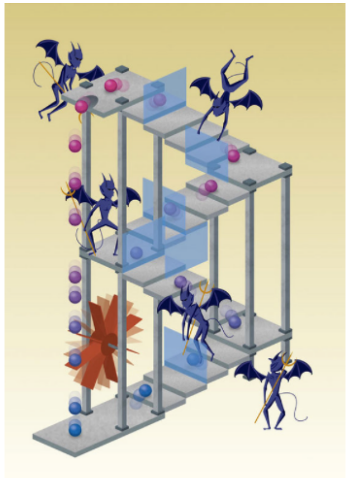
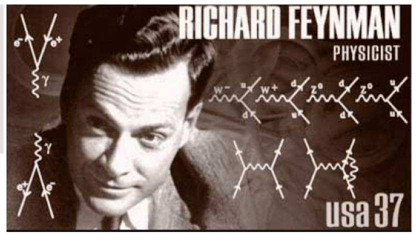


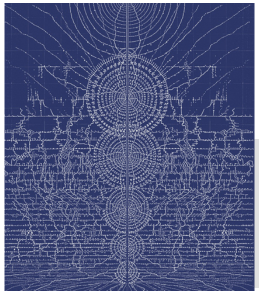
What is energy?

Sergio Carra'

"It is important to realize that in physics today, we have no knowledge of what energy is ".

We should address the issue with caution!





Why Energy is so important?

It plays an important role on the quality of our life and economic development.

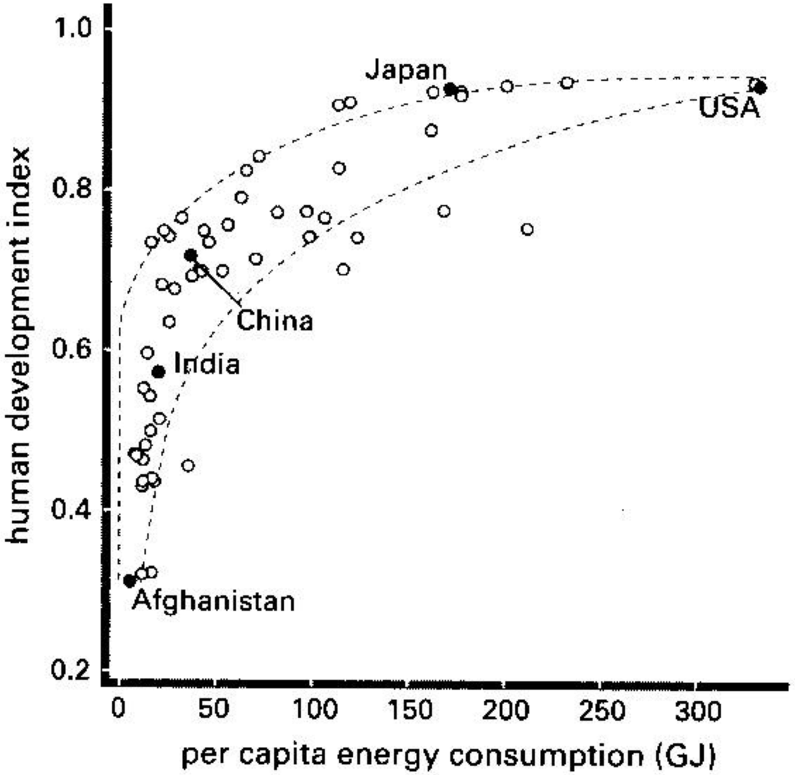
Human Development Index

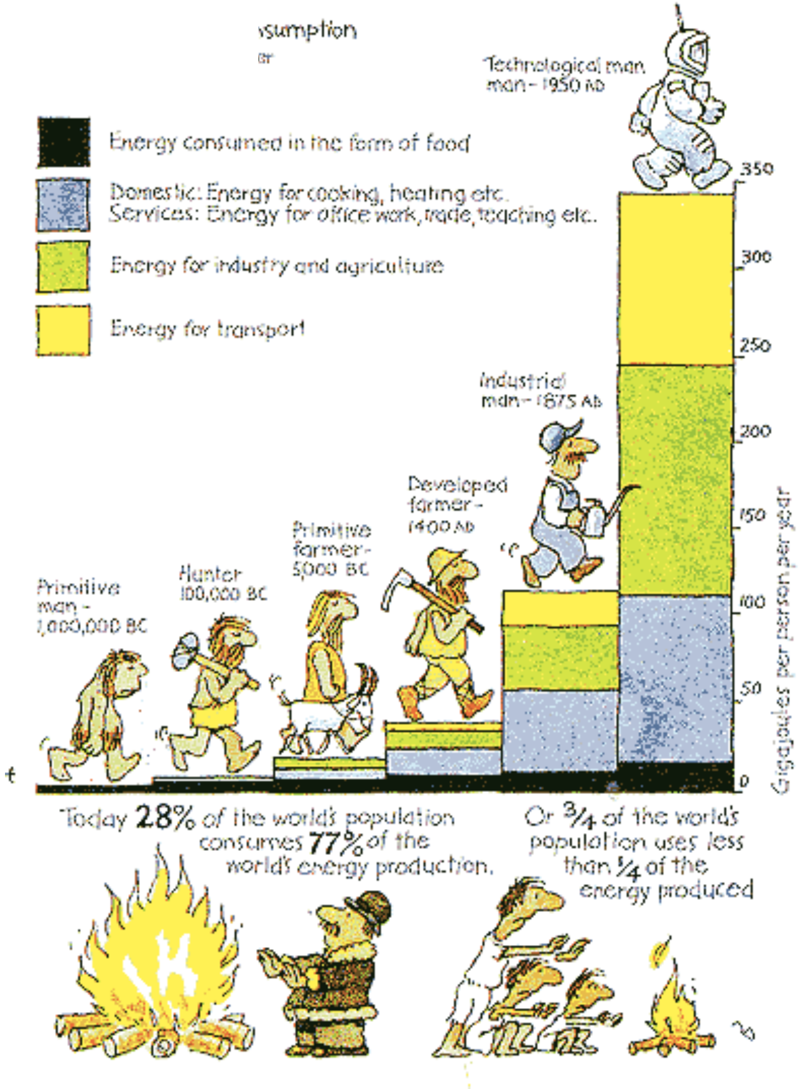
It is a composite of:

life expectancy,

education,

welfare.





Individual energy consumption

LET US START WITH ISAAC NEWTON

Force (ML/t^2) =mass (M) x acceleration(L/t^2)

cause of motion | **property of matter** | **respons: speed variation**

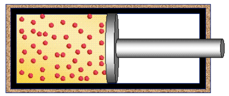
- **gravitation**: it is present between bodies with a mass, therefore it is common to all the matter.
- **electromagnetic**: it operates between particles with an electric charge, negative or positive, and it it is responsable for the formation of atoms and molecules.
- **strong force**: it acts inside the atomic nuclei.
- **weak force**: it is involved in beta decay of nuclei.

Such fundamental forces may be described through particular features of the space, called fields, whose points define the extent and the direction of a force.

