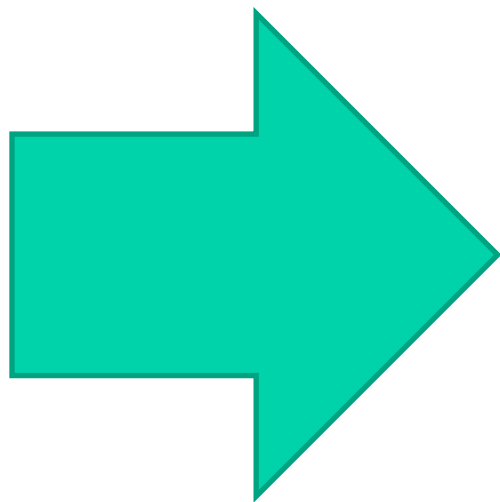
Long distances 400 – 700 km

100% renewable

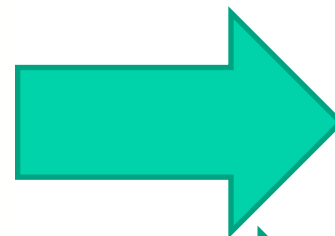
Why Hydrogen cars?

No pollution, only water

Energy
(petrol)



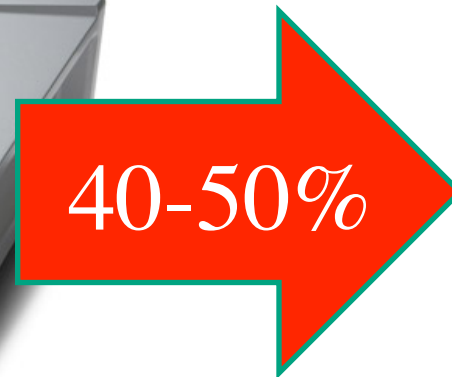
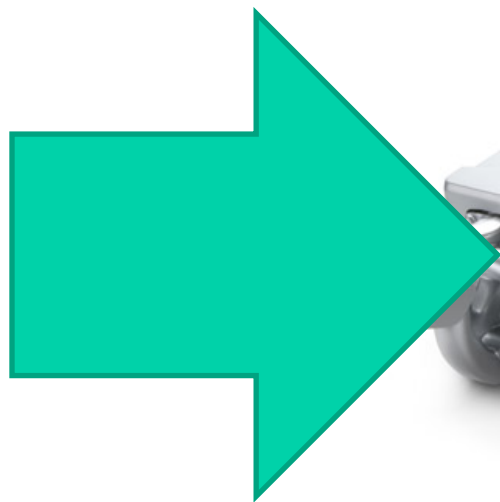
Running



Heat loss

Energy
(H₂)

Running



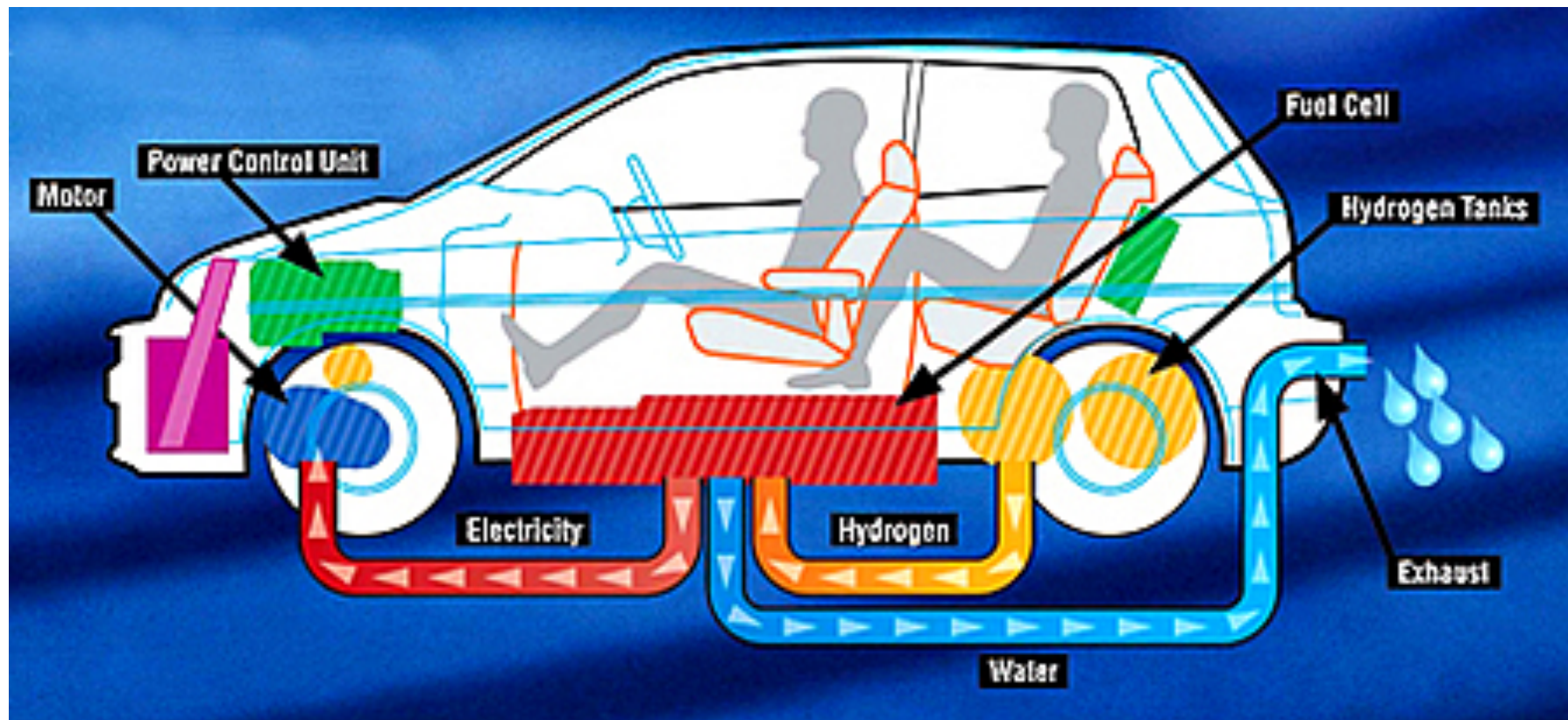
Fuel cell

Heat loss

Hydrogen: 3 x energy/kg
compared to petrol



How a hydrogen car look like



Weighth and Volume of various energy storage systems (500 km range)

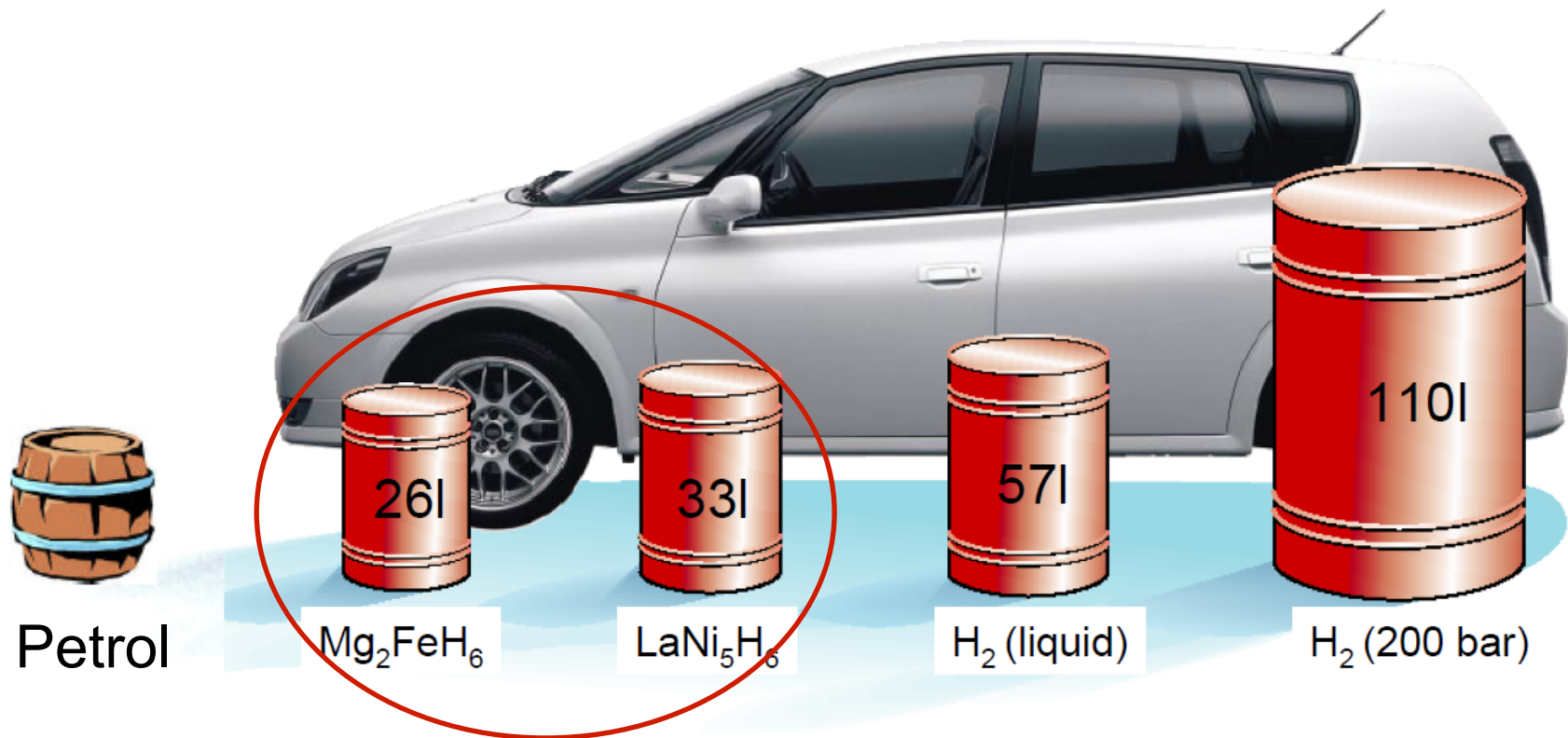


	Diesel	CNG	CGH₂ 700 bar	Li-ion battery
System	43 kg 46 L	170 kg 200 L	125 kg 260 L	830 kg 670 L
Fuel	33 kg 37 L	37 kg 156 L	6 kg 170 L	540 kg 360 L

Volume of hydrogen compacted in different ways

4 kg hydrogen

3 l gasoline / 100 km = 0.3 kWh / km



Research on the effective powder to store hydrogen

PEFC H₂-biler; status/eksempler

- Mercedes B-klasse FCELL
 - Kommersielt salg 2013..2015..2017



- Toyota
 - Fra Prius til Hydrogen FCV
 - Starter kommersiell produksjon nå
 - Kommersielt salg 2015



- Hyundai
 - iX35 FCV kan nå kjøpes kommersielt (2013)
 - 600 km rekkevidde, 100 kW
 - 1 kg H₂ per 100 km

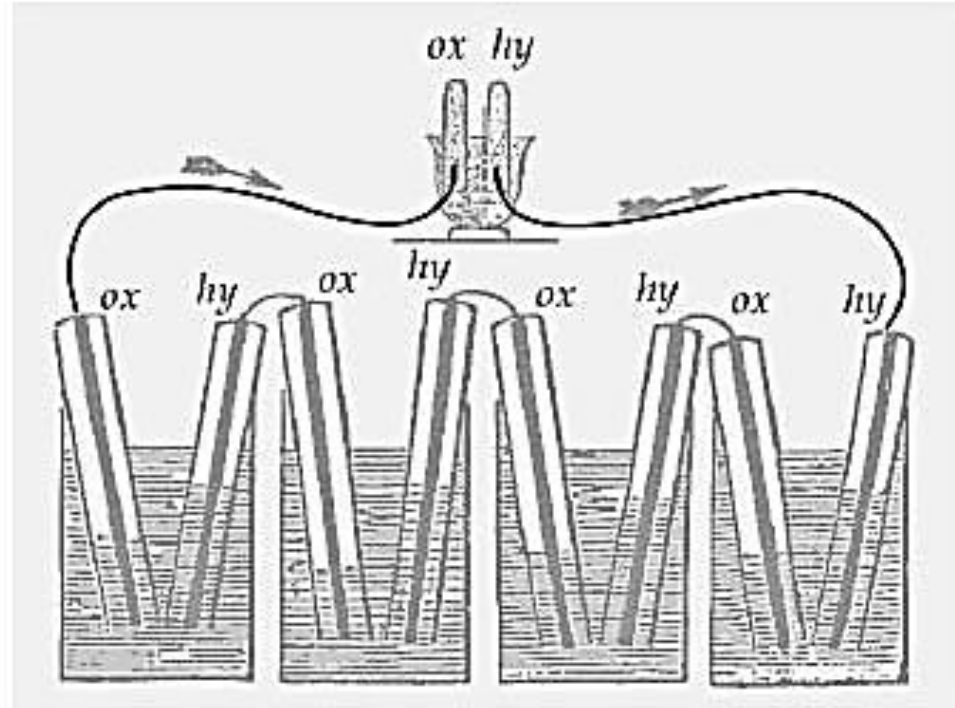


- Nissan, Honda, GM, ...



