Energy harvesting – physical principles

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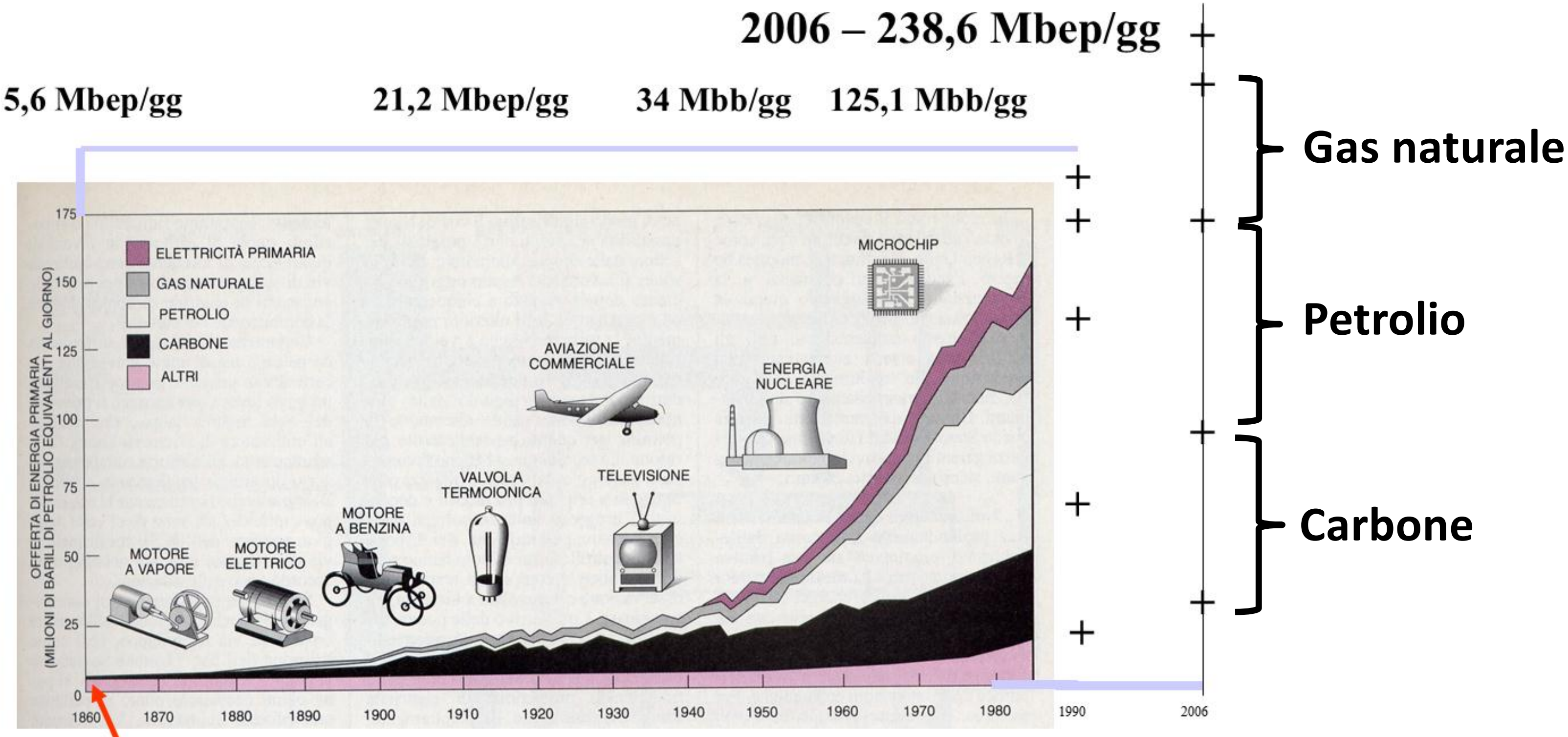
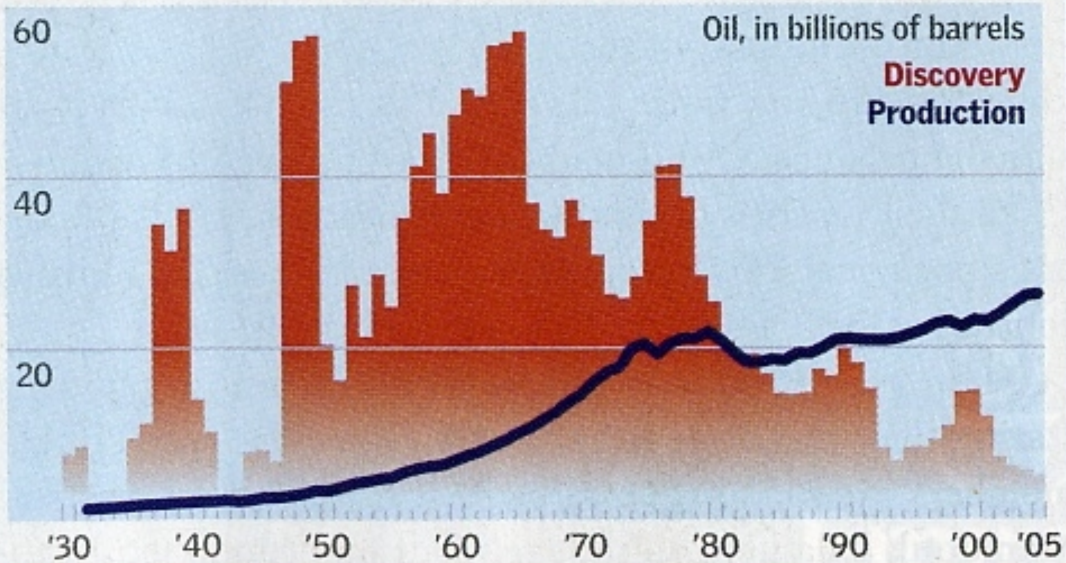
Energy use in history



Dal 1860 abbiamo cominciato ad utilizzare il petrolio come fonte alternativa al Sole

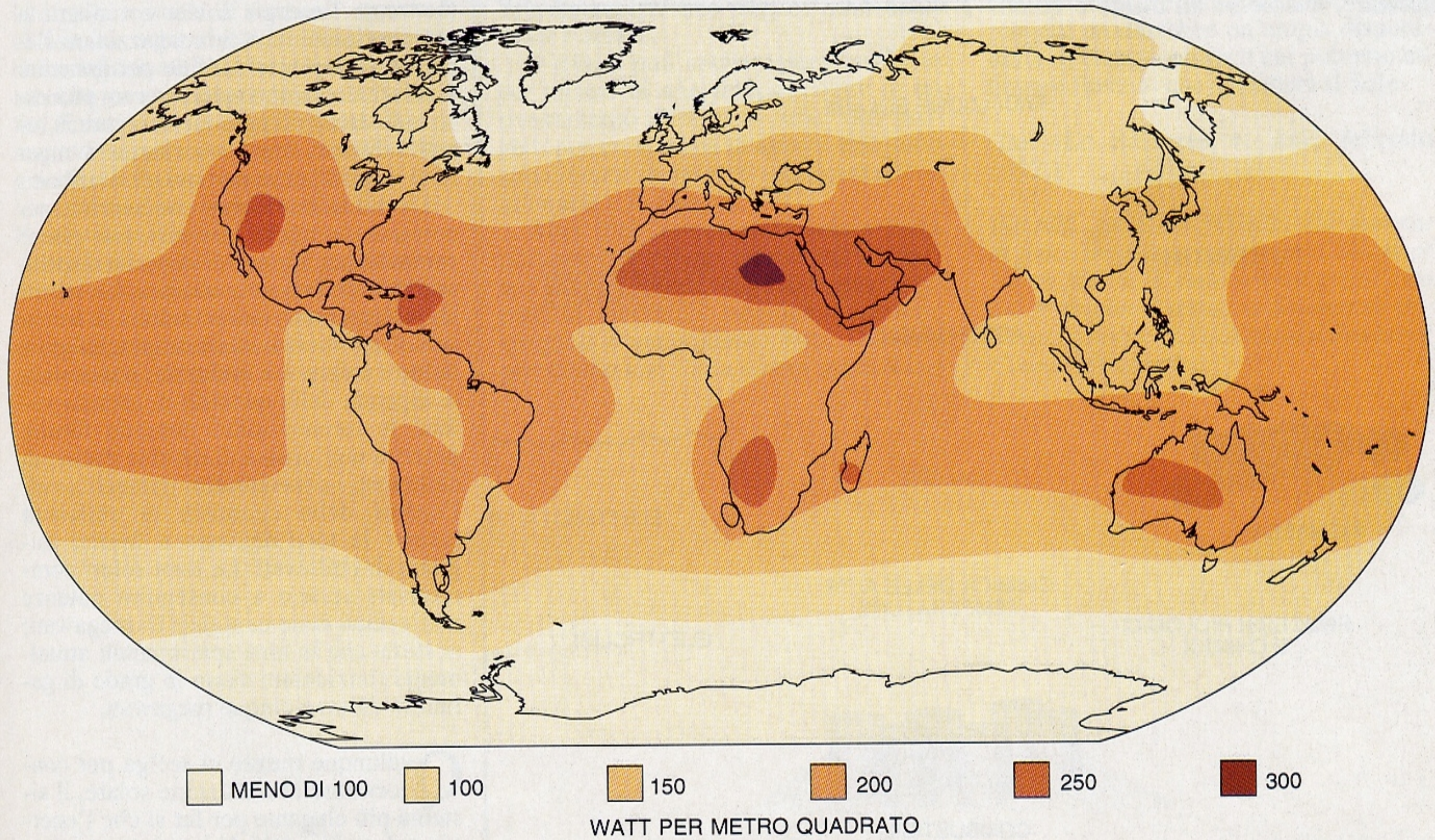
Getting scarce

Global oil finds peaked in 1964; the world now consumes five barrels of oil for every barrel discovered.



