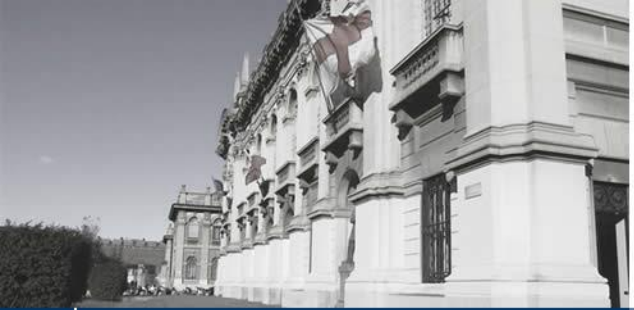


School of Industrial and Information Engineering

Course 096125 (095857)

Introduction to Green and Sustainable Chemistry

POLITECNICO DI MILANO

Renewable Energy Sources.

Prof. Attilio Citterio
Dipartimento CMIC “Giulio Natta”
https://iscamapweb.chem.polimi.it/citterio/it/education/course-topics/

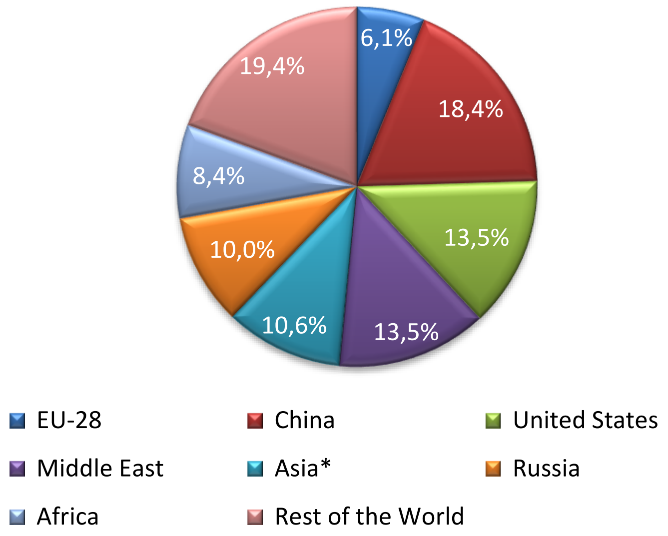
Typical Content of this Section.

Key Principles

- ✓ introducing the key scientific terminologies and concepts
- ✓ Subdividing the Renewable Energy market and application of different sources and technologies (fuels, gases, electricity, etc.)
- ✓ Comparing physical and practical limits to the different renewable energy sources
- ✓ Why is Energy efficiency an Important Energy Resource.
- ✓ The differing characteristics and appropriate applications of the storage technologies: for load-shifting vs. power quality
- ✓ The role of energy saving in EU.

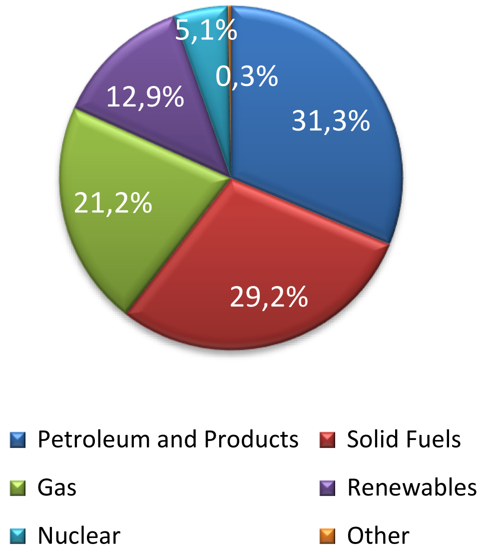
World Energy Production by Region (%) and by Fuel (%) (2011).

Total = 13202 Mtoe (by Region)



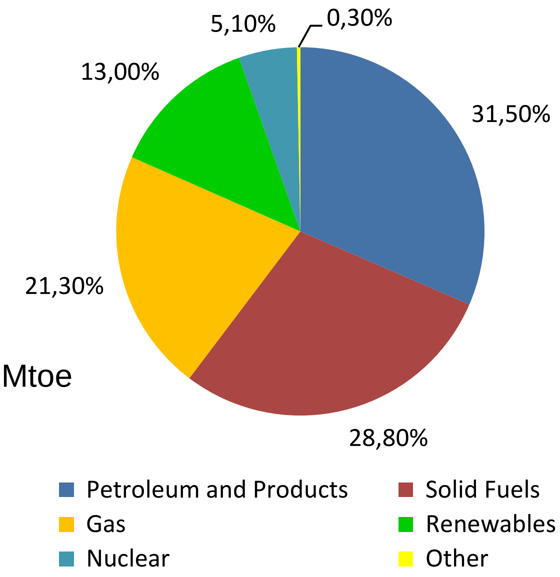
Mtoe	1995	2000	2005	2010	2011	2011 (%)
EU-28	965	950	905	841	809	6,1%
China	1065	1130	1701	2262	2433	18,4%
United States	1659	1667	1631	1723	1785	13,5%
Middle East	1140	1329	1523	1641	1788	13,5%
Asia*	826	934	1121	1373	1405	10,6%
Russia	968	978	1203	1293	1315	10,0%
Africa	772	890	1089	1168	1104	8,4%
Rest of the World	1879	2174	2435	2567	2564	19,4%
World	9274	10052	11608	12868	13203	100,00%

Total = 13202 Mtoe (by fuel)

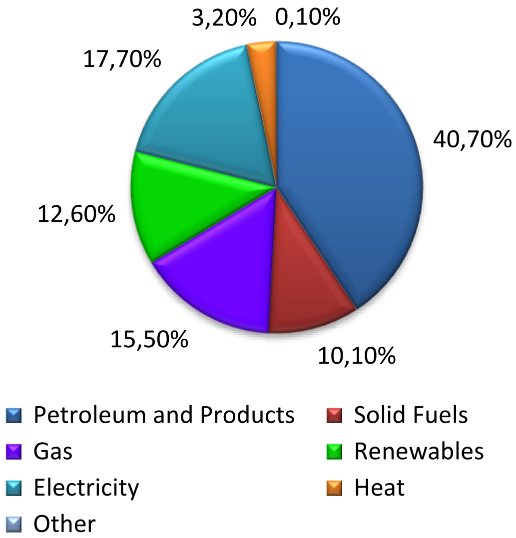


Mtoe	1995	2000	2005	2010	2011	2011 (%)
Petroleum and Products	3395	3702	4050	4078	4133	0,313
Solid Fuels	2233	2294	3012	3648	3851	0,292
Gas	1815	2062	2373	2720	2805	0,212
Renewables	1207	1296	1430	1671	1702	0,129
Nuclear	608	676	722	719	674	0,051
Other	17	22	21	32	37	0,003
Total	9275	10052	11608	12868	13202	1,00

World Gross Inland and Final Consumption by Fuel (2011).



Total 2011 = 13 113 Mtoe



Final

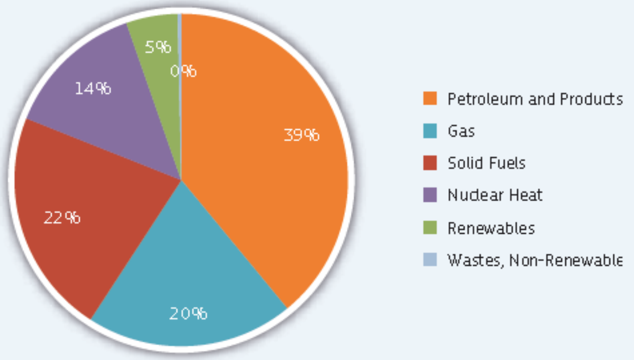
Mtoe	1995	2000	2005	2010	2011	2011 (%)
Petroleum and Products	3371	2358	4021	4146	4136	31,50%
Solid Fuels	2222	2358	2974	3595	3776	28,80%
Gas	1812	2072	2365	2740	2787	21,30%
Renewables	1208	1297	1429	1672	1703	13,00%
* Hydro	213	225	252	296	300	2,30%
* Geothermal	39	52	54	65	66	0,50%
* Solar/Wind/Other	3	8	16	47	61	0,50%
* Biofuels and Waste	968	1033	1127	1295	1312	10,00%
Nuclear	608	676	722	719	674	5,10%
Other	17	23	21	32	37	0,30%
Total	10461	10102	12981	14607	14852	100%

E U-28 Gross Inland Consumption
Energy Mix* – 2012 (%).

EU-28 Gross Inland Consumption

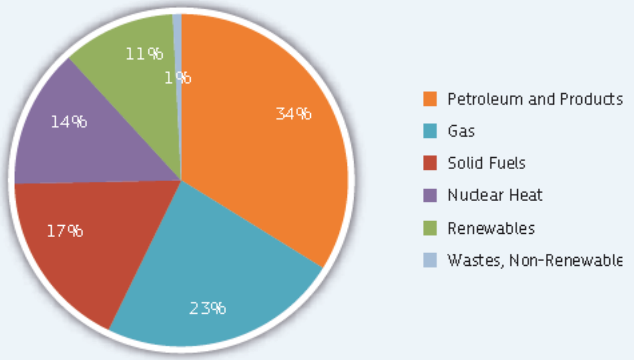
Energy Mix (%) – Primary Products Only

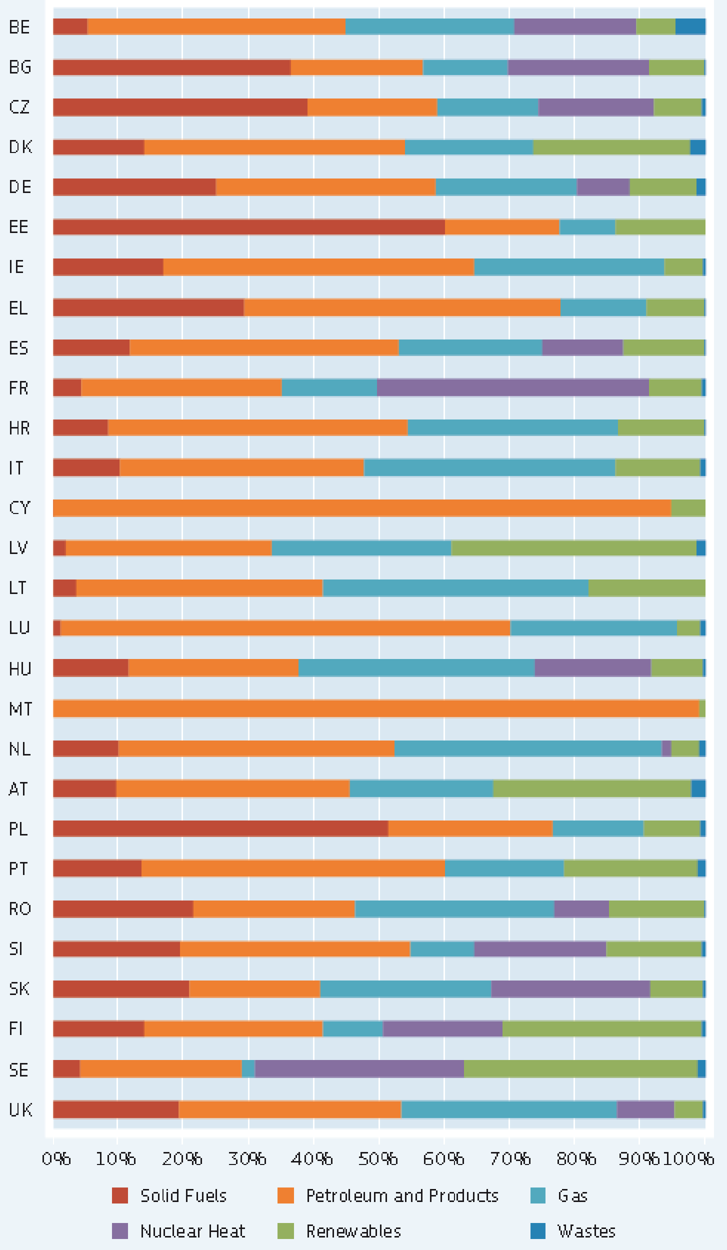
Total Primary 1995: 1 669 Mtoe
(Total Primary and Secondary 1995: 1 671 Mtoe)