Fra kjemisk til elektrisk energi Brenselceller

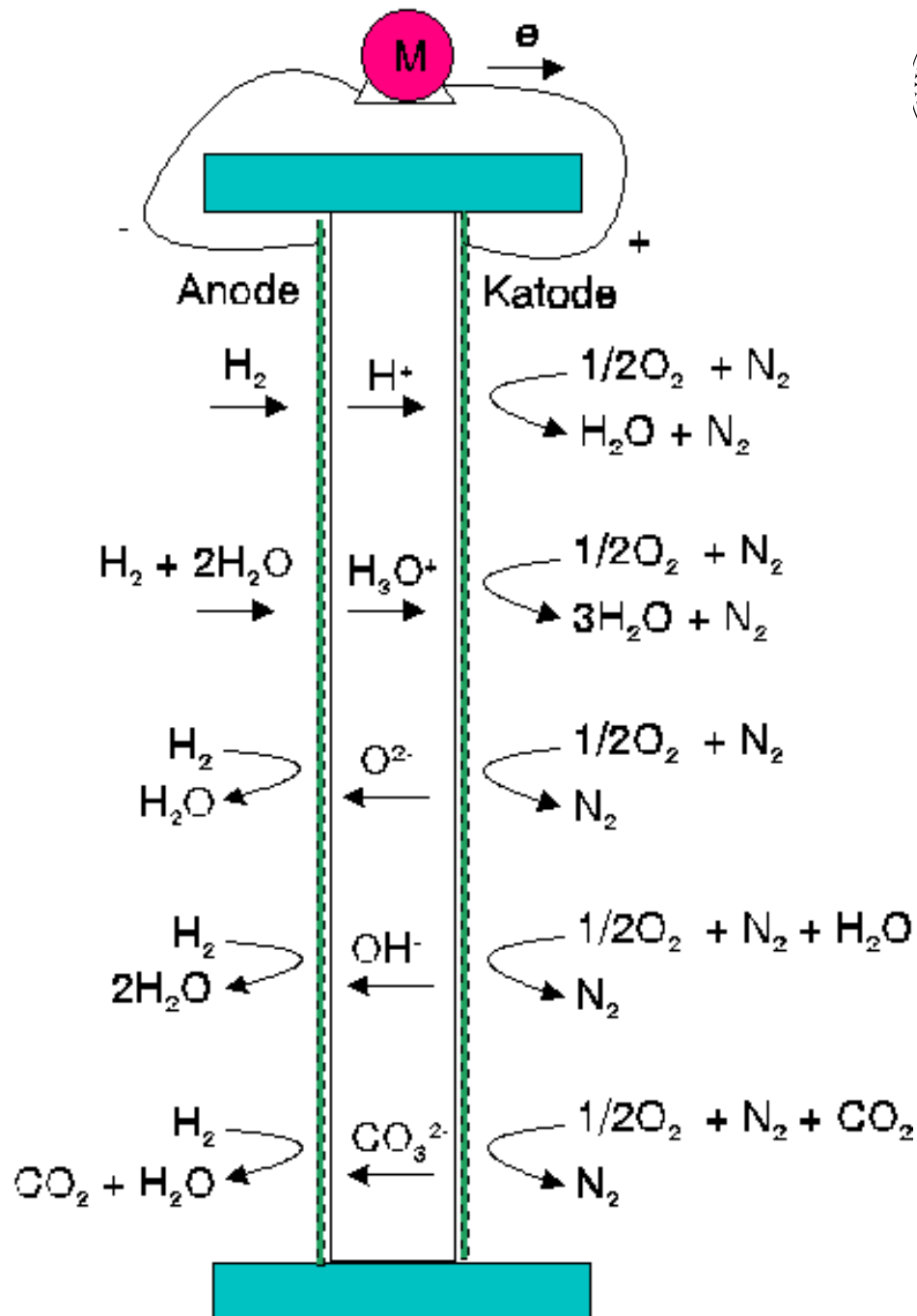
- Sir William R. Grove, 1839
- $H_2 + \frac{1}{2} O_2 = H_2O$
- Svovelsyre som elektrolytt
- H_2 og O_2 som brensel
- Kunne også spalte vann (elektrolysør)



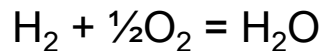
Mange typer
brenselceller

Eksempler: H_2 + luft

Fosforsyre (PAFC)-, Alkaliske (AFC)- og Smeltekarbonat (MCFC)-brenselceller er relativt etablerte og eksisterer i store anlegg, men har problemer med aggressiv flytende elektrolytt. Vi vil i det videre bare behandle brenselcelle-typer med faste elektrolytter; PCFC, PEFC og SOFC.



Brenselcelle med rent protonledende elektrolytt Proton Conducting Fuel Cell (PCFC)



Enkel “balance-of-plant” (BOP)

3 klasser rene protonledere:

Høytemperatur polymerer:

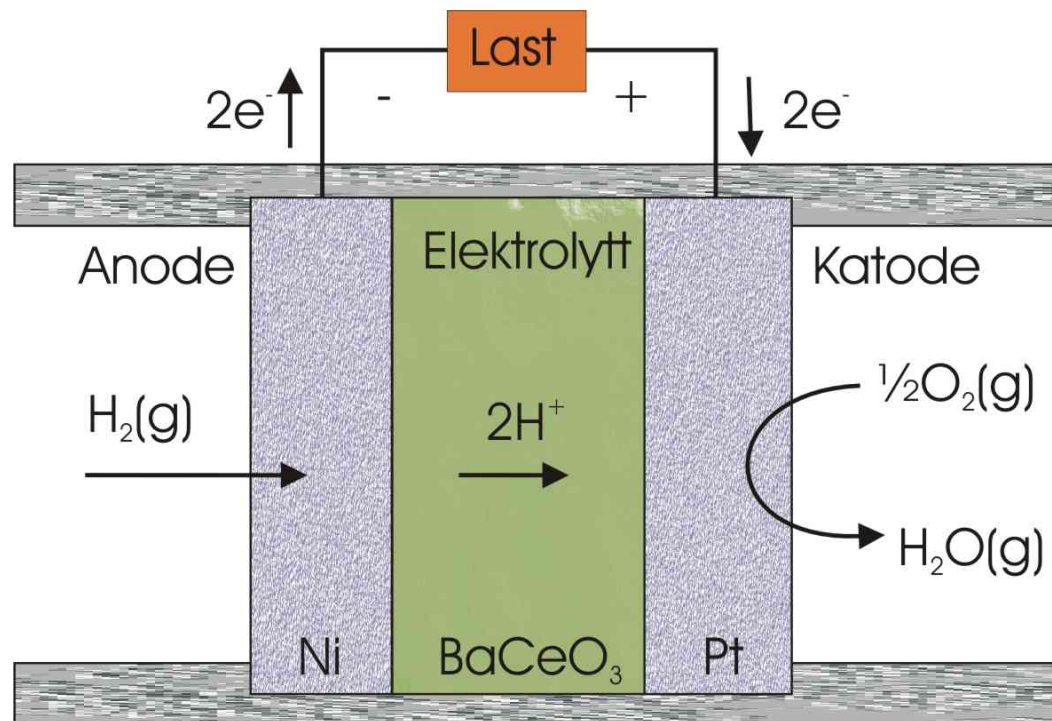
eks. poly-benzimidazol (PBI)

Faste syrer:

eks. CsH_2PO_4

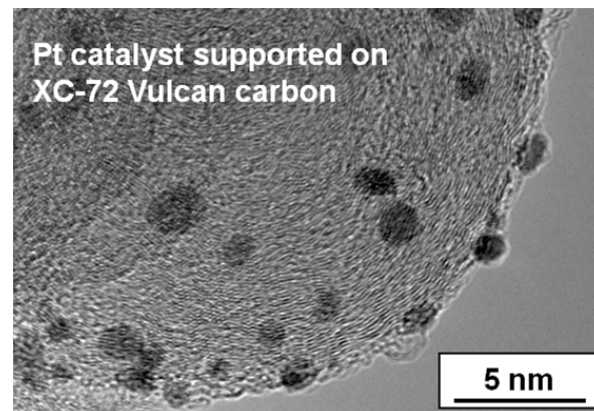
Protonledende oksider:

eks. Y-dopet BaCeO_3

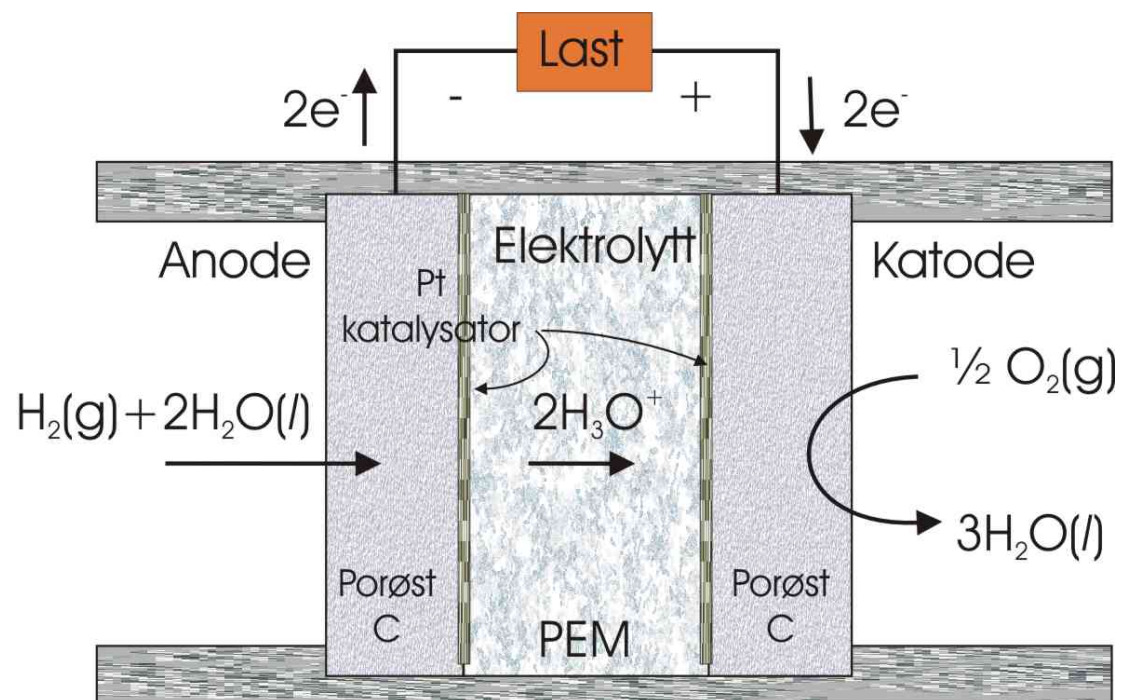


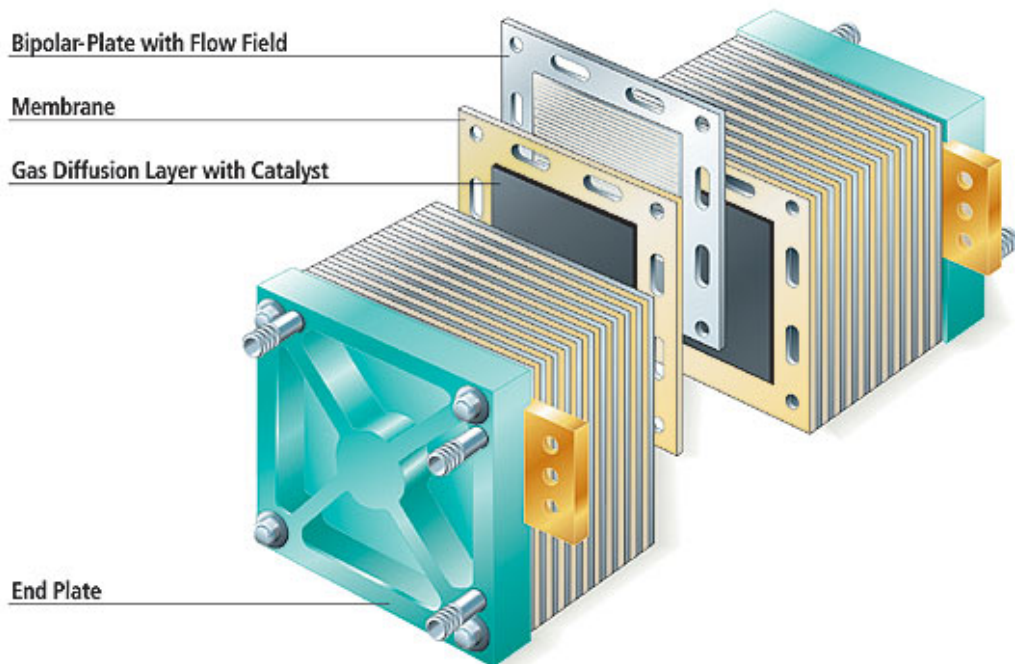
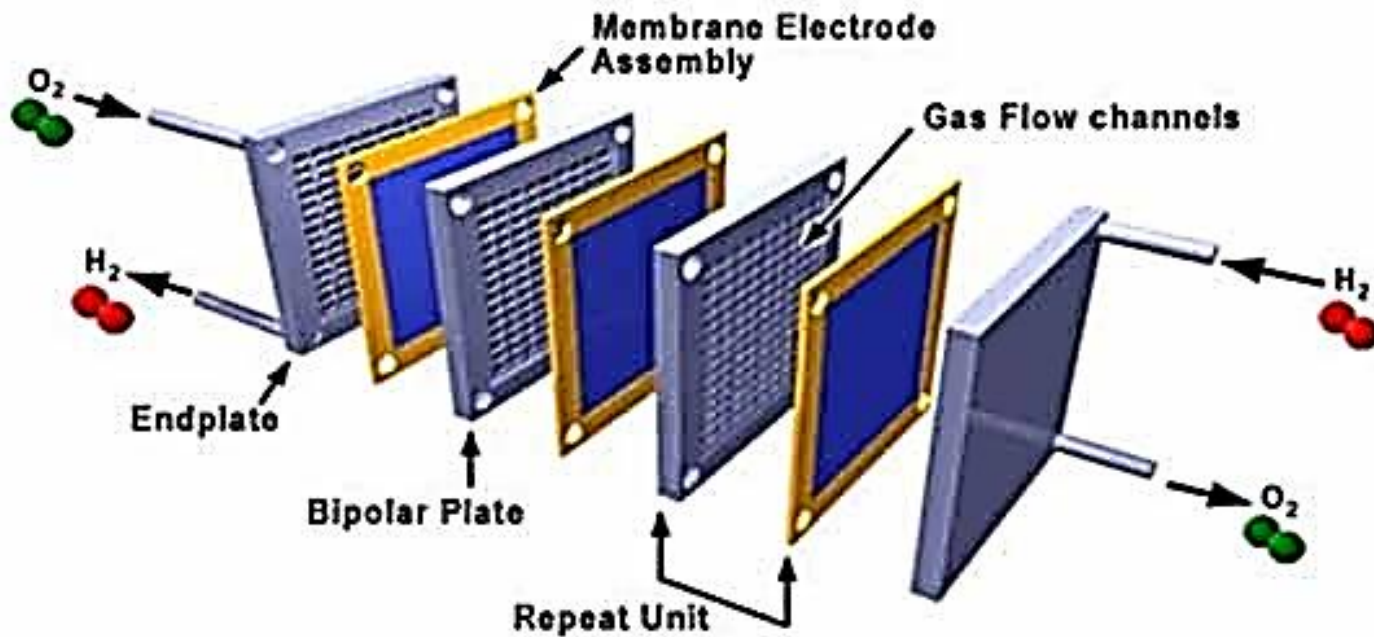
Polymer-elektrolytt-brenselcelle