The Work done by a force on a object that moves at a distance Δz is given by the product:

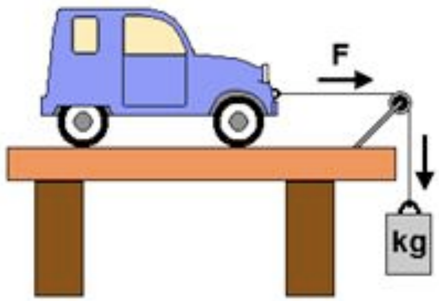
$$work = W(ML^2/t^2) = force \times displacement$$

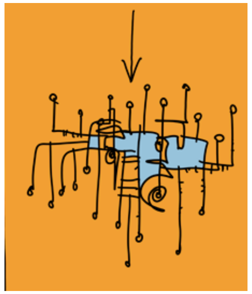
Mechanic $W_m = pressure \times surface \times \Delta z = P \times \Delta V$



Electric $W_{el} = potential\ difference \times transported\ charge = \Delta Y \times q$

Energy is the ability to carry out a work by changing the configuration of a system.



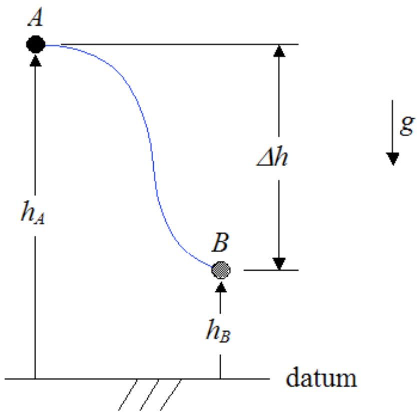


Motion in the gravitational field

$$E = E_k + E_p = \frac{1}{2}mv^2 + mg(h - h_B) = \text{costant}$$

Kinetic energy

Potential energy



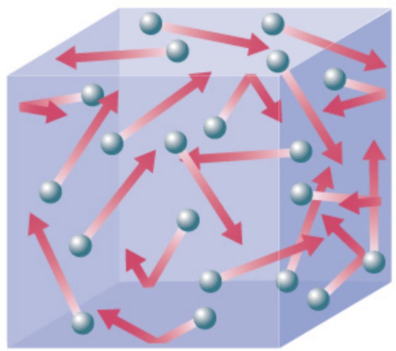
$A, \quad E_k=0, \quad E_p=gm(h_A-h_B)$

$B, \quad E_p=0$ **reference point**

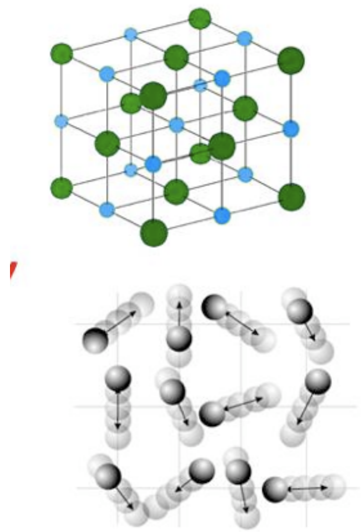
We can't attribute an absolute value to energy; its value depends on a properly chosen reference state.

What is that thing called heat?

Thermal energy, or heat: is associated to the motion of atoms and molecules.



chaotic in gases



oscillations in solids

The internal energy of a body is the sum of the kinetic and potential energy of its particles.
It increases with absolute temperature $T=t(°C)+273,16\ K$
and in phase transitions from solid to liquid and from liquid to gas.

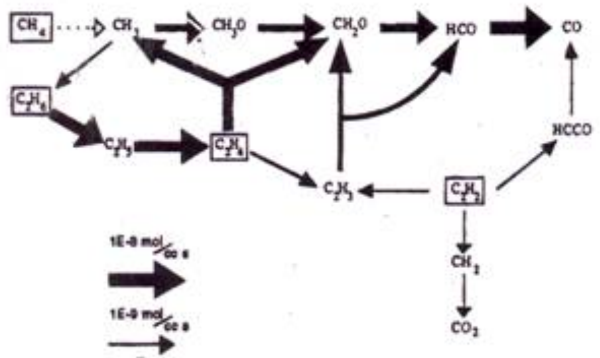
Chemical energy: even if present in the Universe at a negligible amount, it is the prerequisite for the existence of living systems.

The chemical energy connects the atoms in the molecules through the electromagnetic forces and it is released or absorbed as a consequence of their transformations.

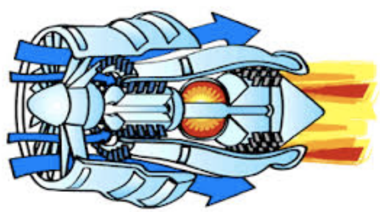
Combustion: energy is produced from hydrocarbons

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + heat$$

Many intermediate species are involved in the combustion process.



The optimized design of the energy power plants requires a detailed knowledge of the rate of the involved reactions.

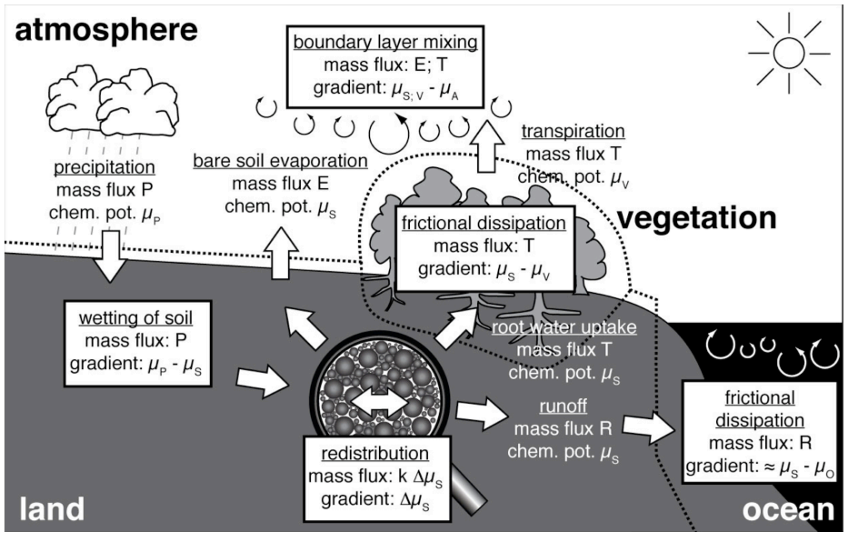


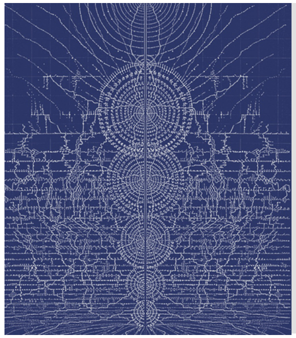
Thermodynamic systems

They are made by a certain amount of matter, which contains different chemical components, and occupy a particular zone separated by the external world called environment.

The boundary conditions, characterizing the matter and energy exchanges between the system and the surrounding environment, are defined on separation surface.

In an **isolated system** the rates of exchange of energy and matter with the environment are equal to zero.



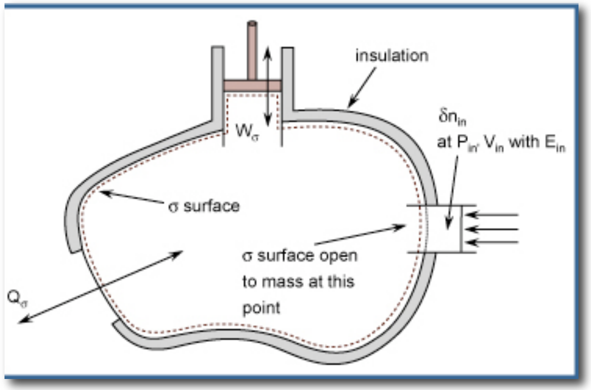


Energy E, heat Q, Work W: key concepts of **thermodynamics**

Equilibrium: an isolated system that does not exchange energy with the environment is in a state of equilibrium if it remains unchanged in time. Therefore its relative amounts of gases, liquids and solids , as well as its chemical composition are not modified.