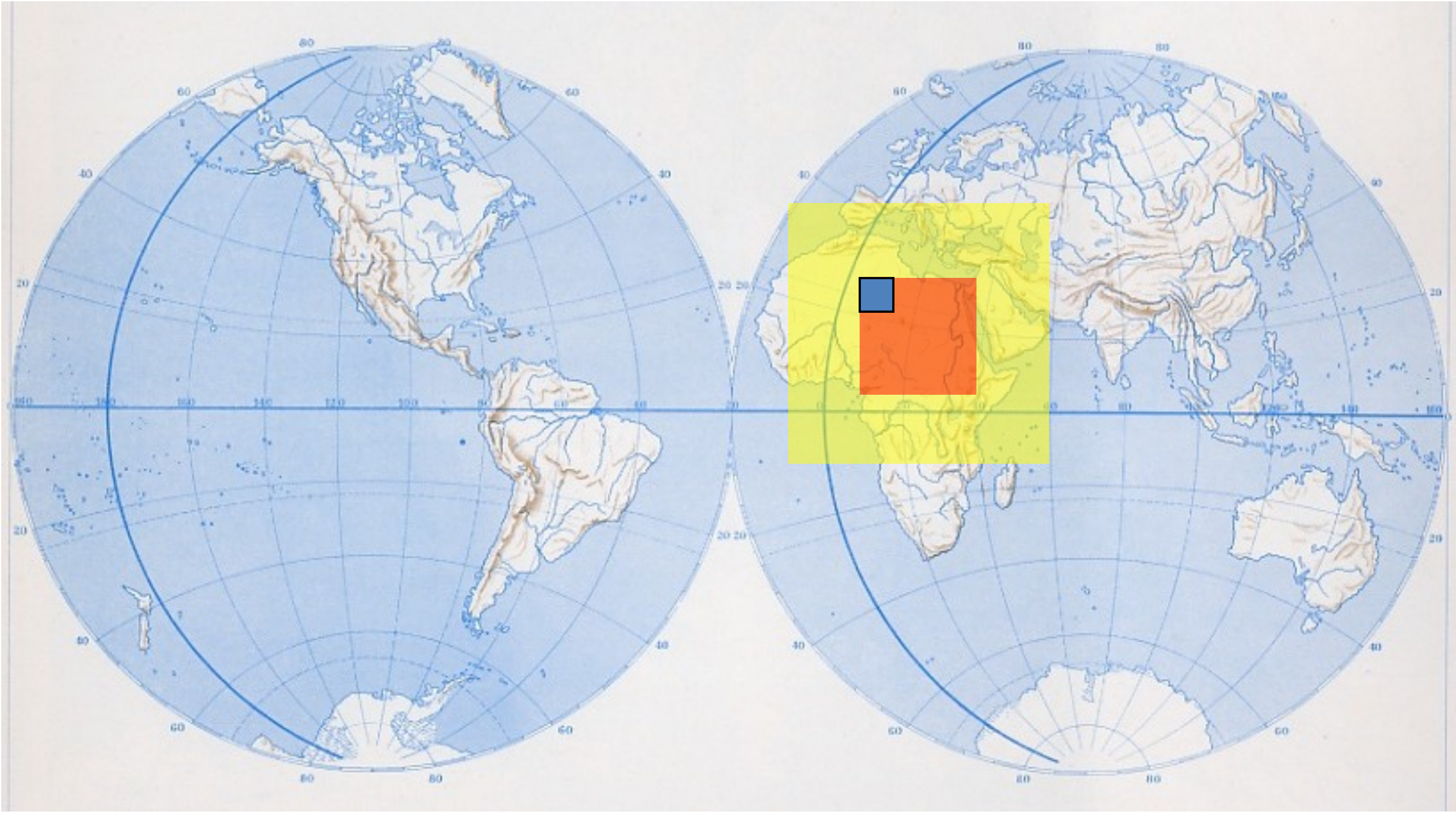
Source: ASPO International

Renewable source: solar power



La quantità media di radiazione solare (watt per metro quadrato) che colpisce la superficie terrestre è mostrata nel corso di 24 ore. La radiazione solare, per la sua disponibilità, è evidentemente un'ottima fonte di energia: perché risulti di pratico impiego, però, l'energia derivata dal Sole deve essere convertita in una forma facile da trasportare e immagazzinare.

Oggi, può un mondo solare sostenere il fabbisogno energetico complessivo?
Il sole ci fornisce un'energia 15000 volte superiore a quella che consumiamo

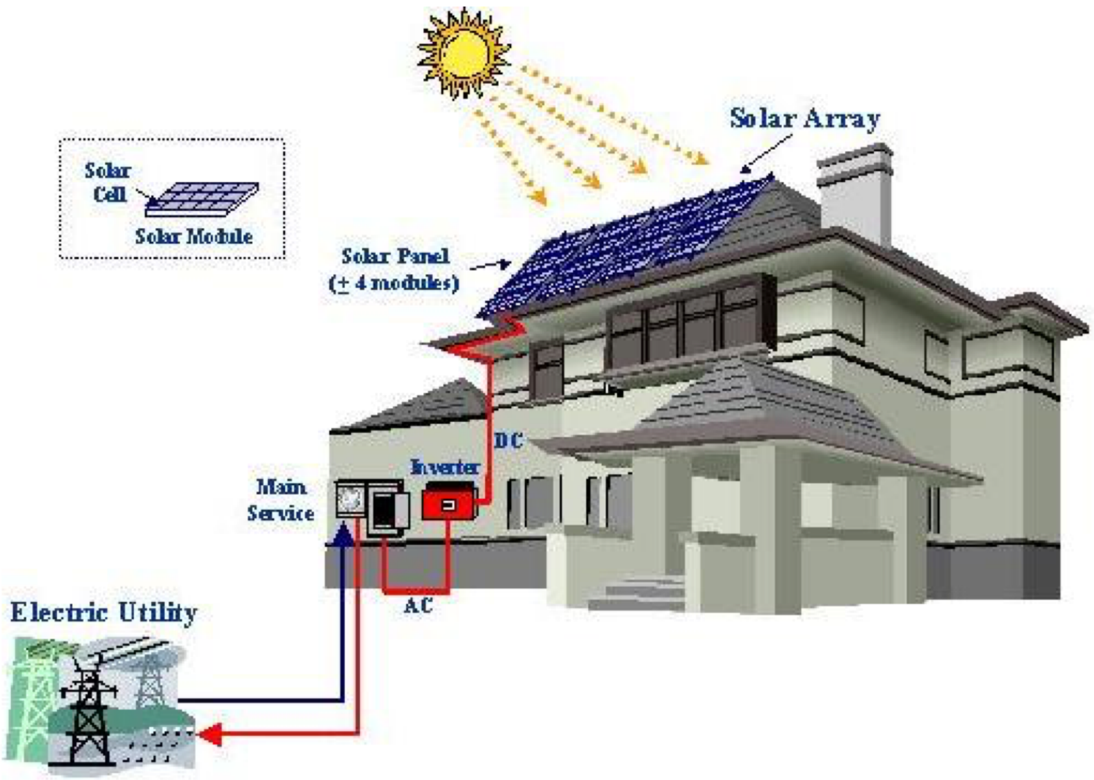


Fotovoltaico

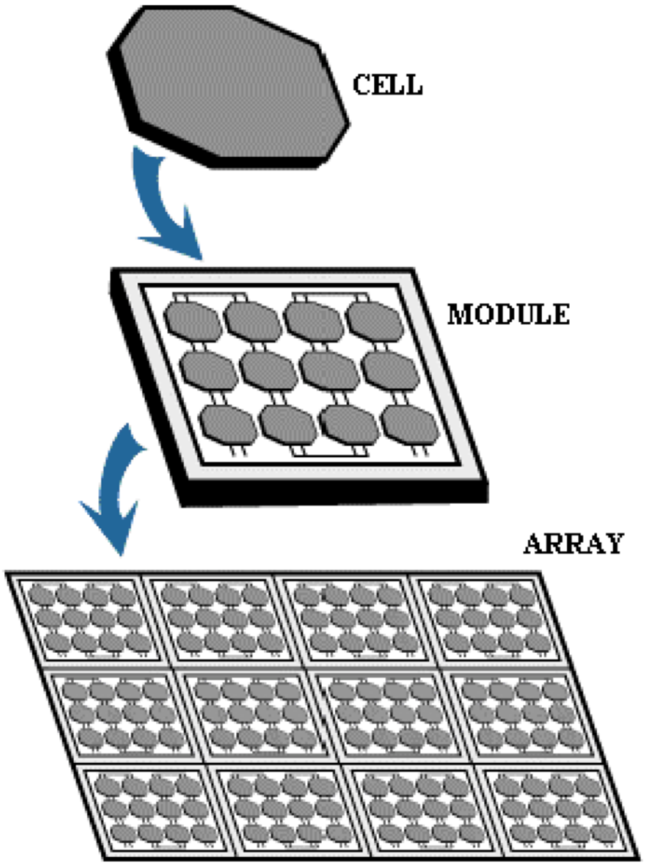
Eolico

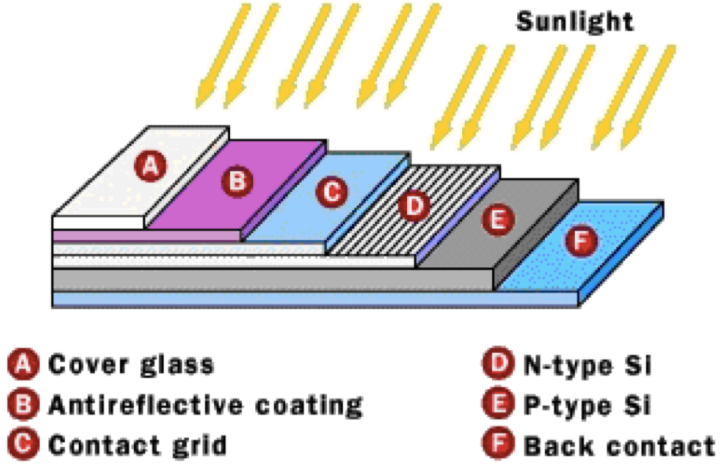
Biomasse

A photovoltaic system employs solar panels composed of a number of solar cells to supply usable solar power.