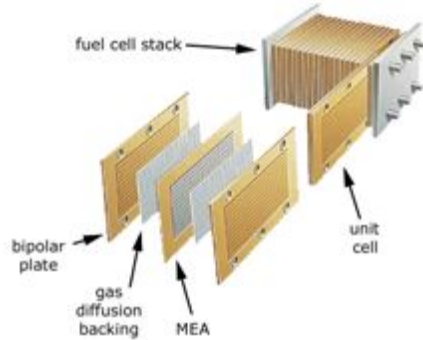
- 50-85°C
- Elektrolytt: Nafion® og lignende
 - H_3O^+ -leder + drag av ca. 5 H_2O
 - Vann må sirkuleres
- Elektroder: Porøs C + Pt
- Brensel: Rent H_2
- Problemer:
 - Katalysatorforgiftning (CO)
 - Pris (Pt + elektrolytt)
- Ledende brenselcelleteknologi for transport (biler, busser...)



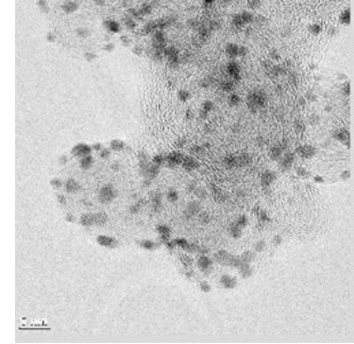
Oak Ridge Natl. Lab.







PEFC



- +
 - Generelt for brenselceller
 - Miljøvennlig
 - Effektiv
 - Fleksibel
 - Modulær
 - Spesielt for PEMFC
 - Rask oppstart
 - Mekanisk robust

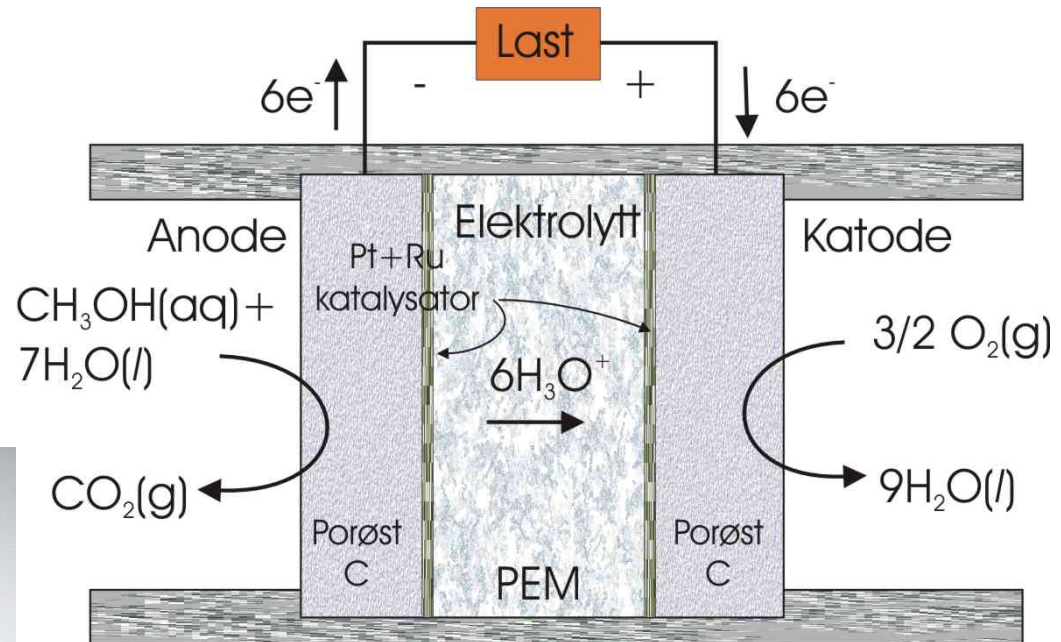
- -
 - Komplisert teknologi
 - Dyrt
 - Nafion
 - Pt
 - Må ha rent H₂ som brensel
 - CO-passivering
 - Transport, lagring
 - Lav verdi på spillvarme

•Forskning

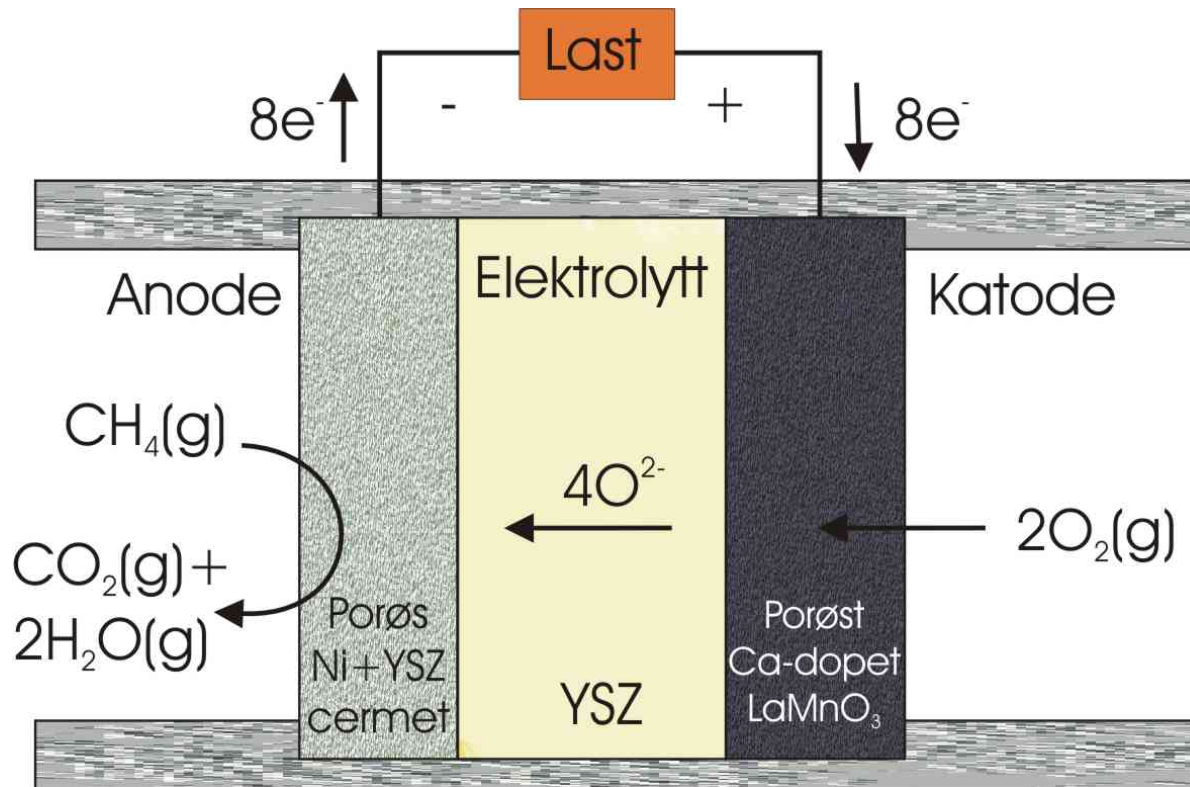
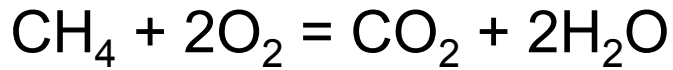
- Høyere temperatur (mindre Pt, høyere CO-toleranse)
- Vannhåndtering eller systemer uten vann (N som proton-vert istedet for O)
- Nye polymerer
- Nanostruktur i elektroder (mindre Pt nødvendig)

Direkte metanol-brenselcelle DMFC

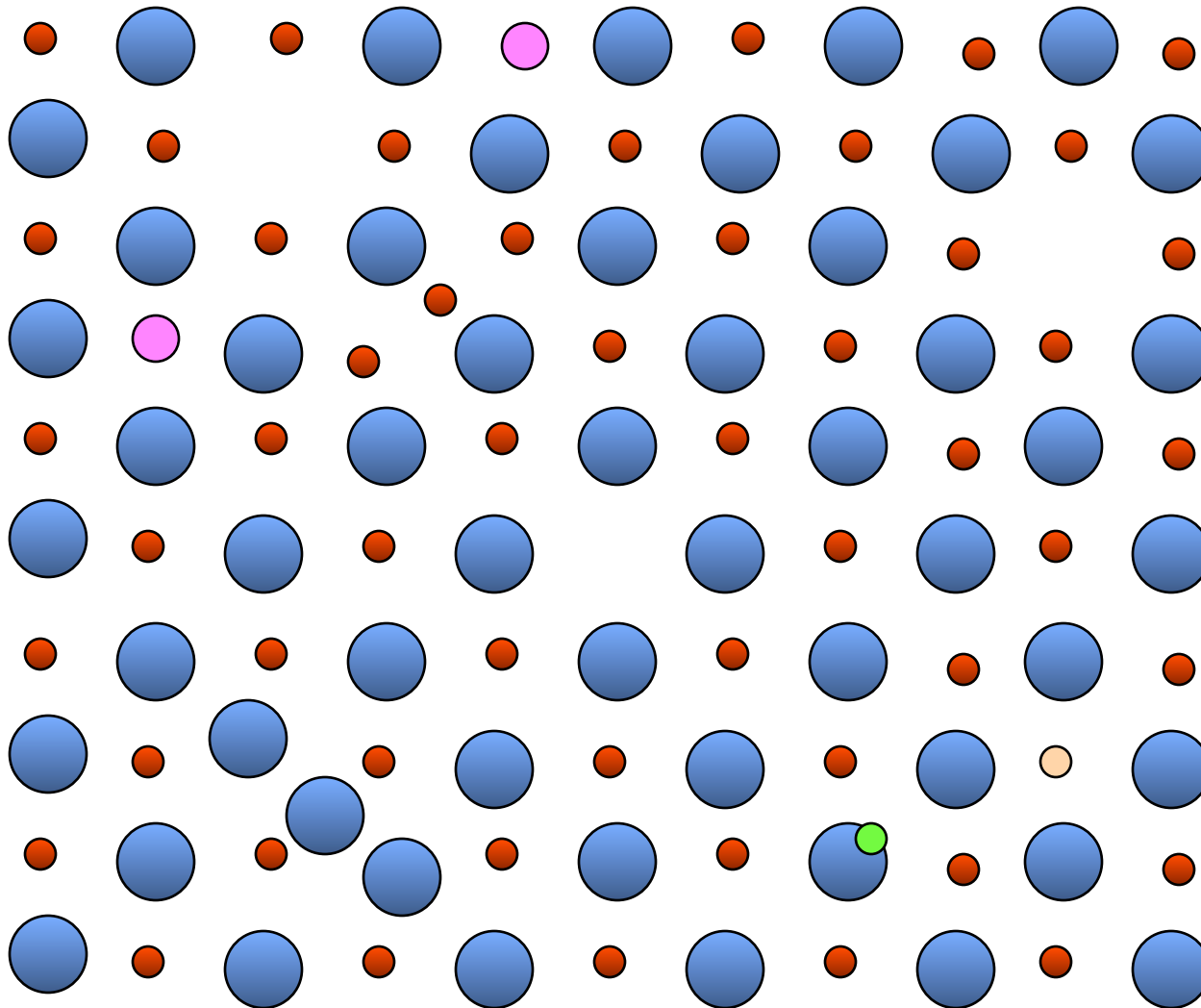
- 50-85°C
- Elektrolytt: Nafion® og lignende
- Elektroder: Porøs C + Pt/Ru
- Brensel: CH₃OH(aq)
- Lav effektivitet
- Løselighet av metanol i elektrolytten; kjemisk kortslutning
- God brukervennlighet



