Course Lecture on book:
Renewable Energy – Power For A Sustainable Future

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Chapter 1: Introducing Renewable Energy

1.1 Introduction

• Sun's power is 380 billion, billion MW.
• Each second, 600 million tons of hydrogen converted to 595 million tons of helium.
• The difference in energy (5 million tons) is equivalent to 1 billion 1 megaton hydrogen bombs (since $E = mc^2$).
• Distance from Earth to the Sun = 150 million kilometers.

• Renewable energy sources: derived principally from the enormous power of the Sun's radiation, are both the most ancient and modern forms of energy used by humanity.

Direct use: heating, illumination—

Indirect use: bioenergy (photosynthesis), water cycle of evaporation, condensation & rain (water wheels etc.) and wind (windmills, sails).

• *Uneven heating of Earth* results in wind and water currents (heat always moves from high to low temperature.

• Can be used to: grind grains, irrigate crops & propel ships and trains

• 1698: "Steam engine" invented.
• **1769**: steam engine improved by using a 'condenser' (for large temperature difference) by James Watt
  • Unleashed the great energy density of **coal**: water pumps (used in coal mines), weaving, cutting, grinding, stream locomotive, ships
• 1801-04: First steam locomotives (trains on rails)
• 1831 (onwards): development of electric generators (coil of wire moving relative to magnetic field) by Michael Faraday and others. **Also first electric motors, a modified generator**.
• 1837: First electric automobile (but difficult because NO good/appropriate battery)
• 1859: first oil well. Refined to kerosene and used for kerosene lamp lighting.
• 1868: First electric power station (plant), using hydro power.
• 1876: first automobiles powered by steam
• 1879: first (practical) electric light bulb.
• 1882: first electric power station using steam engines (burning coal), by Edison.
•1886: first automobile powered by gasoline
• 1903: first airplane flight by Wright brothers

Today, coal (electric power plants), oil (transportation) & natural gas (heating) represent 80% of world's energy.

• A "sustainable source" is one that:

- is not substantially depleted by continued use
- does not entail significant pollutant emissions or other environmental problems
- does not involve the perpetuation of substantial health hazards or societal injustices

• Though people have long known of the environmental and societal problems of fossil fuels, it was not until the 1970s that people started taking them more seriously, and understanding their limitations. (Result of Lovelock's ECD and Rachael Carson's "Silent Springs".)

• During WWII nuclear energy became understood and used. Showed great promise, but over time its negative aspects became apparent. (Three Mile Island, Chernobyl, Fukushima)

Force, energy and power

(steam engine, 1769; oil well (kerosene lamp), 1859; light bulb, 1879)

• Using the SI system (from 1960) of meters, kilograms and seconds:
Newton (N) = force**; Joule** (J) = energy and **Watt** (W) = power.

FORCE: Needed to change the motion of any object.
The newton (N) is defined as that force which will accelerate a mass of one kilogram (kg) at a rate of one meter per second per second (m s^{-2}):

force (N) = mass (kg) x acceleration (m s^{-2}); a = f/m

ENERGY: Whenever a force is accelerating something or moving it against an opposing force, it must be providing energy: one joule (J) is defined as the energy supplied by a force of one newton in causing movement through distance of one meter:

energy (J) = force (N) x distance (m); units of newton meter (N m)

POWER: RATE at which energy is being converted from one form to another, or transferred between places. "Watt (W)" = one Joule (J) per second (J s^{-1})

• Energy can be measured in terms of power used over a given time period. If the power of an electric heater is 1 kW and it runs for one hour, it consumes 1 kilowatt-hour (kWh) of energy:

1 kWh = 3600 (sec/hr) x1000 (W) = 3.6 x 10^6 joules (3.6 MJ)

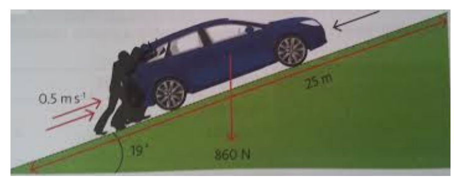
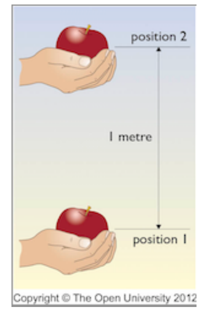


Table 1.1 Multiplier prefixes

Symbol	Prefix	Multiply by	... as a power of ten
k	kilo-	one thousand	10^3
M	mega-	one million	10^6
G	giga-	one billion (one thousand million)	10^9
T	tera-	one trillion (one million million)	10^{12}
P	peta-	one quadrillion (one billion million)	10^{15}
E	exa-	one quintillion (one billion billion)	10^{18}