An open system is able to exchange heat Q and work W with the environment while its internal energy E is subject to variations in agreement to the relation:

$$\Delta E = Q + W$$



It is known as the **first law of thermodynamics**

Energy cannot be created nor destroyed!

Then why worry about its transformations?

Entropy S attributes an order of merit to the different forms of energy.

quality ↑ | entropy ↓

- Gravitational
- Nuclear
- Electromagnetic
- Thermal

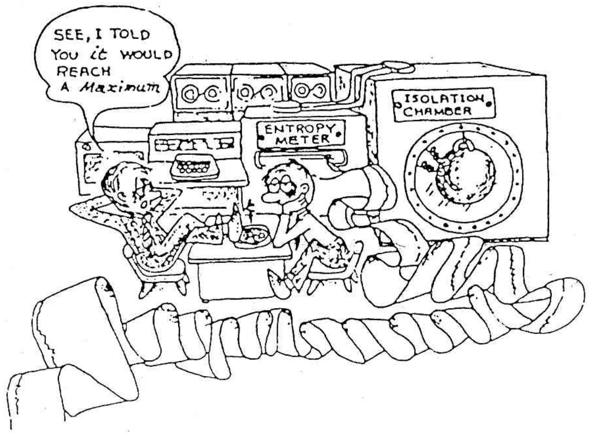
Direction of spontaneous transformations (time arrow).

In a spontaneous process a degradation of energy occurs , because:

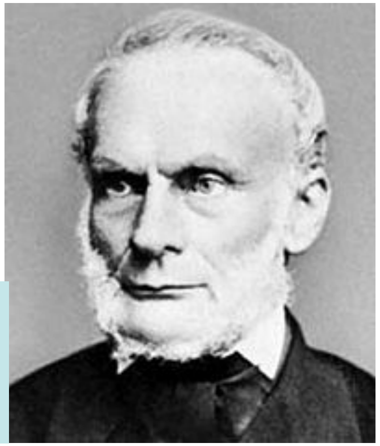
- its quality decreases

- the entropy increases (as taxes).

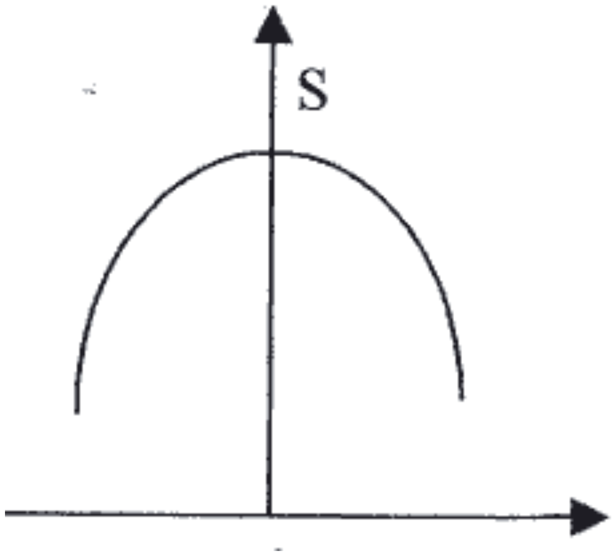
1864: **R. Clausius** formulates an evolutionary general law on thermodynamic transformations.



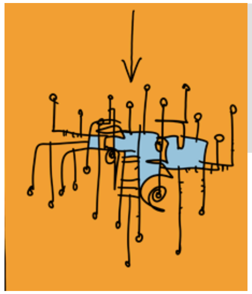
It is known as the **second law of thermodynamics.**



If an isolated system is not in equilibrium it is subject to a spontaneous transformation towards it.



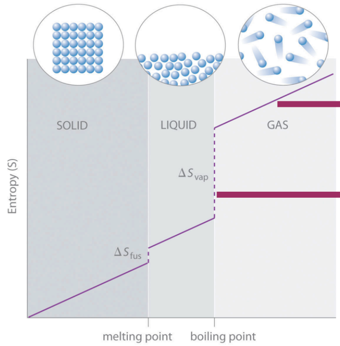
It occurs in the direction in which an increase of entropy takes place, until the achievement of its maximum value.
This aspect is consistent with the existence of an arrow of time.



Question: "what is the entropy?"
Answer: "Just know how to use it!"

But how evaluate entropy?

From thermal properties

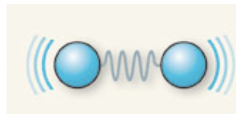


$$\Delta S = \int_{T_1}^{T_2} \frac{dQ}{T} = \int_{T_1}^{T_2} \frac{C_p}{T} dT$$

$$\Delta S = \frac{Q_p}{T}$$

From structural and spectroscopic properties.

$$\frac{S}{Nk} = \ln\left[\left[\frac{2\pi(m_1+m_2)kT}{h^2}\right]^{3/2}\frac{Ve^{5/2}}{N}\right] + \ln\frac{8\pi^2 IkTe}{\sigma h^2} + \frac{h\nu/kT}{e^{h\nu/kT}-1} - \ln\left(1-e^{-h\nu/kT}\right) + \ln\omega_{el}$$

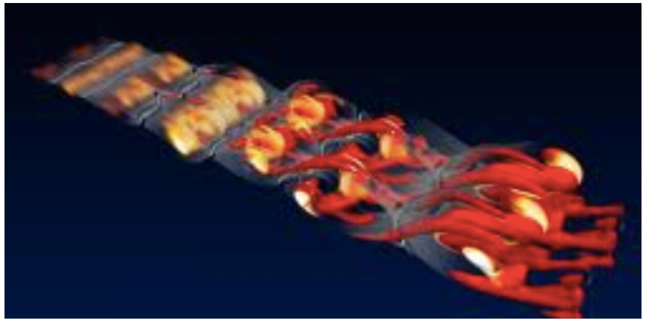


diatomic molecule

But for sheere of elegance we can not beat the **black hole** entropy formula.

$$S = \frac{c^3 k A}{4\hbar G}$$

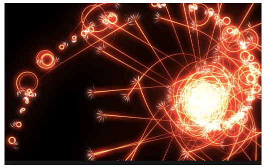
How do take place transformations?



The presence of internal friction causes a degradation of energy towards its less qualified form: the **thermal one**. At the same time it takes place an **increase of entropy** due to the transformation of the coherent motion of mechanics in the disordered motions of thermal energy.

Spontaneous transformations are **irreversible**, leaving an indelible trace in the system.

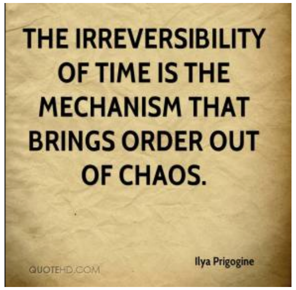
Since in the transformations **energy** is conserved, its total amount remains unaltered.



The unbearable lightness of thermodynamics

Often it is advisable to describe the transformations through a sequence of equilibrium states. In this cases they are called **reversible** and their description results simple from the mathematical point of view.

Actually in the framework of reversible transformations, the real world events concerning chemistry, physics, vital phenomena and socio-economic processes do not happen.

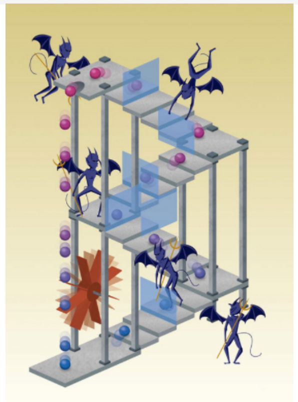


The spontaneous transformations, called **irreversible**, are distinguished from **reversible** ones that are assumed to occur through a succession of states in which the temperature and pressure differences between system and environment are very small.