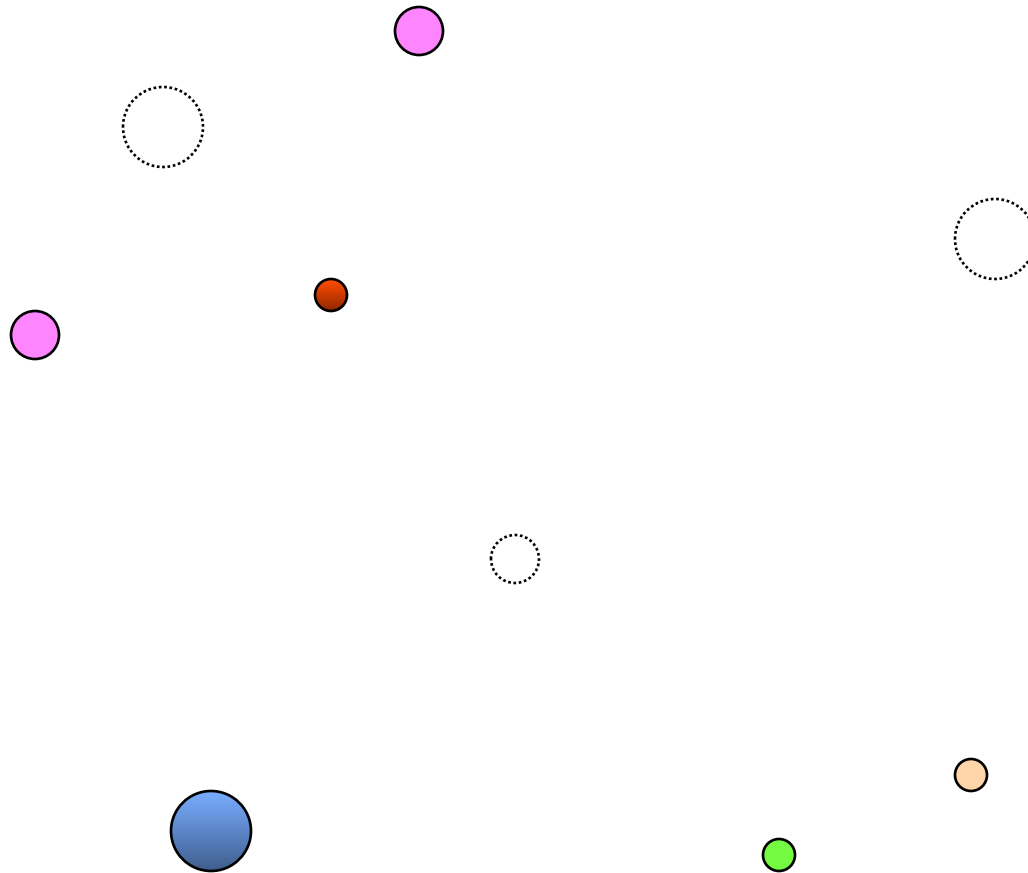
Fastoksid-brenselcelle - Solid Oxide Fuel Cell (SOFC)



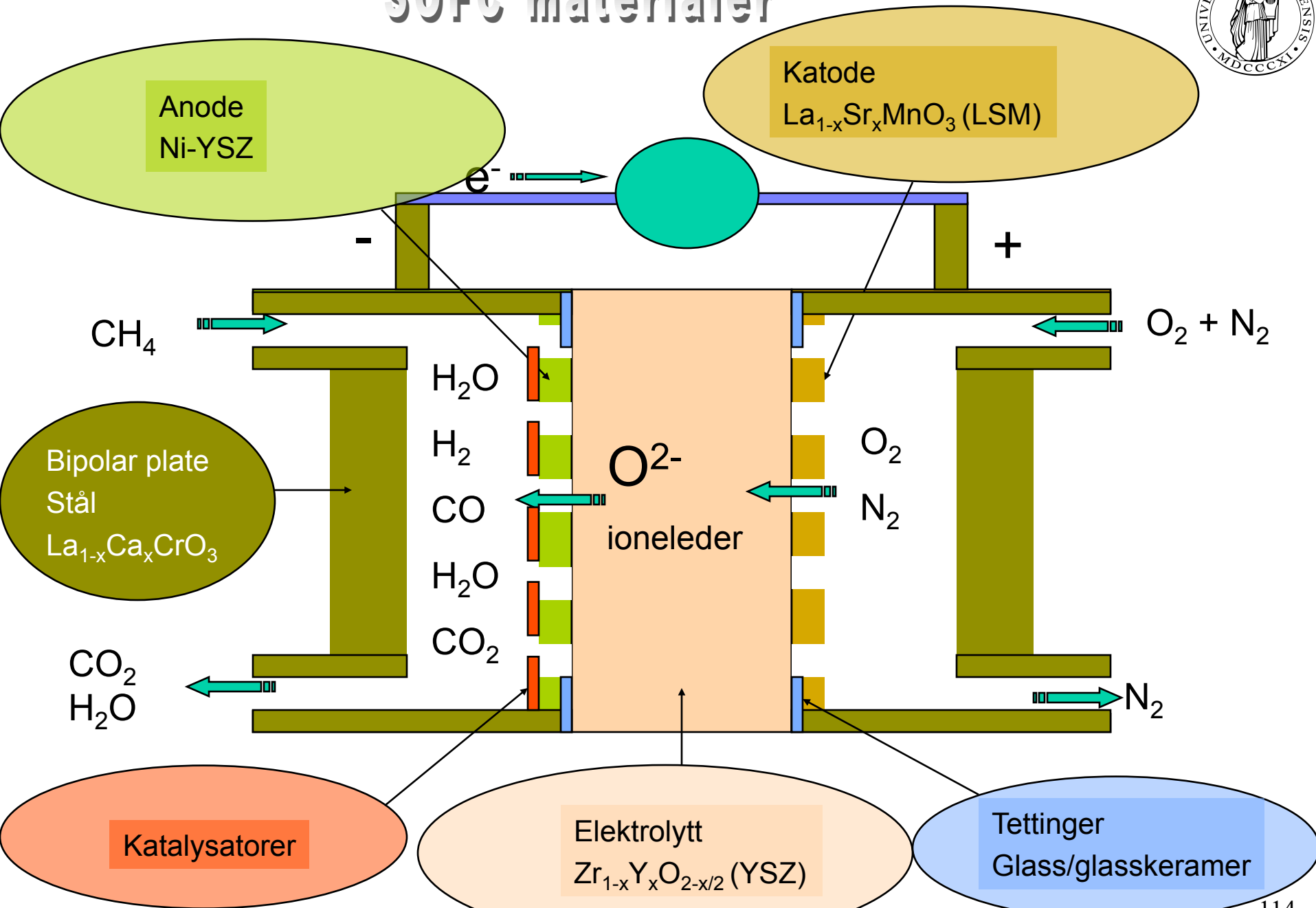
SOFC trenger transport: Punktdefekter - hvor mange ser du?



