Energy System Overview

From the Radiant Sun to the Consuming Ego

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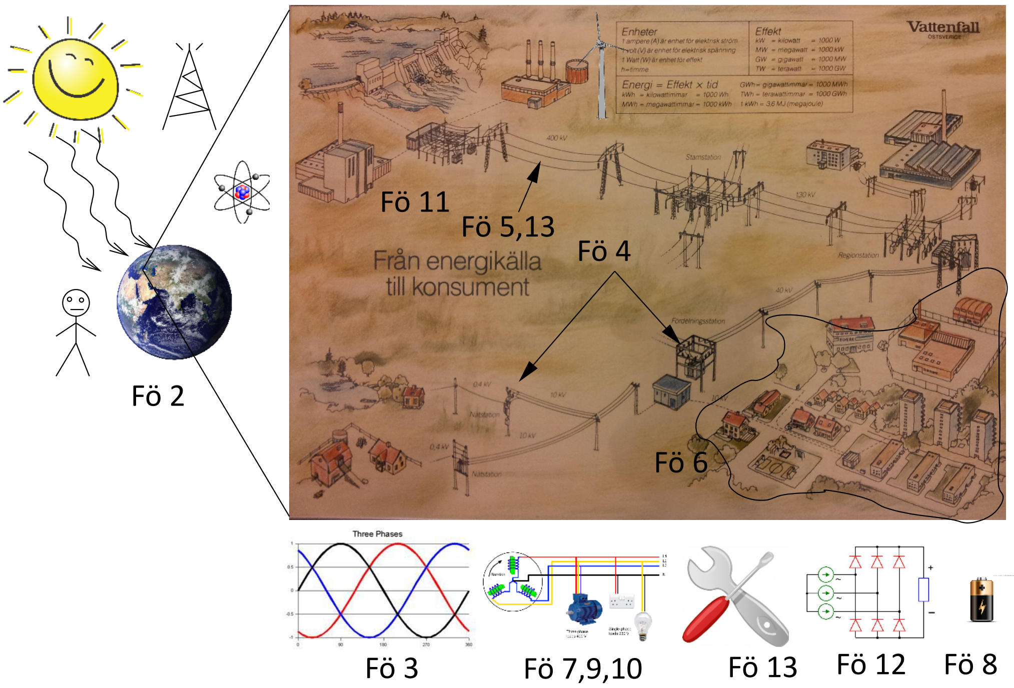
Course Overview



Outline

Thermodynamics definition

What is thermodynamics?

It is the study of energy and its transformations!

What is energy?

This question is simple but there is no generally accepted definition. Atkins (1994) defines it as: "The scientific definition of energy is the capacity to do work or supply heat." This definition relies upon the definitions of heat and work. Another definition is given in Sonntag et al. (1998) which says that "Energy is the capability to produce an effect".

A third example that shows the diversity of the definitions is given in Schmidt et al. (1993) where work and heat are defined based the concept of energy. Heat Q is energy in transition, not associated with mass transfer, and due to a temperature difference. Heat is energy crossing the system boundary. It is not possessed by the system. Heat cannot be stored but must be converted to some other form of energy when crossing the system boundary. Work W is energy in transition, not associated with mass transfer, and due to a difference in a potential other than temperature.

Thermodynamics definition

My View

Most people (especially engineering students) are familiar with the concept of energy, which is a property possessed by a system, and it is not essential to make a precise definition for the usage and treatment of the thermodynamics.
Energy comes in different forms like electrical, thermal, potential, kinetic, chemical, or nuclear.

Definition from Encyclopedia Britannica.

Thermodynamics is the science of the relationship between heat, work, temperature, and energy. In broad terms, thermodynamics deals with the transfer of energy from one place to another and from one form to another. The key concept is that heat is a form of energy corresponding to a definite amount of mechanical work.

My Quote

–You don't learn thermodynamics, you get used to it!

Thermodynamic Concepts

Important but well known concepts.

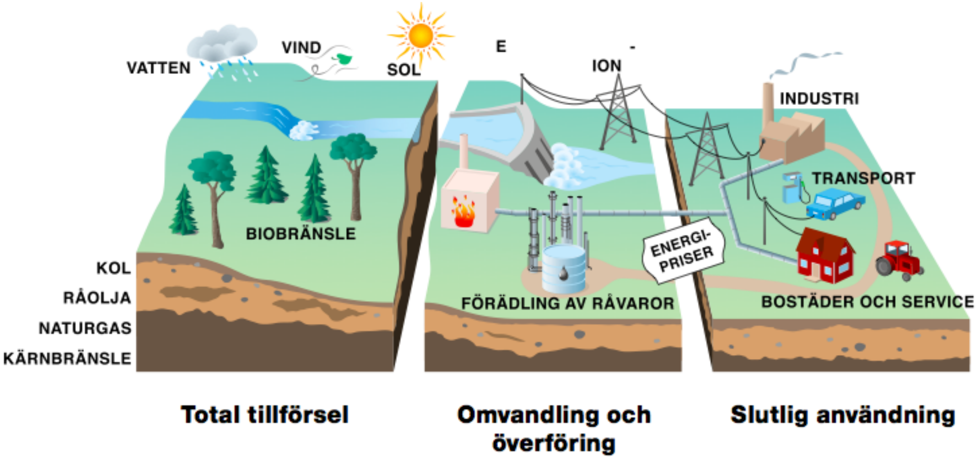
- Systems: Isolated/Closed/Open. System boundary.
- Energy: Potential, Kinetic, Electric, Thermal, Chemical, Nuclear.
- States: Pressure, Temperature, Voltage, Current, Molecules
- Processes and energy transitions: Mechanical, Heat, Electric, Reactions.
- Energy and power.

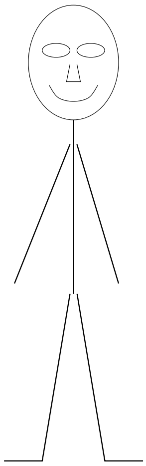
Power: Transfer of energy per time unit: Heat $\dot{Q}$, Work $\dot{W}$, Electriciy $P = U * I$, Mass and Radiation.

A Simple Thermodynamic Model for the Earth

Radiation from Sun to earth and from earth to the universe.
A closed system not isolated (negligible mass transfer).

Thermodynamic View of the Earth or Society





Outline

The Human Being and Its Energy Demand

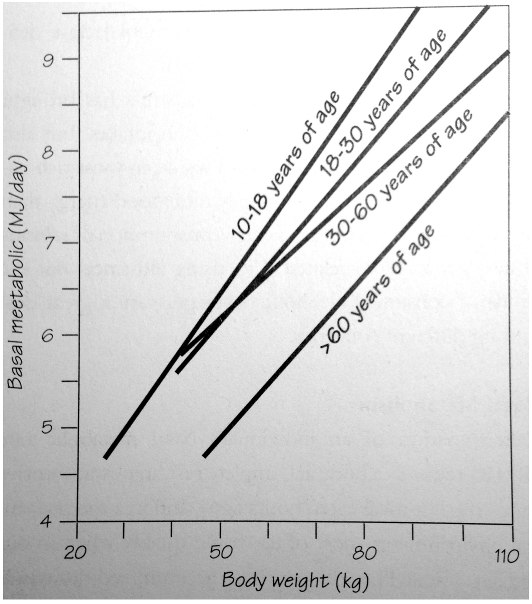
- Human daily average energy input:
  2000 - 2500 kcal (Cal)
  (1600 - 3300 kcal)