The entropy change is given by the sum of a term associated to the heat exchange with the environment, which may be positive or negative, depending if the heat is subtracted or added to the system, plus an always positive term due to the irreversible dissipation of mechanical energy.

$$\frac{W_{diss}}{T} = \Delta S_{irr} > 0$$

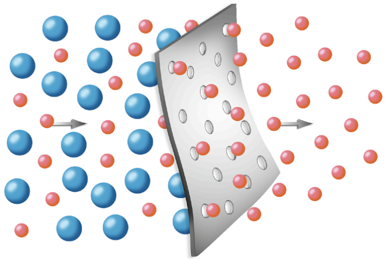
$$\Delta S = \frac{Q}{T} + \frac{W_{diss}}{T} = \Delta S_{rev} + \Delta S_{irr}$$

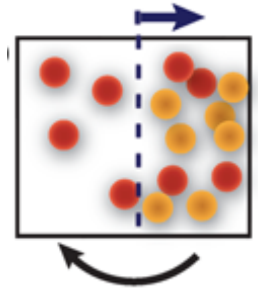


W_{diss} dissipated energy

Entropy and disorder

A library is disordered if books are arranged randomly. Order is restored by grouping together on the same shelves books with common characteristics.
In the same way, if the components of a gaseous mixture are separated, an ordered thermodynamic system is obtained.



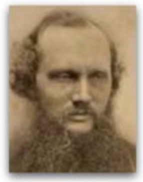


The order of a system is measured by the number Ω of ways in which it can be built on molecular scale (Ω=1 if the system is ordered).

$$S = k_B \log \Omega$$

Boltzmann

End of thermodynamic Nightmare

École Polytechnique	Glasgow school	Berlin school	Edinburgh school
 Sadi Carnot (1796-1832)	 William Thomson (1824-1907)	 Rudolf Clausius (1822-1888)	 James Maxwell (1831-1879)
Vienna school	**Gibbsian school**	**Dresden school**	**Dutch school**
 Ludwig Boltzmann (1844-1906)	 Willard Gibbs (1839-1903)	 Gustav Zeuner (1828-1907)	 Johannes der Waals (1837-1923)

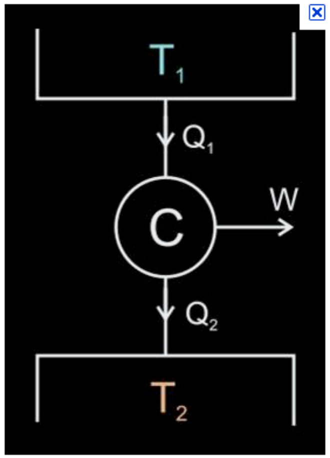
How to use energy?

The total content of energy of a physical system can be divided into two parts:

Total energy (E)= free energy (F) + useless energy (TS)

It depends on macroscopic variables subject to slow variations.

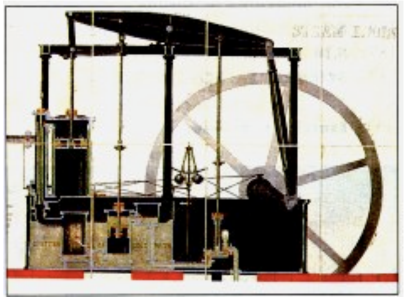
It depends on fast motions of the microscopic atomic variables that increases entropy without making work.



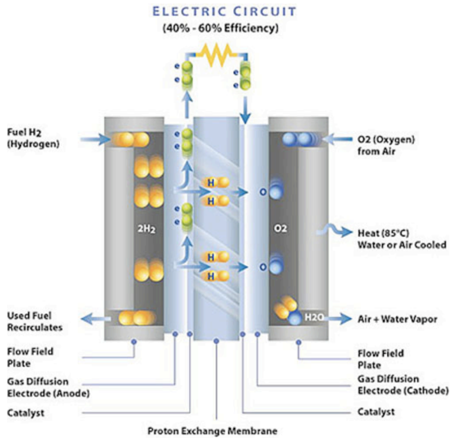
Highest amount of work that can be obtained in a thermal machine:

$$\eta = \frac{W}{Q_1} = \frac{\Delta F}{\Delta E} = \frac{\Delta E - T_1 \Delta S}{\Delta E} = \frac{\Delta E - T_2(\Delta E / T_1)}{\Delta E} = \frac{T_1 - T_2}{T_1}$$

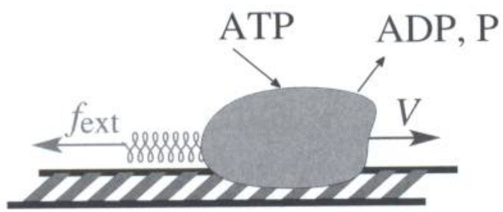
EXAMPLES OF MACHINES ABLE TO PRODUCE WORK



thermal→mechanic



chemical→electric



chemical→mechanic

$$W = \Delta F = \Delta E_T - \Delta E_I = \Delta E_T - T\Delta S$$

$\Delta E_T \equiv$ total energy

$\Delta E_I \equiv$ useless energy, with a high entropy content

$\Delta F \equiv$ free energy (useful)

It supplies the **useful** portion of energy to produce work in its different forms.

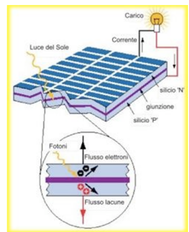
Real Work obtained in a process

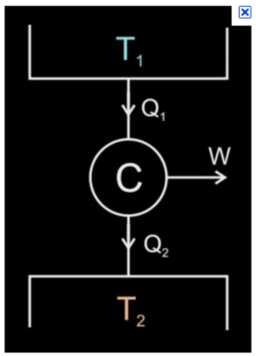
$$W = (\Phi_{fe}^{in} - \Phi_{fe}^{out}) - T_0\sigma_{irr}$$

Φ_{fe} = *flux of free energy*

σ_{irr} = rate of entropy generation due to energy dissipations: its knowledge is required to optimize a process and its performances.

Any device in which exchanges of matter, energy and work take place, can be assimilated to a thermal machine





$$\eta = \frac{W}{Q_1} = \left(\frac{T_1 - T_2}{T_1}\right) - \frac{\sigma_{irr}}{Q_1} T_1$$

Carnot efficiency,

Rate of entropy generation

Its calculation must account different effects, such as:

-dissipation of mechanical energy

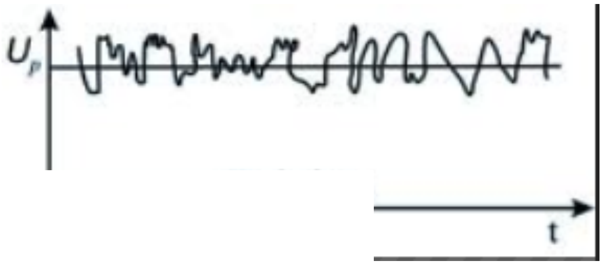
-equalization of temperature

-progress of a chemical reaction

-equalization of gas pressure between two zones

-.......