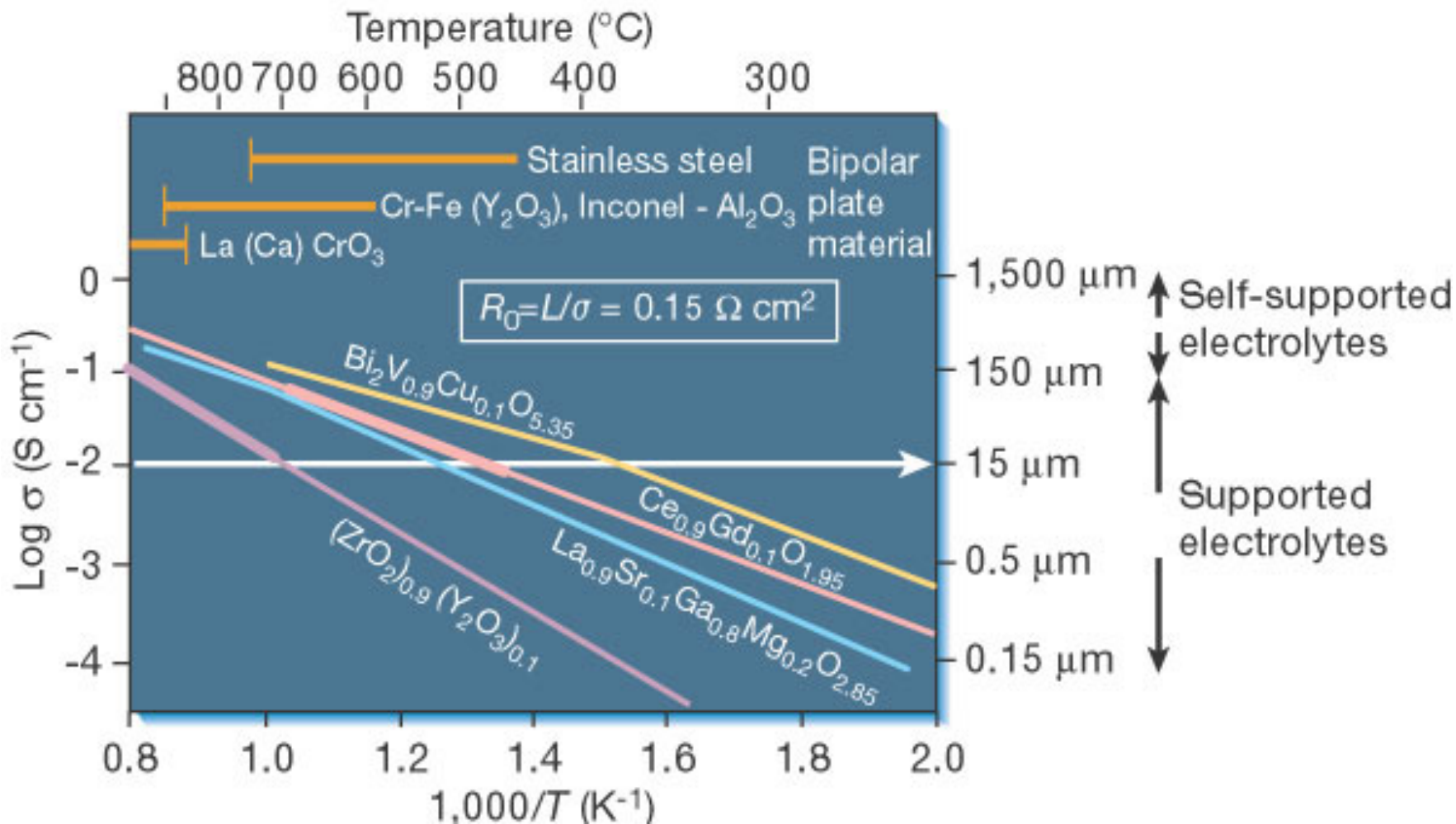
Punktdefekter



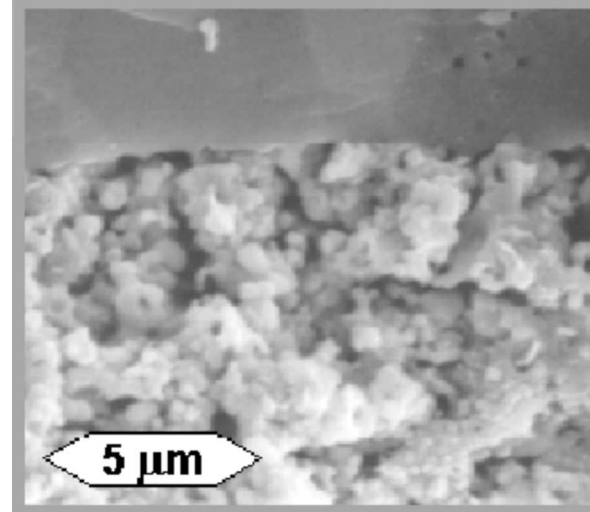
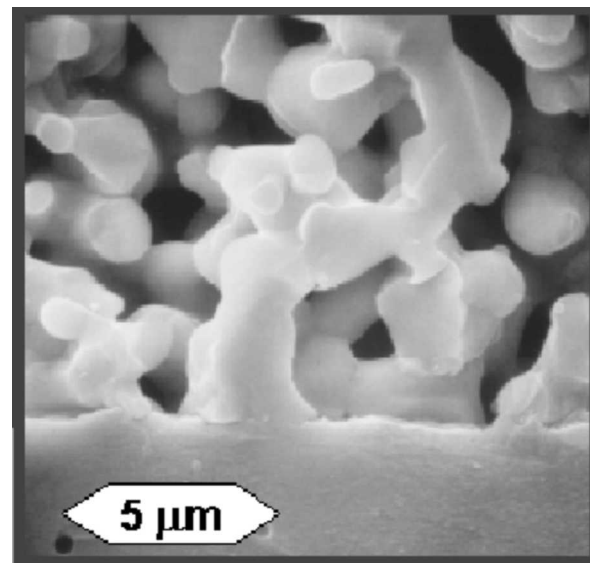
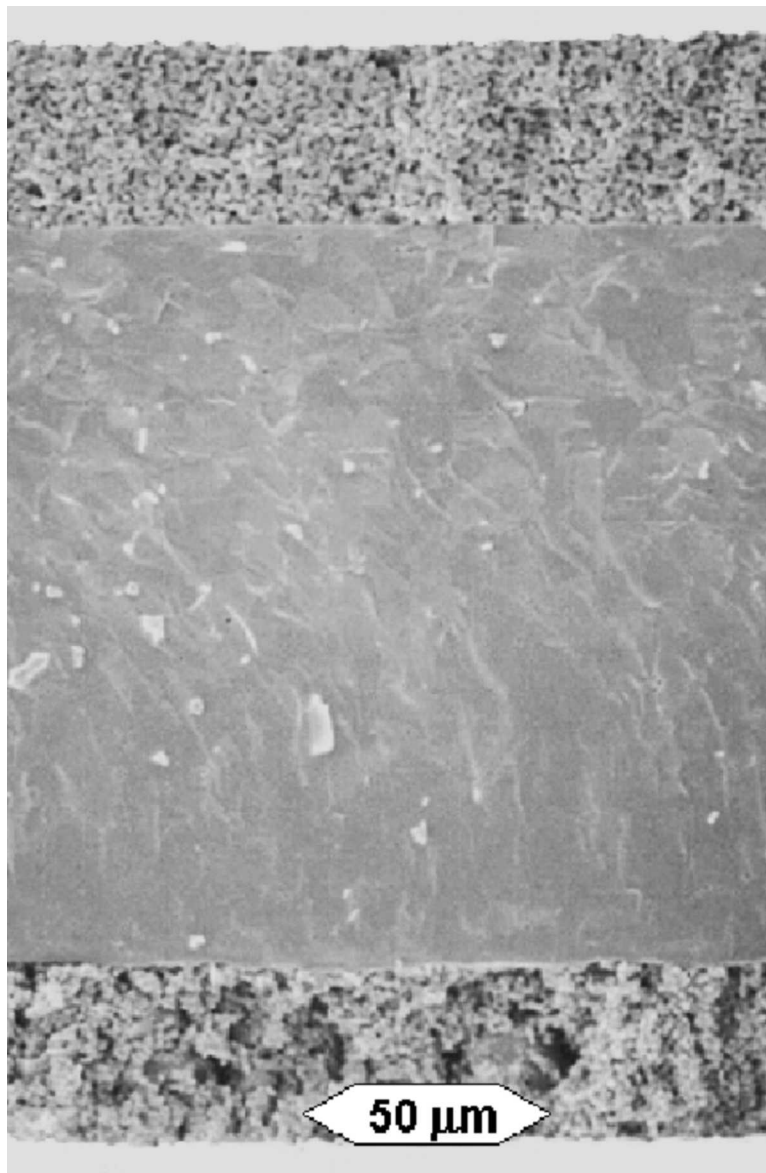
SOFC materialer



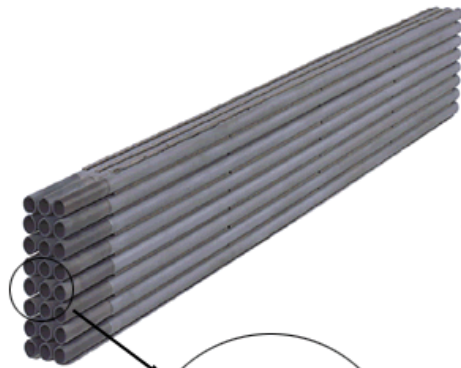
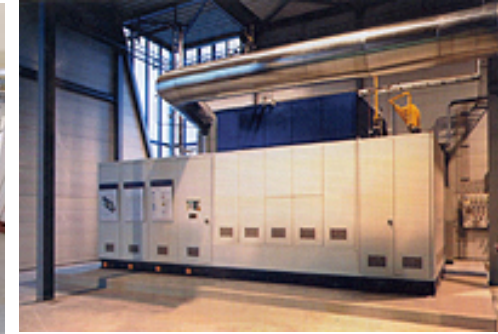
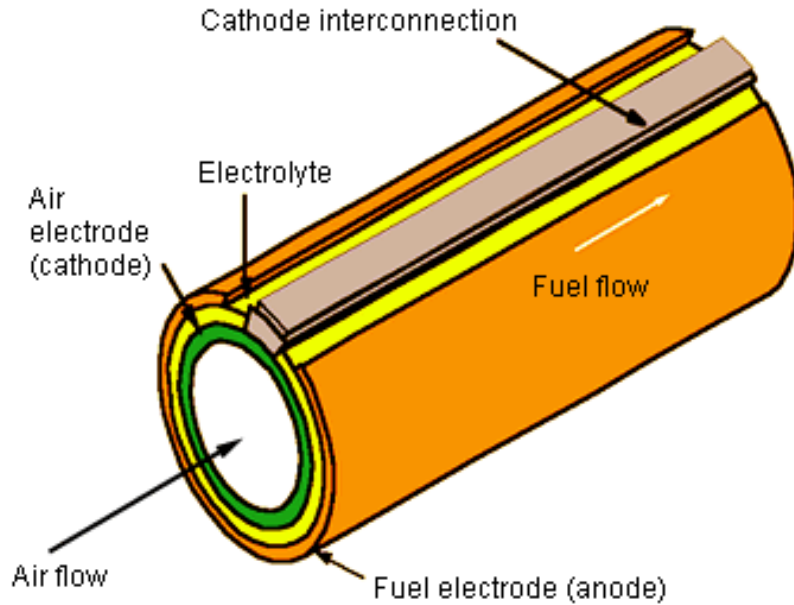
Ledningsevne i SOFC-materialer



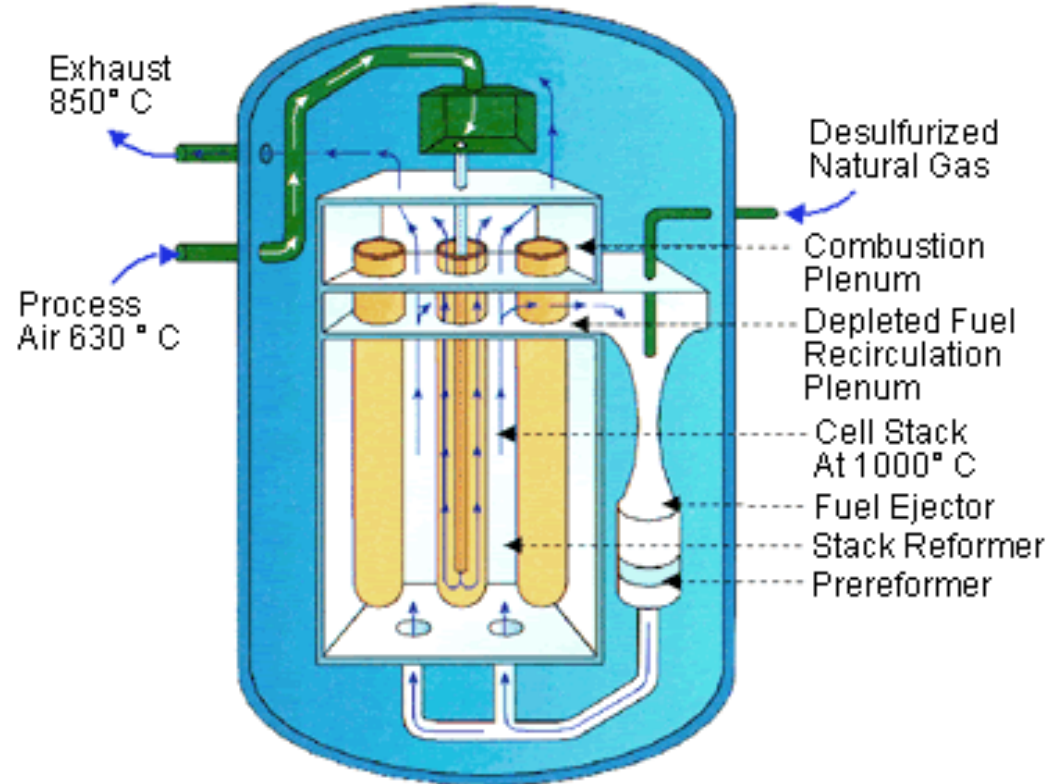
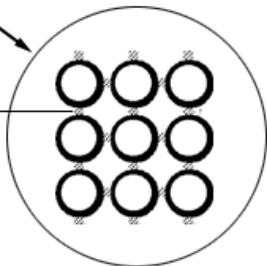
Eksempel på mikrostruktur



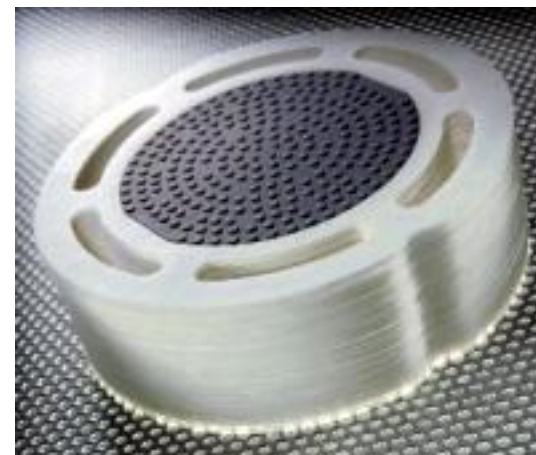
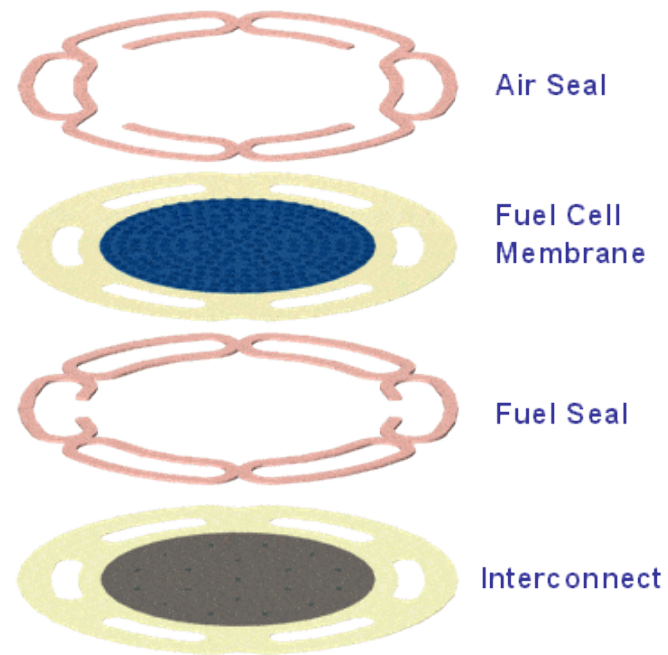
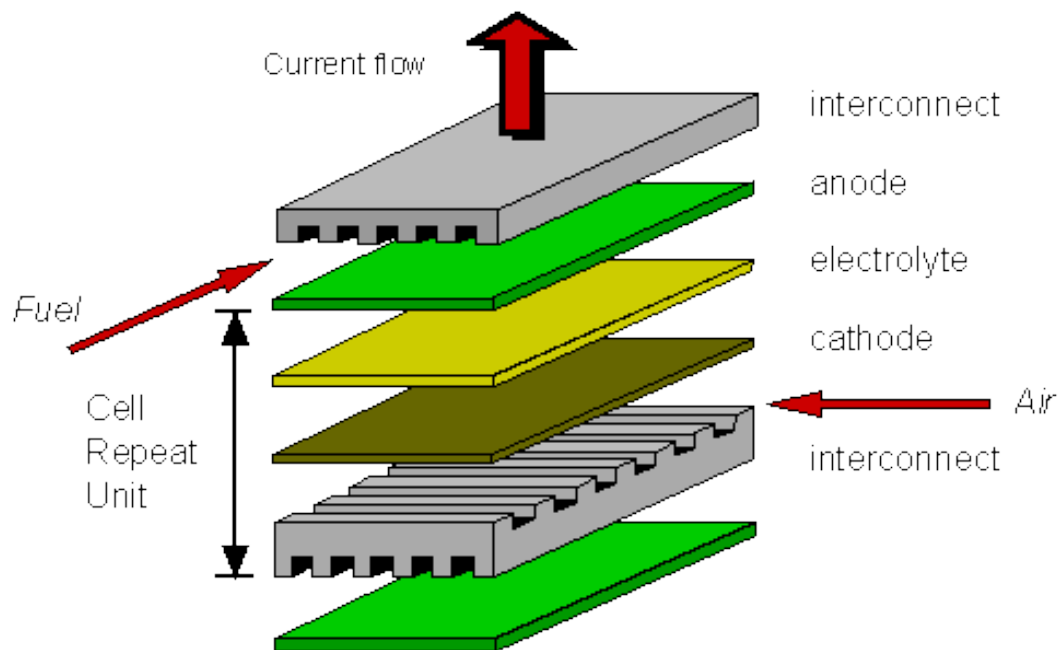
Rørdesign