EU-28 Gross Inland Consumption – Energy Mix (%) – Primary Products Only

Total Primary 2012: 1 682 Mtoe
(Total Primary and Secondary 2012: 1 683 Mtoe)





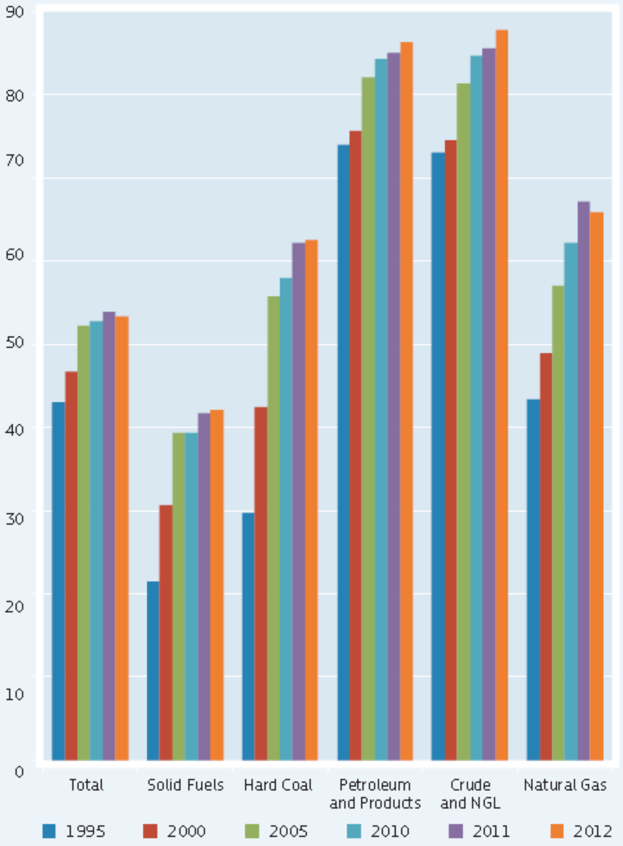
* Primary Products only – Source: Eurostat, May 2014
Methodology and Notes: See Appendix 13 – No 1

EU-28 Energy Import Dependency and Net Import (2012).

By Fuel

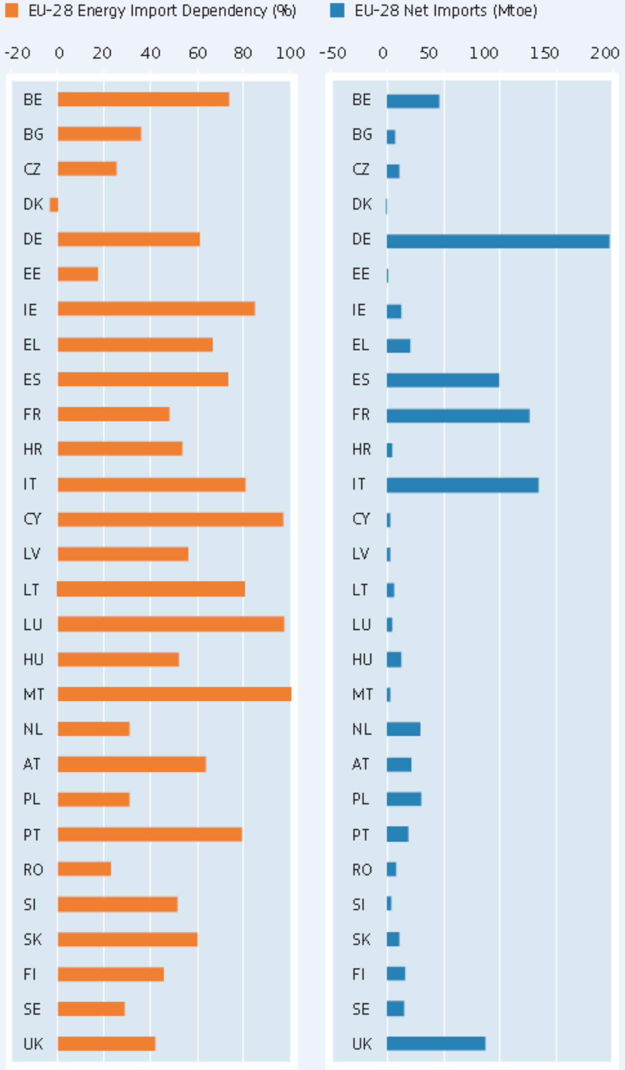
	1995	2000	2005	2010	2011	2012
Total	43.0%	46.7%	52.2%	52.7%	53.9%	53.4%
Solid Fuels	21.5%	30.6%	39.4%	39.4%	41.7%	42.2%
of which Hard Coal	29.7%	42.6%	55.7%	57.9%	62.3%	62.5%
Petroleum and Products	74.0%	75.7%	82.1%	84.4%	85.1%	86.4%
of which Crude and NGL	73.0%	74.5%	81.3%	84.6%	85.5%	87.8%
Natural Gas	43.4%	48.9%	57.1%	62.1%	67.1%	65.8%

EU-28 Energy Import Dependency by Fuel – 1995-2012 (%)



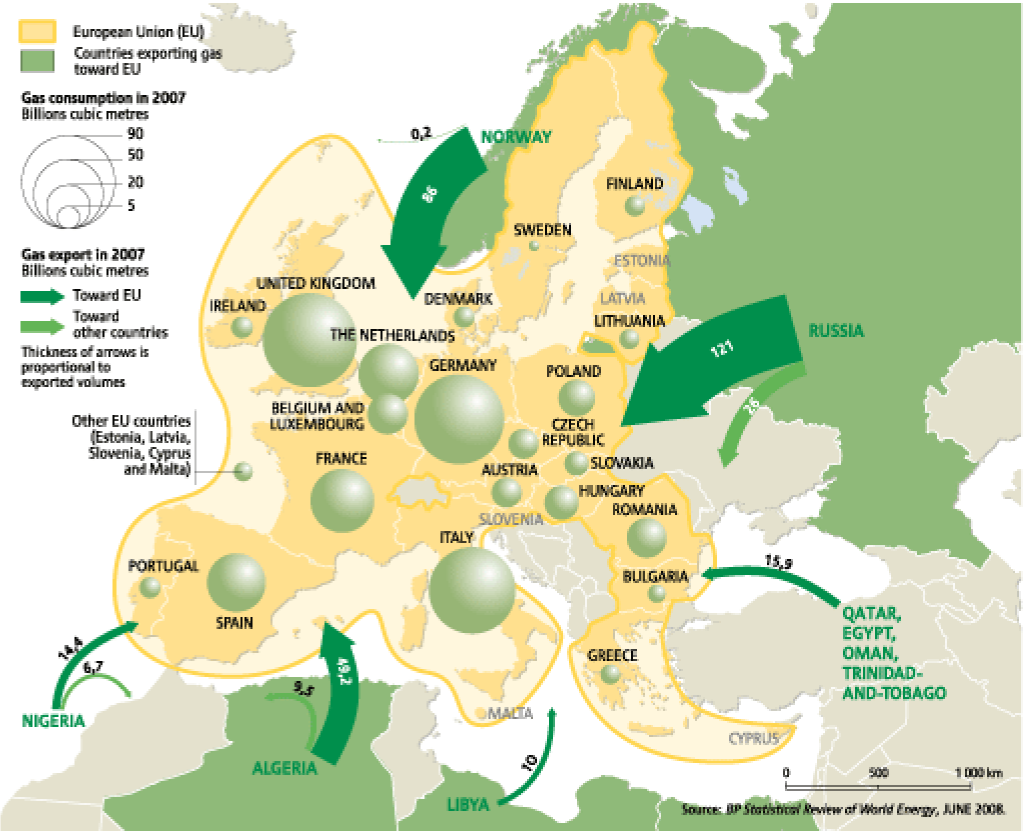
Source: Eurostat, May 2014
Methodology and Notes: See Appendix 13 – No 1

2012



Source: Eurostat, May 2014
Methodology and Notes: See Appendix 13 – No 1

UE Energy Imports.



Source: *BP Statistical Review of World Energy*, JUNE 2008.

The European Union is almost 50% dependent on imports for its energy consumption and it will be 70% in about 15 years. A large part of its oil and gas imports will come increasingly from Russia. However, the last crises over oil & gas deliveries from Russia to Ukraine have again triggered virulent criticism about Russian energy strategies and its abilities at being a safe supplier

EU 2020 Renewable Energy Targets and GHG Emissions Targets.

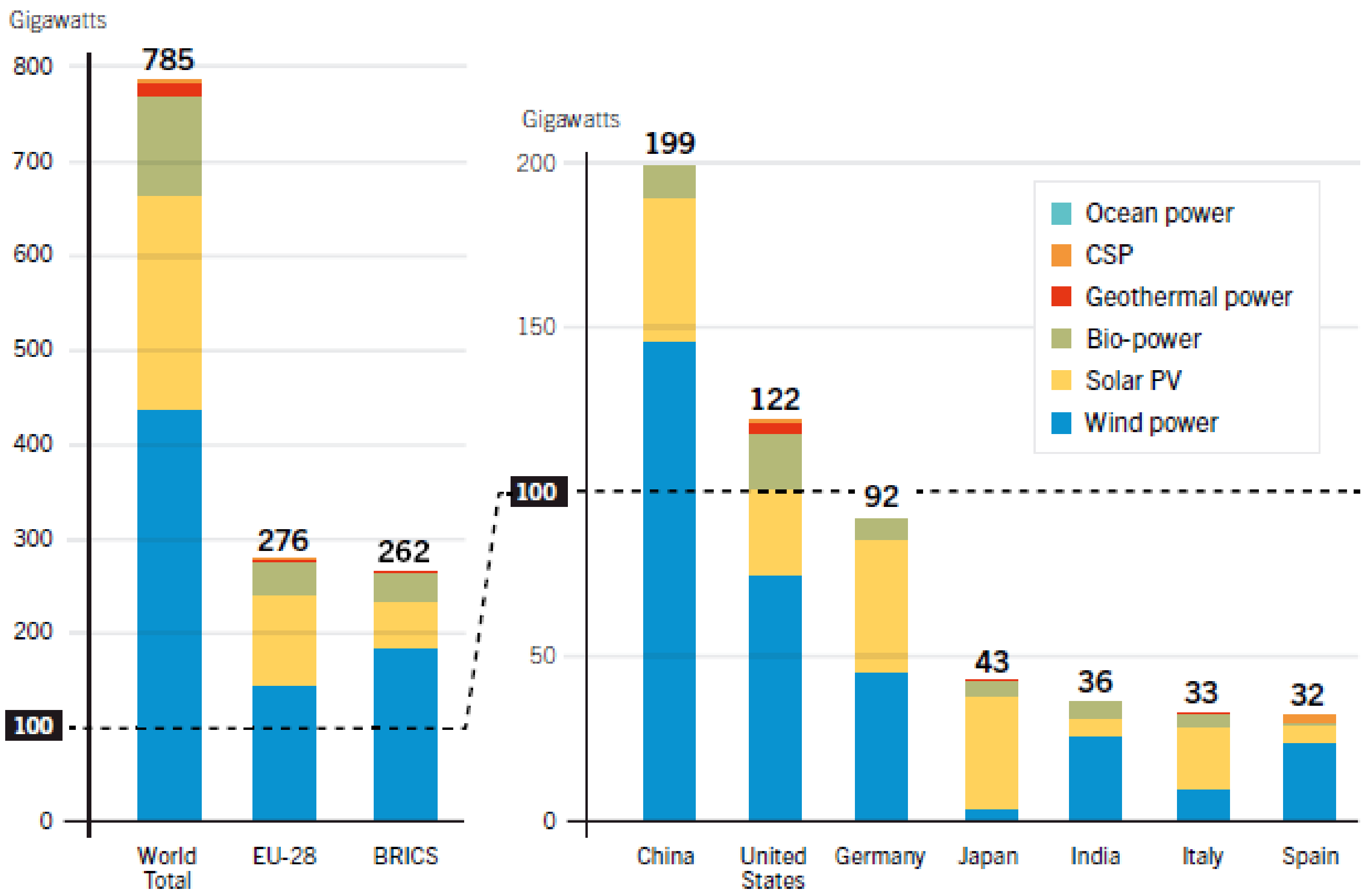
% EU-28	2012 Overall RES Share 14,1 %	2012 RES Interim Target 10,7 %	2020 RES Target 20,0 %
BE	6,80%	4,40%	13,00%
BG	16,30%	10,70%	16,00%
CZ	11,20%	7,50%	13,00%
DK	26,00%	19,60%	30,00%
DE	12,40%	8,20%	18,00%
EE	25,80%	19,40%	25,00%
IE	7,20%	5,70%	16,00%
EL	13,80%	9,10%	18,00%
ES	14,30%	11,00%	20,00%
FR	13,40%	12,80%	23,00%
HR	16,80%	14,10%	20,00%
IT	13,50%	7,60%	17,00%
CY	6,80%	4,90%	13,00%
LV	35,80%	34,10%	40,00%
LT	21,70%	16,60%	23,00%
LU	3,10%	2,90%	11,00%
HU	9,60%	6,00%	13,00%
MT	1,40%	2,00%	10,00%
NL	4,50%	4,70%	14,00%
AT	32,10%	25,40%	34,00%
PL	11,00%	8,80%	15,00%
PT	24,60%	22,60%	31,00%
RO	22,90%	19,00%	24,00%
SI	20,20%	17,80%	25,00%
SK	10,40%	8,20%	14,00%
FI	34,30%	30,40%	38,00%
SE	51,00%	41,60%	49,00%
UK	4,20%	4,00%	15,00%