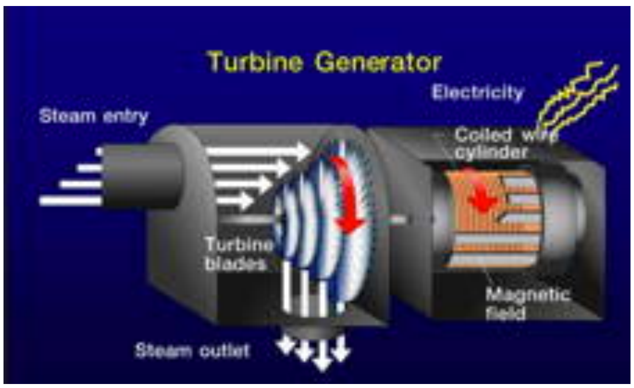
- "energy" facilitates the ability/capacity to do work
    - kinetic energy (in moving substances)
    - gravitational potential energy, etc.
    - electrical energy (in electric circuits)
    - thermal energy (heat; room-temp. air molecules move at about **1,700 km/hr**)
    - chemical energy (in fuels or batteries)

BASIC FORMS OF ENERGY

- Kinetic energy: the energy of motion = $1/2mv^2$
    - The kinetic energy within a material determines related to its temperature.
    - Temperature in 'Kelvin system' (absolute scale) = temperature (^{0}C) + 273
- Gravitational (potential) energy: = force x distance = weight x height (h)
  = (m x g) x h; g = 9.8 m/s^2
- Electrical energy: viewed at the atomic level, can be considered to be a form of chemical energy. When a fuel is burned, the energy liberated is converted to heat energy. Essentially, the electrical energy released as the electrons are rearranged. That is, the net release of energy from the breaking and forming of bonds is converted to the kinetic energy of the molecules of the combustion products.
    - "Voltage" (in volts) is measure of the electrical "potential difference" between two points in an electrical circuit, analogous to the potential energy concept in a gravitational field
    - power (W) = voltage (V) x current (I)
- Electromagnetic energy: that energy carried electromagnetic radiation, like solar energy that reaches Earth
- Nuclear energy: like that from a nuclear power plant (fission reactor), or the Sun (fusion process)

ENERGY CONSERVATION: THE FIRST LAW OF THERMODYNAMICS:

- The TOTAL energy (in an isolated system) is ALWAYS conserved
- Thus, in any energy technology a certain amount of energy is converted while some energy appears as hot "waste energy", but the TOTAL is always constant



In a typical power station, fuel is burned to produce high-pressure steam, which turns a turbine. This drives an electrical generator, operating on a principle discovered by Michael Faraday in 1832: a voltage is induced in a coil of wire spinning in a magnetic field. Connecting the coil to an electric circuit allows a current to flow. The electrical current can be transformed into heat, light, motion etc., depending on the circuit. Electricity is often used in this way, allowing energy released from one source to be converted to another quite different form, usually at some distance from the source.

Conversion, efficiencies and capacity factors

- When energy is converted from one form to another, the useful output is never as much as the input. The ratio of the useful output to the input (usually expressed as a percentage) is called the "efficiency" of the process:

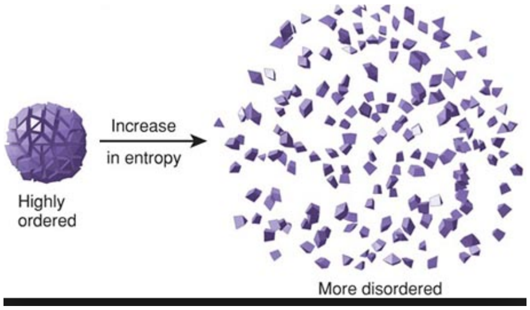
Efficiency (as percentage) = (energy output/ energy input) x 100

- 90% (up to) in water turbines, or like that of a well-run electric motor,
- 35-40% thermal power station (coal, petroleum, natural gas) (when waste heat is not used),
- 10-20% (*only*) in a typical internal combustion engine (vehicles)

- The lowest efficiencies are for technology involving "heat engines" where random motion is involved. No machine can efficiently convert chaos into the order associated with mechanical or electrical energy:

Second law of thermodynamics: there is *necessarily* a limit to the efficiency of any heat engine, or any process. Some energy must always be lost to the external environment, usually as low-temperature heat.

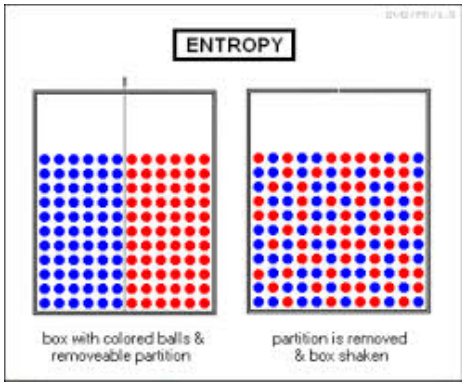
'Entropy' is a measure of the 'usefulness/quality' of energy. Low entropy is related to high order & temperature and thus quality energy. High entropy is related to high disorder, low temperature, and thus low-quality energy.