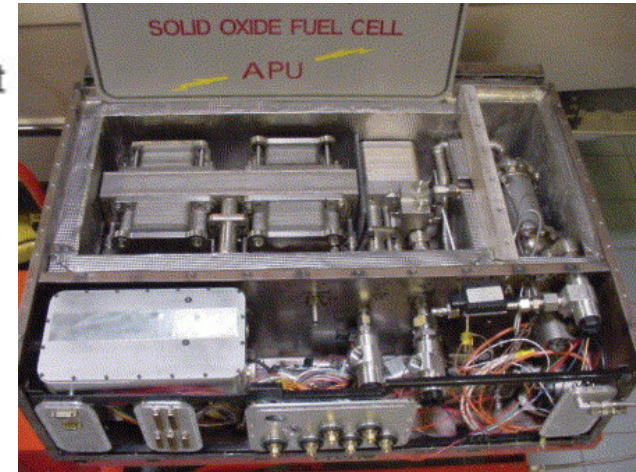
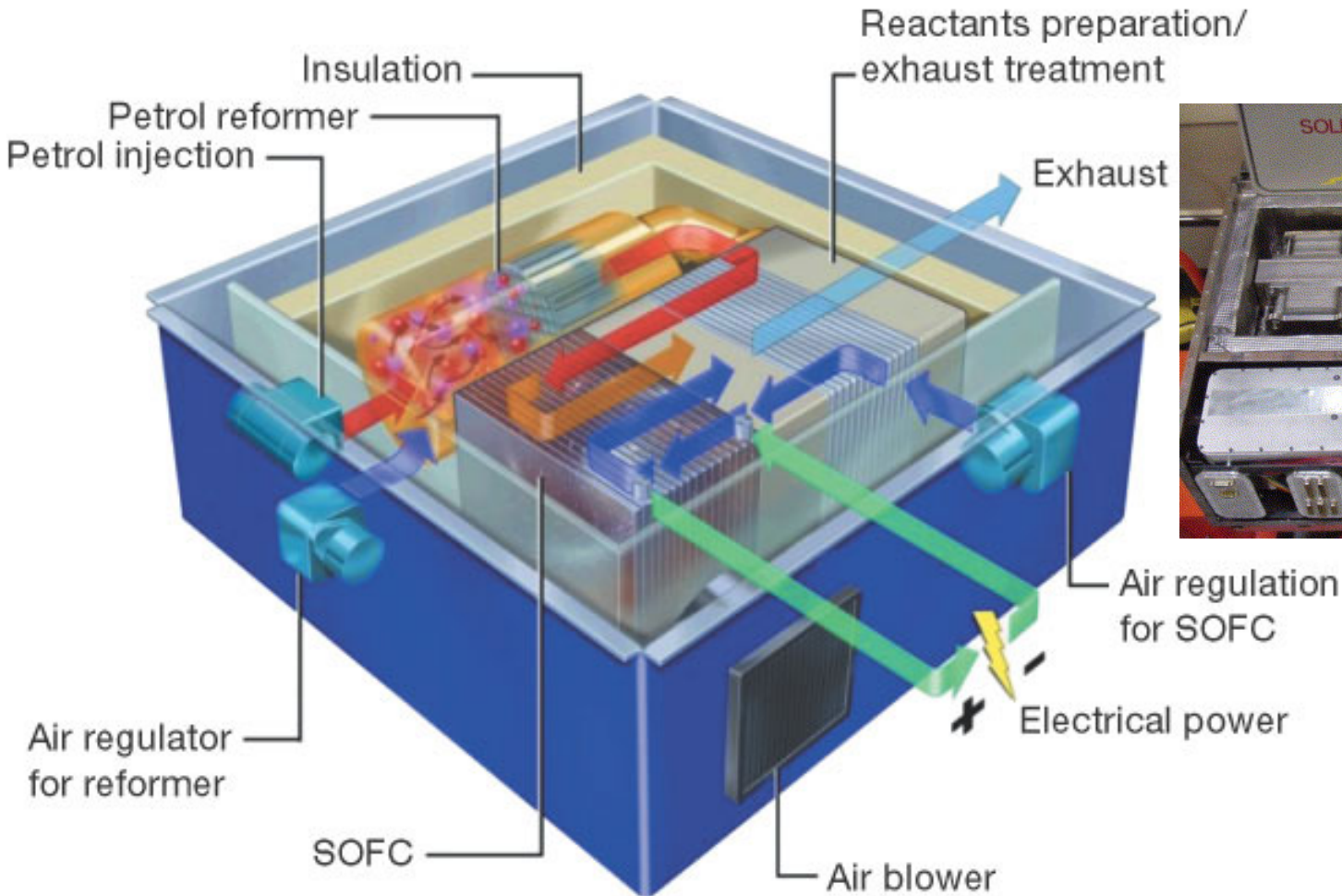
Nickel felt attachment



Planare design



SOFC Auxiliary Power Unit (APU)



SOFC



- +
 - Generelt for brenselceller
 - Miljøvennlig
 - Effektiv
 - Fleksibel, modulær
 - Spesielt for SOFC
 - Brensel-tolerant
 - Høy verdi på spillvarme
 - Integrasjon i prosesser

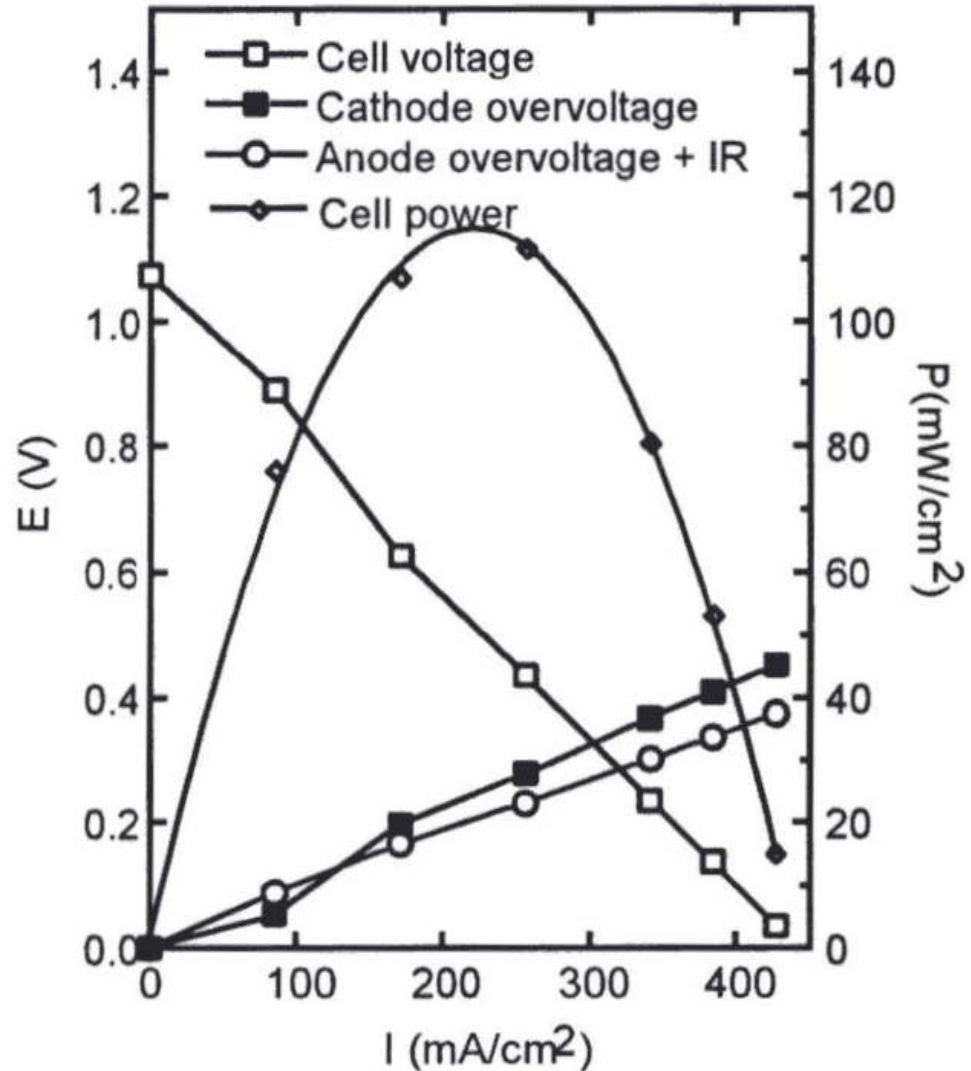
- -
 - Komplisert teknologi
 - Dyrt
 - Avanserte keramer
 - Sjeldne grunnstoffer
 - Mekanisk lite robust
 - Lang oppstartstid
 - Degradering ved høy temperatur

•Forskning

- Lavere temperatur (mindre korrosjon, rimeligere bipolare plater)
 - Tynnere lag. Bedre katalysatorer.
- Nye materialer. Protonledende oksider.
- Prosessintegrasjon. Kombinerte el-varme anlegg med brenselcelle og gassturbin.

Potensial og effekt vs strøm for en brenselcelle

- Eksempelet i figuren:
 - 1 mm tykk YSZ elektrolytt
 - Ca-dopet LaCrO_3 elektroder
 - H_2 + luft
- Cellen har elektrisk tap i
 - elektrolytten ("IR")
 - overpotensialer i katode og anode
- Cellepotensialet E faller fra Nernst-potensialet når vi øker strømmen.
- Den elektriske effekten P går fra 0, via et maksimum, tilbake til 0.
- Den elektriske effektiviteten går tilsvarende fra 100%, via 50%, til 0.
- Vi opererer ofte brenselceller ved 2/3 av maksimums-effekten



Elektrisk effekt og virkningsgrad

- Elektrisk effekt ut P_e er lik P_{in} multiplisert med faktorer som beskriver effektiviteten:

$$P_e = \eta_G u_f P_{in}$$

- η_G elektrisk virkningsgrad
- u_f brenselutnyttelsesgrad
- $P_e / P_{in} = \eta_G u_f$ Virkningsgrad for cellen

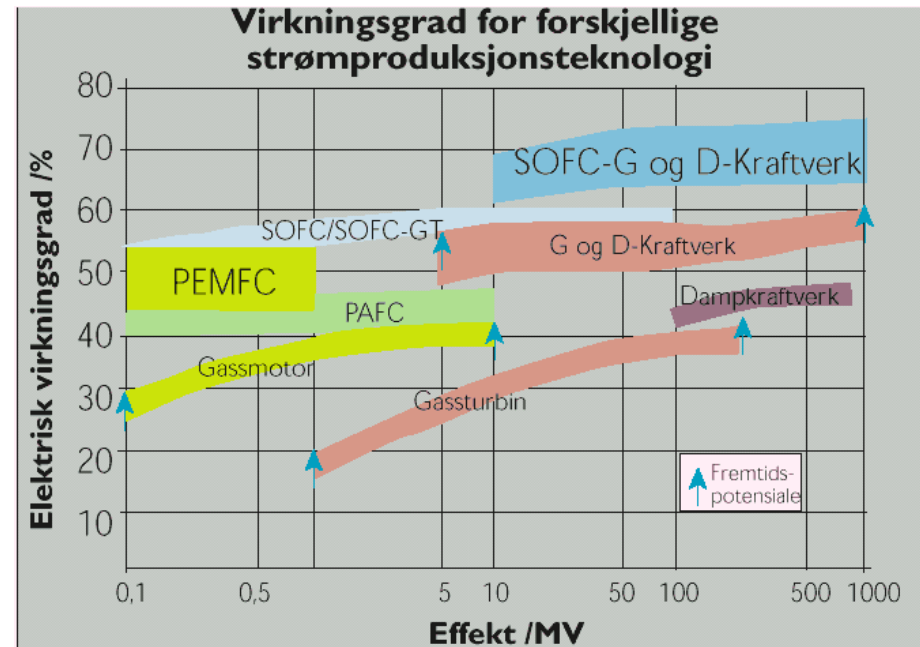
– Typisk 50%

- $\eta_G = P_e / (P_{in} u_f) = w_{el} / w_{tot} = \eta_G / \eta_H$

– Teoretisk kan η_G være >100%

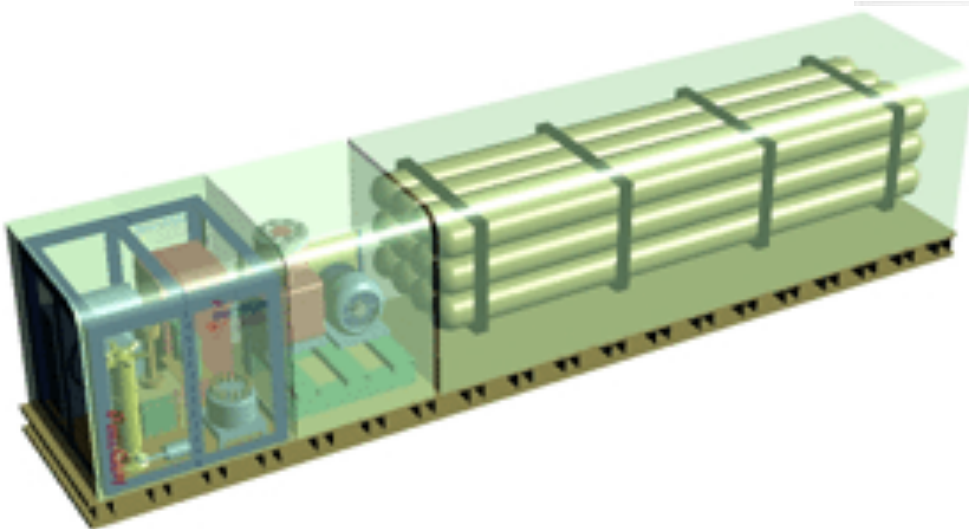
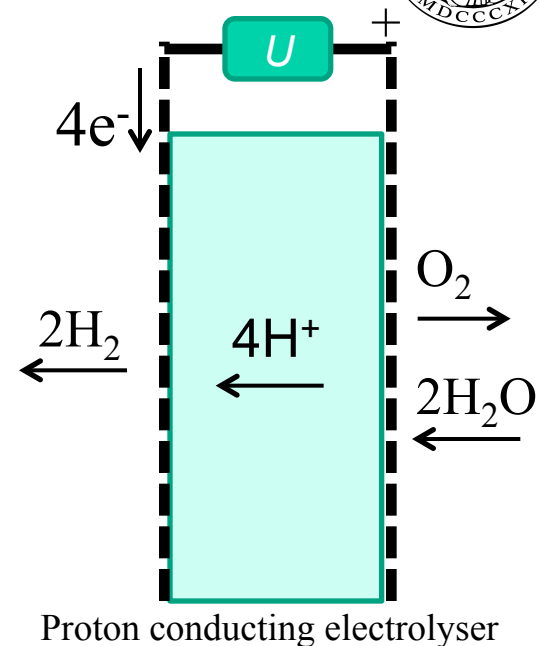
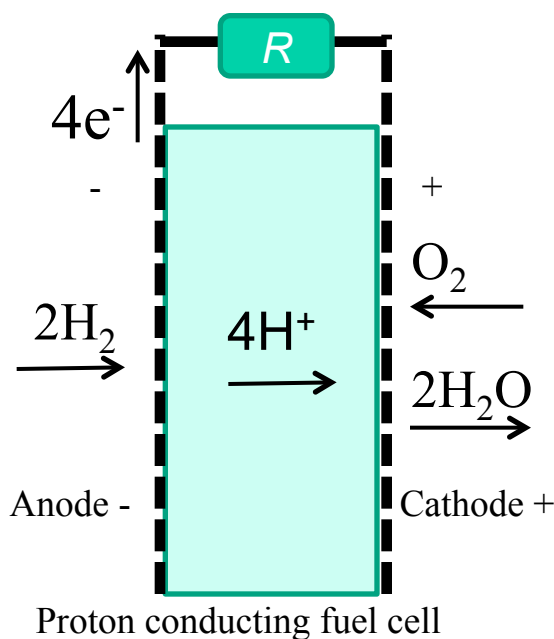
Brenselceller; egenskaper