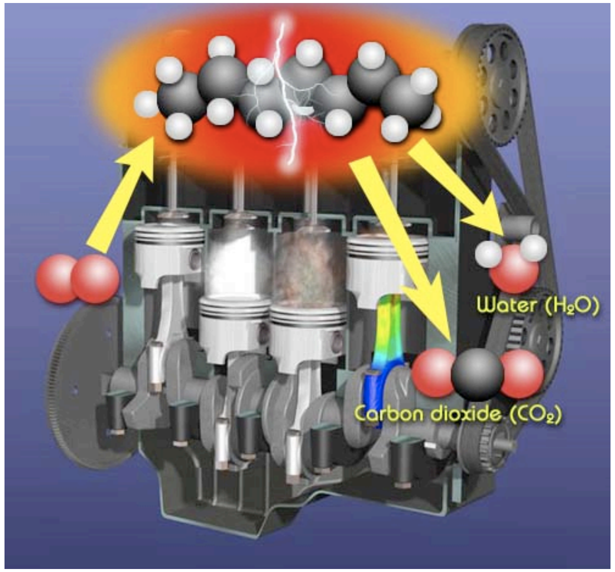
In turbulent flow (*hic sunt leones!*)



$$\sigma_{irr} = \sum_k X_k J_k \equiv \int \{ \overline{\frac{\tau_{ij}}{T} \nabla u^{"}} - \overline{\frac{q}{T^2} \nabla T} - \overline{\frac{1}{T} \sum_k \mu_k R_k} - \overline{\sum_k \frac{J_k}{T} \nabla \mu_k} \} dV$$

The computational fluid dynamic (CFD) must be combined with the combustion kinetics.

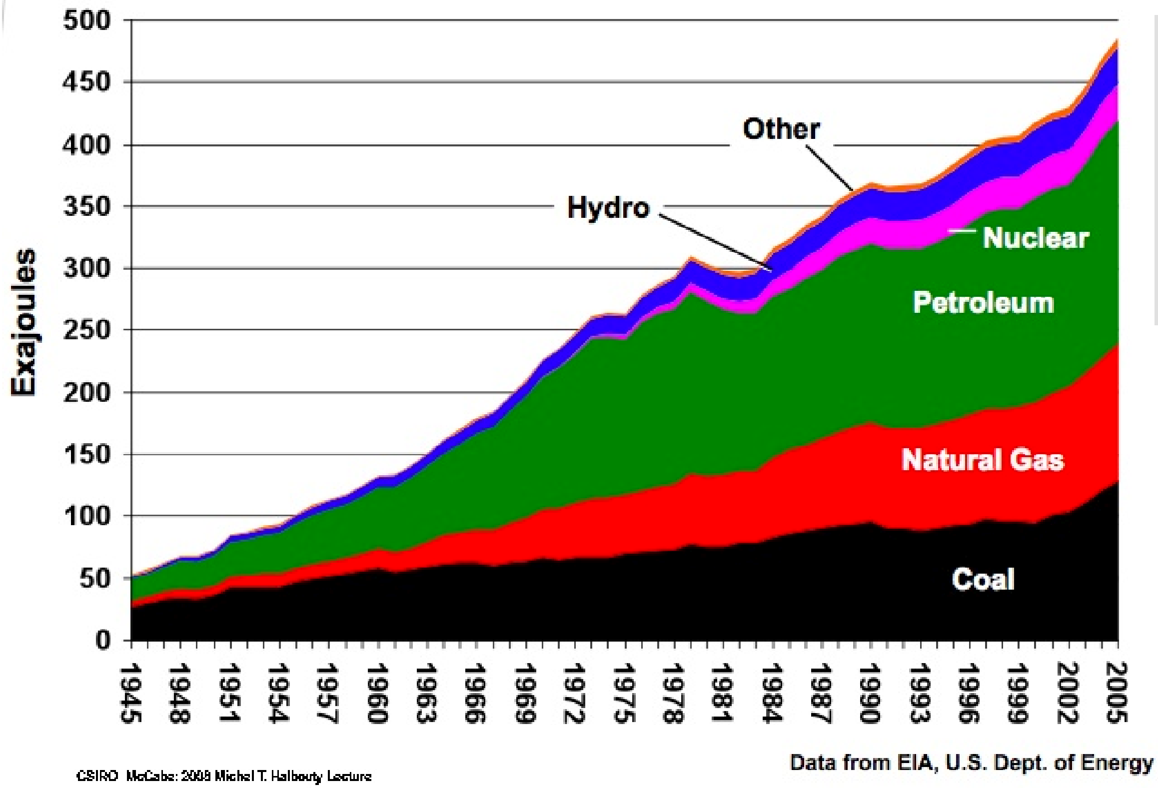
Machine	Efficiency
Steam Newcomen 1712	1%
Watt 1764	10%
Internal combustion	30%
Combined cycle	60%



Carnot efficiency of internal combustion engine > 70%.
So there is room for improve the situation.

The evaluation of entropy production remains a crucial problems in order to increase the efficiency of thermal machines and processes.

Yearly world energy consumption, shown by different sources.



Exajoule= 10^{18} joule, terawatt=TW=10^{12} watt

500 exajoule correspond to14,7 TW

Fossil fuels play the lion share.

"Modern industrial economies are carbon-based and their main activity is combustion"

Annual Energy Review(2001).

What are the strength points that make the use of hydrocarbons hegemonic?

-Low cost of the energy (about 0.05$/KWh).

-Availability of big infrastructures for the transport of oil (1000 barrels per second), its extraction, refining and distribution of fuels.

-Availability of an efficient energetic vector constituted by a mixture of hydrocarbons.

In sum, the energy is available in every place, in every moment at the desired power.

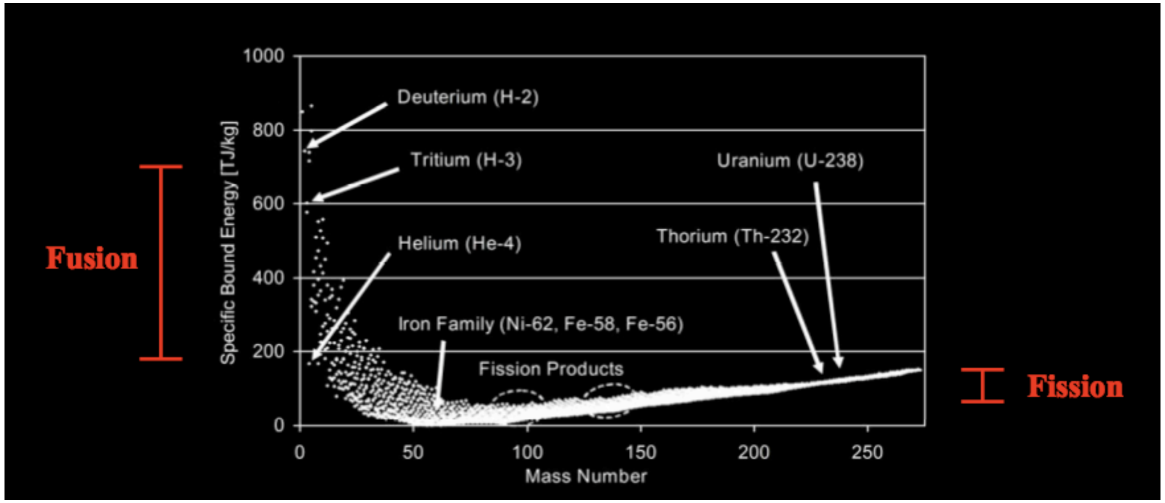
Energy resources: they are constituted by matter not in equilibrium with the environment.