Photovoltaics (PV) is the name of a method of converting solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect.





Basic structure of a generic silicon PV cell

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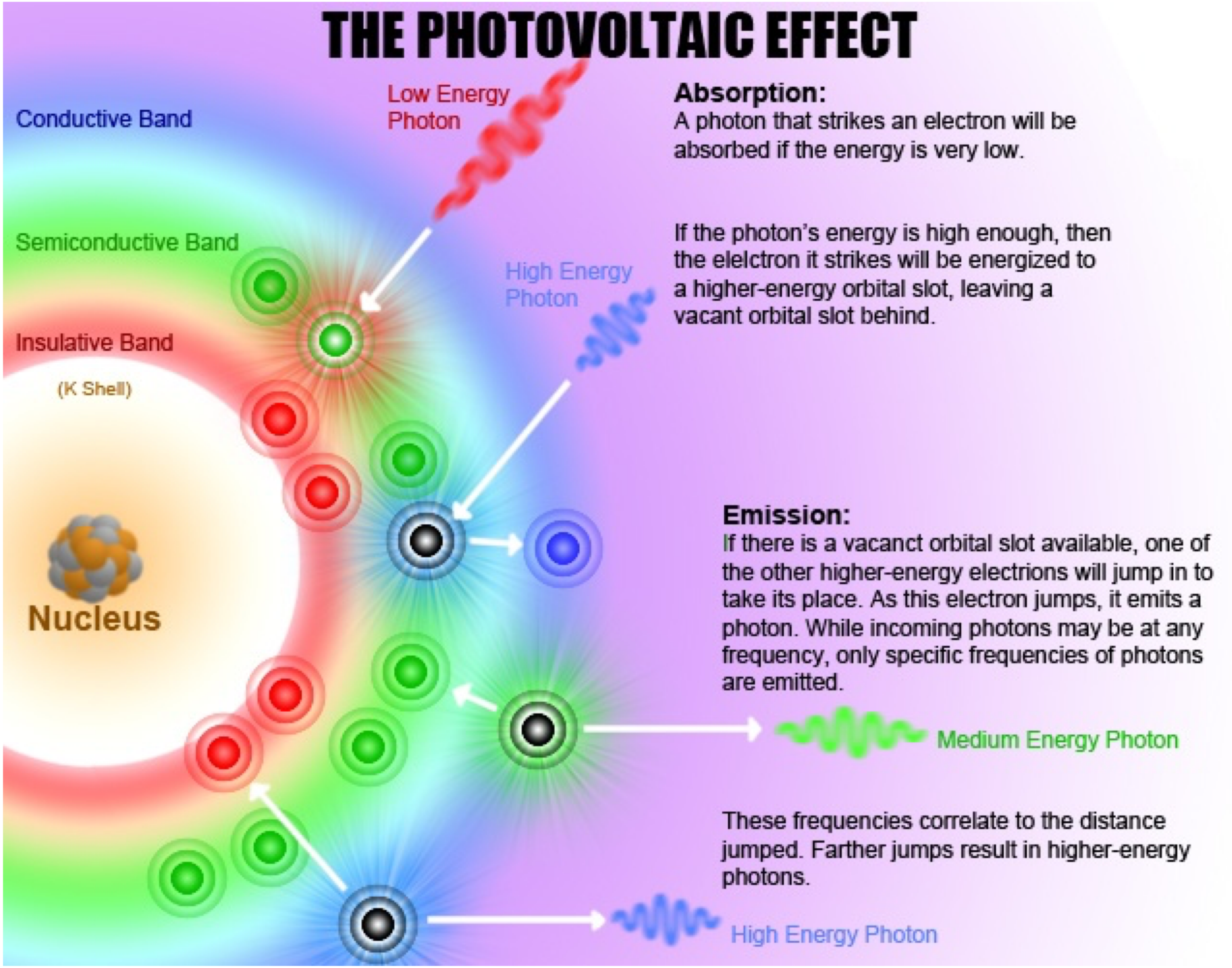
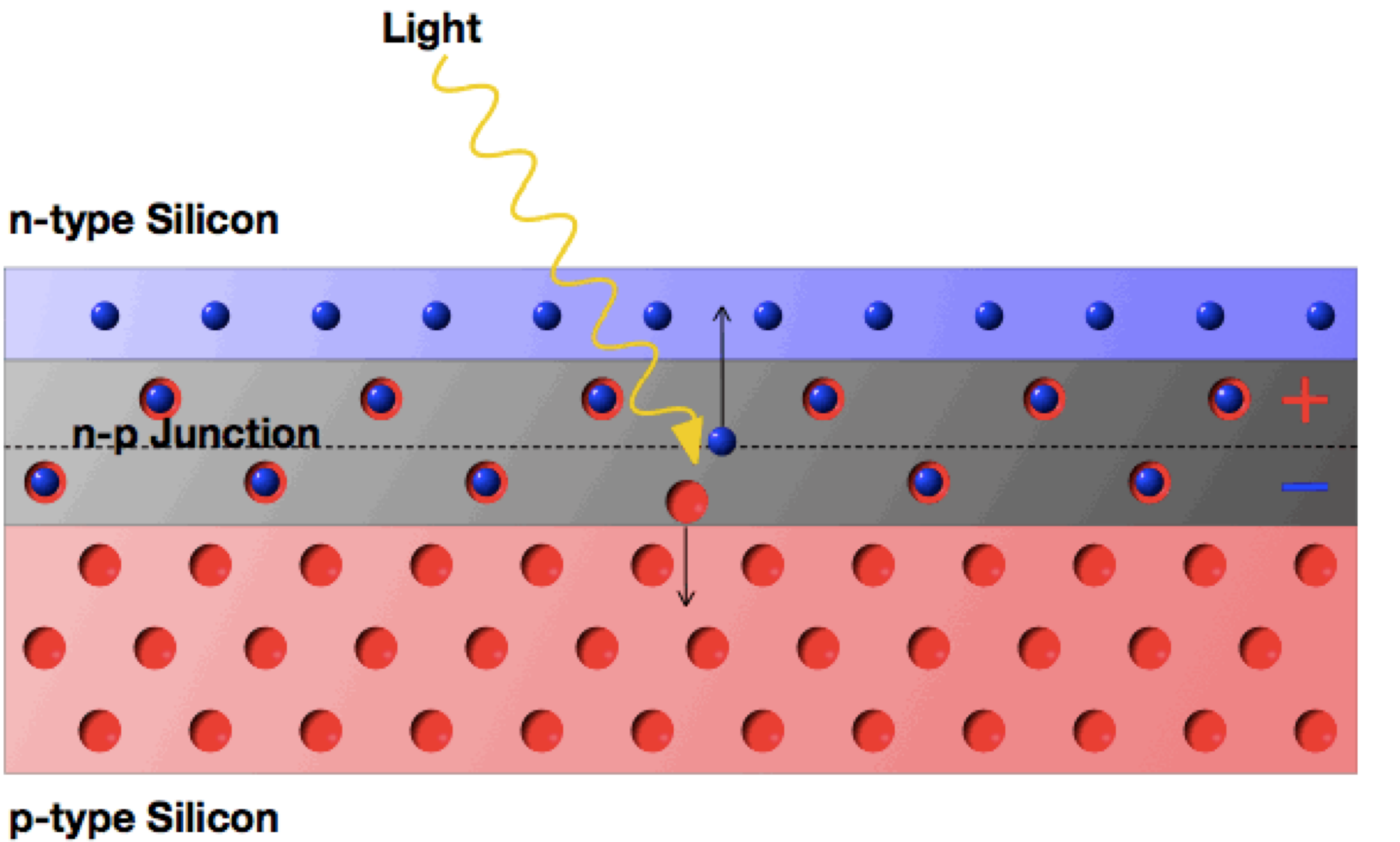
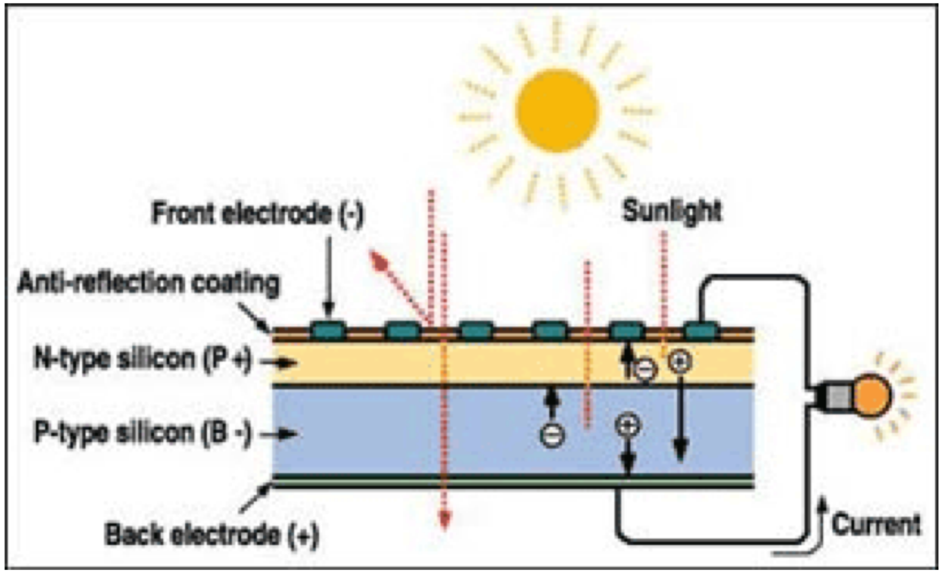
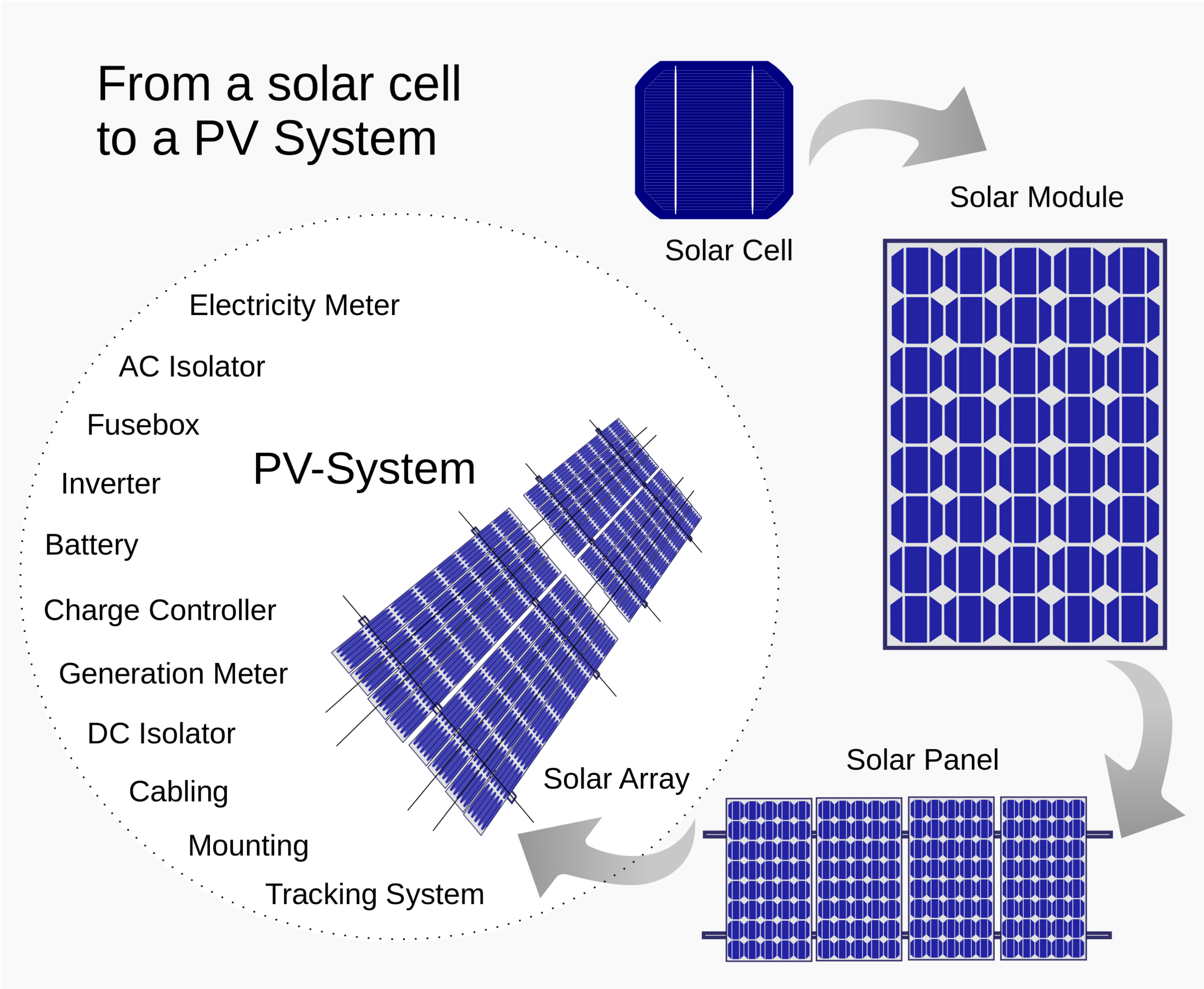