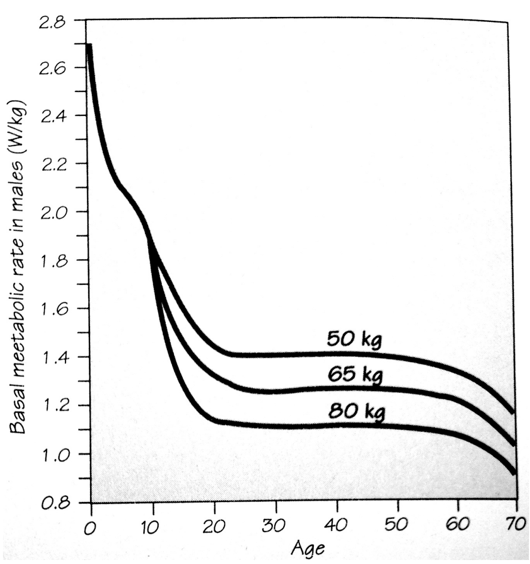
1 cal = [energy to heat 1 g of water 1°C] = 4.184 J

- Written in engineering units
  - $2500 \cdot 1000 \cdot 4 \approx 10$ MJ/day — 3.6 GJ/year
  - $10/3.6 \approx 2.8$ kWh/day — 1 MWh/year
- Perspectives on our daily eating
  - Butter 3000 kJ / 100 g ⇒ 350 g
  - Sugar 1600 kJ / 100 g ⇒ 625 g
  - Wheat flour 1400 kJ / 100 g ⇒ 710 g
  - Corn seeds 360 kJ / 100 g ⇒ 2700 g
    (75 % water)

The Human Being and Its Energy Demand

Basal metabolic rates





The Human Being and Its Energy Production

Human power production

Peak work generation	1000 W
A horse power	736 W
Sustained work athletic	300-500 W
Sustained work full day	100 W
Heat generation	100 W

- One work day, 8 hours at 125 W = 1 kWh
- Work year, 40 weeks with 5 days = 200 kWh

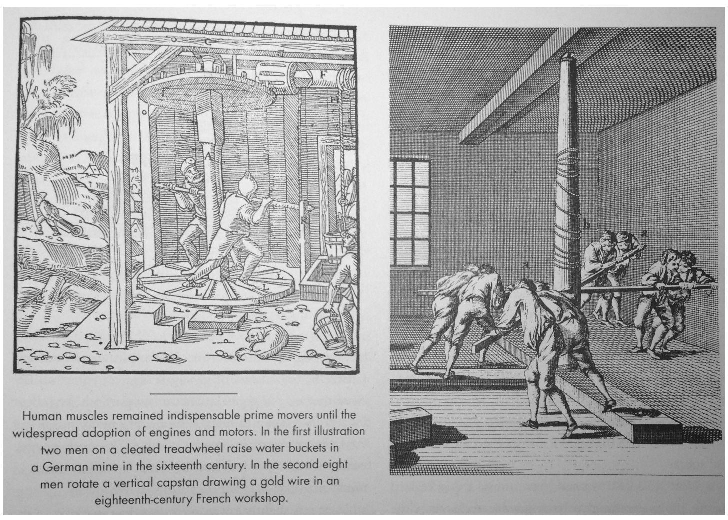
The Energy Production of a "Slave"

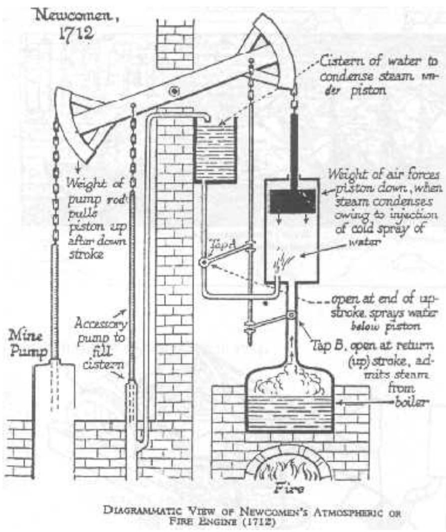
1 kWh/day 200 kWh/year

Converting to the unit – MJ

3.6 MJ/day 720 MJ/year

- Prior to industrialization
  – Human, horse, ox, ... were the prime movers.
- After industrialization
  – Machines become our "work horses" or "energy slaves".





Manual labor vs Newcomen's Steam engine (pump water from mines.)

Perspective on the Human Efficiency

Summary from previous slides

- Energy input 10 MJ /day
- Energy output 0.28 MJ /day (modern slave)

Putting our achievements into perspective

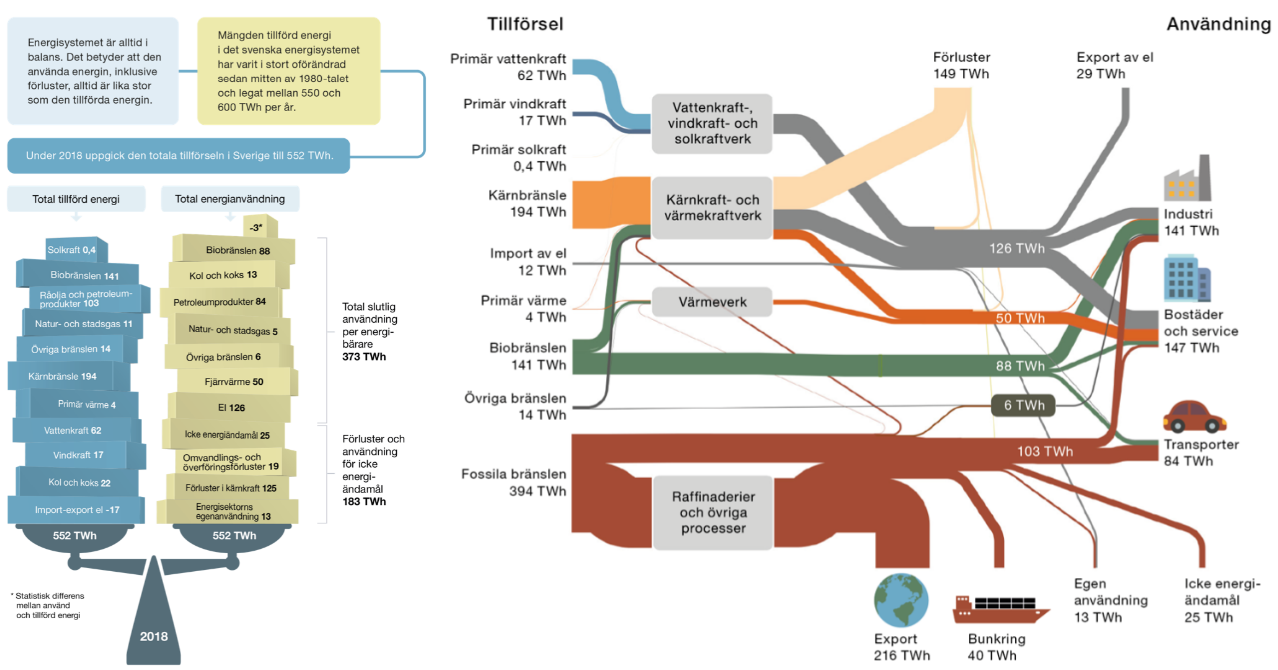
Perspective 1:

- Human efficiency on a work intense day 2.8%.
- Muscle efficiency peaks at about 20%.

Perspective 2:

- Millions of years of evolution $\eta = 3\%$.
- A diesel engine $\eta = 30\%$, peak $\eta = 50\%$.
  After 300 years of engineering.