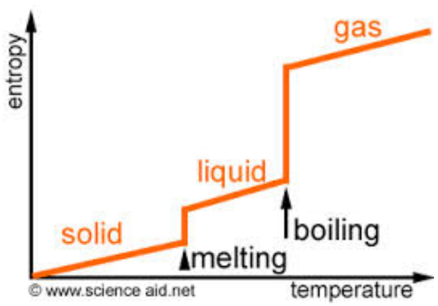
• Matter confined to a very small space is considered to have LOW entropy.

• As it spreads out the entropy INCREASES.

• Our universe seems to have started from a singularity, so basically an especially low entropy of zero.



• In the figure on the right blue and red balls are separated. This is very organized, and these fore expresses a lower entropy than the situation on the left where the red and blues balls are RANDOMELY mixed



• In the figure on the left matter changes from solid to liquid to gas as the temperature increases. Obviously a solid is more ORGANIZED than a liquid, which is more so than a gas. Higher temperature means more chaos & randomness.

• Thus the entropy INCREASES with temperature.

• **BUT**, even so, in a situation where the gas can interact with its surroundings, higher temperature has a **HIGHER QUALITY for doing something**.

1.2 Present-day energy use

World energy supplies

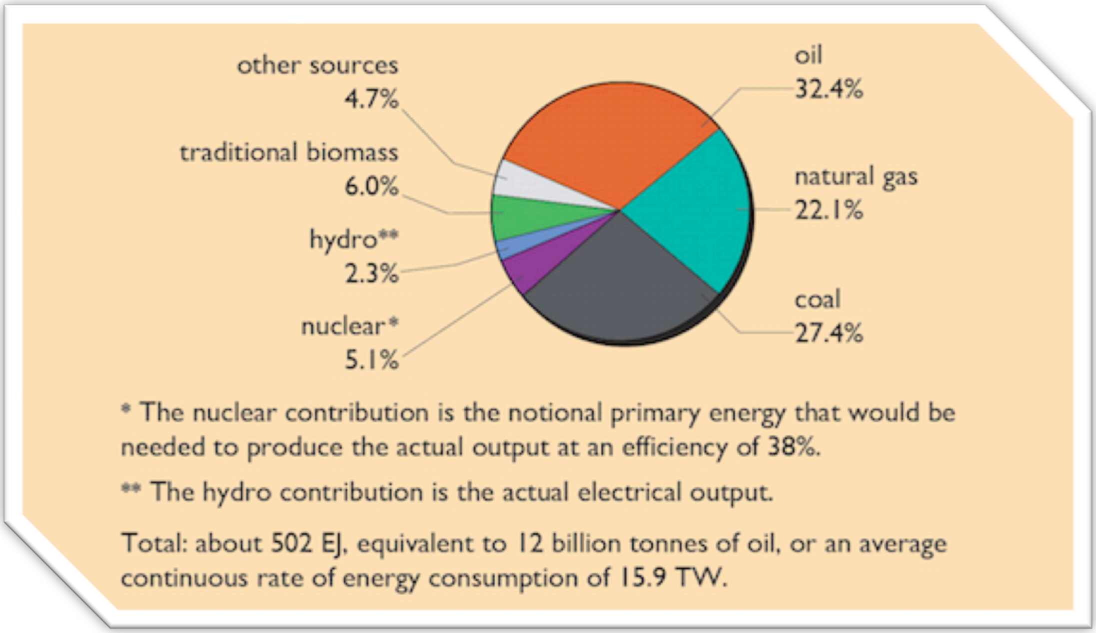
• Energy moves through a series of processes to its final use (while ALWAYS DECREASING):

- Primary energy: the original source, like that released when coal is burned;

- Delivery energy: Like for instance the amount of electricity reaching the consumer, after conversion losses in the power station and transmissions losses in the electricity grid;

- Useful energy: If used to heat water, it is that after further losses in the tank and pipes, and comes out the hot water tap.

Percentage contributions to world (PRIMARY) energy consumption in 2009.