THE PHOTOVOLTAIC EFFECT
Conductive Band
Low Energy Photon
Absorption:
A photon that strikes an electron will be absorbed if the energy is very low.
Semiconductive Band
High Energy Photon
If the photon's energy is high enough, then the elelctron it strikes will be energized to a higher-energy orbital slot, leaving a vacant orbital slot behind.
Insulative Band
(K Shell)
Nucleus
Emission:
If there is a vacanct orbital slot available, one of the other higher-energy electrions will jump in to take its place. As this electron jumps, it emits a photon. While incoming photons may be at any frequency, only specific frequencies of photons are emitted.
Medium Energy Photon
These frequencies correlate to the distance jumped. Farther jumps result in higher-energy photons.
High Energy Photon

p-n junction


Light
n-type Silicon
n-p Junction
+
−
p-type Silicon
www.f-alpha.net

This voltage difference is typically in the range of 0.5V for as long as the cell is in sunlight. If you short-circuit the upper and lower layer a current runs of about 3 Amps.
If you arrange sufficient cells in series, the result is a PV module or PV panel. Let's say 36 cells in series produce 36 x 0.5V = 18V at 3 Amps = 54Watts.




From a solar cell
to a PV System
Solar Cell
Solar Module
Solar Panel
Solar Array
PV-System
Electricity Meter
AC Isolator
Fusebox
Inverter
Battery
Charge Controller
Generation Meter
DC Isolator
Cabling
Mounting
Tracking System

Quanta energia si può ottenere?

In generale, l'andamento della produzione media segue la classica curva a campana, come nel caso delle curve riportate in figura 1, ricavate per un impianto da 3 kW ubicato a Firenze, orientato a Sud, con inclinazione di 30° e privo di ombreggiamenti rilevanti.