Energy Balance and System in Sweden 2018



Energy Usage in Sweden (Numbers from 2011)

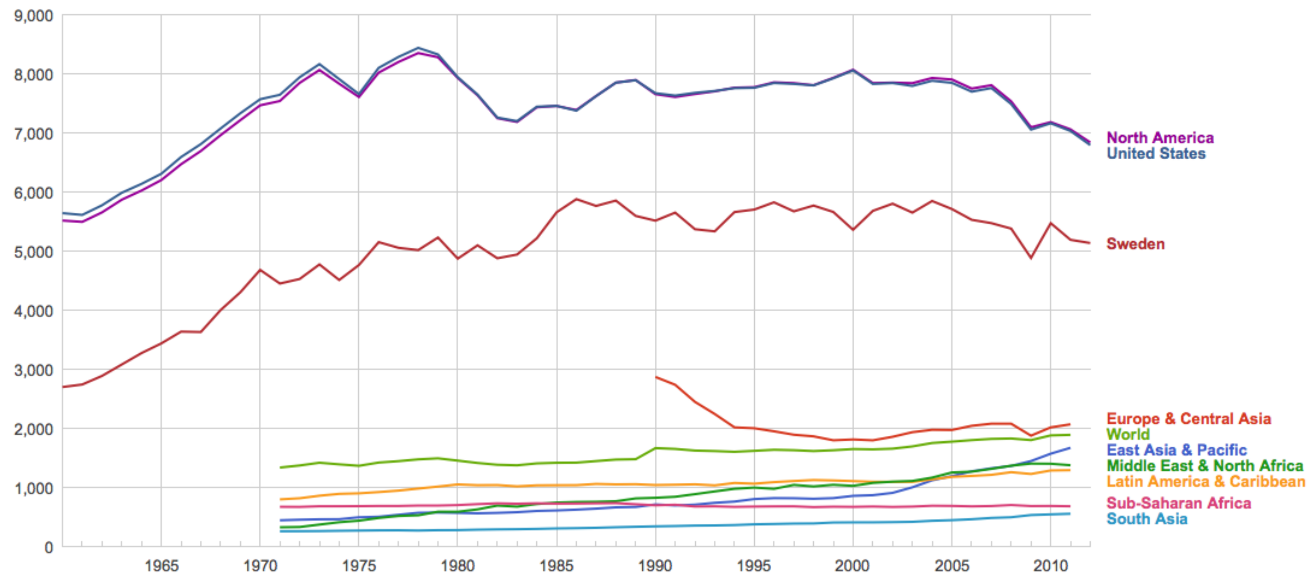
Energy input 580 TWh/year and output 380 TWh/year.

How many energy slaves do we have?

- Energy consumption in Sweden 380 TWh/year.
- Energy per capita 40 MWh (150 GJ)/year and person.
- Energy production of the slave per capita 200 kWh.
- We have approx 200 energy slaves per person.

Energy Consumption in the World

Energy usage per capita (kg oil equivalent, $q_{LHV} = 42$ MJ/kg)

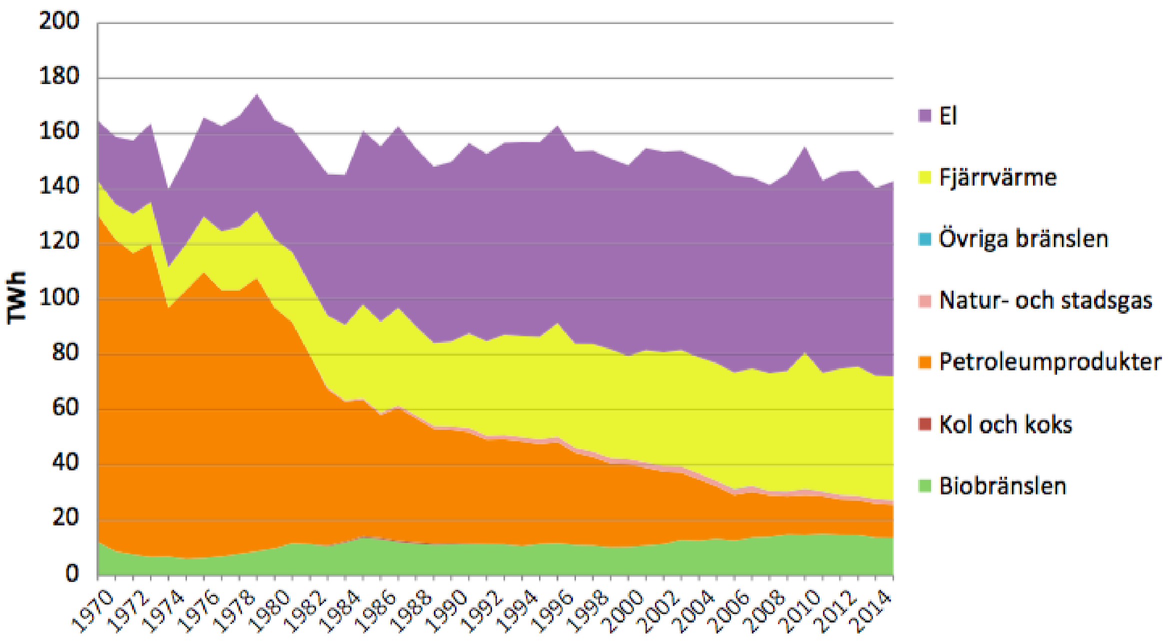


1 kg oe ca 42 MJ

7 toe ≈ 300 GJ, 5 toe ≈ 200 GJ, 2 toe ≈ 80 GJ

80 GJ * 7e9 persons ≈ 560e18 J = 560 EJ

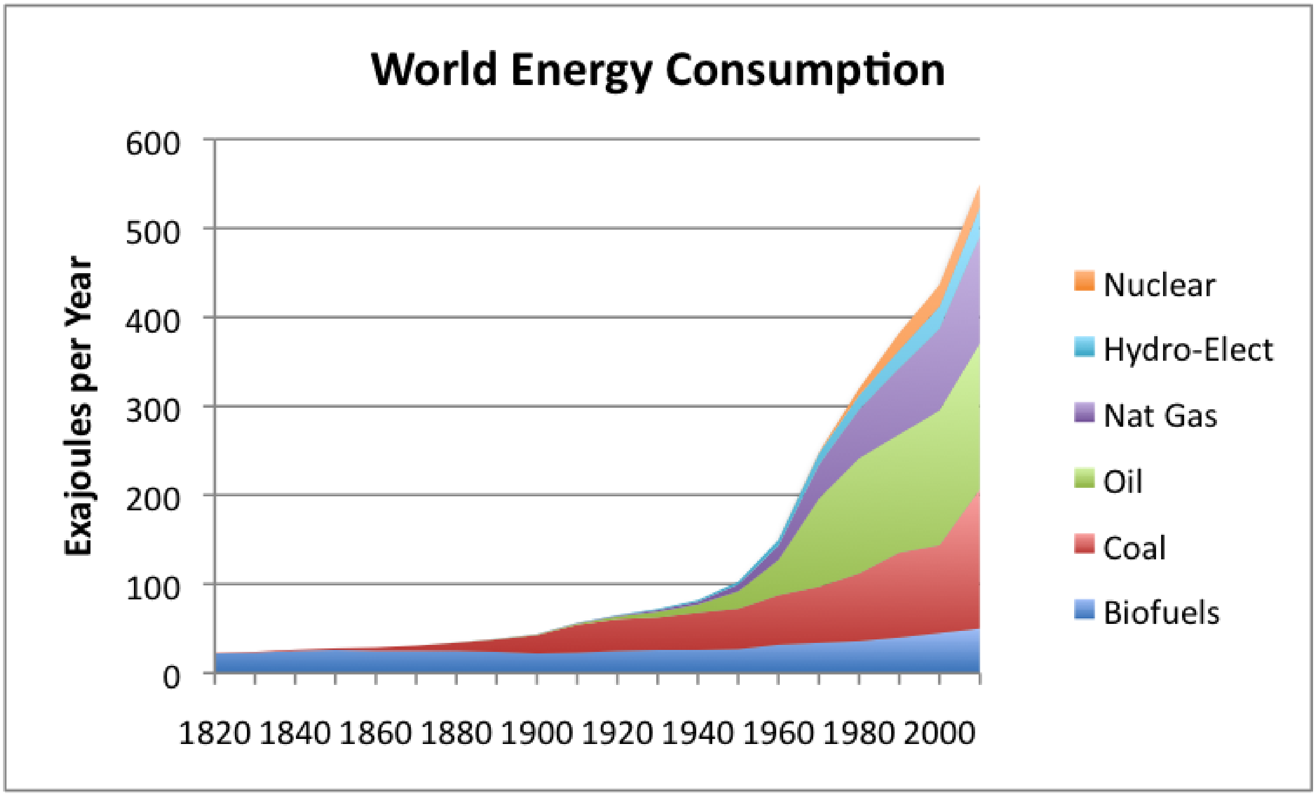
A Snapshot



Figur 5 Energianvändning i bostads- och servicesektorn 1970–2015, TWh.
Källa: Energimyndigheten.