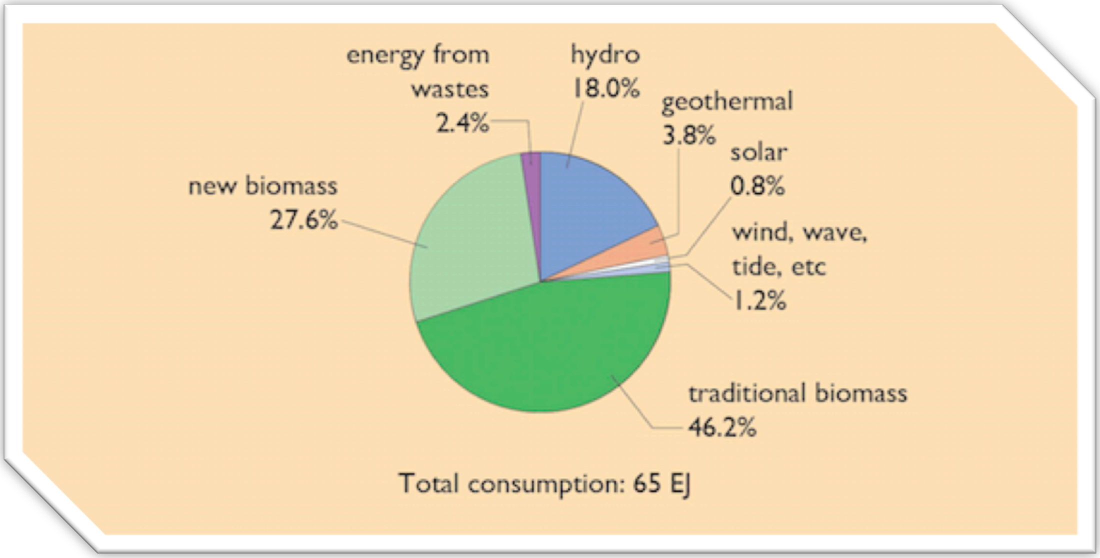


• Fossil fuels provided more than 4/5 of the total. Because world population in 2009 was 6.8 billion, , average energy used per person was 74 GJ, equivalent to the energy content of approximately 5.5 liters of oil per day for every person.

BUT, USA = 250 GJ per year; Europe used half this amount; and poorer countries used 1/5 this amount, much from local biofuels.

• 'Traditional biomass', hydro power and other renewable sources - contributed about 13%

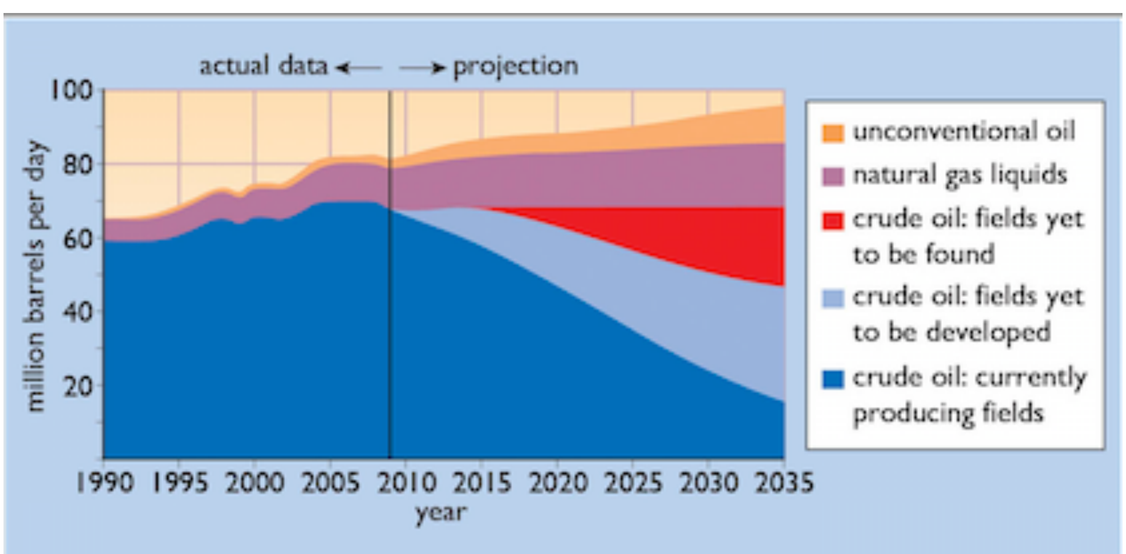
• World total energy consumption of all forms of PRIMARY ENERGY increased by more than TEN FOLD in the 20th century, and by the end of 2009 had reached an estimated 502 EJ, or some 12,000 million tons oil equivalent (Mtoe (million tons of oil equivalent)).



• Chart showing percentage breakdown of individual ALTERNATE) non-fossil) energy sources' contribution to world primary energy supplies in 2008.