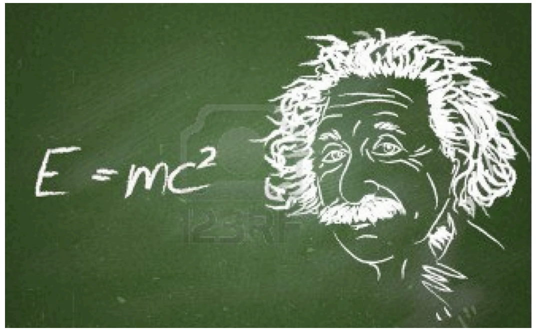
CHEMICAL ENERGY

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + energy$$

out of equilibrium   in equilibrium

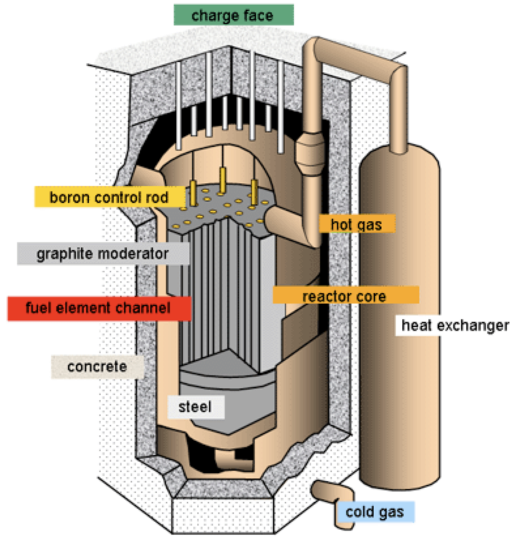
NUCLEAR ENERGY





$$U_{92}^{235} + n \rightarrow Ba_{56}^{142} + Kr_{36}^{91} + 3n$$

Nuclear fission



At the present in the world it exists almost 443 reactors that produce almost 6% of energy in the form of electricity.

"A reactor is simple (at least conceptually) until it starts operating" (*John Wheeler*).

The necessity of limiting the use of fossil fuels and therefore carbon emissions implied its relaunching, but its revival appears uncertain, above all because of safety worries.

Moreover, public opinion is not in favour of it.

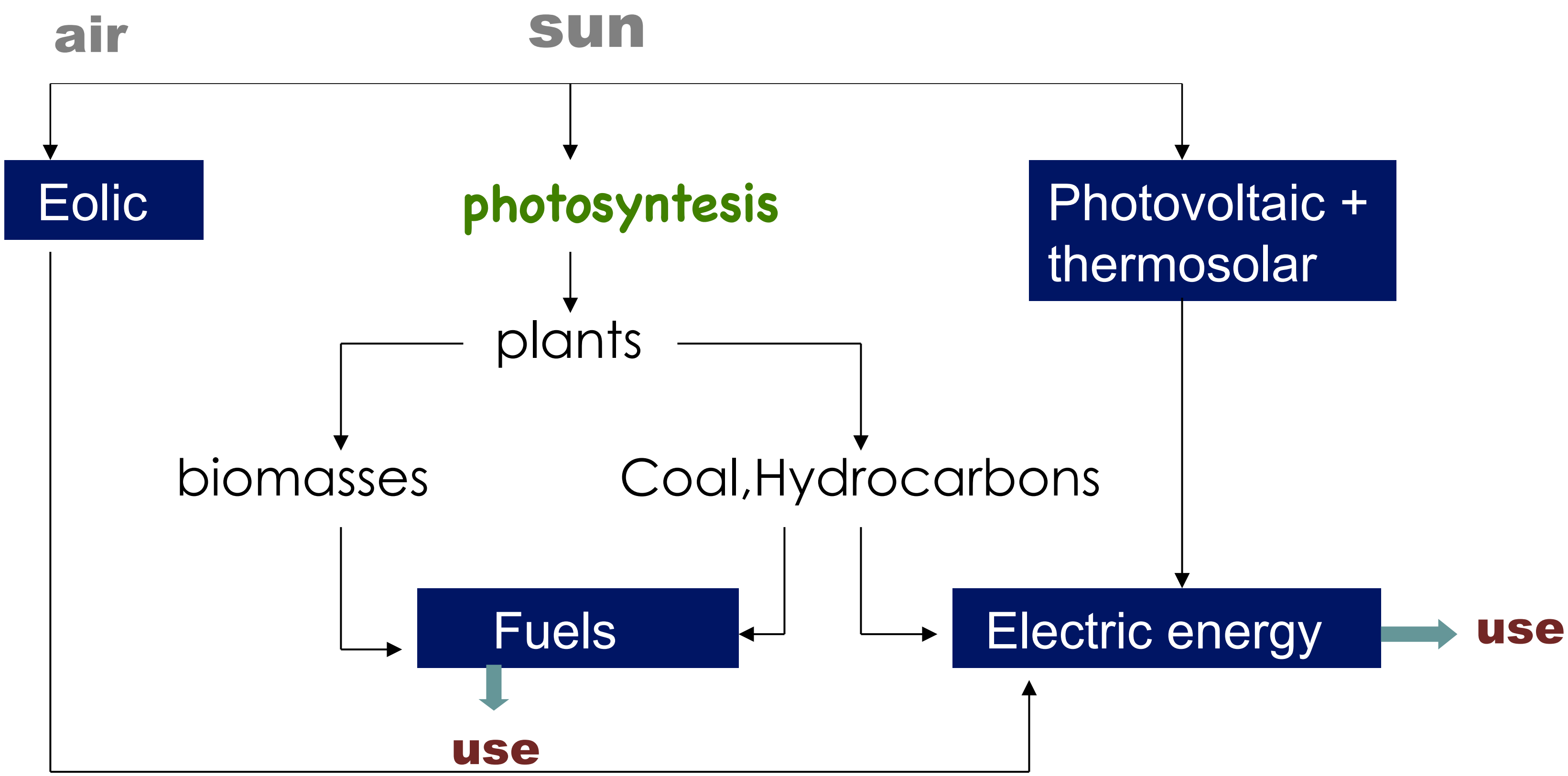
Post second world war predictions on the future of the energy scenario.

By the end of the century :
complete usurpation of fossil fuels by nuclear fission.
At the beginning of 21-th:
replacement of nuclear fission with nuclear fusion.

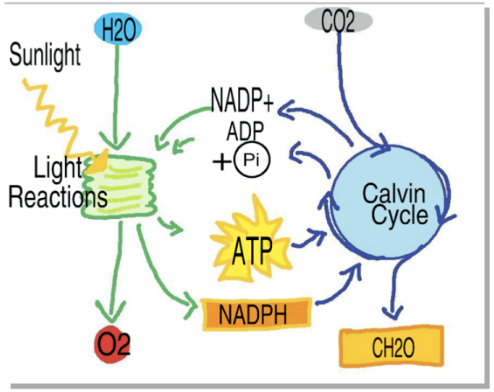
The forecast was wrong, and the future is uncertain.

Sun pours on earth an amount of energy four order of magnitude higher then the quantity used by mankind. Therefore it is reasonable to assume that it may provide to all our necessities.

"It is the stars,the stars above us, govern our conditions"
Shakespeare



Exploitation in nature of the quality of the solar energy: a task exerted by photosynthesis.



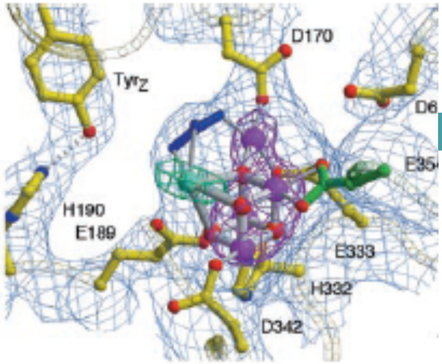
Energy, in form of photons, is captured by photochemical reactive centers and it is then transferred on the chemical bonds present in molecules with high free energy content as the carbohydrates.