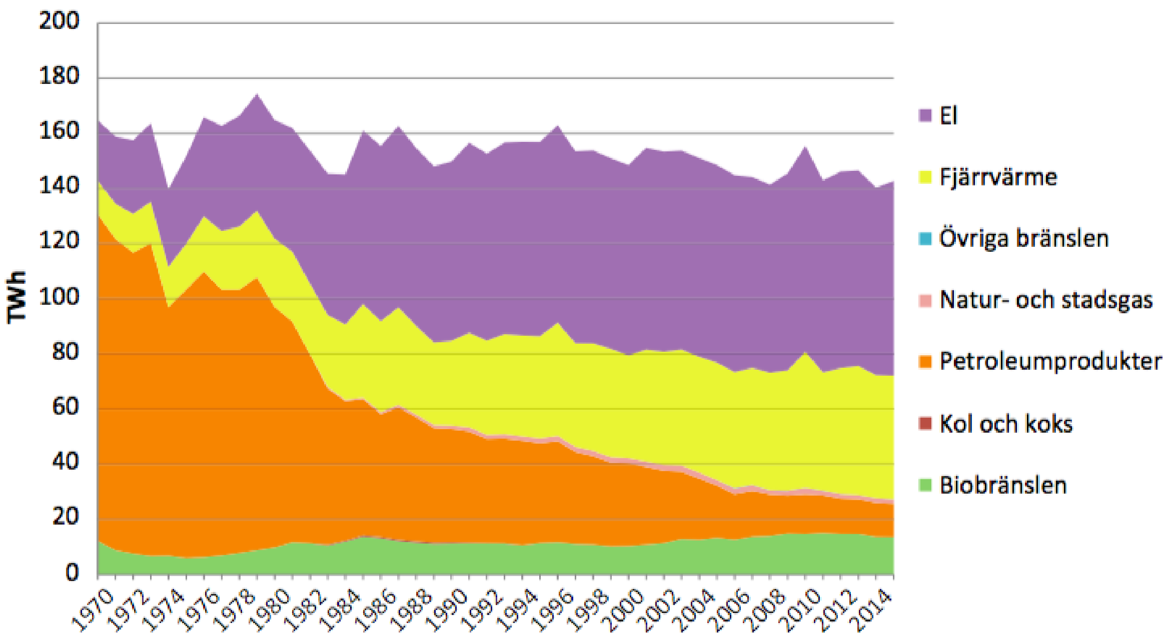
Looks a little bit better.

Energy Consumption in the World - By Source



Looks bad from CO_2 perspective.

Swedish house



Figur 5 Energianvändning i bostads- och servicesektorn 1970–2015, TWh.
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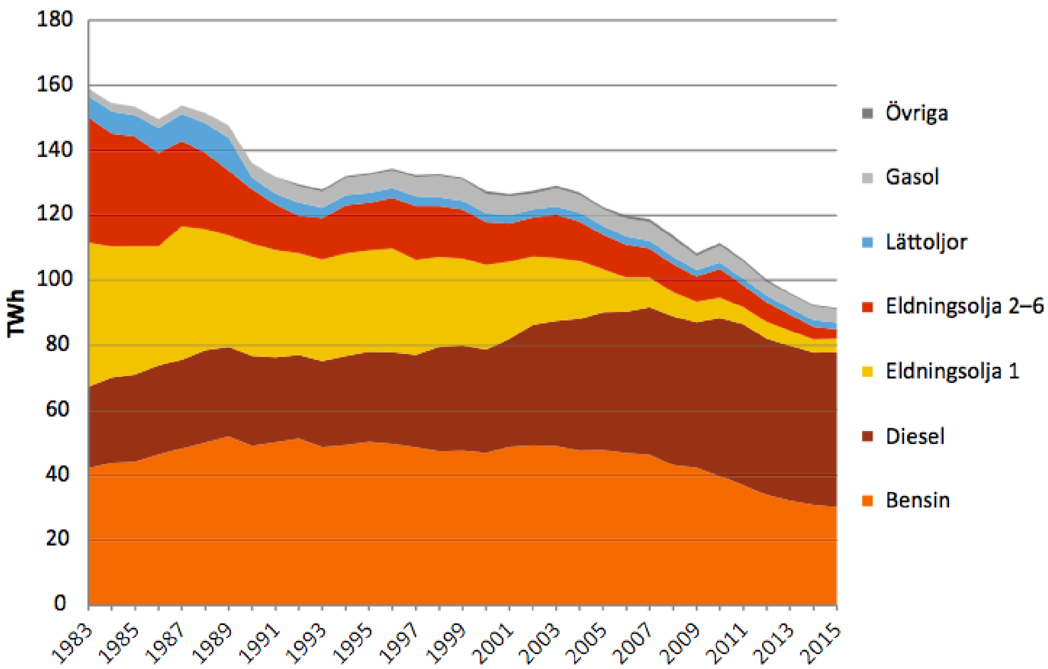
Swedish Oil Products



Figur 30 Användning av oljeprodukter inklusive utrikes sjöfart, 1983–2015, TWh.
Källa: Energimyndigheten.

Decreasing trend

The Fact and Challenge

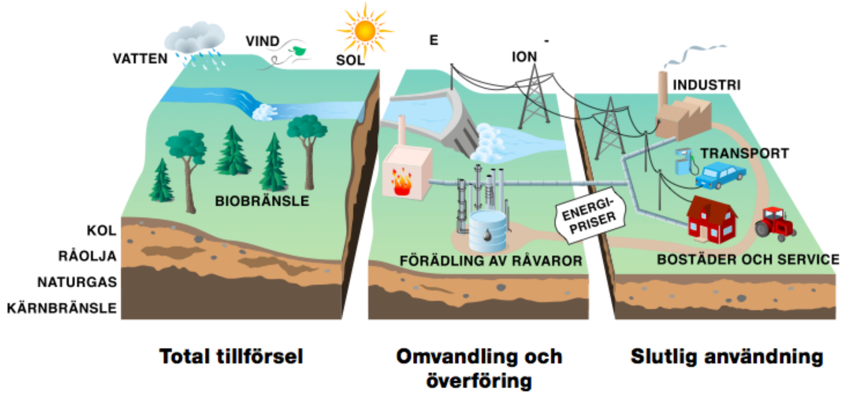
Work (or energy) is strongly connected to our well being and social status.
–Play with `gapminder.org`.

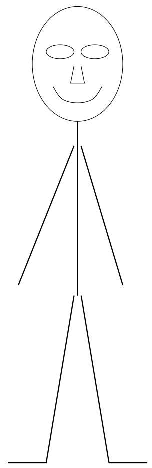
The Trend

- The demand for *work* will increase...
- ...which will increase the energy consumption.
- Our (engineering) challenge is to:
  - meet the demand for work with more efficient products and processes
  - and attenuate the increase in energy consumption.