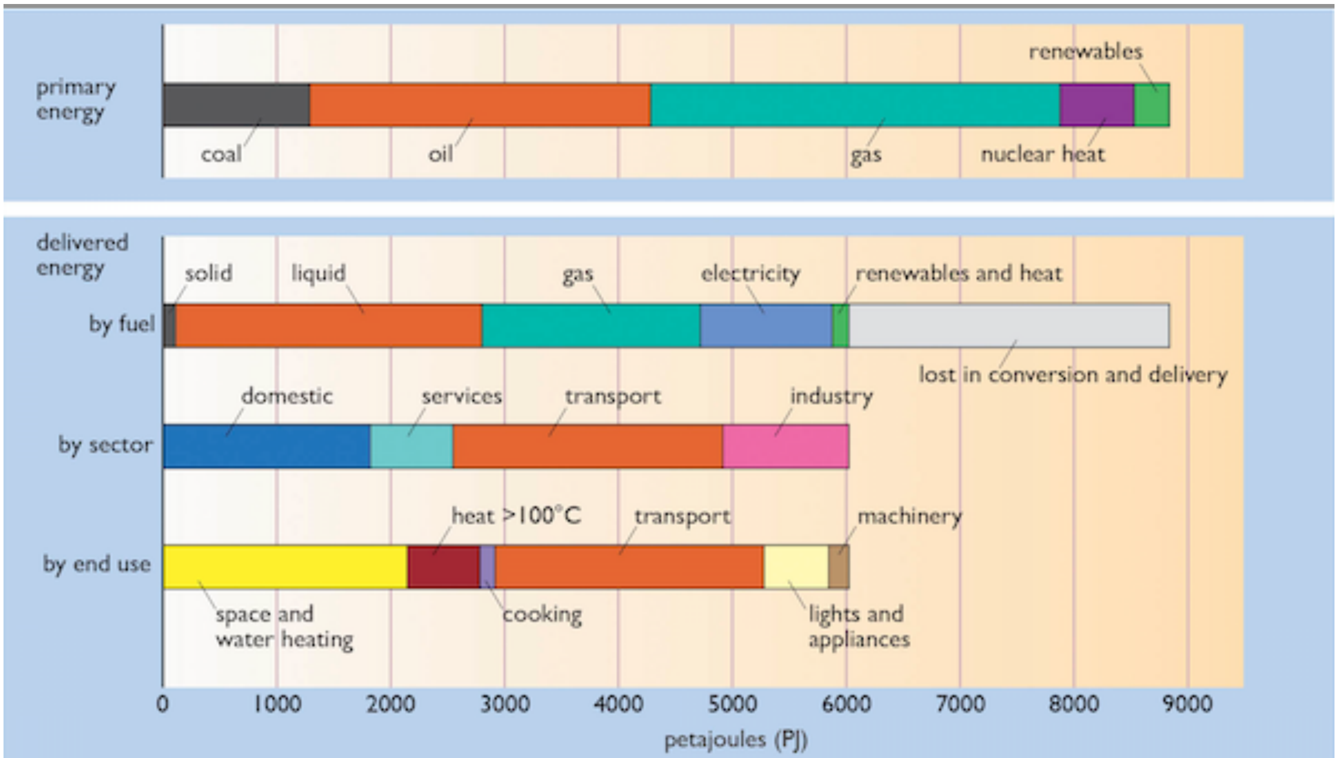
• We must always remember that a huge amount of the both fossil and renewable energy is wasted in the production of electricity as WASTE HEAT, in cooling towers, etc.

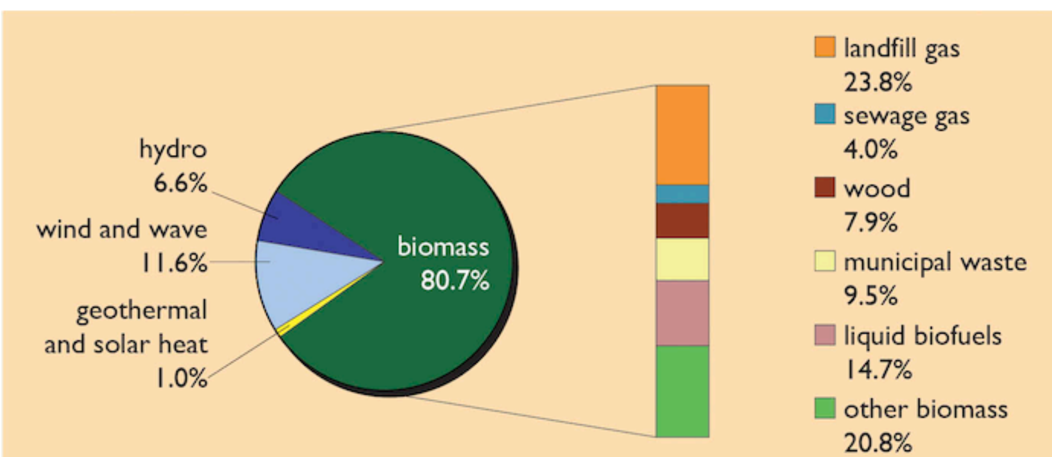
How long will the world's fossil fuel reserves last? Estimated coal, 120 years; oil, 45 years; natural gas, 60 years. Ever more difficult to find new fields and squeeze more oil and gas out of existing fields by hydraulic fracturing, etc.



An International Energy Agency chart indicating the challenges involved in maintaining current levels of conventional oil production.

UK primary and delivered energy use in 2009.





(a) Total contribution: 288 PJ or 3.3% of UK primary energy consumption

Primary energy contributions from renewable energy in the UK in 2009. The total, 6875 Mtoe, is equivalent to 288 PJ. The main contributors were wind, biomass in various forms, and hydropower.