GHG Emissions Targets*

Emissions Compared to 1990

Index 100=1990	1990	1995	2000	2005	2010	2011	2012
EU-28	100	93	92	93	86	83	82
BE	100	105	103	100	93	85	83
BG	100	70	54	58	55	60	56
CZ	100	77	75	74	70	68	67
DK	100	111	100	94	90	83	77
DE	100	90	84	81	77	74	77
EE	100	49	42	46	49	52	47
IE	100	107	124	128	113	106	107
EL	100	105	120	128	112	110	106
ES	100	111	135	154	125	126	122
FR	100	99	101	102	94	89	89
HR	100	73	83	96	90	89	83
IT	100	102	107	112	97	95	90
CY	100	121	138	150	151	147	148
LV	100	48	38	42	47	45	43
LT	100	45	40	48	43	44	44
LU	100	81	81	108	102	100	97
HU	100	81	80	81	69	67	64
MT	100	123	130	147	150	151	157
NL	100	107	103	102	101	95	93
AT	100	103	104	120	110	108	104
PL	100	95	84	85	88	88	86
PT	100	117	138	145	119	116	115
RO	100	71	55	58	48	50	48
SI	100	101	103	110	106	106	103
SK	100	74	69	71	64	63	58
FI	100	100	99	98	107	97	88
SE	100	102	96	93	91	86	81
UK	100	93	90	89	80	75	78

Renewable Power Capacities* in World, EU-28, BRICS and Top Seven Countries, End-2015.



*Hydroelectric non included

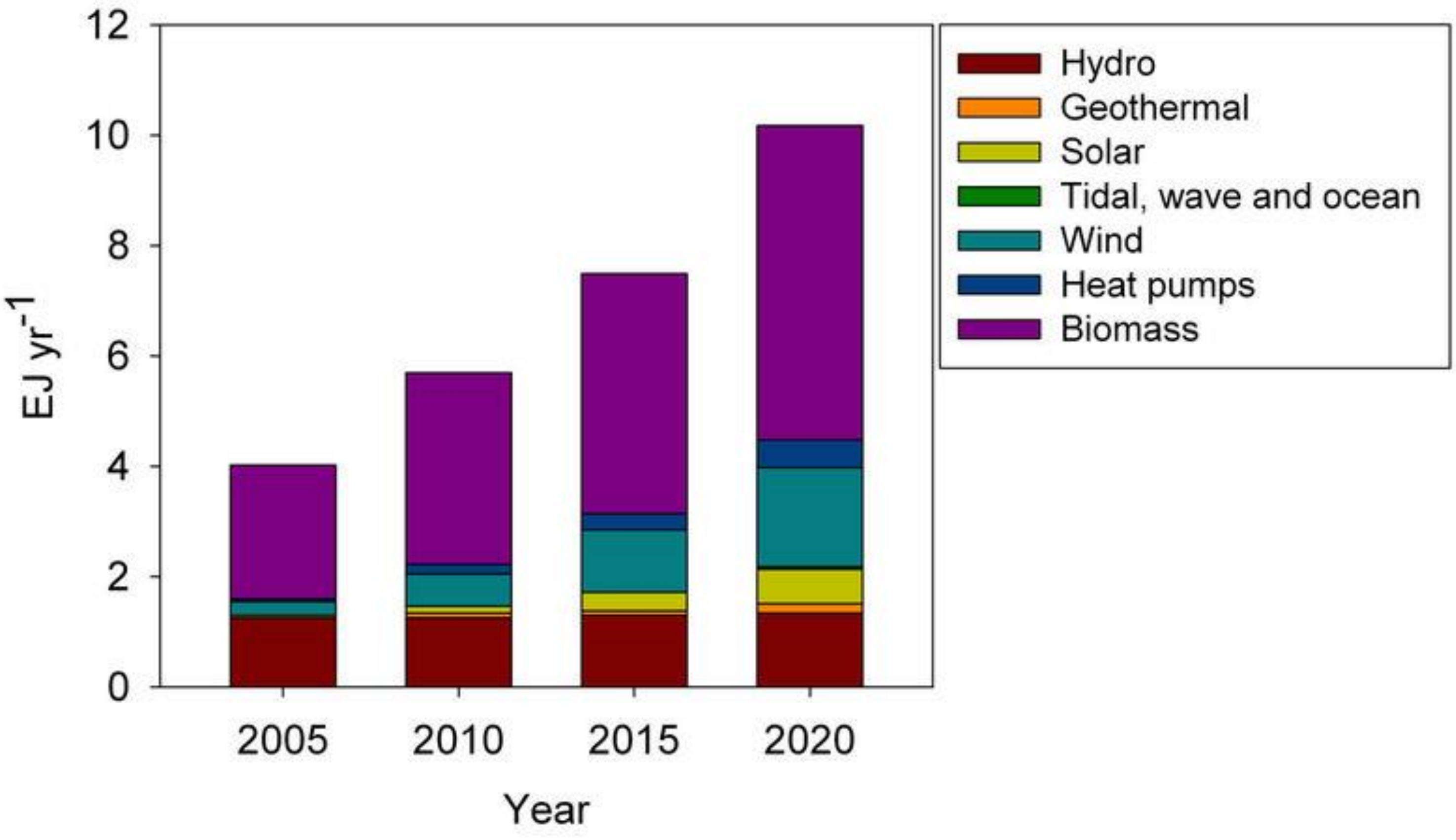
The five countries of BRICS: Brazil, Russia, India, China e South Africa

Source:
REN21 (2016).

EU27 – Projection of Energy produced from Renewable Sources.

Projections on the stipulated production of energy from renewable resources in the EU27 countries based on national renewable energy action plans,

Beurskens LWM, Hekkenberg M: Renewable Energy Projections as Published in the National Renewable Energy Action Plans of the European Member States. Petten, NL. Energy Research Centre of the Netherlands and European Environment Agency; 2011.



Renewable Energy Sources: Data and Targets.

Hydropower

- Resources: the potential scale of hydropower
- Infrastructure: dame, storage plant, turbines

Ocean Energy (Wave & Tidal)

- Resources: the potential scale of wave and tidal power
- Tidal barrages vs. tidal streams: pros, cons, technologies
- The variety of wave machines and their status
- Commercial and forecast technology rollout

Renewable Energy Sources: Data and Targets (2).

Solar Power

- How solar energy varies with location and other key factors
- Key concepts in solar energy capture, including direct vs. diffuse irradiation, collector angles, spacing, tracking, concentration
- Photovoltaic (PV) and concentrated photovoltaic (CPV) technologies, from cells and modules
- Understanding the significant information on module and other supplier brochures
- Inverters, trackers and other key components
- Comparing and contrasting Concentrating Solar Power (CSP) with Photovoltaic (PV): complementary or competing ways to convert solar radiation to electric power?
- CSP types: troughs, towers, dishes, Fresnel, plus CSP storage
- Theoretical, lab and real-world efficiency (PV cells vs. modules vs. arrays; and comparisons with CSP)
- Solar farm layouts and planning

Geothermal Energy

- Different types of geothermal resource: Locations and geologies; Depths, T, flow rates and fluids
- Understanding resource limits on the sustainability of geothermal power generation: Over-exploit.
- Geothermal power and earthquakes
- Geothermal Projects: Explore, confirmation, build, operation; • Drilling: methods, challenges, costs
- EGS – Enhanced/engineered geothermal (“hot dry rock”): Technical and engineering challenges
- Comparing geothermal power plant designs (Flash steam, dry steam, binary and combined cycle)
- Operational issues related to geothermal fluids
- Cascading systems: both power and heat for ultimate energy utilization
- Emerging technologies such as supercritical fluids, co-production with oil & gas

Renewable Energy Sources: Data and Targets (3).

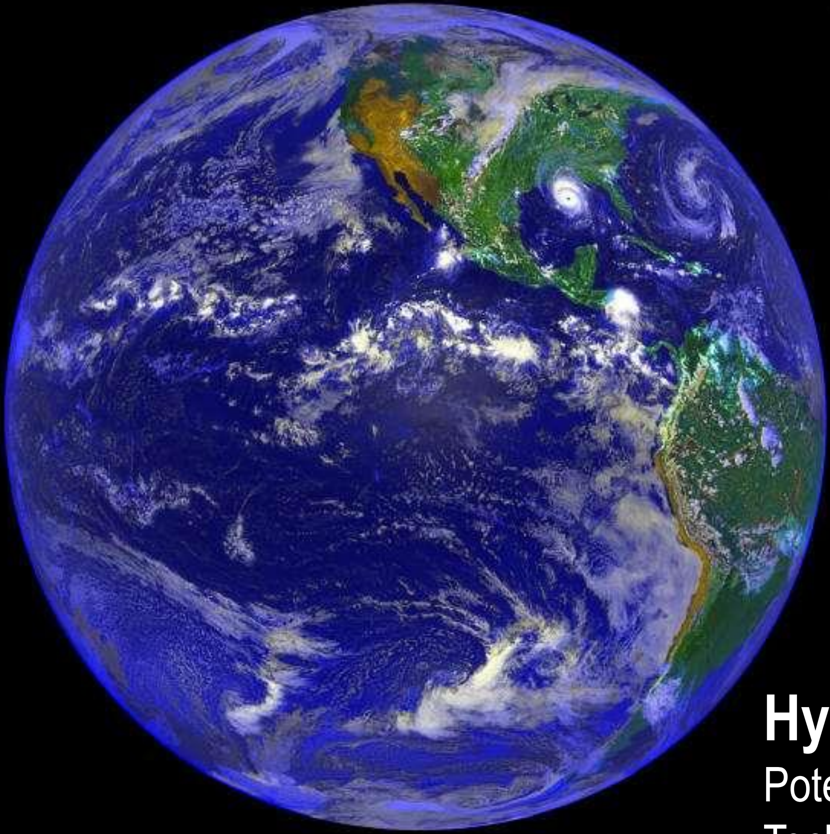
Wind Power

- How wind energy varies with speed, height and other factors
- Techniques and technologies for gathering wind data, including emerging methods
- “Average” wind speed: what this means in practice
- Wind turbine designs: HAWTS, VAWTS - the differences and similarities, pros and cons
- Wind turbine power curves and coefficients
- Basics of operation & control, including power, RPM, torque
- Other system components that make up turbines and farms
- Key components, including gearboxes and generators: evolution, O&M, risks and reliabilities
- Wind Farm layout, land/area usage and planning; (concerns: wake effects and transmission cabling)
- Specific installation, foundation and O&M challenges for offshore wind

Bioenergy

- Key constituents of “biomass”
- Different “generations” and sources of biomass, including crops, wastes (solid, liquid, municipal & agricultural), algae
- Energy potential (and limits) of biomass, including land-use
- The basics of biomass conversion processes: chemical, biological and thermal pathways
- Current bioethanol & biodiesel conversions
- Advanced and emerging biofuel pathways, including jet fuels
- Biomass for power, including direct firing and coal co-firing
- Routes to power via fuel intermediates (e.g. gasification)
- Biomass pre-processing technologies, including pelletisation and torrefaction
- Biorefineries and multi-product concepts
- The status of technologies: commercial or not?