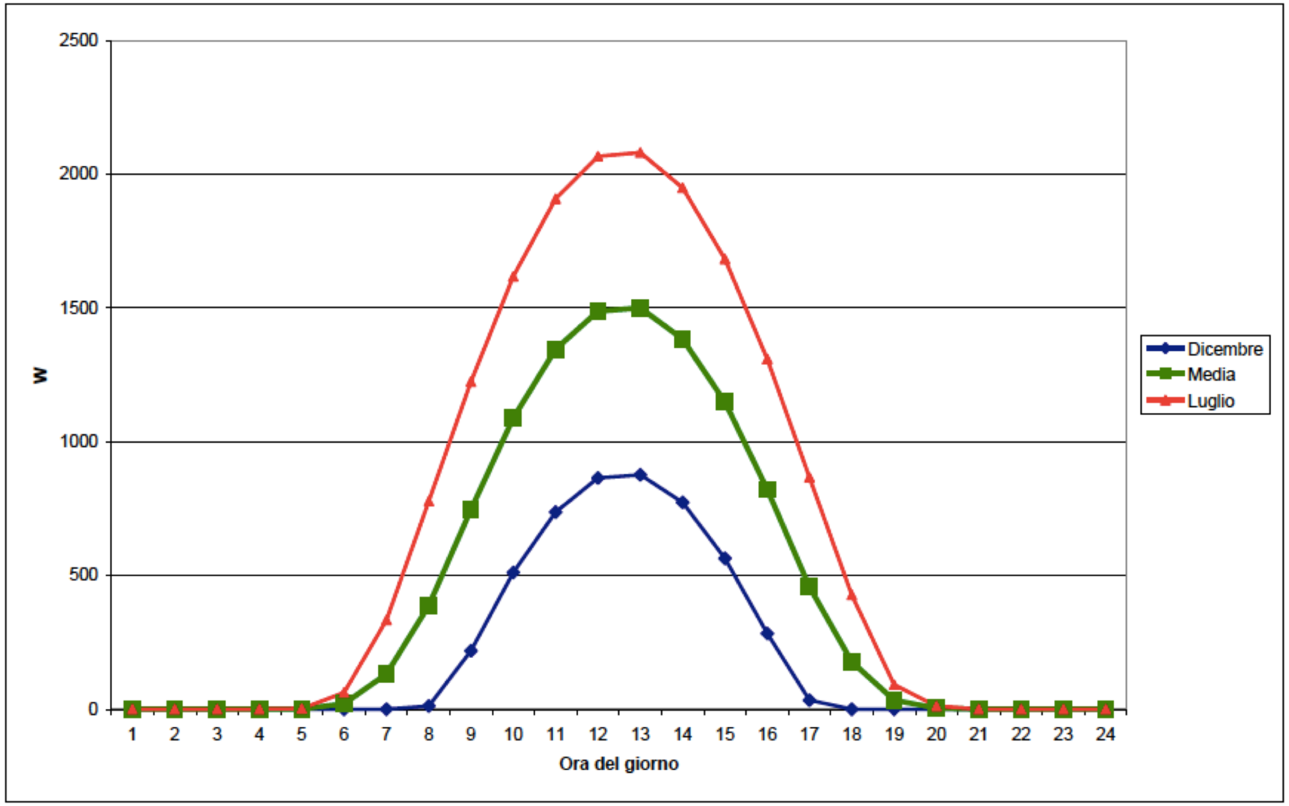
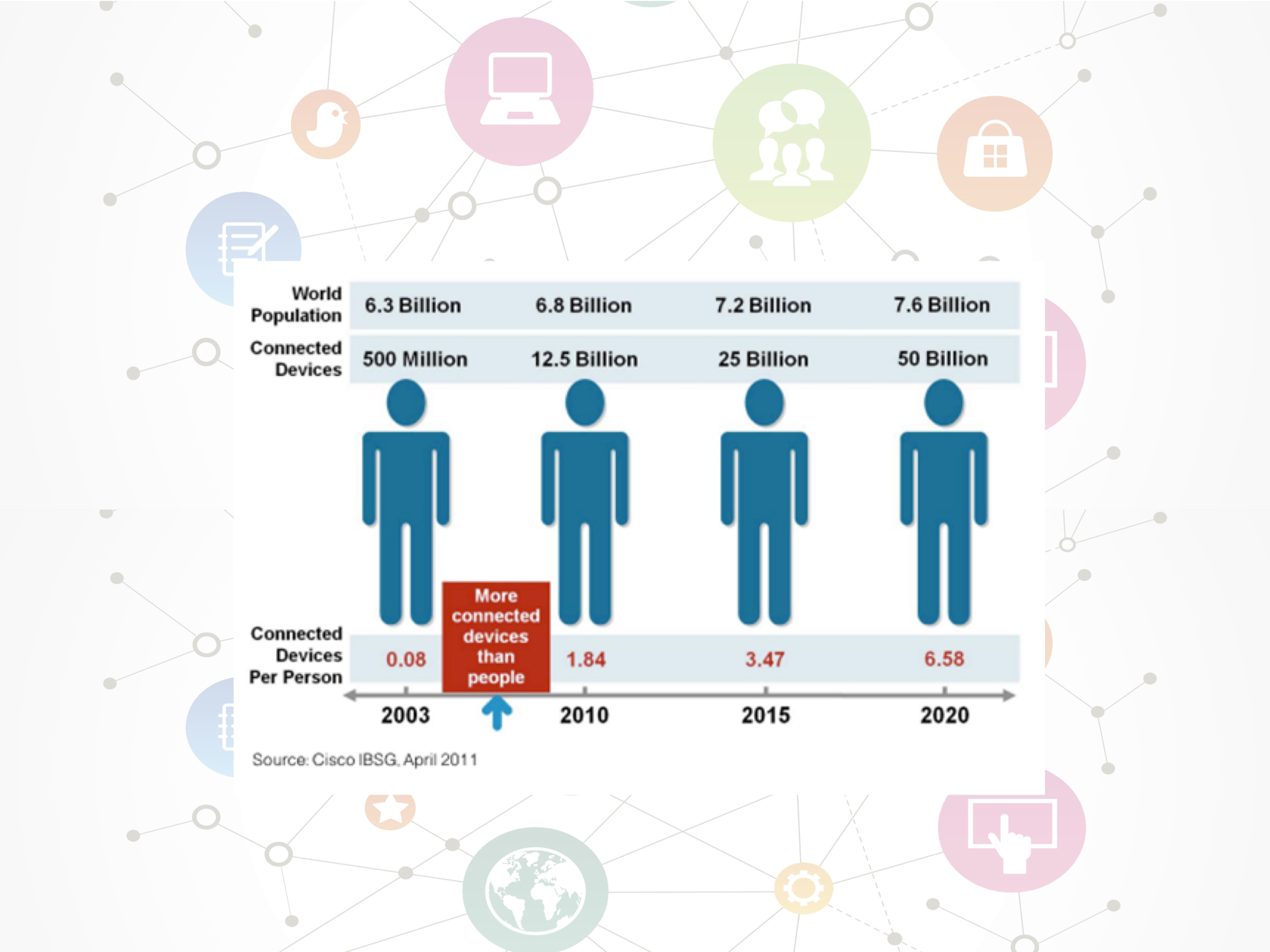


Figura 1 – Andamento giornaliero della potenza media prodotta da un impianto fotovoltaico di 3 kW ubicato a Firenze (dati forniti dal programma SunSim)

Quanta energia serve?

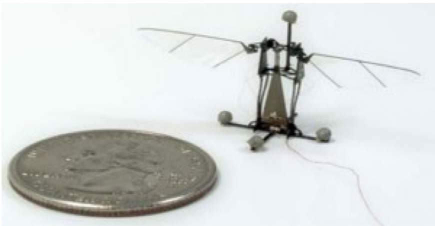
Apparecchio	Potenza assorbita [W]		Durata [minuti]		Utilizzi / giorno	Energia media giornaliera [kWh]
	Intervallo	Media	Intervallo	Media		
Lavabiancheria	650÷1000	825	60÷110	85	1,0	1,17
Lavastoviglie	450÷750	600	70÷130	100	1,0	1,00
Ferro da stiro	700÷1000	850	30÷60	45	0,5	0,32
Aspirapolvere	800÷1200	1000	10÷30	20	1	0,33
Computer, stampanti, ecc.	200÷300	250	-	200	1	0,83
Totale						**3,65**

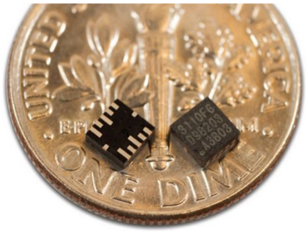
Tabella 1 – Valori medi di consumo relativi ai carichi temporalmente trasferibili

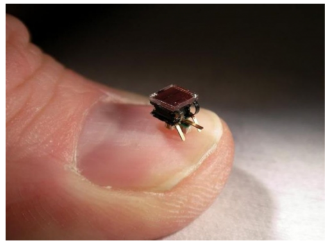

World Population
6.3 Billion
6.8 Billion
7.2 Billion
7.6 Billion
Connected Devices
500 Million
12.5 Billion
25 Billion
50 Billion
Connected Devices Per Person
0.08
More connected devices than people
1.84
3.47
6.58
2003
2010
2015
2020
Source: Cisco IBSG, April 2011

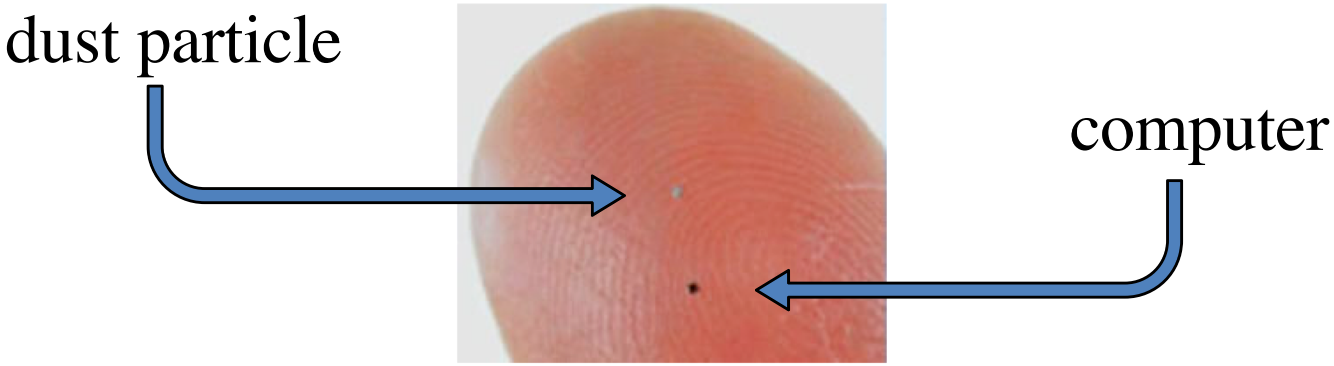
Devices of different nature and dimensions

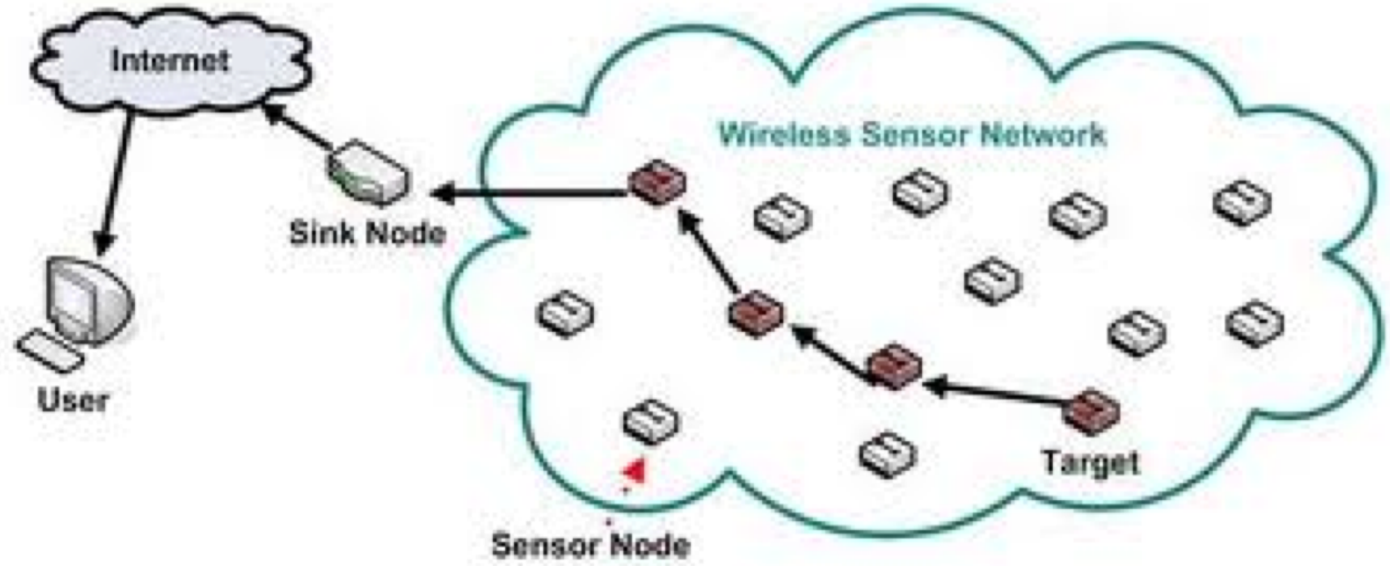
Autonomous microdevices, micro robots, wireless sensor networks