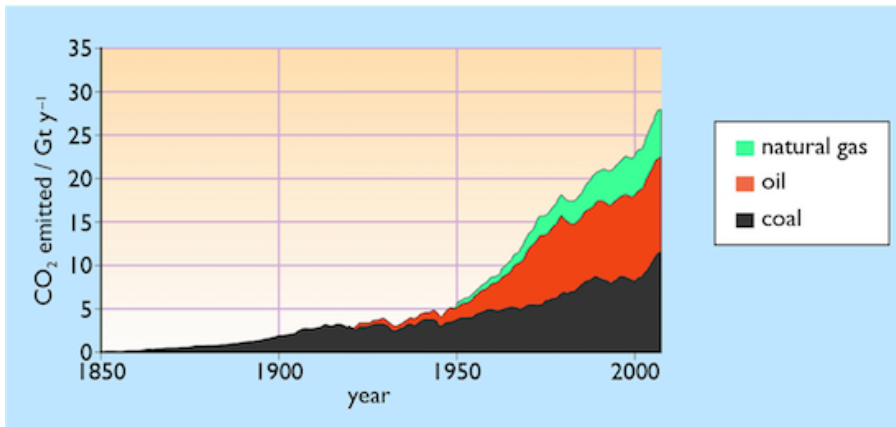
1.3 Fossil fuels and climate change

• There are many adverse consequences of using fossil fuels and nuclear energy: air pollution, acid rain, depletion of natural resources and dangers of nuclear radiation.

• The surface temperature of Earth establishes itself as a balance between the incoming radiation energy impinging on Earth and the long wavelength infrared (IR) energy that is radiated back into space. If Earth had no atmosphere the surface temperature would be -18 ^{0}C.

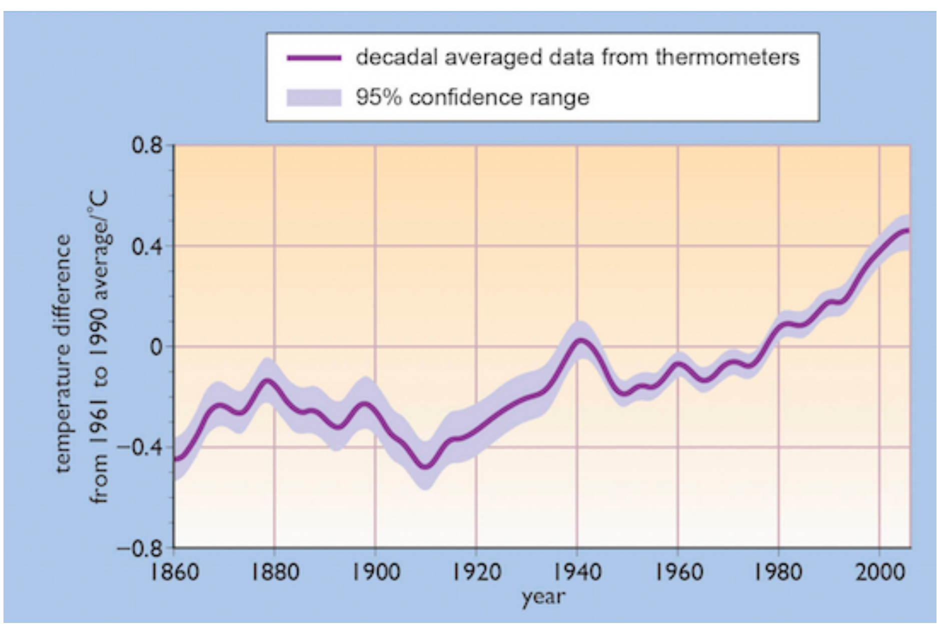
• BUT there IS an atmosphere, and the greenhouse gases among it (H_2O, CO_2, CH_4, and others) maintain the surface temperature at about 15 ^{0}C, which is suitable for life. (Gaia)

• Since the Industrial Revolution humans have added a huge amount of CO_2 by burning fossil fuels, especially after 1950, as well as methane. Between 1950 and 2005 a mean surface temperature rise of 0.7 ^{0}C occurred. If steps are not taken to stop this, it could rise by 1.4 to 5.8 ^{0}C by the end of 21st century.



CO_2 emissions from the burning of fossil fuels 1850-2009.

• This would cause: floods and/or droughts, serious disruptions to agriculture and natural ecosystems. Thermal expansion of ocean water would cause a sea level rise of around 0.5 m.



• Above: Observed changes in global average surface temperatures 1860-2005, relative to corresponding averages for the period 1961-1990. The term '95% confidence range' indicates that there is only a one in 20 chance of a measurement lying outside this range.

1.4 Renewable energy sources

- Renewable energy can be defined as:
    - energy obtained from the continuous or repetitive currents of energy recurring in the natural environment, or
    - energy flows which are replenished as the same rate as they are used.