- Ingen flamme – direkte fra kjemisk til elektrisk energi
 - Mindre NO_x
- I prinsippet Gibbs energi; ingen Carnot-syklus
 - men andre tapsledd
 - Elektrisk virkningsgrad
 - Brenselutnyttelse
- Fleksible
- Modulære
- Støyfrie
- Mer effektive enn motorer ved varierende effektuttak



Elektrolysører

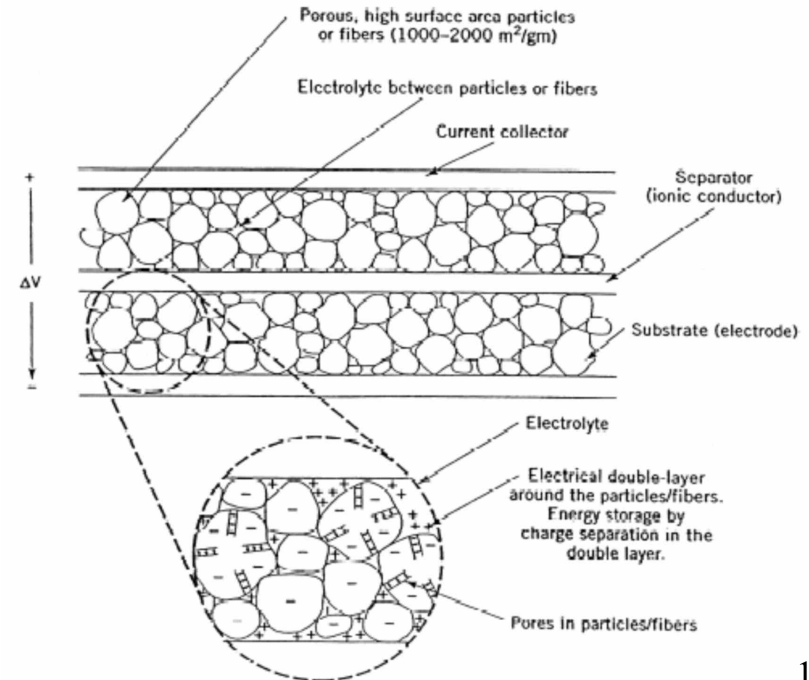
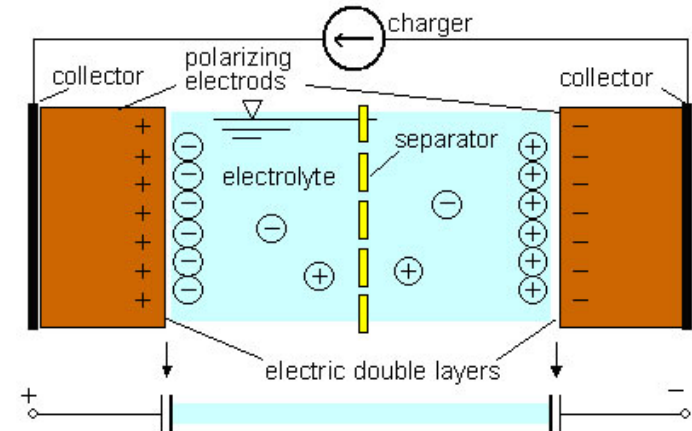
- Reversert brenselcelle
- AFC- og PEFC-deriverte typer mest utbredt
- H₂-fyllestasjoner med elektrolysør; fra elektrisitet til H₂ on-site



Lagring av elektrisk energi

Kondensatorer

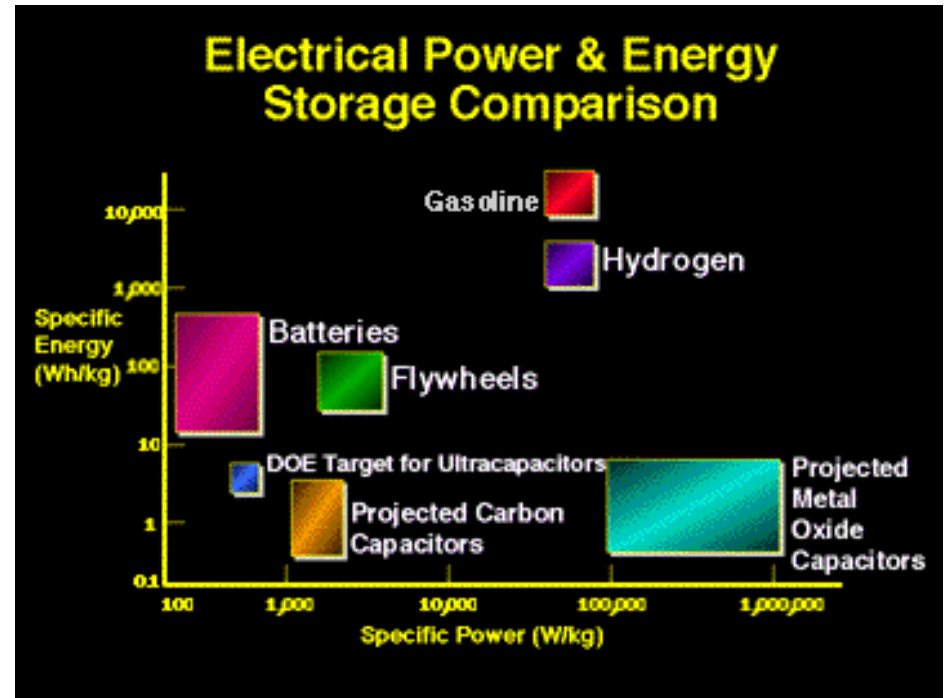
- Platekondensator
- Keramisk kondensator (dielektrika, ferroelektrika)
- Elektrolyttkondensator
 - Utnytter elektrokjemiske dobbeltlag mellom en elektrolytt og en elektrode
- Super/ultra-kondensatorer
 - Forbedrede elektrolyttkondensatorer
 - Nano-karbonpartikler
 - Nano-metalloksidpartikler
- Hybride kondensatorer/batterier



Capacitors: store energy as charge on the surface of the electrodes, rather than by chemical reaction of the bulk materials (as in batteries)

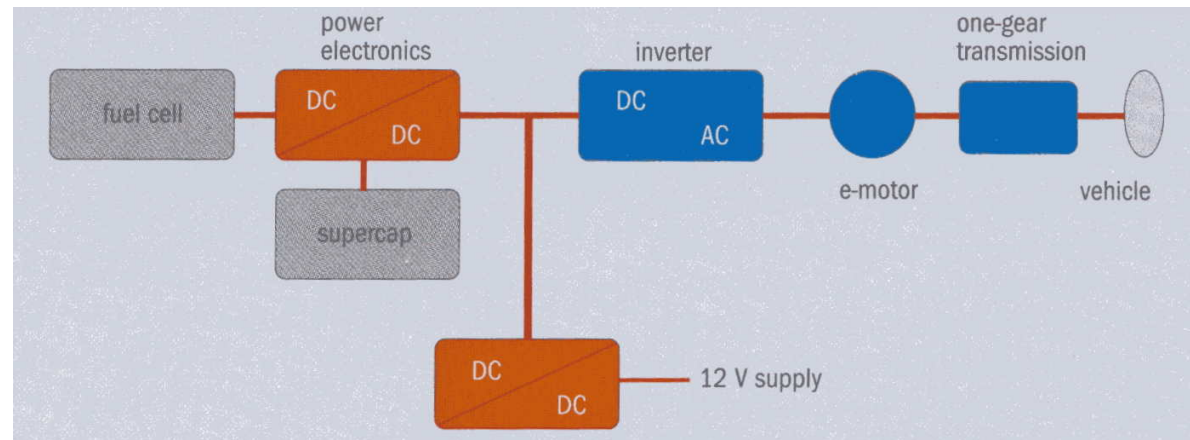
Superkondensatorer

- Raske effektuttak i elektriske transportmidler



Capacitors have higher rate capabilities (fast charge/discharge) than batteries but are very limited in energy storage capability (because only surface)

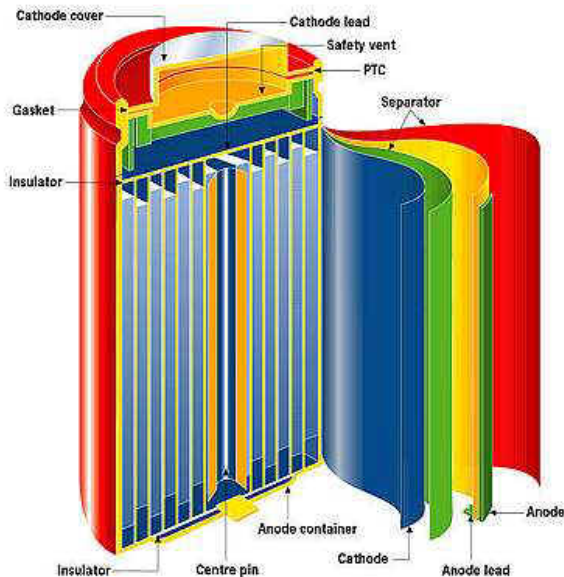
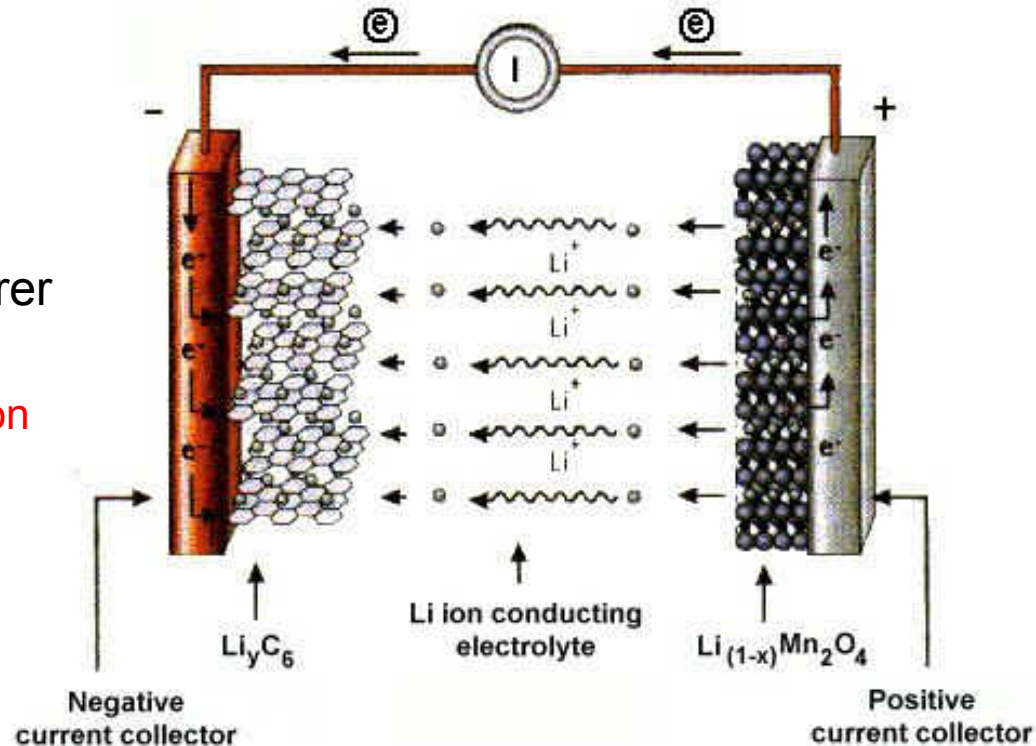
Flywheels: they use the kinetic energy stored in a rotor, often referred to as mechanical batteries