Potentiality of Renewable Energy (2012).



Solar

Potential: 1.2×10^5 TW
Practical: 600 TW
Installed: 0.001 TW

Biomass

50% of all cultivated lands: 7-10 TW
Installed: 0.13 TW

Wind

Used 4%: 2-3 TW
Installed: 0.003 TW

Geothermic

Potential Total: 40 TW
Installed: 0.01 TW

Hydropower

Potential: 4.6 TW
Technical. Usable: 1.6 TW
Economic: 0.9 TW
Installed : 0.6 TW

(NathanS.Lewis, Caltech.)

Renewable Energy : An Alternative to Fossil and Atoms.

Unlike the limited deposits of fossil and nuclear fuels that the earth will never replenish, there are many renewable forms of energy that can be exploited to obtain serviceable power.

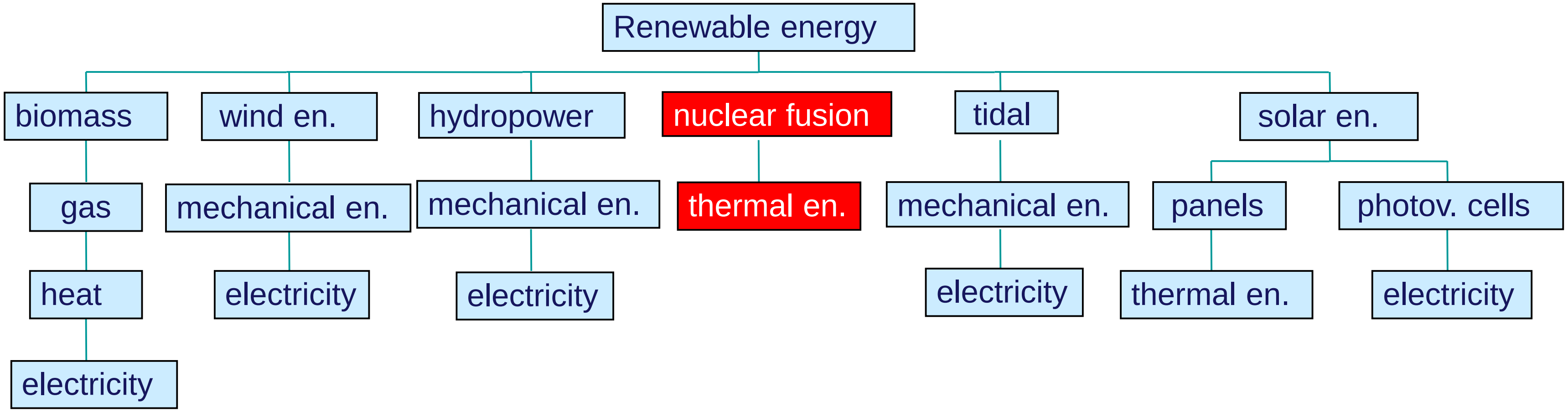
<u>Relevant</u> sources of renewable energy include (by origin):

- Solar Power:
  - Hydropower
  - Wind energy
  - Photovoltaic energy
  - Tidal/ocean thermal energy
- Geothermal energy
- **Biomass energy**
- Fuel-cell energy

Renewable Energy Sources.

- Biomass Energy :
    - From combustion of wood, manure, and biogas.
- Geothermal Energy.
    - Produced by trapping the internal heat flow of Earth (Italy, Iceland, U.S., Philippine).
- Solar energy: Eolic, tidal, wave
    - Winds and waves are both secondary expressions of solar energy.
    - Winds have been used as energy sources from thousand years ago with the aid of sails on boat and mills.
    - Stationary winds represent only about 10 % of the energy used
- Solar energy: Hydropower.
    - Due to potential energy of water between two different height, converted into electric energy.

Renewable Energy and Related Conversions.



- Renewable energy
  - biomass
    - gas
      - heat
        - electricity
  - wind en.
    - mechanical en.
      - electricity
  - hydropower
    - mechanical en.
      - electricity
  - nuclear fusion
    - thermal en.
  - tidal
    - mechanical en.
      - electricity
  - solar en.
    - panels
      - thermal en.
    - photov. cells
      - electricity

Solar Energy

Potential: 1.2·10^5 TW

Practical: 600 TW

Installed: 0.005 TW

Tidal/Thermal Energy.

Advantages:

Endless source

Non polluting

Against:

Difficult to use

Mechanical energy:

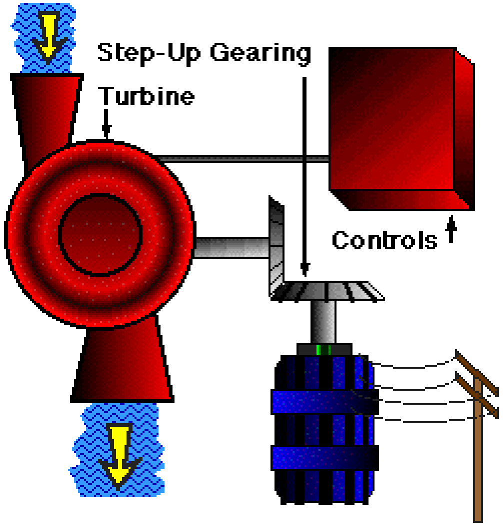
- Due to gravity
  - Hydropower from dams
  - Tides
- Due to Waves
  - Ocean Currents

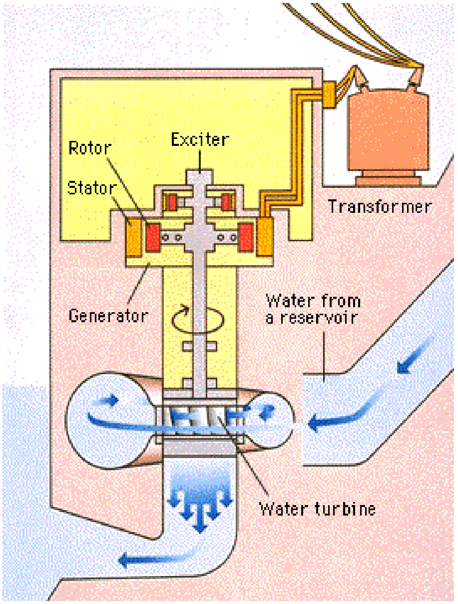
Hydropower.

- $E = m \cdot g \cdot h = \frac{1}{2} mv^2$
- $P = m' \cdot g \cdot h$
  - E = potential energy (*kJ*)
  - P = power (*kW*)
  - m' = mass flow rate ($kg \cdot s^{-1}$)
  - h = height
- $v = (2\, g \cdot h)^{1/2}$
  - v = water velocity at inlet to the turbine ($m \cdot s^{-1}$)

Hydro Plants

- Unlike steam power plants, work instead of heat is directly available.





Hydropower (2).

Advantages	Disadvantages:
Clean Renewable	Environmental impact
No waste	Local ecosystem changes
No thermal pollution	
Diffused	

Clean energy, with no thermal pollution. Nowadays its potential has been nearly fully explored. There are problems with big plants owing to relevant accidents (i.e. Vajont), landscape change (Adda, Oglio river), dry rivers and water pollution, climate change.

Mechanical energy – Electricity Mountain plants with dam and basin with a constant flow rate in turbine, or plant on the plain with damming and parallel course. (Bernoulli law)

The produced energy is a function of jump and flow rate in $m^3 \cdot sec^{-1}$.

Hydropower (3).

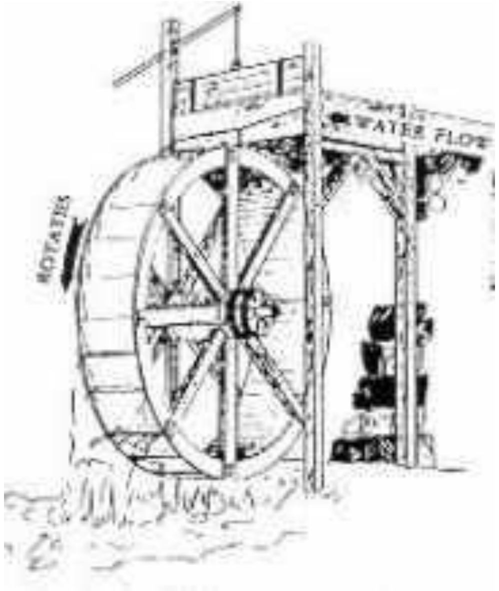
Its use is documented to Greeks. With Romans and in the Middle Ages water mills were used to grind cereals.

Only in nineteenth-century technologies for use water to manufacture products and tools were developed.

The first Hydroelectric plant in Italy was build at Isoverde (Genova) in 1890, ten years after the Niagara Falls (1879) and English falls at Northumberland, near Scottish border (1880).

Hydropower represents 18% of the total electric energy used in Italy (Norway produce 99%; New Zeeland 75%).

The Hydropower need dams and nearly all big sources have been exploited world-wide.



Pumped Hydroelectric Energy Storage.