Outline

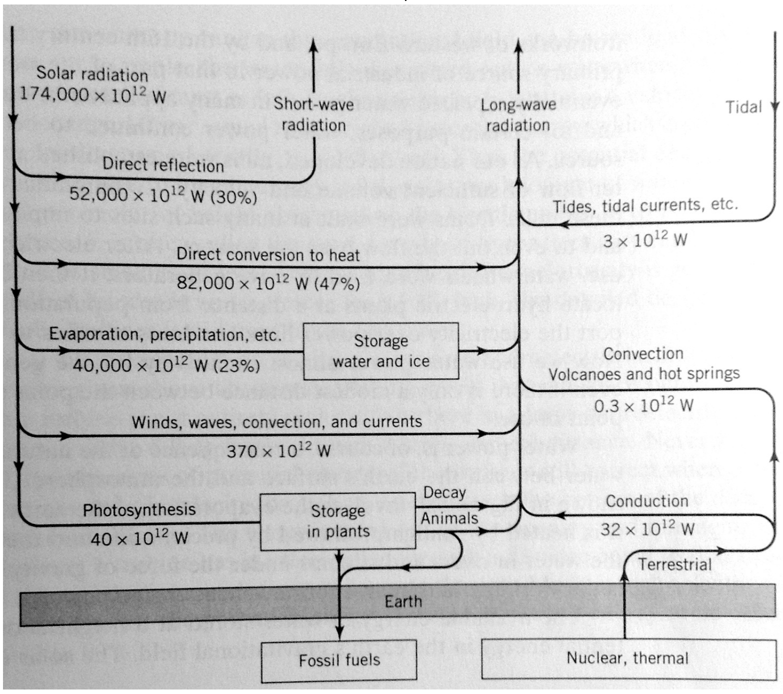
Energy System and Sources



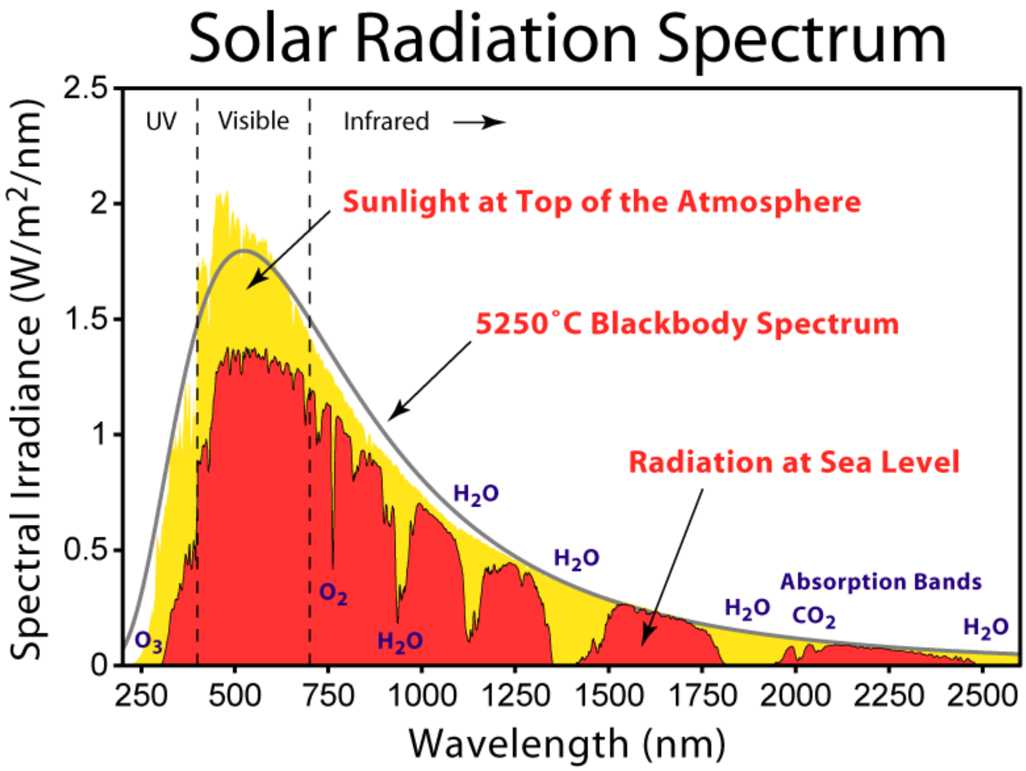


Total Radiation Power and The Earth

Sun Radiation 1370 W/m^2 – view factor – Inbound to Earth



Radiation Spectrum – Black body



Perspectives on Energy Stores

Table 2 Energy Stores

Energy of	Magnitude
Global coal resources	200,000 EJ
Global plant mass	10,000 EJ
Latent heat of a thunderstorm	5 PJ
Coal load in a 100-t hopper car	2 TJ
Barrel of crude oil	6 GJ
Bottle of white table wine	3 MJ
A small chickpea	5 kJ
Fly on a kitchen table	9 mJ
A 2-mm raindrop on a blade of grass	4 µJ

Energy "Flows" Per Event

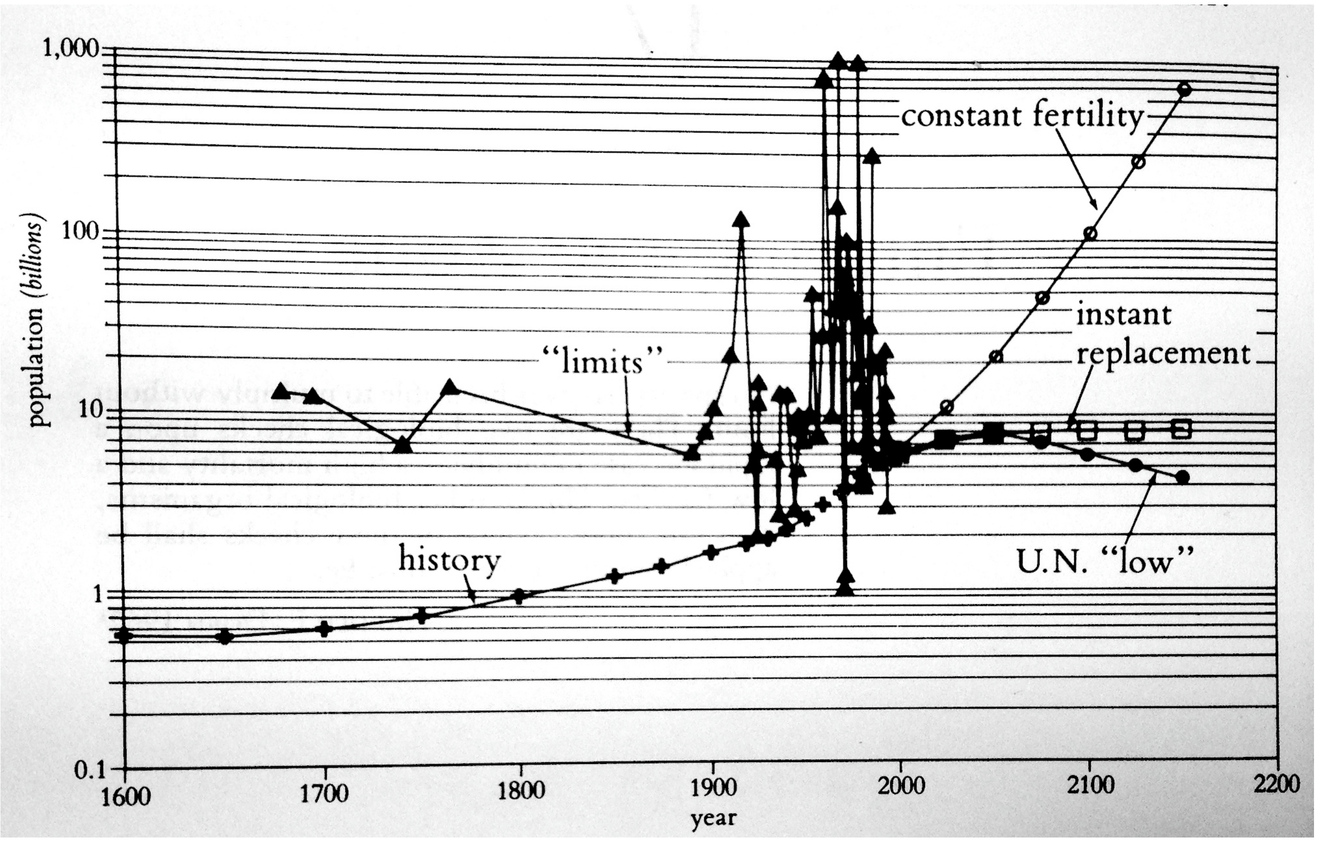
Energy of	Magnitude
Solar radiation reaching the Earth	5500000 EJ
Global net photosynthesis	2000 EJ
Global fossil fuel production	300 EJ
Typical Caribbean hurricane	38 EJ
Largest H-bomb tested in 1961	240 PJ
Latent heat of a thunderstorm	5 PJ
Hiroshima bomb of 1945	84 TJ
Basal metabolism of a large horse	100 MJ
Daily adult food intake	10 MJ
Striking a typewriter key	20 mJ
Flea hop	100 nJ