Lagring av elektrisitet

Elektrokjemisk konvertering; akkumulatører

- Primære batterier
 - Energien lagres av fabrikken
 - Kastes/resirkuleres etter bruk
- Sekundære batterier = akkumulatører
 - Kan reverseres; lades opp
 - Mange typer: Pb, NiCd, NiMH, **Li-ion**



Elektriske biler



- Drives av elektromotorer
- Oppladbart batteri
 - Kan ha superkondensatorer som akselerasjonshjelp
 - Plug-in lading
 - Med forskjellige typer "range extenders"
 - Motordrift
 - Motor + generator
 - Brenselcelle



(mange typer hybrider)

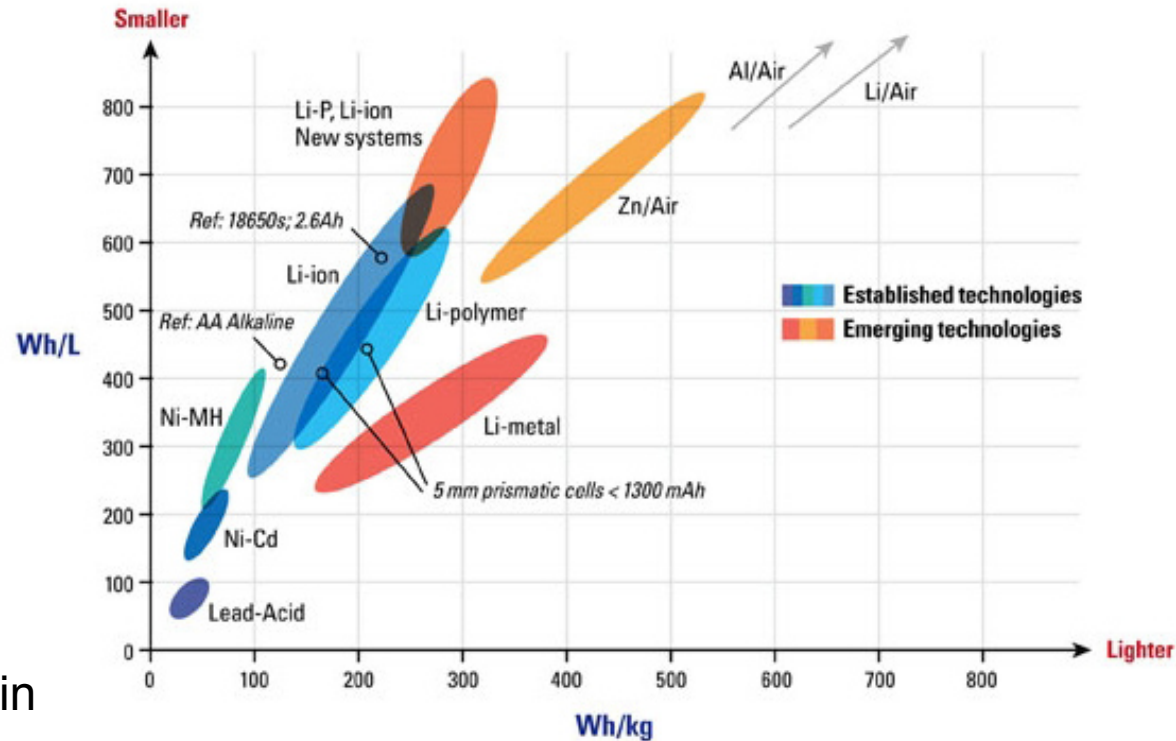
- Brenselcelle

Motorer kan gå på mange typer brensel; bensin/ diesel, gass, biodrivstoff, hydrogen.
Brenselcellene er av PEFC-type; Går på hydrogen (komprimert eller fra on-board prosessert drivstoff)

Metall-luft-batterier

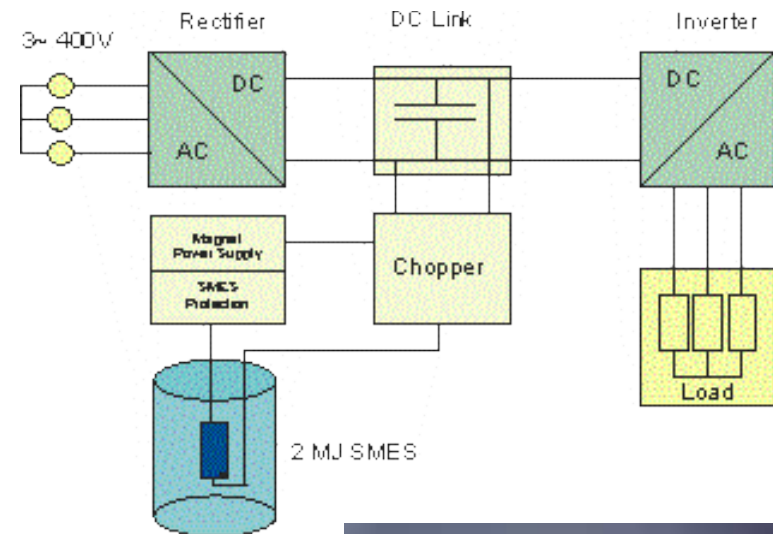
- Blanding av batteri og Brenselcelle
- Brensel: Metallstaver
 - Al, Zn, Mg
- Oksidant: Luft, evt. luft løst i vann
- Metal anode/separator +electrolyte/porous cathode in contact with air-O₂:

$$\text{O}_2 + 2\text{e}^- + 2\text{Na}^+ \longrightarrow \text{Na}_2\text{O}_2$$
- I den senere tid også utviklet i retning av oppladbare batterier; akkumulatører



Lagring av strøm i superledere

- Superconducting Magnetic Energy Storage (SMES)
- Likestrøm induseres i en tykk, superledende ring (tyroid)
- Fortsetter å gå "uendelig"
- Kan tas ut ved behov; induserer da strøm i den utenforliggende spolen
- Brukes i UPS (Uninterruptible Power Supplies) for oppstart+noen sekunder etter strømbrudd
- Dyrt, men bra!

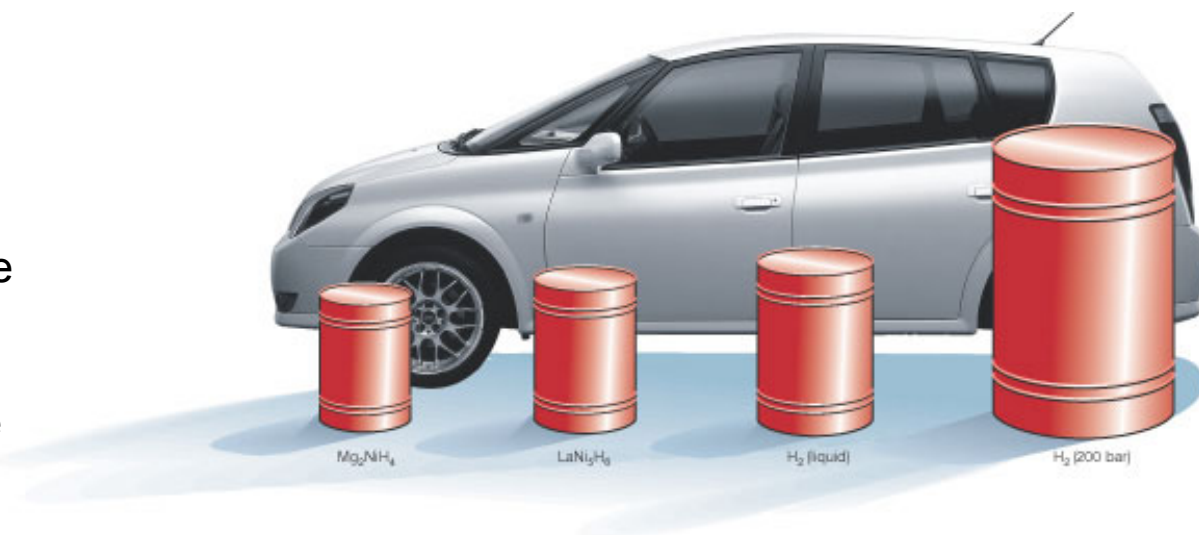


Hydrogen



- Men lagring og transport er dyrt
- Gass
- Flytende
- Hydrogenlagringsmaterialer
 - Metaller og legeringer
 - Alanater, boranater
 - Nanokarbon
 - Hybridmaterialer
- Flytende hydrogenbærere
 - Alkoholer og andre C-holdige
 - NH_3 og andre N-holdige

<u>Medium</u>	<u>Volume density of hydrogen, 10^{22} atoms/cm³</u>	<u>Hydrogen weight density, wt %</u>
H_2 gas at 100 atm	0.5	100
H_2 liquid (20K)	4.2	100
H_2 solid (4.2K)	5.3	100
LiH	5.9	12.6
$\text{PdH}_{0.6}$	4.3	0.6
H_2O (liquid)	6.7	11.2
MgH_2	6.7	7.6
TiH_2	9.2	4.0
VH_2	11.4	3.8
UH_3	4.0	1.3
TiFeH_2	6.0	1.9
LaNi_5H_7	7.6	1.6
LiAlH_4	5.7	10.6
Mg_2NiH_4	5.9	3.6



Andre energilagringmetoder

- Mekanisk potensiell energi
 - Lufttrykk – tomme gruveganger
 - Vanntrykk – pumping opp til bassenger og sjøer
- Mekanisk kinetisk energi
 - Løpehjul (flywheel)
 - Superledende magnetisk friksjonsfri opplagring
 - Sikkerhetsaspekt?
- Termisk
 - Varmekapasitet
 - Faseomvandlingsmaterialer



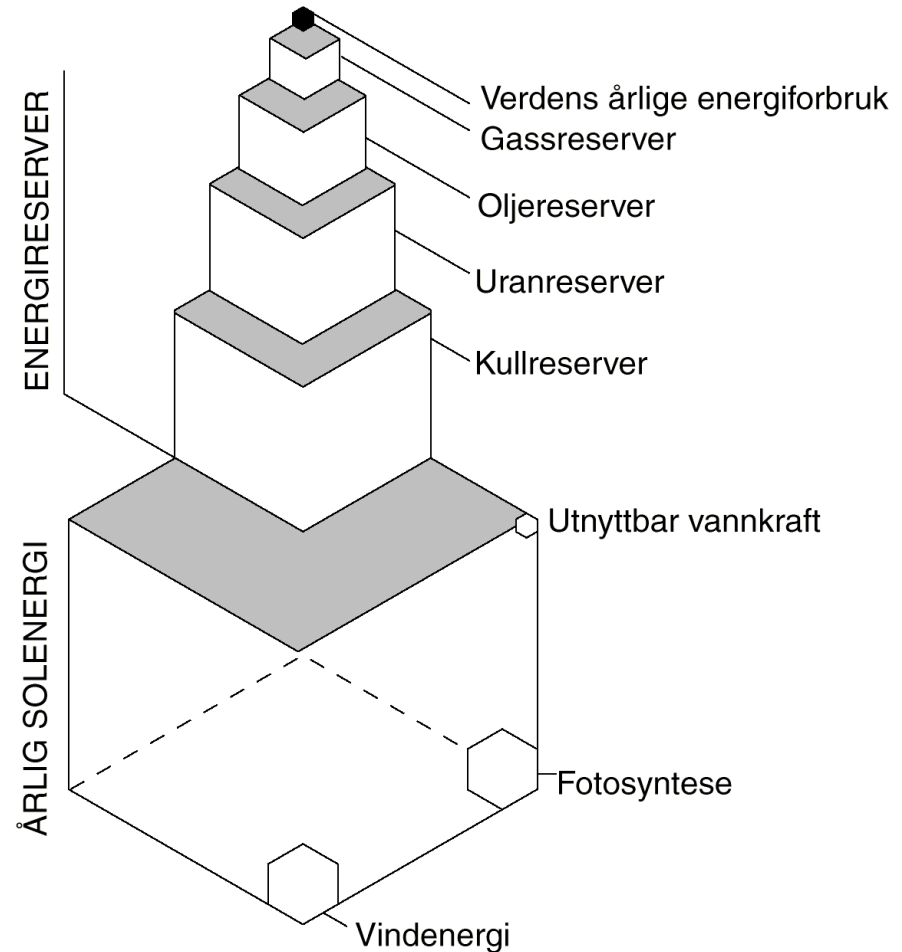
Forbruk, nedbrytning og gjenvinning av materialer

- Å lage teknologi for fornybar energi koster også energi
- Degradering
- Nedbrytning
- Kostnad ved skrotning
- Gjenvinning



Oppsummering - Energikilder

- Bærekraftig bruk av energi:
 - Bedre bruk av fossile reserver
 - Med reduserte CO₂-utslipp
 - Utbygge fornybare kilder
 - Ta i bruk hydrogenteknologi
 - med hydrogen fra både fossile og fornybare kilder
 - Effektivisere bruk av energi
- Nøkkelen ligger i ny og bedre konvertering, lagring og transport av energi (neste kapittel). For dette trenger vi nye og forbedrede materialer.



Oppsummering Energikonvertering og -lagring

- Energikonvertering

- Fra sollys til elektrisitet m.m.
- Fra vind/vann til mekanisk
- Fra kjemisk til varme
- Fra nukleær til varme
- Fra varme til mekanisk
- Fra mekanisk til elektrisk
- Brenselceller
 - mange typer; lær en eller to godt!

- Energilagring

- Elektrisk
 - Spenning (ladning)
 - Strøm
- Kjemisk
 - Akkumulator
 - Lær Li-ion m.m.!
 - Hydrogen
- Mekanisk

100µm