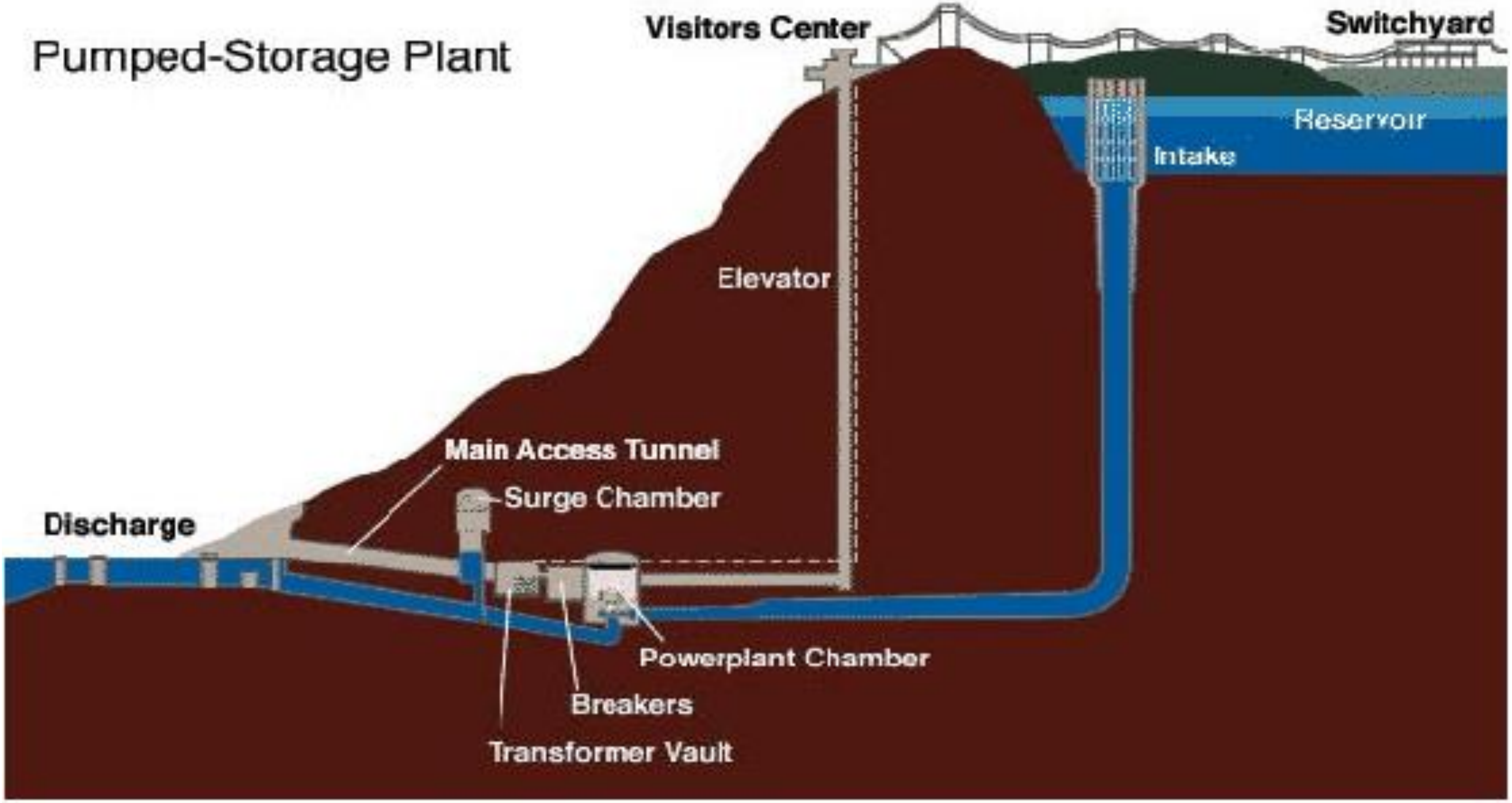
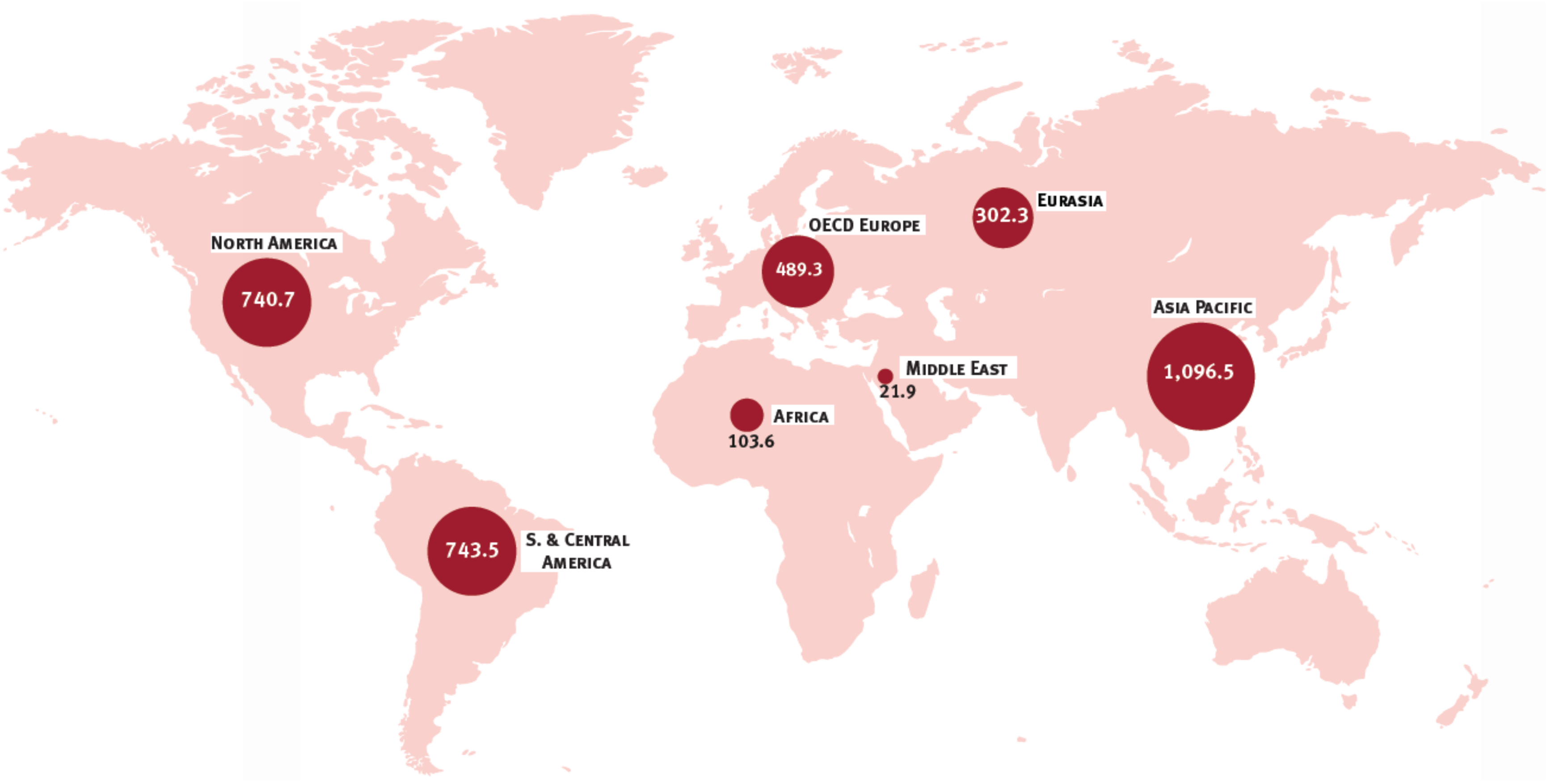


Figure 5.1: Operation of a pumped hydroelectric storage plant.

Word Hydroelectric Energy Consumption (2011).

Terawatt hours



Fonte: BP Statistical Review of World Energy 2012

Tides.

Advantages

- Clean Renewable
- No waste, No thermal pollution
- Protecting coastlines against storm surge

Disadvantages

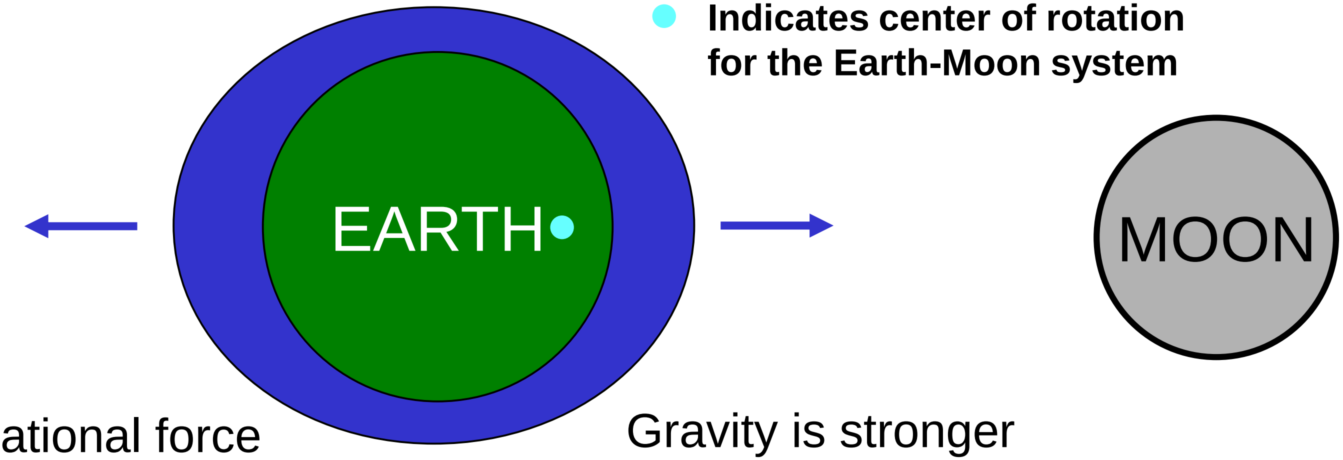
- Intermittent
- Disruption in local ecosystem (seabirds and fish habitats)

Tides Power plant is in the Bay of Rance Estuary

- Built in 1967
- Power Production = 160 MW
  - R=11.4 m; A=22 km^2

Tides (2).

- Gravity and centrifugal forces are in opposite directions

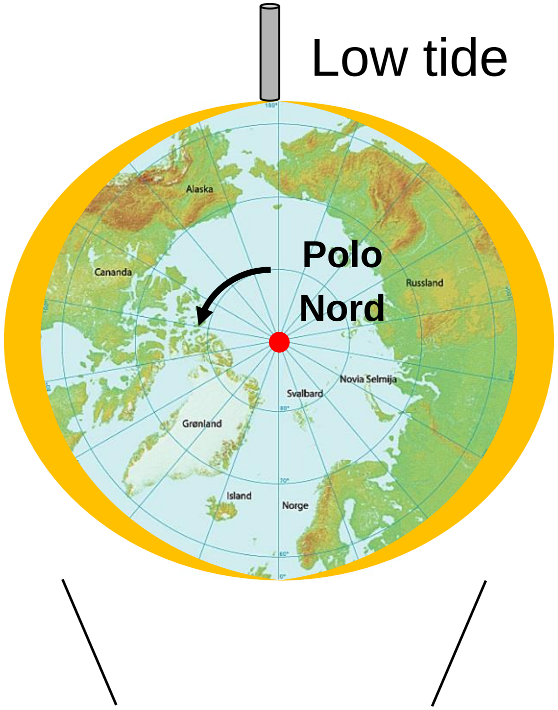


● **Indicates center of rotation for the Earth-Moon system**

The rotational force is stronger than gravity

Gravity is stronger than the rotational force

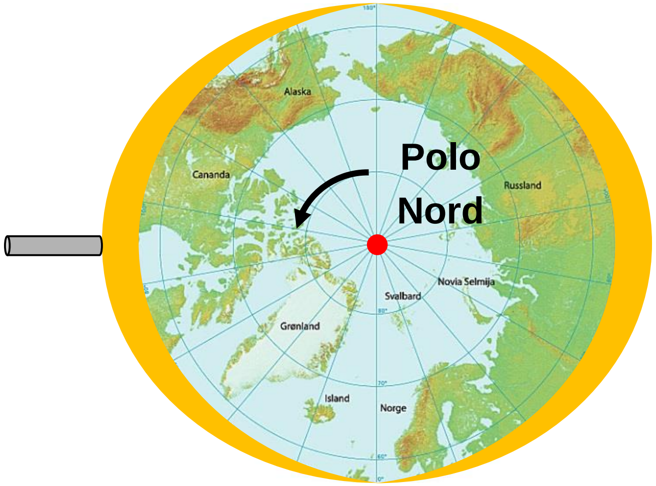
Low and High Tides.