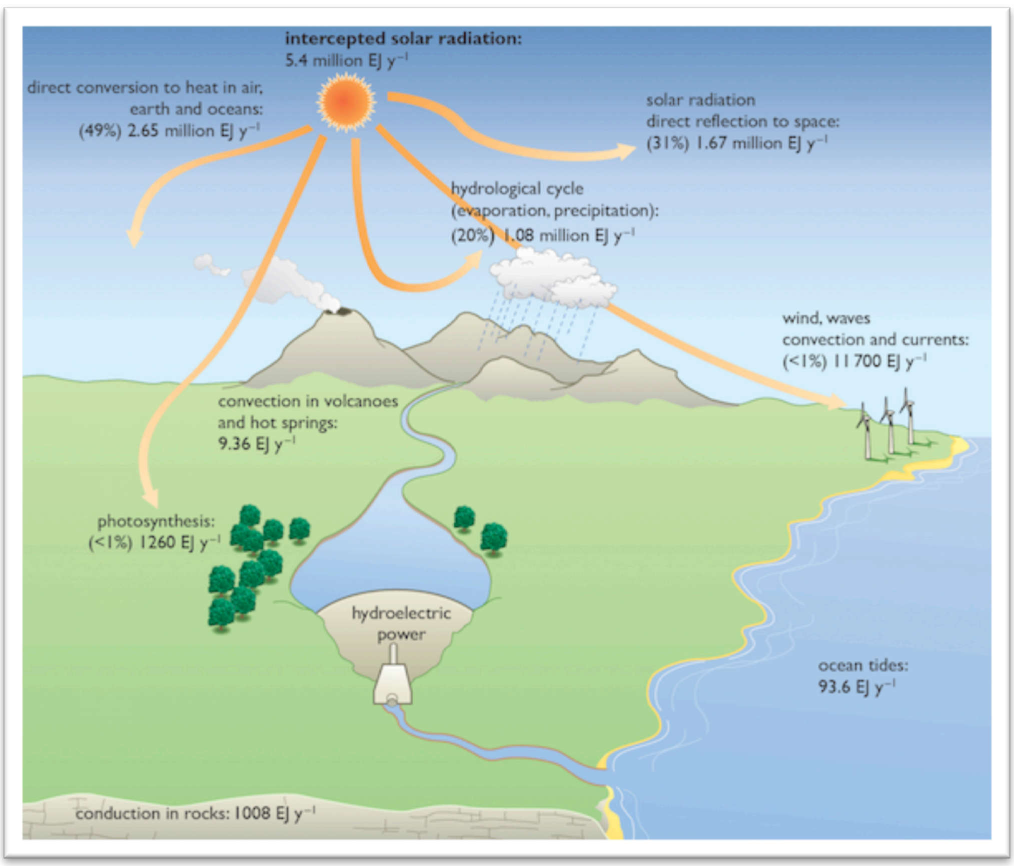
- The various forms of renewable energy depend primarily on incoming solar radiation, which totals some 5.4 million EJ per year.

Solar energy: direct use

- Absorbed in "solar collectors", which can provide hot water and space heating. Buildings can be designed for passive solar heating.

- Solar energy can be concentrated by mirrors to provide high-temperature heat for generating electricity.

Solar radiation can also be directly converted into electricity by solar Photovoltaics.



Solar energy: *indirect* use

- Radiation heats the oceans, causing cloud formation, to rain, to rivers, to dams, to turbines to electricity.

- Uneven solar radiation results in the atmospheric and ocean currents. Wind cause waves. All of these phenomena contain energy that can be extracted by technology.

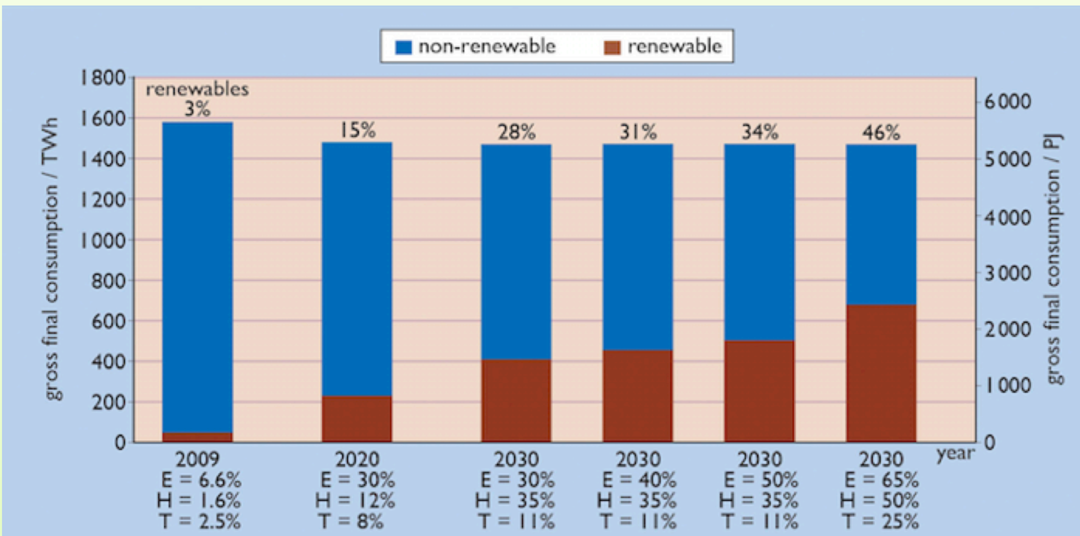
- Photosynthesis stores solar energy as chemical energy in plants. This energy can be extracted by technology.