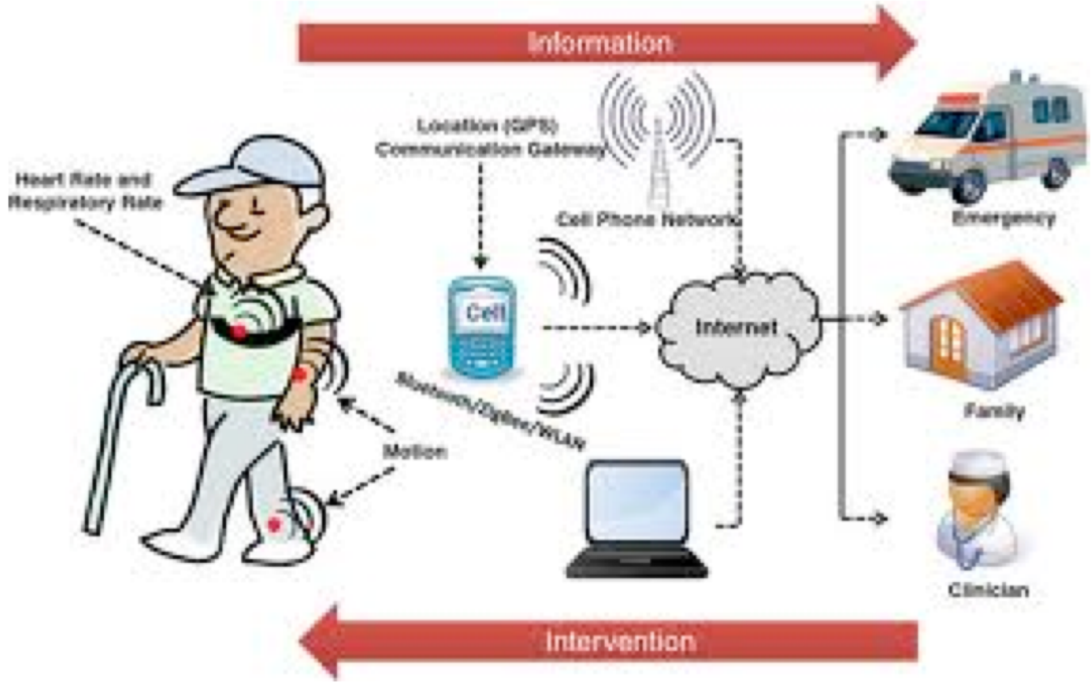









Internet
Wireless Sensor Network
Sink Node
User
Target
Sensor Node


Information
Location (GPS)
Communication Gateway
Heart Rate and
Respiratory Rate
Cell Phone Network
Cell
Internet
Bluetooth/Zigbee/WLAN
Motion
Emergency
Family
Clinician
Intervention

Un mondo interconnesso dove l'uomo è uno dei soggetti

Eco sistema naturale

Eco sistema

Ogni ecosistema è costituito da una comunità di organismi viventi che interagiscono tra di loro;
una comunità è a sua volta l'insieme di più popolazioni costituite ognuna da organismi della stessa specie.
L'insieme delle popolazioni e cioè la comunità, interagisce anche con la componente abiotica formando l'ecosistema, nel quale si vengono a creare delle interazioni reciproche in un equilibrio dinamico.

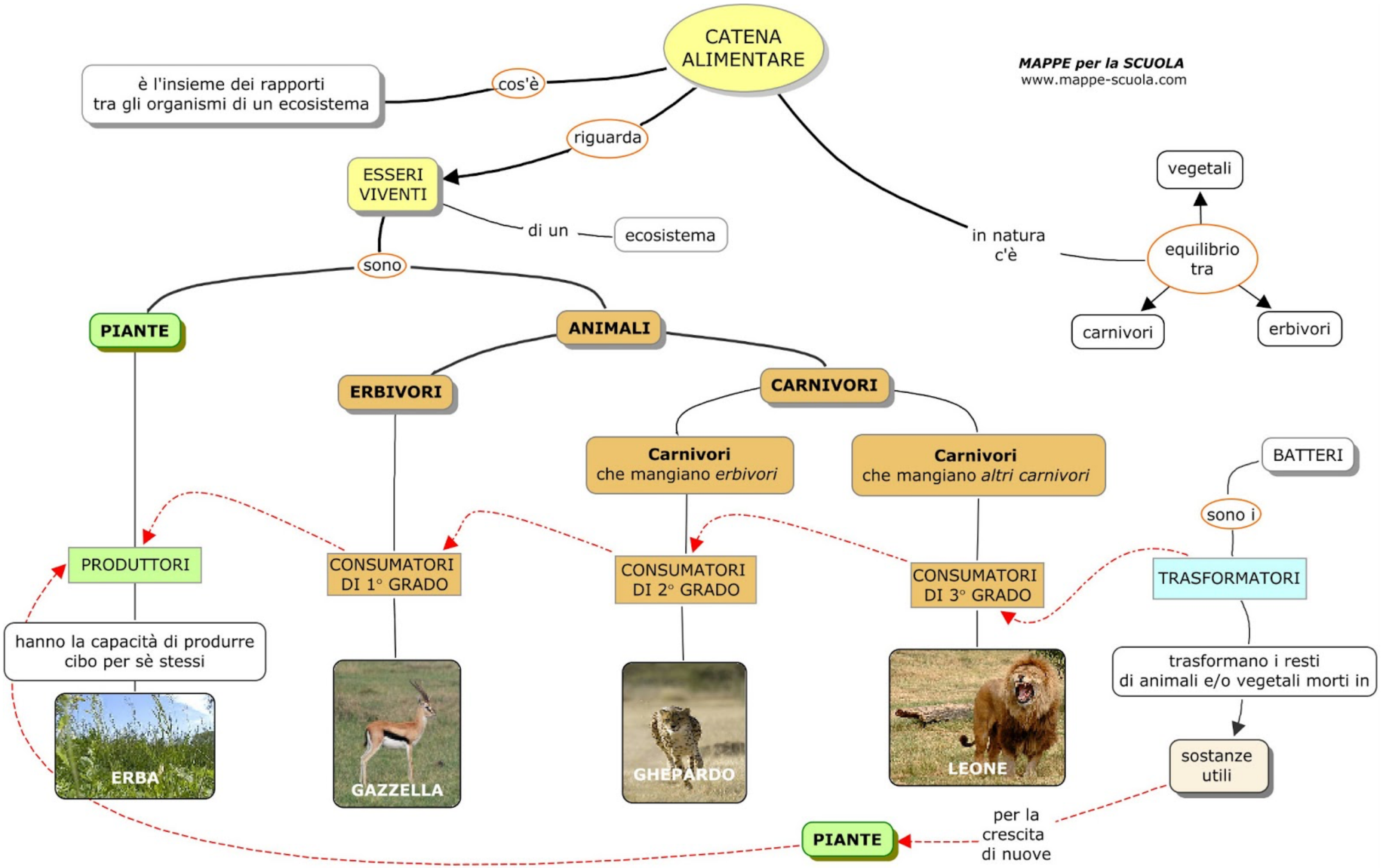
Un ecosistema viene definito come un sistema aperto, con struttura e funzione caratteristica determinata da:

- flusso di energia;
- circolazione di materia tra componente biotica e abiotica.

Gli ecosistemi presentano quattro caratteristiche comuni:

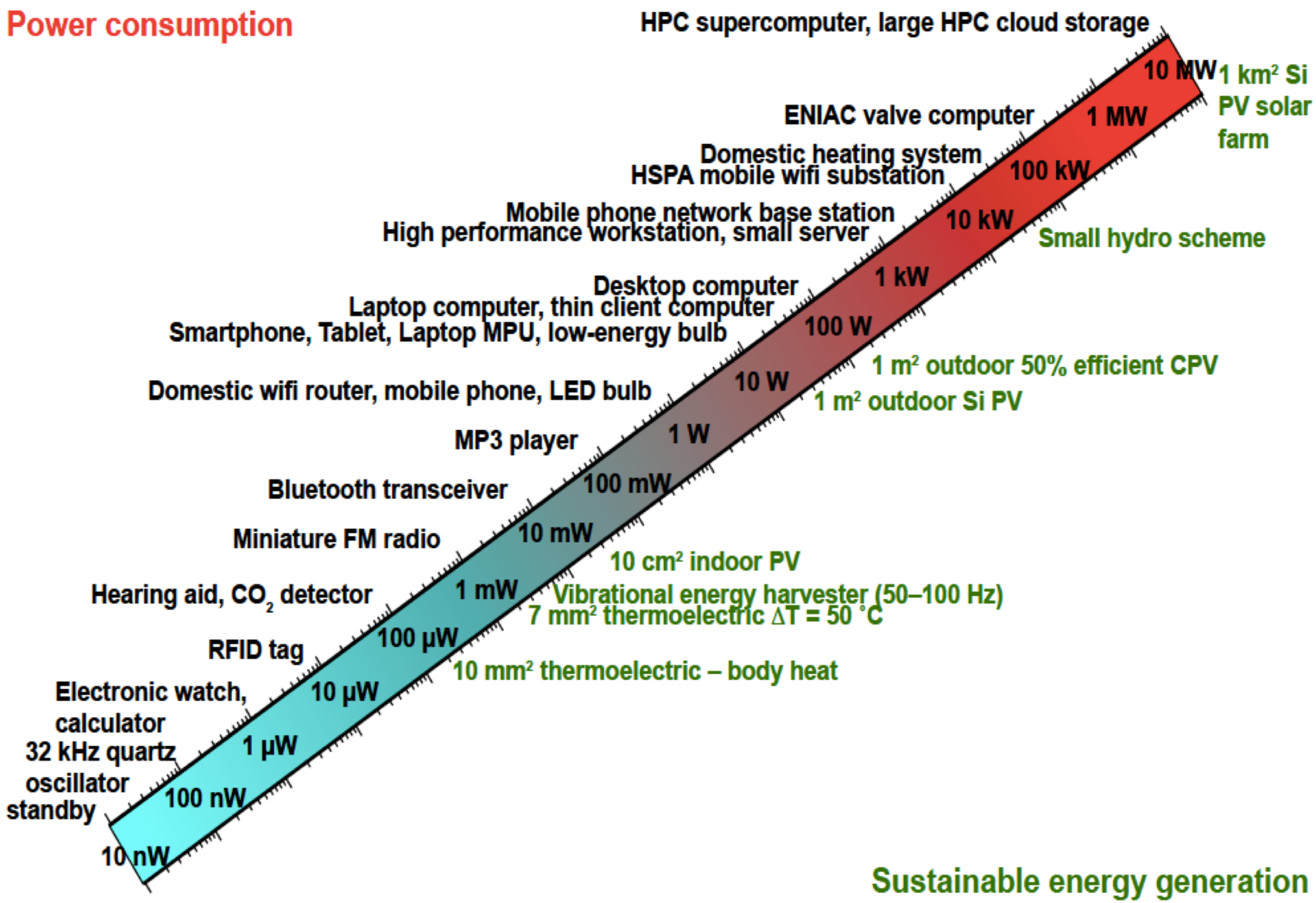
- sono sistemi aperti;[2]
- sono strutture interconnesse con altri ecosistemi;
- tendono a raggiungere e a mantenere nel tempo un certo equilibrio dinamico e quindi una particolare stabilità mutevole;
- sono sempre formati da una componente abiotica e da una componente biotica.

Il problema dell'approvvigionamento energetico



Eco Sistema ibrido: natural + artificiale

ICT energy requirements

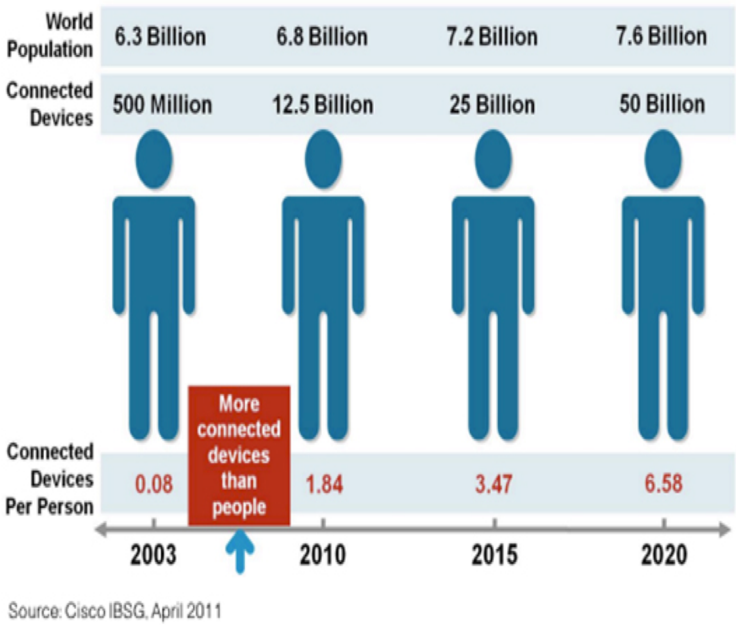


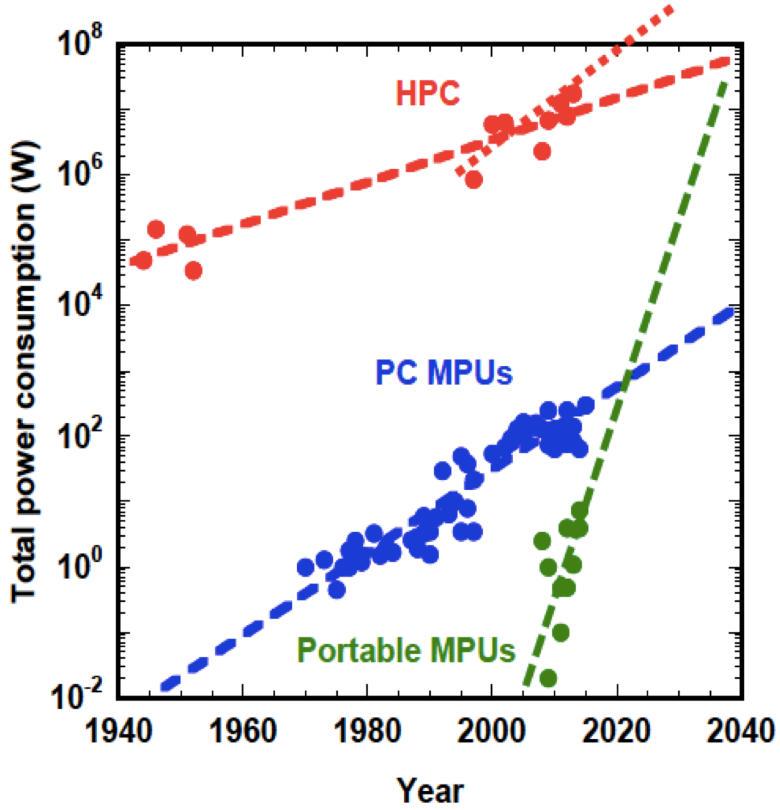
Source: D. Paul, ICT-Energy Research Agenda, 2015

[redacted]

Fact

Mobile computing is growing exponentially. The so called Internet of Things scenario requires reliable low-power devices capable of computing and communication.

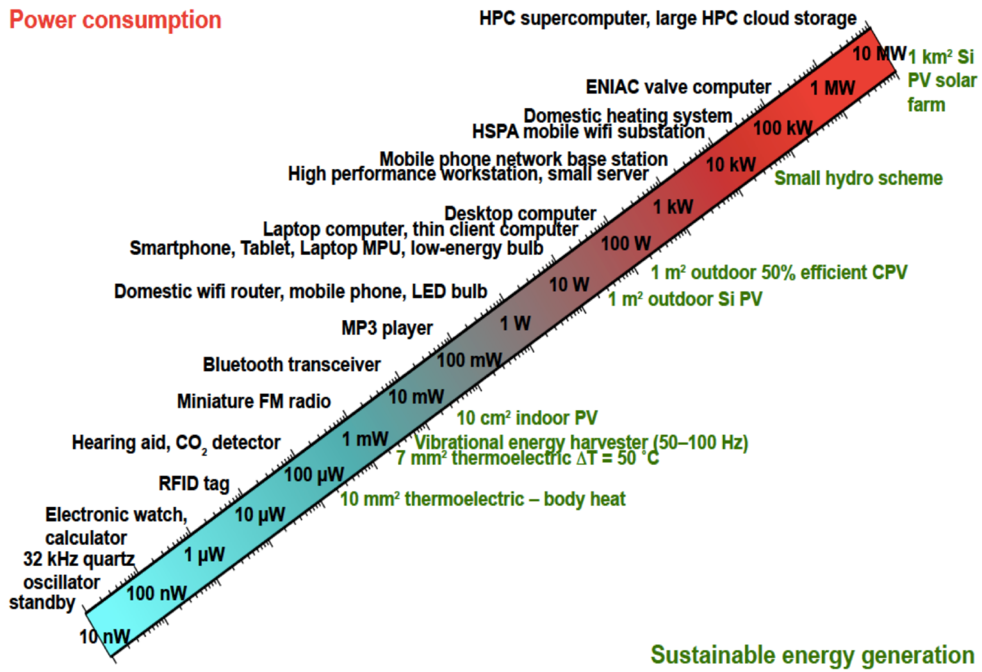




Source: D. Paul, ICT-Energy Research Agenda, 2015

Need for autonomous power

Energy required to operate the portable devices



Energy available from portable sources (energy harvesting)