Low tide

Tidal bulges

(a)

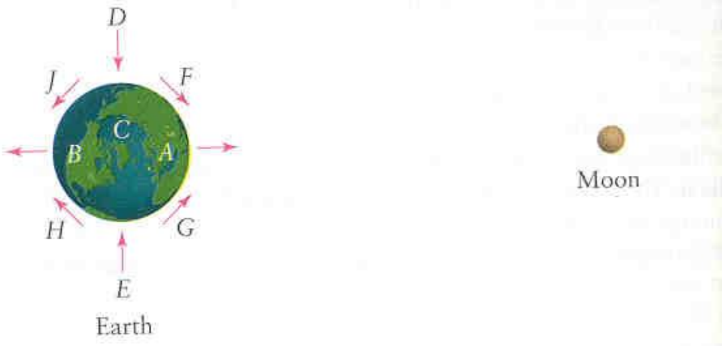


High tide

6 hours later

(b)

Earth-Moon System.

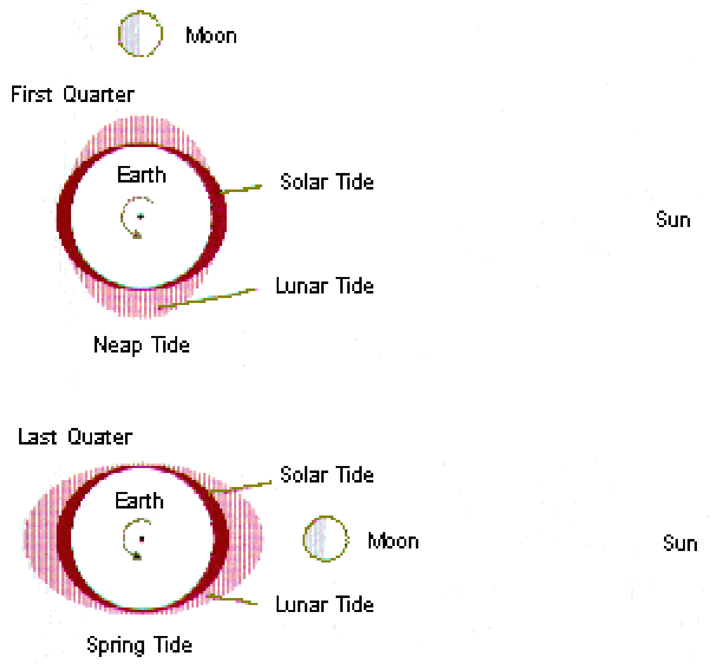


- Pull is stronger on A than B, than C
- Observer outside Earth/Moon system sees Earth is stretched out
- Observer at C still see the same stretching, but feels forces from A and B pulling from both sides

- D and E feel less force than C, so forces are toward C.
- Relative to C, forces at F, G etc. are tangent to earth.
- These forces pull water to accumulate at both ends and B along the Moon/Earth line (high tides)
- Six hours later, Earth has rotated by 90 degrees relative to the moon (low tides)

Earth-Moon-Sun System.

- Spring Tides
  - The Moon is at right angle to the Sun
  - Lower than average tides
  - Minimum amplitudes
- Neap Tides
  - The Moon is aligned to the Sun
  - Higher than average tides
  - Maximum amplitudes



Tides.

- Range (Peak-to-peak amplitude)
  - Open oceans ~ 0.7 m
  - Estuaries ~ 10 m
- Power generated increases as square of the range

$$P = A \cdot R^2$$

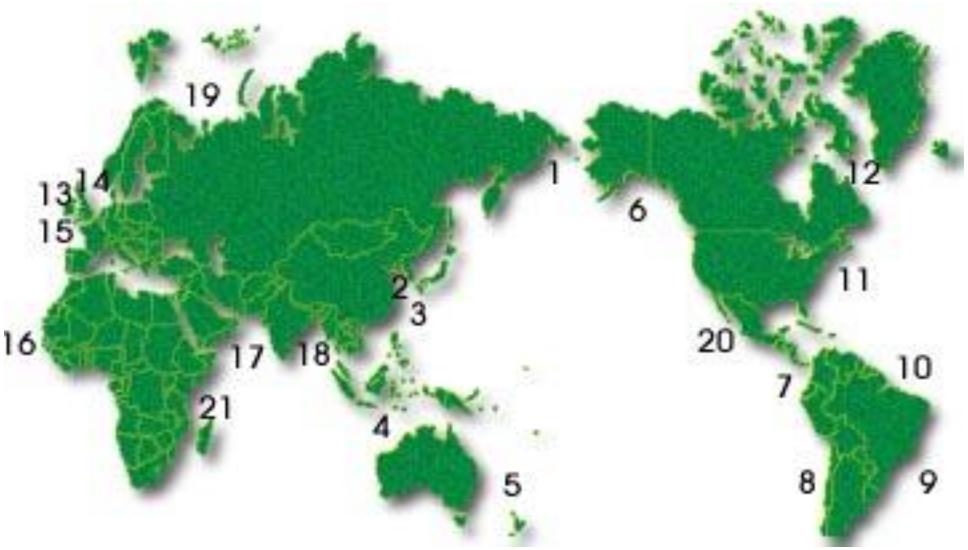
where:

A = Area of the basin (km^2)

R = Range (m)

P = Electric Power produced (MW)

1-20: Tidal power plants potential sites



Solar Energy.

Advantages:

- Inexhaustible
- Diffused
- no pollution

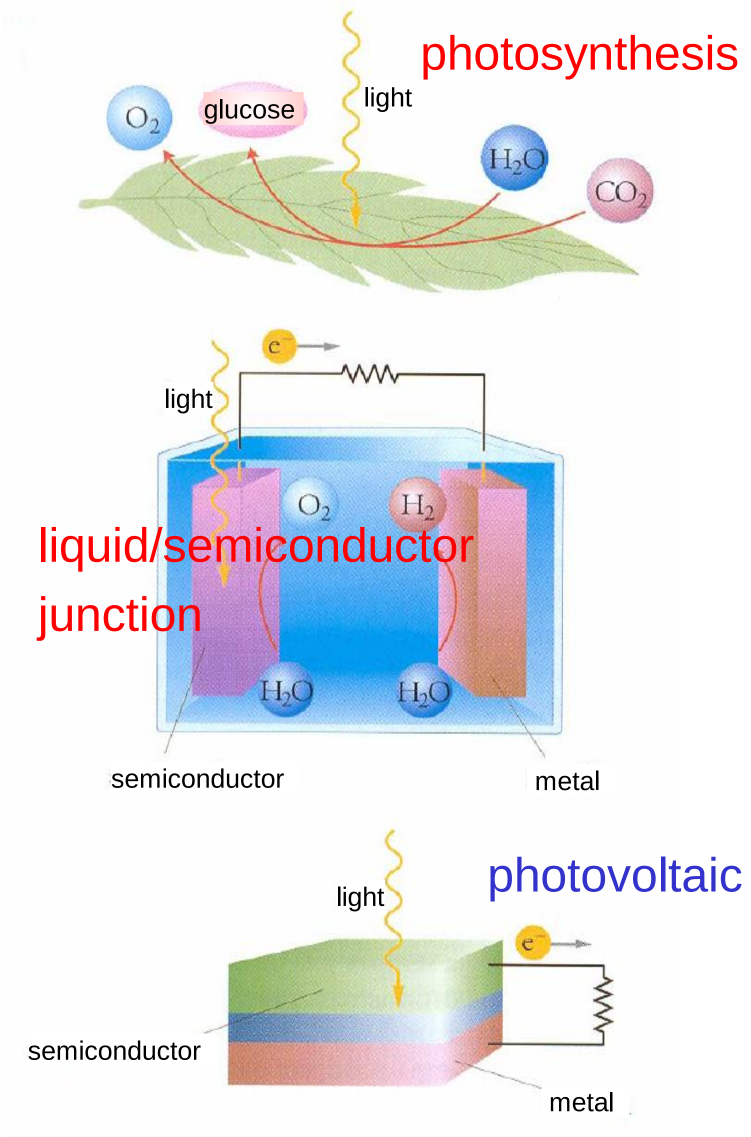
disadvantages:

- Discontinue
- High cost (photovoltaic)
- Environmental Impact
- Small dimension plant

With clear sky and sun at zenith the power available is:

- 1000 *W* per m^2: problem of concentration and collection of energy in economic and efficient way. Maximum: 4 *KWh* in a day per 1m^2
- For solar panels 0.13 *KWh* per m^2 , but the manufacture of silicon is costly, and the installation cost is high.

Recovery of Solar Energy.



Types of solar energy:

Solar Photovoltaics (PV) – photons strike semiconductor and generate electrons to produce a current

Solar Thermal – photons strike another fluid or material to make heat that is circulated through the facility (e.g., solar water heat)

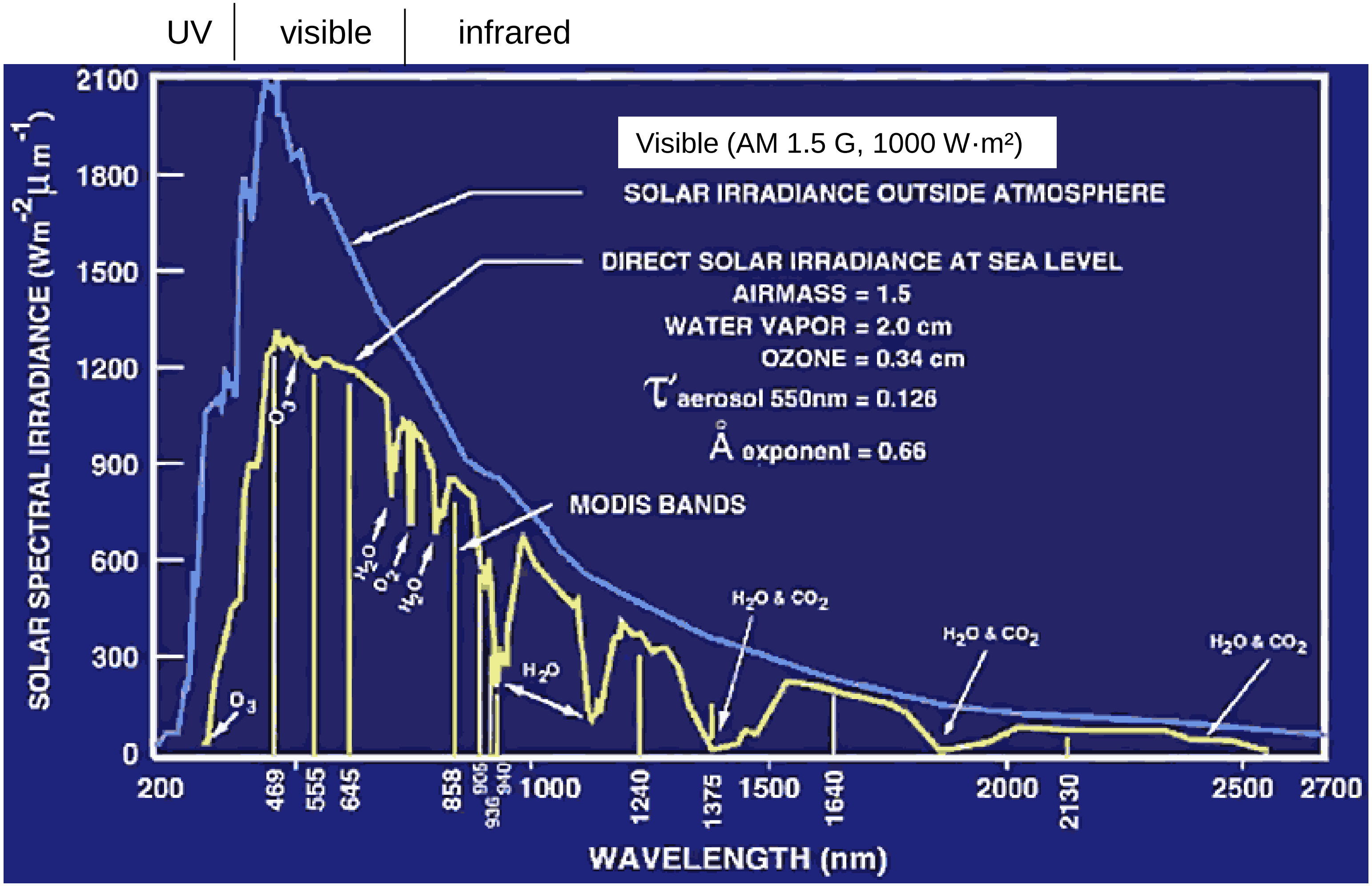
Passive Solar – utilizing building angles w.r.t. to the sun; controllers on blinds, awnings, roofing materials etc.