Energy Flows in W

Energy flows	Power
Global intercept of solar radiation	170 PW
Wind-generated waves on the ocean	90 PW
Global gross primary productivity	100 TW
Global Earth heat flow	42 TW
Worldwide fossil fuel combustion	10 TW
Florida Current between Miami and Bimini	20 GW
Large thermal power plant	5GW
Basal metabolism of a 70-kg man	80 W

Outline

How many people can the earth support



Source: "How many people can the Earth Support", Joel E. Cohen, (1998)

How many people can the earth support

TABLE 10.4 De Wit's (1967) estimates of the Earth's potential carbohydrate production (assuming photosynthesis were the sole limit on growth) and the human population that could be fed from the calories grown

				square meters per person to support life				
				no allowance for urban and recreational needs		750 square meters per person for urban and recreational needs		
north latitude[a] *(degrees)*	land surface *(100 million hectares)*	number of months above 10°C	carbohydrate per hectare per year *(1000 kilograms)*[b]	square meters per person	number of people *(billions)*	square meters per person	number of people *(billions)*	percentage of agricultural land
Column 1	2	3	4	5	6	7	8	9
70	8	1	12	806	10	1,556	5	52
60	14	2	21	469	30	1,219	11	38
50	16	6	59	169	95	919	17	18
40	15	9	91	110	136	860	18	13
30	17	11	113	89	151	839	20	11
20	13	12	124	81	105	831	16	10
10	10	12	124	81	77	831	11	10
0	14	12	116	86	121	836	17	10
−10	7	12	117	85	87	835	9	10
−20	9	12	123	81	112	831	11	10
−30	7	12	121	83	88	833	9	10
−40	1	8	89	113	9	863	1	14
−50	1	1	12	833	1	1,583	1	53
total	131				1,022		146	

Source: "How many people can the Earth Support", Joel E. Cohen, (1998)

Outline

1. Thermodynamic View of the Earth
2. The Human Being and Its Energy Demand
   - Energy Slaves
   - Energy Consumption in the World
3. Energy Sources
   - The Sun
   - Oil/Coal/Natural gas
   - Nuclear
   - Perspectives on Energy Sources
4. How many people can the earth support
5. **Examples of Game Changers**
   - Shale Fracture
   - Legislation and Vehicles
6. More on Human Energy

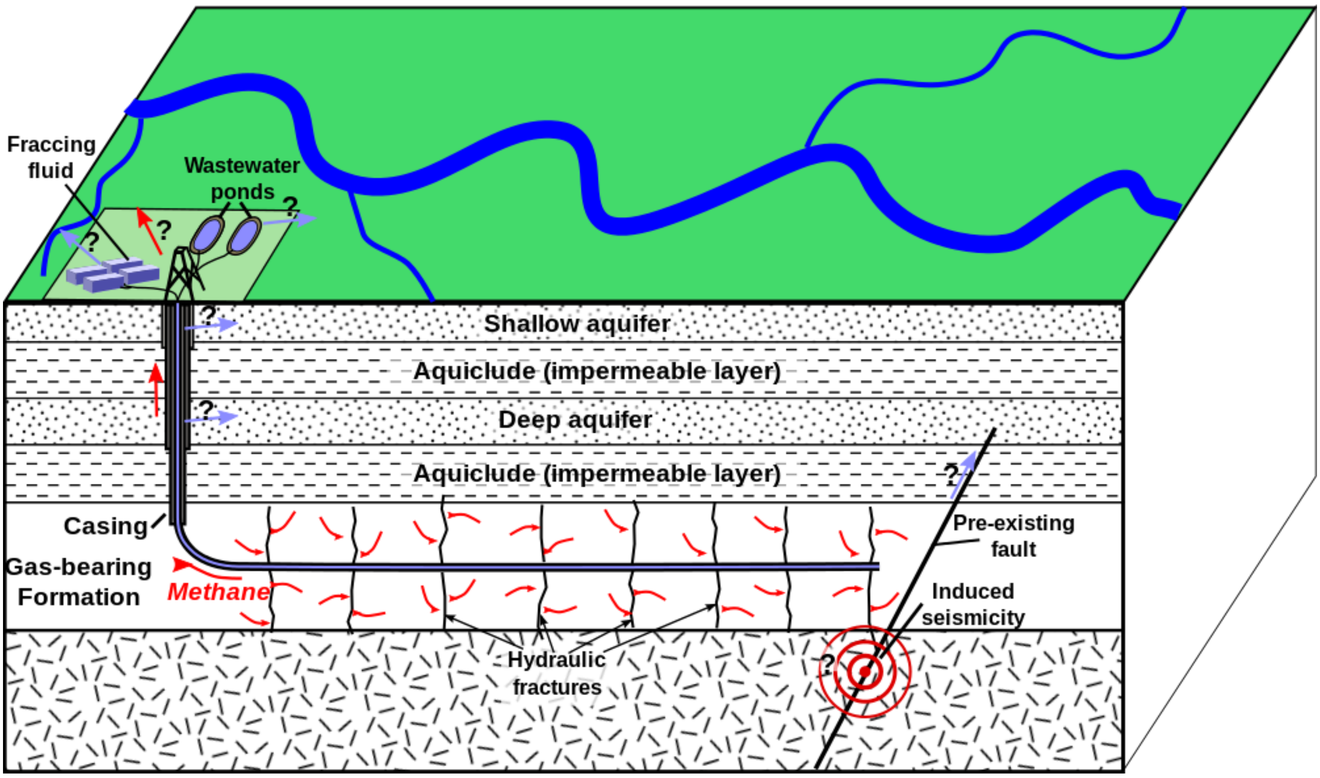
Game Changers

New knowledge and input changes the world.