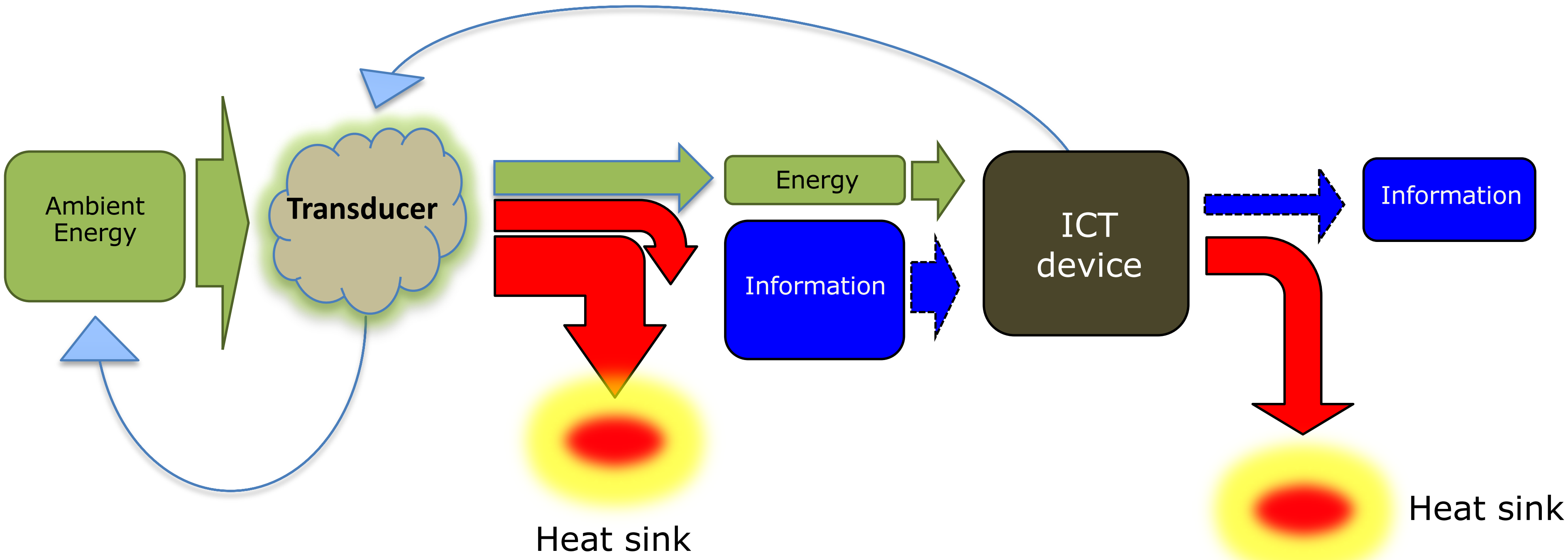
Source: IDTechEx, "Energy Harvesting and Storage 2009-2019", Cambridge 2009.
EH: Energy Harvesting; WSN: Wireless Sensors Network

The device powering issue:

1) How much energy is needed to power a device ?

2) Where does the device get the needed energy ?

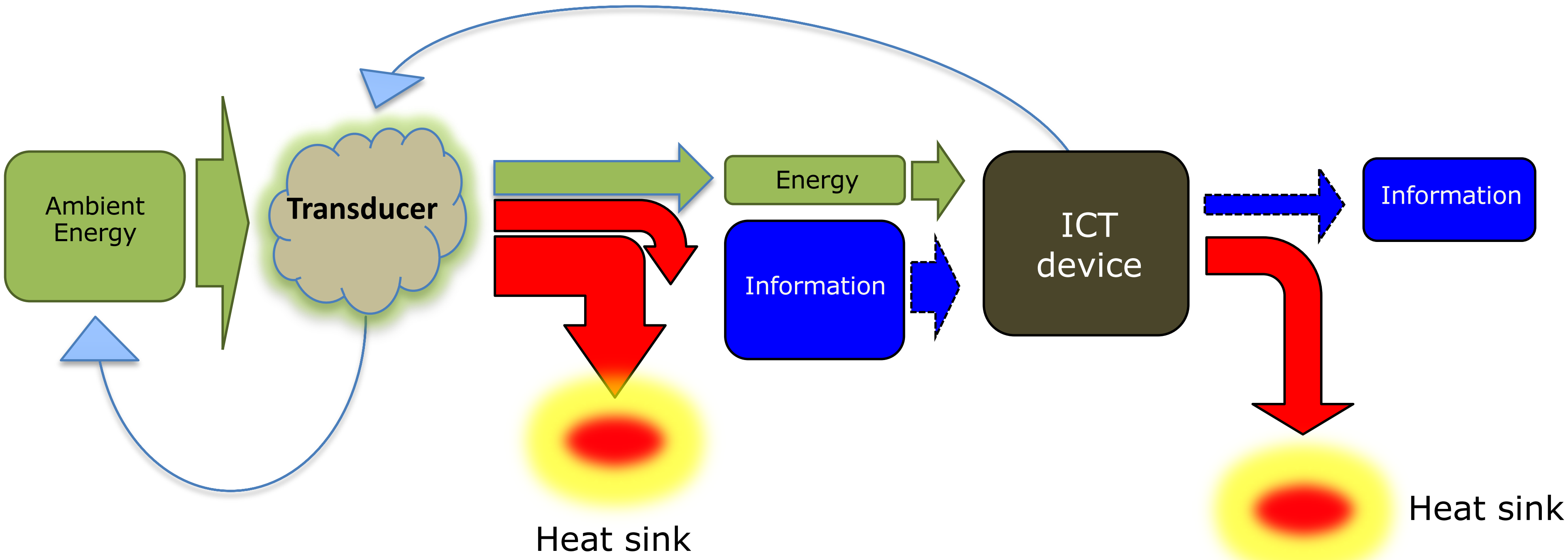
We consider devices at MEMS scale and below
We consider “ICT devices”: i.e. devices mainly devoted to computing task



An ICT device is an info-thermal machine that inputs information and energy (under the form of work), processes both and outputs information and energy (mostly under the form of heat).

Some interesting questions:

Why all the energy ends up in heat?
What does it mean "energy dissipation"?
Can be avoided?



We need a physical model…

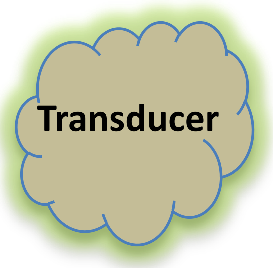
Two physical systems:

They transform energy

They have many d.o.f. (presence of fluctuations)

They are operated in a changing environment

~~Thermodynamics~~ ~~Statistical mechanics~~ Non-equilibrium statistical mechanics



In this framework we can describe the device behavior in terms of few relevant d.o.f. via a procedure called “adiabatic elimination” or “coarse graining approach”: we exchange the dynamics of a *not small isolated system* with *small not isolated system.*

Let’s see an example…

Two physical systems whose dynamical behavior can be described in the framework of non-equilibrium statistical mechanics.

Langevin equation approach

$$m\ddot{x} = -\gamma \dot{x} + \zeta + F_{ext}$$

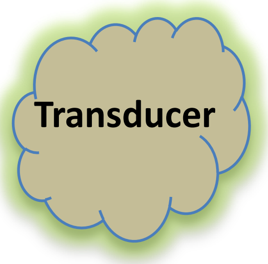
$$F_{ext} = -\frac{dU(x,t)}{dx} + \zeta_z$$

Deterministic force depending on *x, t*

Random force depending on *t*

If $F_{ext} >> \zeta$ then the thermal noise contribution can be ignored

$$m\ddot{x} = -\frac{dU(x,t)}{dx} - \gamma \dot{x} + \zeta_z$$



Langevin equation approach

$$m\ddot{x} = -\frac{dU(x,t)}{dx} + \zeta_z - \gamma \dot{x} + \zeta$$

This is a stochastic dynamics whose solution *x(t)* appears like

Probability density *P(x,t)*.
P(x,t)dx represents the probability for the observable *x* to be in (*x* , *x+dx*).

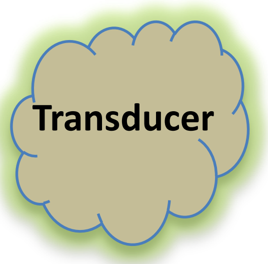
P(x,t) is a deterministic quantity and its time evolution of can be described in terms of the associated Fokker-Planck equation.

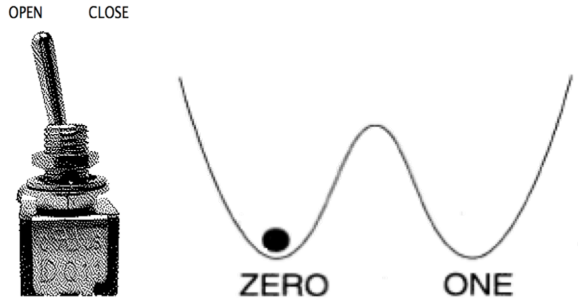
Two physical systems whose dynamical behavior can be described in the framework of non-equilibrium statistical mechanics.

Langevin equation approach

Two physical systems whose dynamical behavior can be described in the framework of non-equilibrium statistical mechanics.

Langevin equation approach





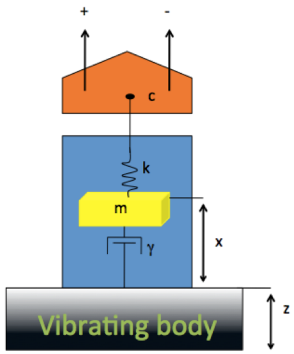
(example from a digital binary switch)

$$m\ddot{x} = -\frac{dU(x)}{dx} - \gamma \dot{x} + F_{sw} + \zeta$$

$$< \zeta(t)\ \zeta(0) > = 2\ K_B T\ \gamma\ \delta(t)$$

Two physical systems whose dynamical behavior can be described in the framework of non-equilibrium statistical mechanics.

Langevin equation approach



(example from vibration harvester)

$$m\ddot{x} = -\frac{dU(x)}{dx} - \gamma\dot{x} - c(x,V) + \zeta_z + \zeta$$

$$\dot{V} = F(\dot{x},V)$$

The device powering issue:

1) How much energy is needed to power a device ?

2) Where does the device get the needed energy ?