Non-solar renewables

- Tidal (moon power) and geothermal (radiation and gravitational energy)

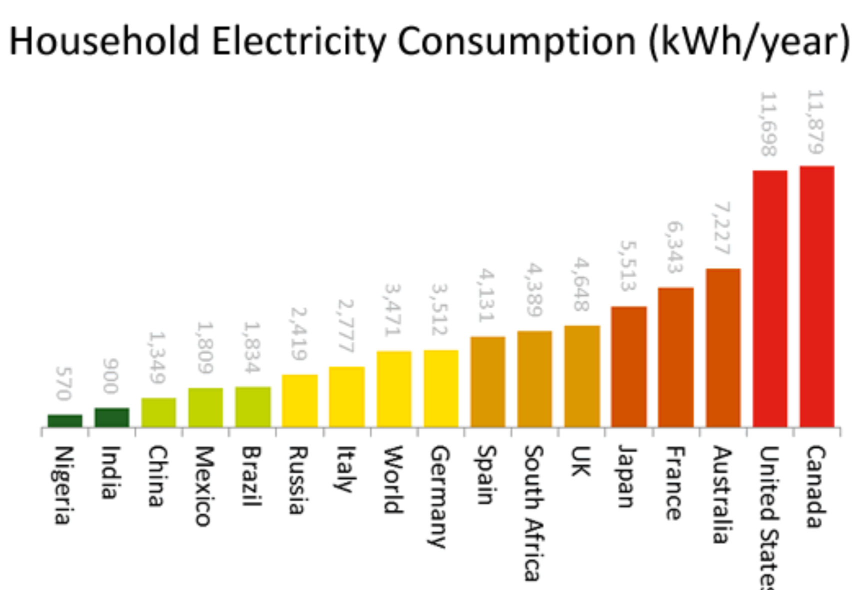
1.5 Renewable energy in a sustainable future

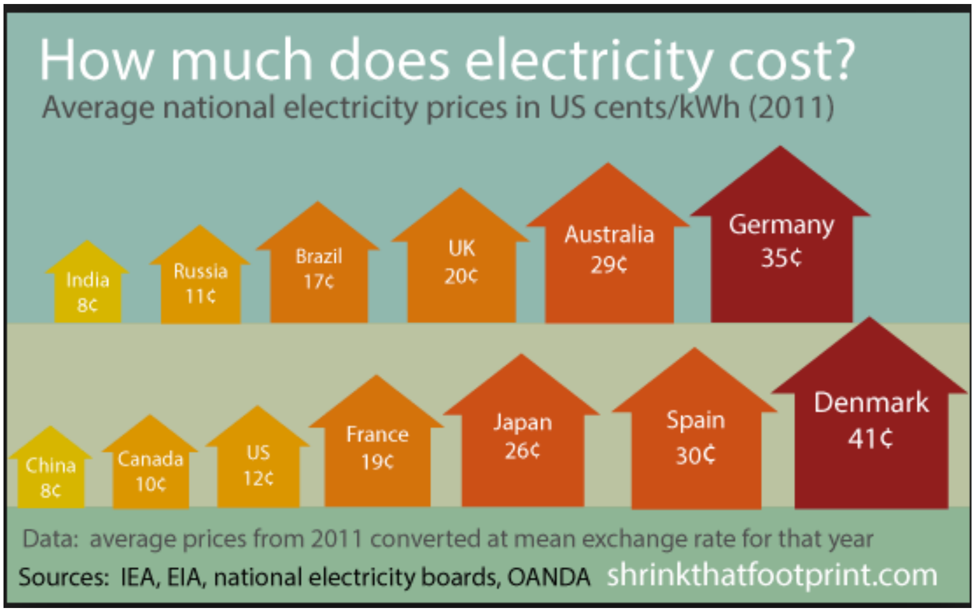
• UK and other countries have goals to expand renewable technology, with definite goals by 2020, 2030 and 2100



H = Heat; E = electricity; T = transport

For 2030 several different projections / scenarios




How much does electricity cost?
Average national electricity prices in US cents/kWh (2011)
India 8¢
Russia 11¢
Brazil 17¢
UK 20¢
Australia 29¢
Germany 35¢
China 8¢
Canada 10¢
US 12¢
France 19¢
Japan 26¢
Spain 30¢
Denmark 41¢
Data: average prices from 2011 converted at mean exchange rate for that year
Sources: IEA, EIA, national electricity boards, OANDA shrinkthatfootprint.com