1. Energy worldwide—some numbers

Different units are used:

- $1\ \text{GW} = 8.76\ \text{TWh/a}$,
- $1\ \text{ktoe} = 1\ \text{Gcal} = 0.01163\ \text{TWh}$ (kilotonnes oil equivalent),
- $1\ \text{Btu} = 0.293\ \text{Wh}$ (British thermal unit).

Exergy

In thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir, reaching maximum entropy.

- Exergy is the energy that is available to be used.
- When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment.
- Energy is neither created nor destroyed during a process. Energy changes from one form to another.
- In contrast, exergy is always destroyed when a process is irreversible, for example loss of heat to the environment. This destruction is proportional to the entropy increase of the system together with its surroundings.

http://www.stockholmexergi.se

Power magnitudes

- Humans: consumption of 2000-2500 kcal per day means an average energy supply of **100 W**.
- Work output from an average efficiency $\approx 25\% \Rightarrow 25$ W.
- Heat per capita delivered to buildings: about 80 W.
- Maximum human work from climbing stairs: $P = mgh/t$. With 7 stairs (≈ 23 m) in 23 s and body weight of 70kg this gives **700 W**. (Close to 1hp=745 W.)
- Electric hot plate or electrical radiator ≈ 1 kW.
- Taking a shower ≈ 12 kW. (Flow 0.1 ℓ/s, $\Delta T \approx 29^\circ$C, 4.2 kW/$\ell$/$^\circ$C.)
- Big hydropower station (Stornorrfors outside Umeå) 0.33 GW.
- Total average power consumption for Sweden, 43 GW.

The sun

This is interesting since most of the energy that we make use of, directly or indirectly, comes from the sun.

- Total power 3.8×10^{26} W.
  - Average power density only 0.27 W/m^3!!
  - Generated close to the core. Maximum ≈ 280 W/m^3.
- Inflow to Earth's atmosphere, 1.37 kW/m^2 — the solar constant.
  Inflow reaching the ground $\approx$ **1 kW/m**^{2}.
  Compare with geothermal energy flow ≈ 0.1 W/m^2.
- Total inflow: 1.7×10^{17} W $= 1.5 \times 10^{21}$ Wh/a $= 1.5 \times 10^9$ TWh/a.
- Compare with the World's energy consumption $\approx 1 \times 10^5$ TWh/a.

Supply and consumption

Statistics are given for both supply and consumption. Rather different!
Sweden:

- Energy supply = 565 TWh,
- Energy consumption = 378 TWh.

One big reason for the difference is the wasting of heat from nuclear reactors. With an efficiency of 35% the supply of 184 TWh gives a consumption of only 64 TWh. (The loss is 118 TWh.)

Energy consumption

Sources: International energy agency, `www.iea.org`,
Energimyndigheten, `www.energimyndigheten.se`.
Energy for one year, 2017 or 2018.

	World wide	Sweden	US	Africa
For one year				
energy (ktoe)	9.66×10^6			6×10^5
energy (Btu)			101.3×10^{15}	
energy (TWh)	112 021	**378**	29 681	6 978
power (GW)	12 788	43.2	3 388	797
population/10^9	7.6	0.01	0.3272	1.2
pow/cap (W)	1 683	4 320	10 355	664

kilotonnes oil equivalent: 1 ktoe = 1 Gcal = 0.01163 TWh,
10^{12} Btu = 0.293 TWh.

2. Energy supply—different fuels

Energy supply—fossil fuels

Statistics from `www.iea.org`

Fossil fuels:

	World	Sweden	Sweden adjusted[1]
oil	31.8%	20.1%	26%
natural gas	22.2%	2.0%	2.6%
coal	27.1%	4.5%	5.8%
total	81.1%	26.6%	34%

[1] Adjusted by not including the waste heat from nuclear power in the energy supply

Electrical power in Sweden, 2017

Energy per year, TWh/a

Hydropower		64.632
Wind		17.609
Sun		0.230
Nuclear power		63.008
Conventionel “heat-power”	“värmekraft”	15.003
“Power-heat”	“kraftvärme”	14.689
Total production		160.481

- Electricity 160 TWh/a = 18 GW.
- Total 378 TWh/a = 43.2 GW.
- Hydropower, Wind, and sun: 51.4%.
- Power from heat is to some degree from biofuels.

3. Technologies for renewable energy

Energy densities

	energy density
gasoline, 31.5 MJ/ℓ =	45.7 MJ/kg
fat	37 MJ/kg
alcohol	29 MJ/kg
protein	17 MJ/kg
carbohydrate	16 MJ/kg
Lead-acid battery	0.17 MJ/kg
Lithium-ion	0.36—0.875 MJ/kg
Tesla 2170, 250 Wh/kg =	0.9 MJ/kg

Wind power

Wind Power Capacity Worldwide Reaches 597 GW in 2018.

- China—the first country with an installed wind power capacity of more than 200 GW.
- US—96 GW.
- Sweden—2 GW.

Photovoltaics

PV is the conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect.

- Solar photovoltaics is growing rapidly. By the end of 2018, global cumulative installed PV capacity reached about 512 GW.
- By the end of 2018, China had 175 GW of photovoltaics capacity, 3.3% of their total consumption of electricity.
- Germany had 45.9 GW of photovoltaics capacity, 7.9% of their domestic electricity consumption.

However, the power from the direct sun light fluctuates a lot. This has to be compensated for with other power sources.

Concentrated solar power

CSP systems generate solar power by using mirrors or lenses to concentrate a large area of sunlight onto a small area.

- Electricity is generated when the concentrated light is converted to heat, which drives a heat engine connected to an electrical power generator.
- CSP had a world's total installed capacity of 5.5 GW in 2018. Spain accounts for almost half of the world's capacity, at 2.3 GW. The United States follows with 1.74 GW.
- The BIGGEST Concentrated Solar Plant in the World is in Morocco `https://www.youtube.com/watch?v=eTE7rGEb3tU`

. . . but perhaps outdated

> *Would there be a way to sell this kind of energy to other continents? It would be interesting if African countries could become a literal power house for solar energy thanks to the huge exposer to the sun and also be able to create jobs and sustainability in Africa, while selling huge amounts of power to other countries.*

This has been a common dream, however. . .

- Large costs for maintaining such big plants. Water needed for cleaning the mirrors.
- Expensive to make cables to Europe. Energy losses at transportation.
- The price of photovoltaic devices has dropped a lot since the building of this plant. More cost efficient to install such equipment in Europe.

4. Electricity in vehicles

Two alternatives

- Store energy in batteries
- Store energy as liquid hydrogen—fuel cell converts to electricity

Batteries

Main concerns

- A car needs lots of batteries.
- Batteries usually need metals that are difficult to get. Bad working conditions in mines in Congo.
- How environmently-friendly is the production of these batteries?
- Concerns about how to handle worn-out batteries. Possible to recycle?

Hydrogen gas with combustion

Now available in Umeå, see `https://www.oazer.se/`

- "En vätgasstation står nu klar för tankning på Västerslätt i Umeå. Det är det lokala uppstartsbolaget Oazer som utvecklat en småskalig tankstation med egen produktion av grön vätgas."

Concerns:

- The flammability of the fuel.

Hydrogen and fuel cells

Advantage:

- High efficiency. In practice 40-60%.
- "Even if the hydrogen is from natural gas the emission can be cut by 30%."

Promising example from Mariestad, Sweden:

- Solar energy produces hydrogen gas from electrolysis of water.
- 500 SEK to fill the tank.
- For a car with a fuel cell this is enough for 700 km.

Concerns:

- Danger of electrical shock and the flammability of the fuel.