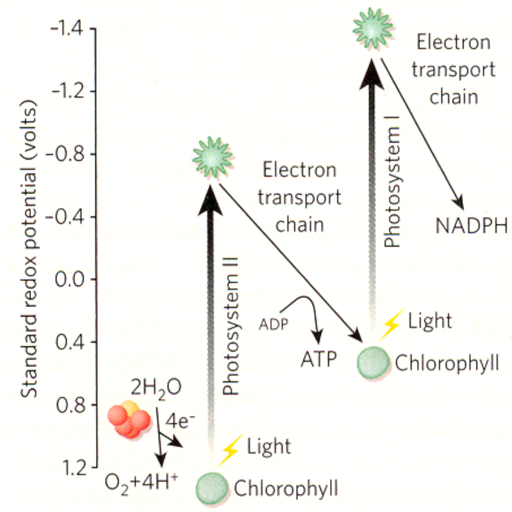
$$CO_2 + H_2O \rightarrow [CH_2O] + O_2 \qquad \Delta G^0 = 97.85 Kcal / mole$$

The capture of the photons and the transfer of their energy to complex molecules is at the basis of the organization of vital processes.

The surface of the Earth does not gain energy by the sun.
It is not energy that supports life, but its flow.

LIGHT PROCESS in which the solar energy is captured.



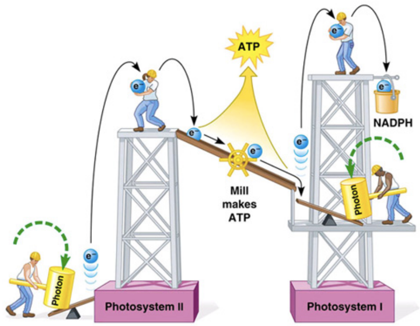


Active center apt to reduce water (OEC=Oxygen Evolving Center CaO_4Mn_3).

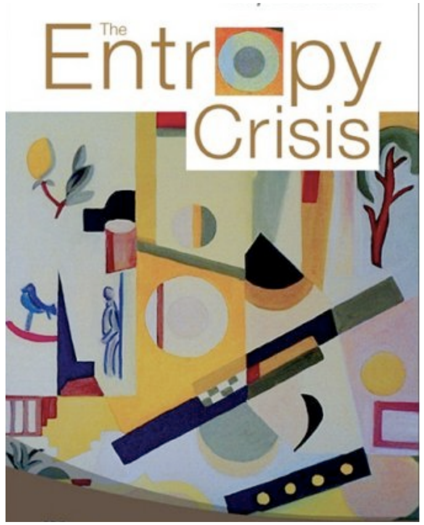
J.Barber, Nature (2004)

$$H_2O + h\nu \rightarrow O_2 + 2H^+ + 2\,e-$$

The energy of the photons is captured through electronic transfers.

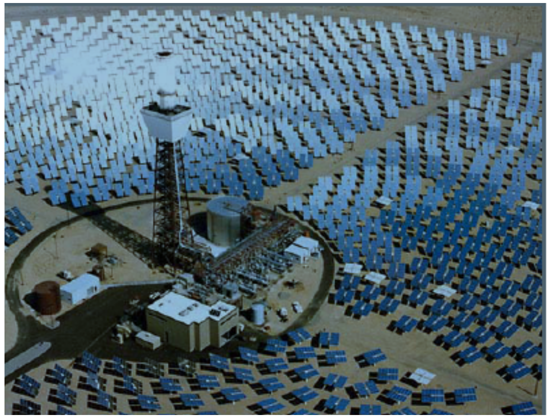


Mechanical analogy

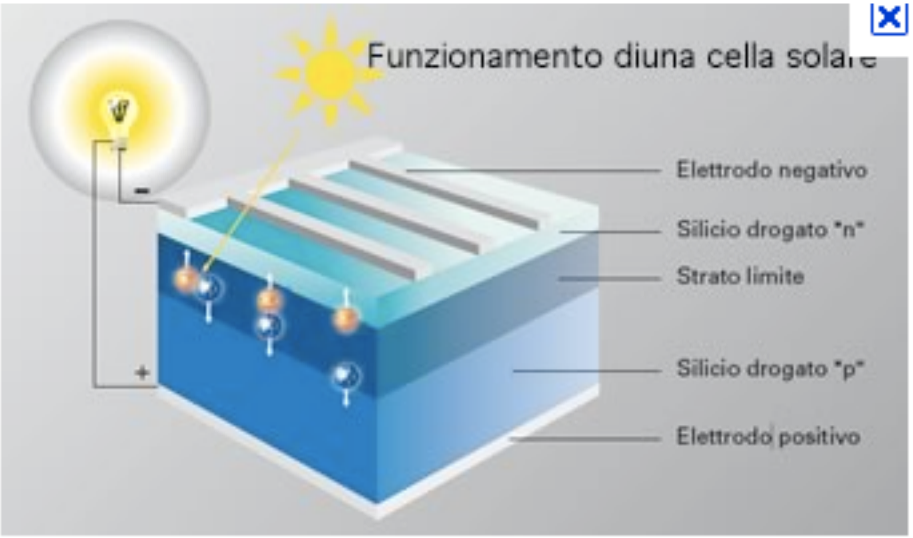


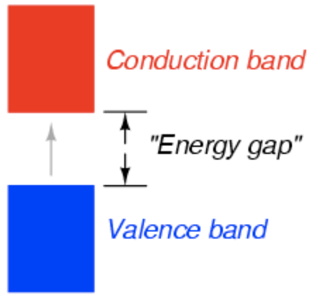
"The general struggle for existence of animate beings is not a struggle for raw materials – these, for organisms, are air, water and soil, all abundantly available – nor for energy, which exists in plenty in any body in the form of heat, but of a struggle for entropy, which becomes available through the transition of energy from the hot sun to the cold earth." L. Boltzmann

Solar thermodynamic plants :
the radiation produces steam that through a turbine, creates electric energy.



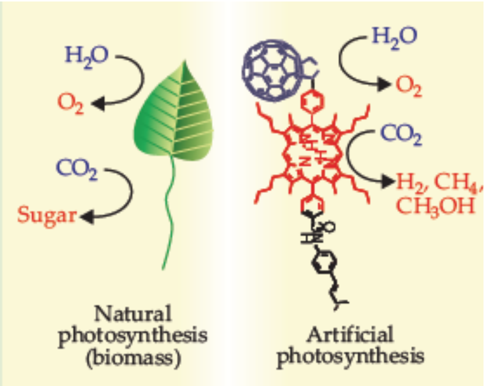
Photovoltaic cells:
they convert a photon flow in electric energy.





The charge separation takes place in the *p-n* junction of a semiconductor.

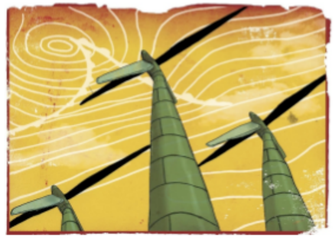
New concepts



The challenge is the search of new technology able to fill the space between photovoltaic cells and the much more complex leaves.
That is: finding a hybrid between nature and industry.

At the present the use of silicon cells rule over the market and it is still unknown how and when these ideas will be able to revolutionize the energy business.

Where to find carbon-free sources competitive with fossil ones?