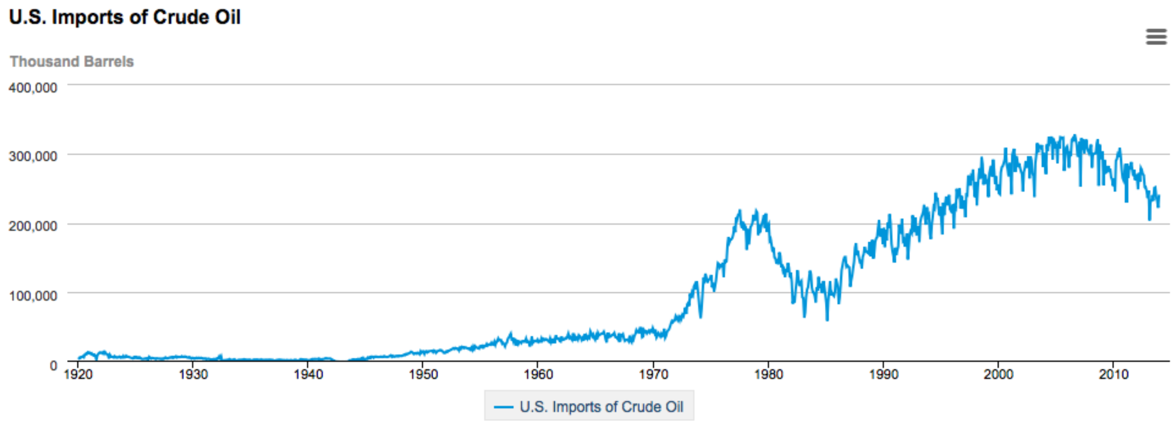
Three small examples

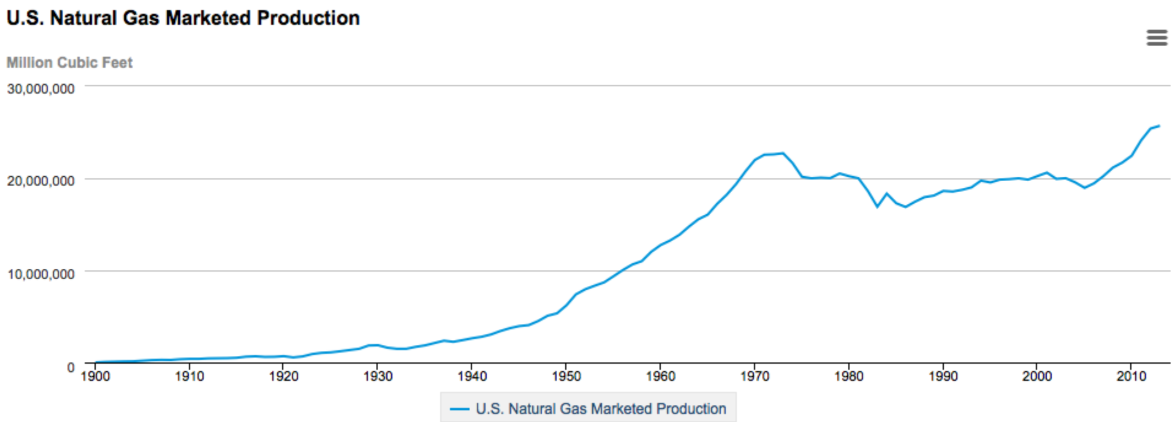
- Oil crisis
- Shale fracture, natural gas in US.
- Legislation.

Hydro fracture



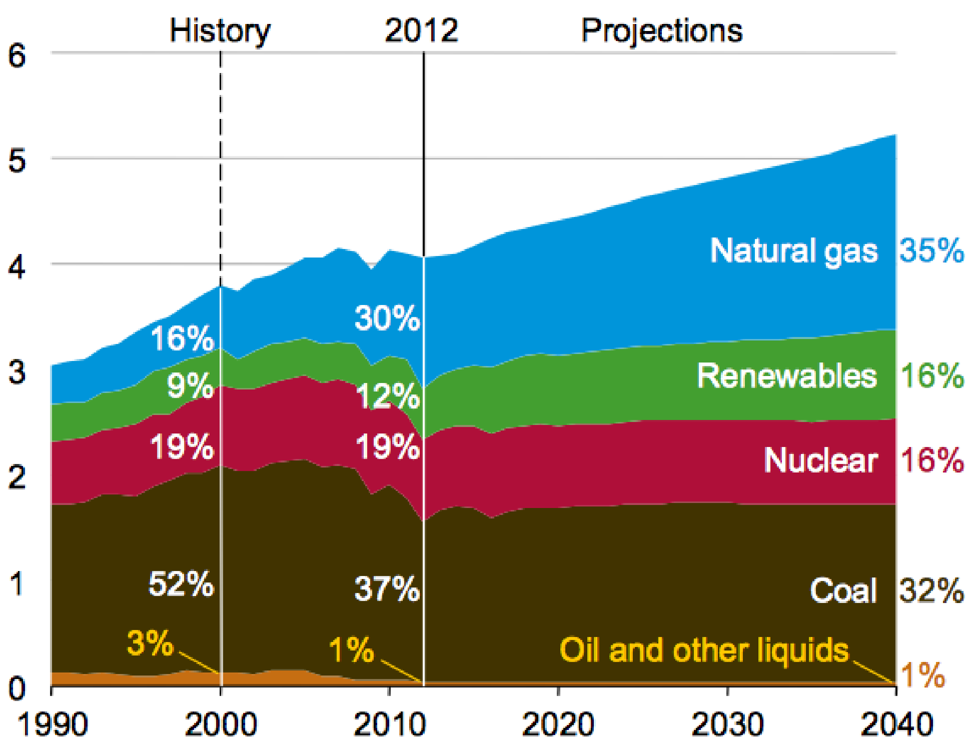
Oil Import and Natural Gas





Natural Gas Impact on Electricity

Figure 13. Electricity generation by fuel, 1990-2040 (trillion kilowatthours)



Natural gas and CO_2

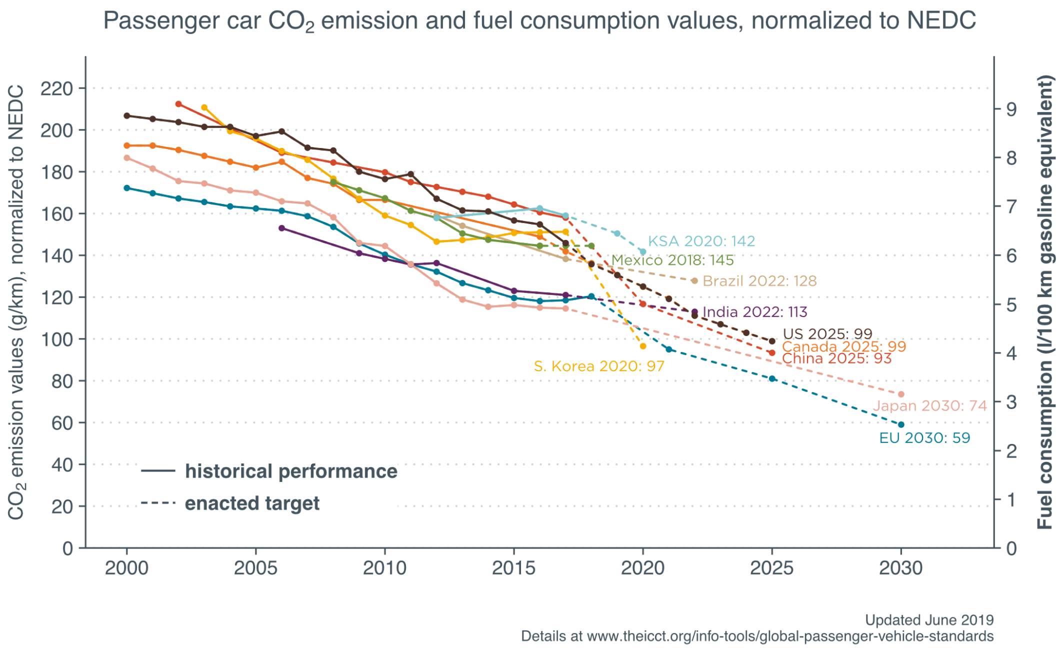
Natural gas CH_4 vs Oil products C_nH_{2n+2} $(n > 10)$ vs Coal C

- Coal produces only CO_2 and no H_2O, so it has a high CO_2 factor.
- Oil (gasoline diesel) produces water H_2O and CO_2 the CO_2 factor is reduced with a factor 1.3 compared to Coal.
- Natural gas produces even more water H_2O compared to CO_2 and the factor is reduced with a factor 1.3 compared to Oil.
- Natural gas has a factor 1.3 less CO_2, than Oil, and 1.7 less than Coal, for the same energy.
- Often comes out as a top candidate for CO_2 reduction.

Natural gas is better than coal and oil, considering CO_2, but it is not sustainable.

CO_2 performance and legislations

Fleet average from manufacturer.



130 g/km $\sim$ 0.55 l/10 km, 95 g/km $\sim$ 0.4 l/10 km
70 g/km $\sim$ 0.3 l/10 km

Possible Technical Solutions - Engine or Powertrain Efficiency

How can we reach the 59 g CO_2/km goals?

My personal reflections

- Improving vehicle/powertrain efficiencies?
  – No, already well optimized, can shave off a few percent.
- New vehicles?
  – Yes, but will customers accept new vehicles.
- Bio fuels?
  – Yes, but not yet ready
- Electrification of vehicles?
  – Yes, the most probable short term solution

EU Legislation - ECE R101 rev 3 (12 April 2013)

3.4.2.1. In the case of testing according to paragraph 3.2.3.2.1.:

$$M = (De \cdot M1 + Dav \cdot M2)/(De + Dav)$$

Where:

- M = mass emission of CO2 in grams per kilometer.
- M1 = mass emission of CO2 in grams per kilometer with a fully charged electrical energy/power storage device.
- M2 = mass emission of CO2 in grams per kilometer with an electrical energy/power storage device in minimum state of charge (maximum discharge of capacity).
- De = vehicle's electric range, according to the procedure described in Annex 9 to this Regulation, where the manufacturer must provide the means for performing the measurement with the vehicle running in pure electric operating state.
- Dav = 25 km (assumed average distance between two battery recharges).