But also …..

With clear sky and sun at zenith we have:

- 1000 *W* per m^2: problem of concentration and collection of energy in economic and efficient way. Maximum: 4 *KWh* in a day per 1 m^2

Solar Spectrum.



AM 1.5 is the intensity of sun light after travelling 1.5 thickness of the atmosphere

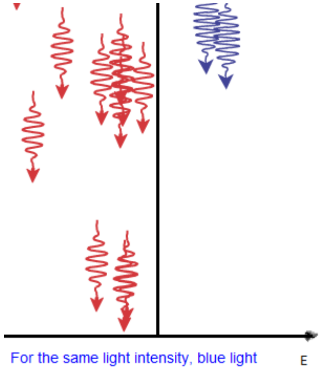
1100 nm ~ 1.1 eV = band gap of silicon

Photovoltaics: Fundamentals.

Energy of a photon (E):

- $h = 6.626 \times 10^{-34}$ joule·s
- $c = 2.998 \times 10^{8}$ m·s^{-1}
- λ = wavelength

$$E = \frac{h \cdot c}{\lambda} \qquad E = 1.24 eV \cdot \mu m \frac{1}{\lambda}$$



For the same light intensity, blue light requires fewer photons since the energy content of each photon is greater.

Photonic Flow (Φ) in # photons·m^{-2}·s^{-1}

is the number of photons per second per unit area (to calculate power density, or total power incident)

Power Density (H)

is calculated by multiplying the photon flux by the energy of a single photon.

$$H\left(\frac{W}{m^2}\right) = \Phi \times \frac{h \cdot c}{\lambda} \text{ using SI units}$$

$$H\left(\frac{W}{m^2}\right) = \Phi \times qE\left(eV\right) \text{ for energy in eV}$$

$$H\left(\frac{W}{m^2}\right) = \Phi \times q\frac{1.24}{\lambda\left(\mu m\right)} \text{ for wavelength in } \mu\text{m}$$

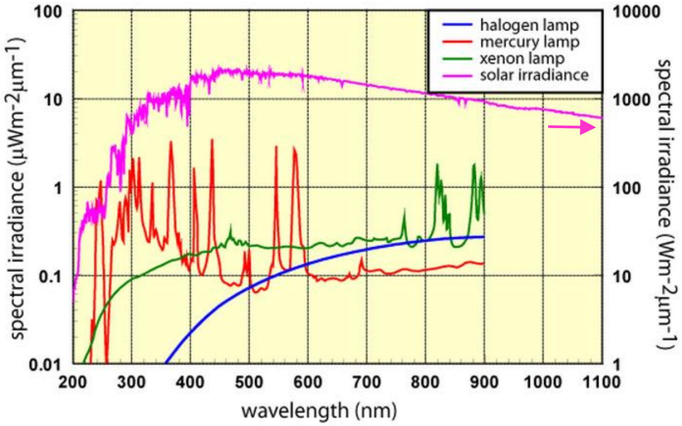
Photovoltaics: Fundamentals (2).

Spectral Irradiance $F(\lambda)$ in $W \cdot m^{-2} \cdot \mu m^{-1}$

is the power density at a particular wavelength $$F(\lambda) = \Phi \times E \times \frac{1}{\Delta\lambda} \text{ in SI units}$$

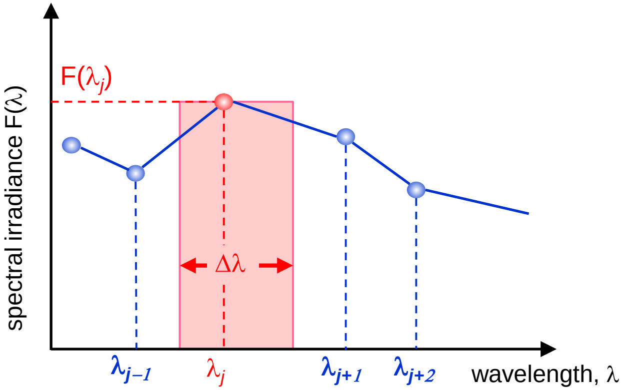
If measured in $W \cdot m^{-2} \cdot \mu m^{-1}$ the spectral irradiance expressed in term of wavelength is:

$$F(\lambda) = \Phi \times q \times \frac{1.24}{\lambda(\mu m)} \times \frac{1}{\Delta\lambda(\mu m)}$$



So (Radiant) Power Density is:

$$H = \int_0^\infty F(\lambda)\, d\lambda$$



where H is the total power density from the light source in $W \cdot m^{-2}$

e $F(\lambda)$ is the spectral irradiance in $W \cdot m^{-2} \cdot mm^{-1}$

Solar Photovoltaics.

Advantages

- Clean renewable energy
- Perfect for off-grid and specialty applications
- Power production pattern fits very well with wind often times
- Source of hydrogen via electrolysis in distributed power applications
- Costs are decreasing rapidly.

Disadvantage

- High cost
- Uses materials that have relatively high, non-renewable environmental burdens (LCA), e.g., semiconductor metals and batteries.

Solar PV is not storable except by using batteries or producing hydrogen.

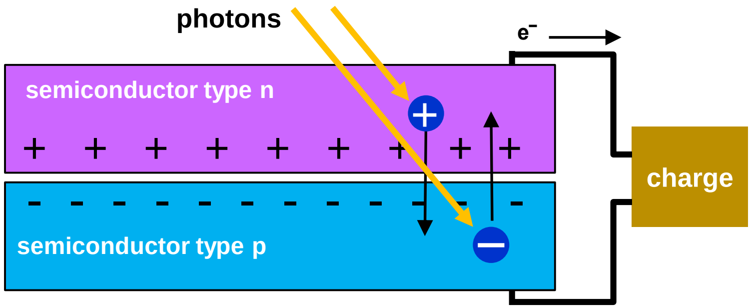
Solar Cell Construction – Materials Science.

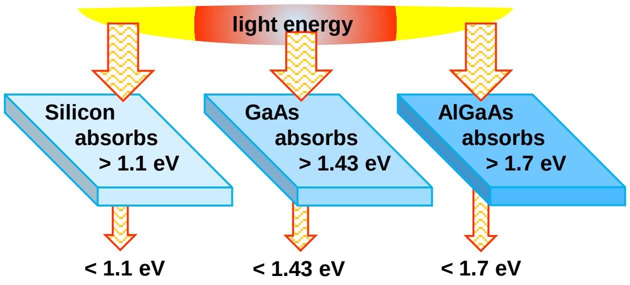
- Each solar cell consists of a semi-conducting surface (like silicon dioxide in thin films) to receive the sun's photons and convert them into electrons of current (the photoelectron effect)
- Electronic circuits are fitted on the back of the cell to carry the electricity away
- The circuits can be of various designs including flexible plastic substrates (organic electronic devices).

From Raw Material-to-Installation

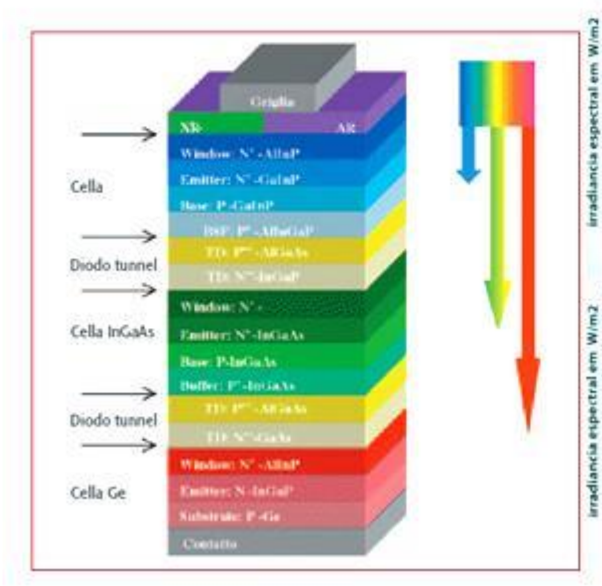
Raw Material & Machinery Suppliers	Design & Development Services	Component Suppliers	Product Manufacturers or Integrators	Construction & Installation Services	Solar Power Developers
•Silicon •Organic Polymers •Nano Tubes •Other materials	•Design •Engineering •University Research •Machining •Automation •Assembly	•Thermal Collectors •Thermal Balance of system •PV Cells •PV Balance of system •Mounting structures	•OEMs •PV electric generation •Passive heating •Solar Packagers	•Engineering & Procurement (EPC) • Installation Enterprises •Transportation Services •Operation & Maintenance	•Feasibility Analysis Firms •Project Developers •Utilities

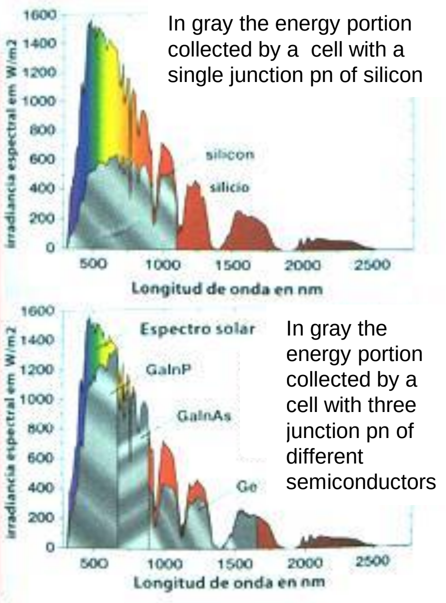
Solar Photovoltaic (2).





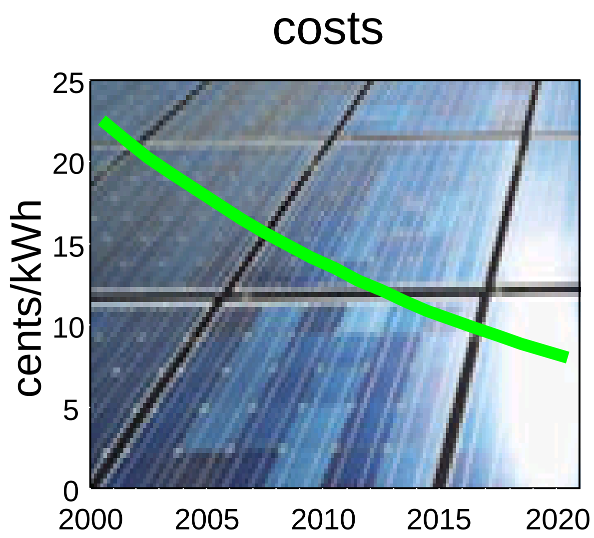
Improvements are strictly associated to new materials.