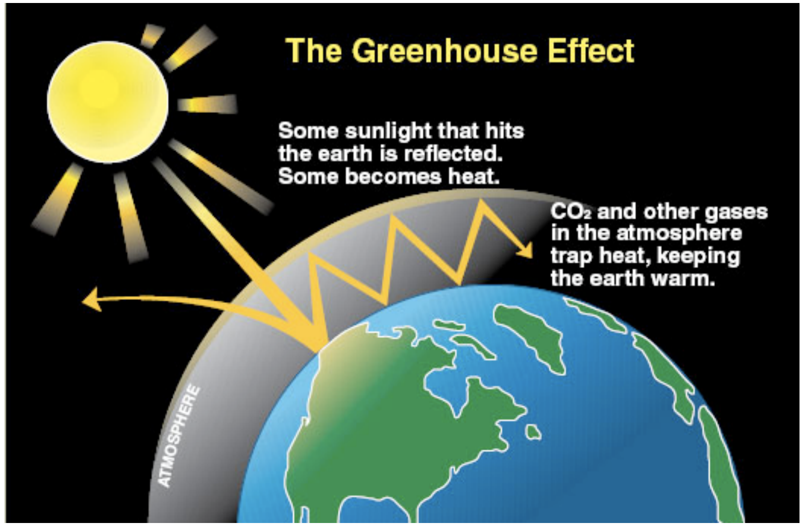


	present (TW over 15 TW total)	
Idroelectric	0,3	(2,0%; 0,015$/kWh)
Geothermal	0,1	(0,7%; 0,05$/kWh)
Eolic	0,16	(1,1%; 0,07$/kWh)
Biomass	1,3	(8,7%)
Solar	0,09	(0,6%; 0,35$/kWh)
total	1,95	(13%)

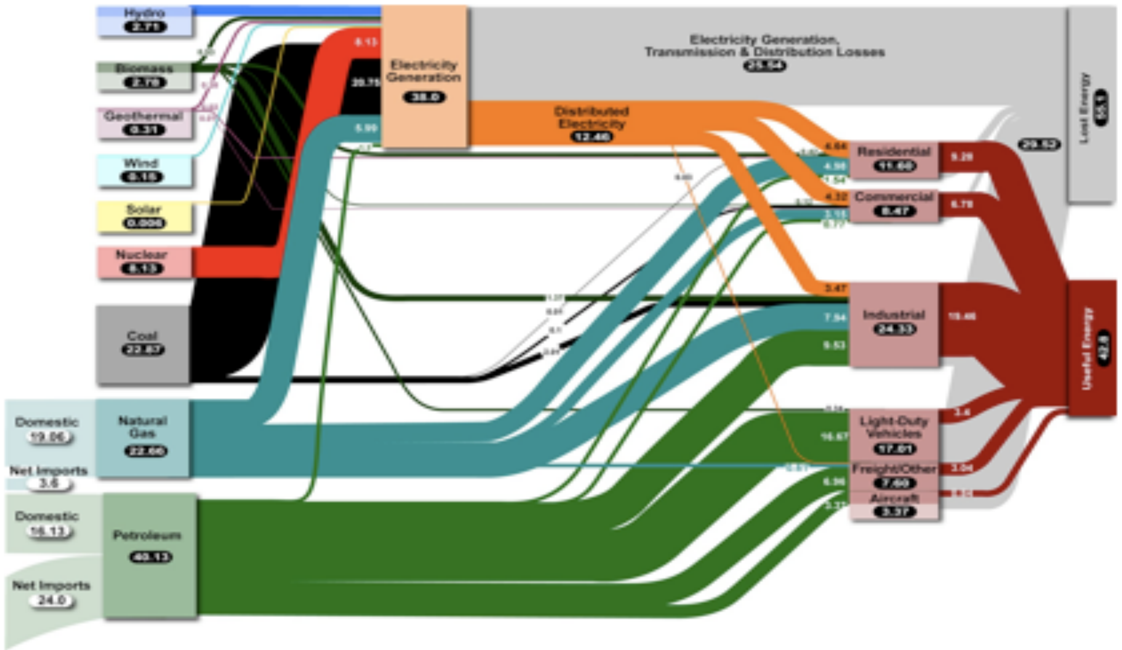
Hydroelectric power: precious but close to exhaustion.
Geothermal: cheap but its use limited though, is strictly connected to the geological and logistic local characteristics.
Biofuels: (fat acids esters, ethanol) they supply around 1,5% of energy thanks to incentives. In its actual form its usage is controversial because they subtract space needed for food supply.

Energy the big culprit: CO_2 accumulation in the atmosphere due to combustion, contributes to the global warming of the planet.

Is there a limit in the use of fossil energy imposed by carbon dioxide that is accumulating in the atmosphere?
CO_2 concentration in the preindustrial era : 280 ppm.
Present: 400 ppm.
Temperature increase almost 1 °C.

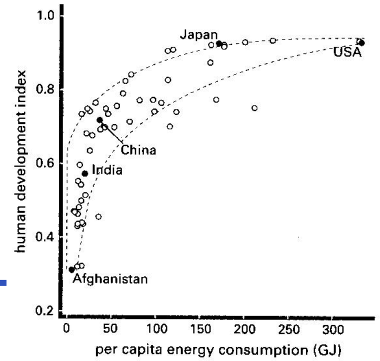


Energy Balance USA (Units:QUADS/year= 33,3400 GW)



The examination of the first nation energy-consumer of the world underlines the great incidence of losses, superior of the half of produced energy.
Therefore there is room to a great effort in the improvement of the efficiency.

How to overtake the critical transition due to the oil exhaustion?



Energy request

Malthusian hypothesis
Oil exhausted

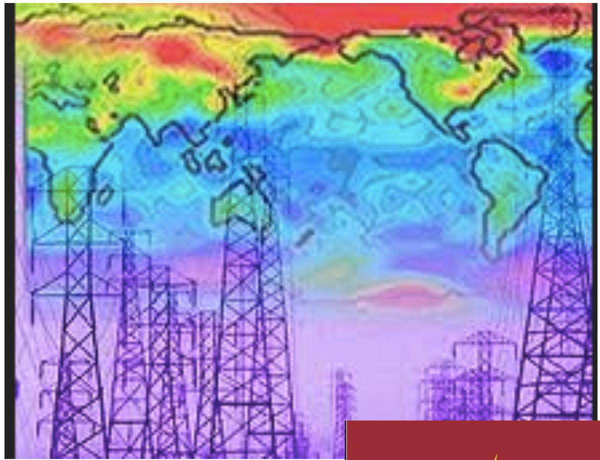
New sources (*post petroleum era*)
- Renewable
- Nuclear
- Biomass

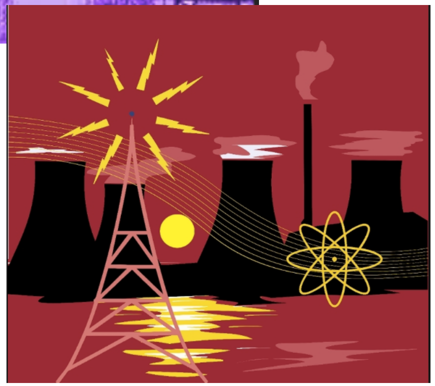
Availability of energy

Economic development

Saving
?

Renewable energies: the creation of adequate infrastructures is an indispensable requirement for their achievement.
Nuclear energy: it gives rise to concerns.
Lignocellulosic biomasses: only with the help of genetic engineering they may offer energy suitable for the already existing infrastructures without jeopardize the food requests.





Economics is facing a dilemma:
- use energy in order to support the development.
- save energy to protect the environment

Relevant initiatives:

- **Increase** the efficiency of energetic processes, by improving and developing the related technologies.
- **Create** the needed infrastructures for the achievement of renewable sources.
- **Incentivize** the search for innovative solutions.

Thank you for the attention