CO_2 Calculations – PHEV

According to the legislation proposal

PHEV – Electricity for charging no CO_2 emissions

- M = (De·M1 + Dav·M2)/(De + Dav) Where:
- M1 = 0
- Dav = 25 km

Reduction factor

- F = (De + 25)/25 reduction factor
- M = M2 / F
- De = plug-in distance in kilometer
- M2 = mass emission of CO2 in grams per kilometer with an electrical energy/power storage device in minimum state of charge. (Normal hybrid mode)

Technical Solution – Toyota Prius - PHEV

Hybrid

- I4, 1.8l, 60 kW (99 hp)
- Electric range < 1.6 km
- Weight > 1440 kg
- 3.9 l, 89 g/km
- 26800 EUR (DE)

Plug-in

- I4, 1.8l, 60 kW (99 hp)
- Electric range 25 km
- Weight > 1500 kg
- 2.1 l, 49 g/km (-45%)
- 36550 EUR (DE) (+36%)

Technical Solutions – Merceces S500 - PHEV

Normal

- V8, 320 kW
- Electric range 0 km
- 210 g/km

Plug-in

- V6, 254 kW + 80 kW el
- Electric range 30 km
- 69 g/km (-67%)

ECE reduction factor

F=(25+30)/25=2.2 (=55% reduction)

Side note: S300 BlueTec Hybrid 150 kW (204 hp), 4 cyl, Diesel, 20kW el, 115 g/km

Game changers

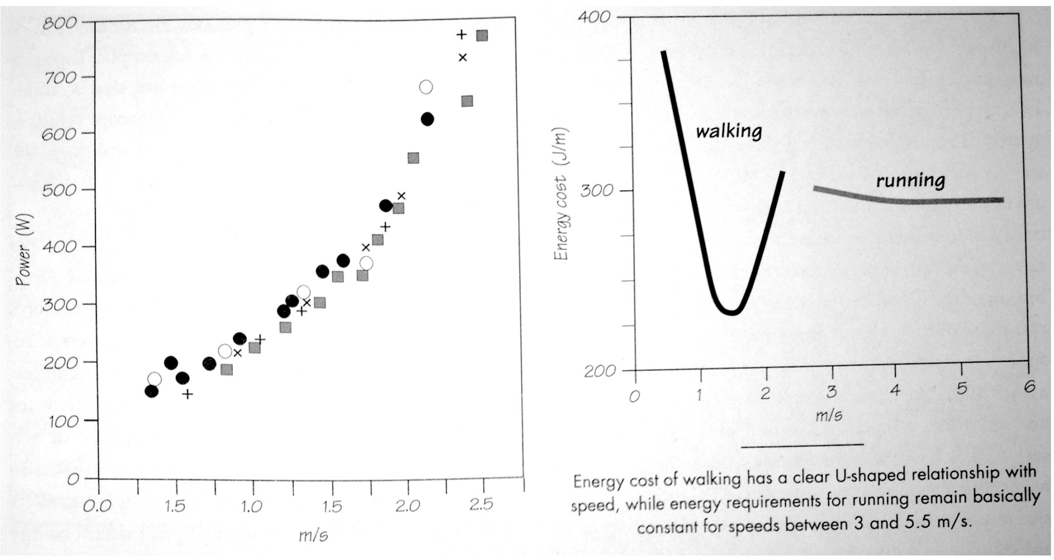
Some examples of game changers

- Global events
- Local events can evolve to global
- Technical development and evolution
- Political decisions

Difficult to predict

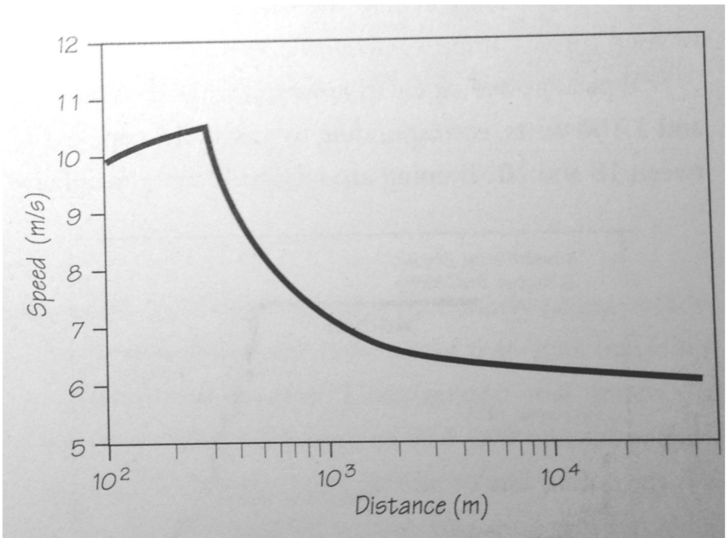
Outline

Walking and Running, Power and Distance



Energy cost of walking has a clear U-shaped relationship with speed, while energy requirements for running remain basically constant for speeds between 3 and 5.5 m/s.

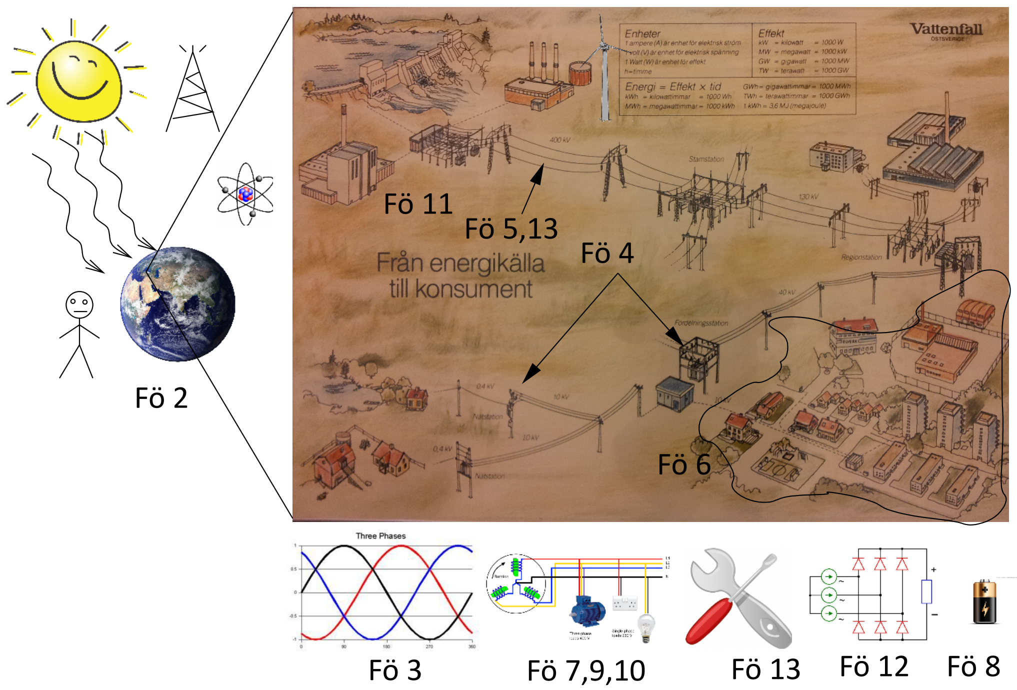
Running – Power vs Distance



Maximum running speed as a function of distance. Up to about three hundred meters, runners can rely on stored energy converted anaerobically; above that level their speeds must decline to conform to the slower aerobic balance.

Stored energy in muscles: anaerobic vs aerobic energy conversion.

Course Overview



Purpose of Lecture

- Show some fragments of the Big Picture of Energy.
- Reflect upon the human and its energy use.
- Inspire to interest and after-thought.
- Eye opener for view points that can help use understand and reach a sustainable society.