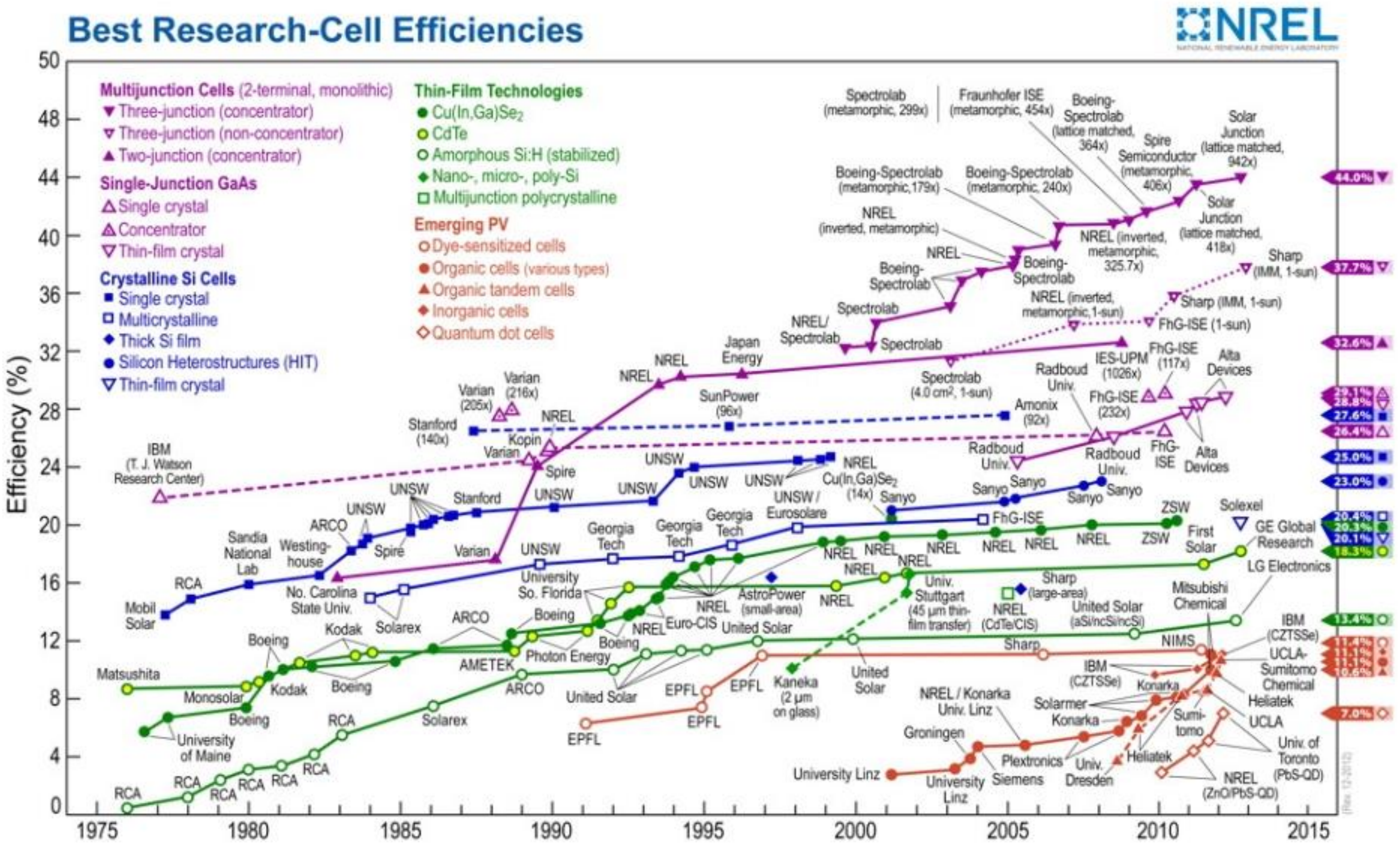


In gray the energy portion collected by a cell with a single junction pn of silicon

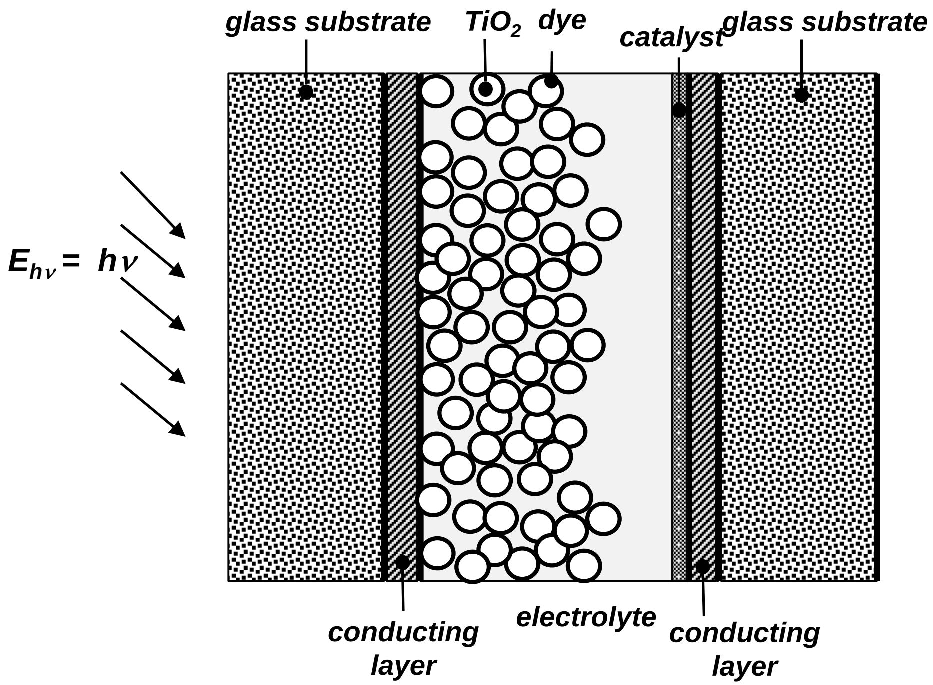
In gray the energy portion collected by a cell with three junction pn of different semiconductors



Overview of Solar Cell Efficiencies.



Dye Sensitised Solar Cells (DSSC): Structure.



① Electrons of dye are excited by solar energy absorption

② Electrons transfer from dye to FTO via TiO_2

③ Electrons get to counter electrode after working at external load

④ $\frac{1}{2} I_3^- + e^- \rightleftarrows 3/2\ I^-$ at counter electrode

⑤ $3/2\ I^- \rightleftarrows \frac{1}{2} I_3^- + e^-$ at dye

Working electrode

- Conductive glass
- Blocking layer
- Titania nanostructured mesoporous thin film

Photoactive dye

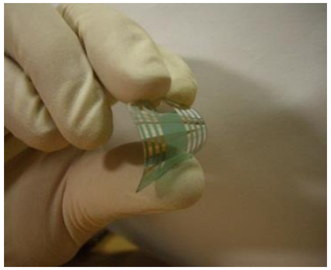
- Strong chemical bonding with titania surface promotes efficient electron transfer

Counter electrode

- Conductive glass
- Catalytic Pt layer

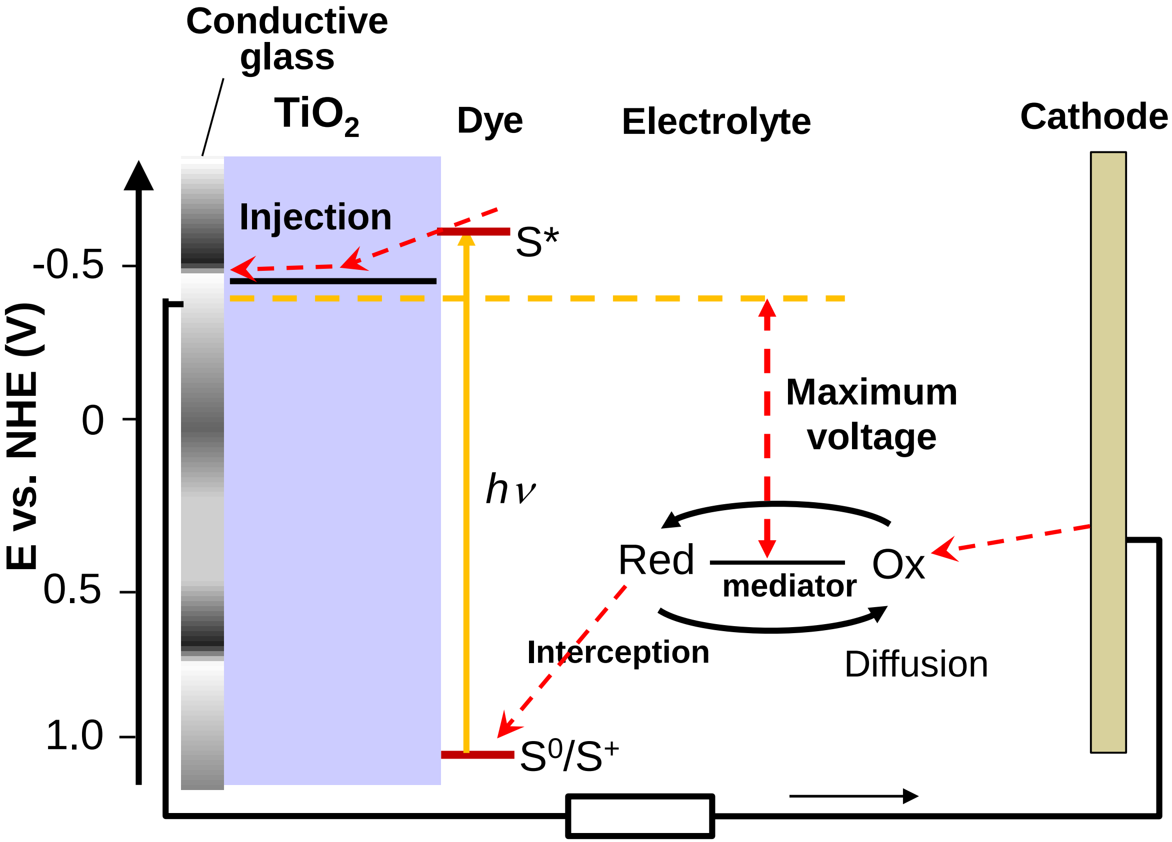
Redox mediator

- I^-/I_3^-



J. Hart et al., J. Nanosci. Nanotechnol. 8, 1 (2008).

DSSC: Operational Principle.



Ideal dyes properties:

- The dye should be attached strongly to the semiconductor surface
- Intensive absorption in the whole solar spectrum
- LUMO with higher energy than the conduction band edge of the semiconductor and good orbital overlap to facilitate electron injection.
- Charge recombination between the injected electron and the oxidized dye should be slow enough for the electron transport to the external circuit.

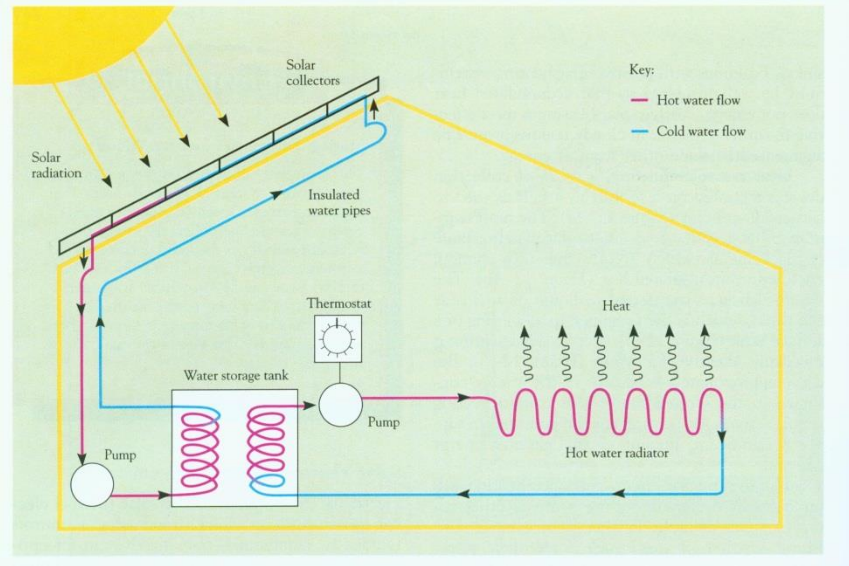
Charge separation by kinetic competition like in photosynthesis

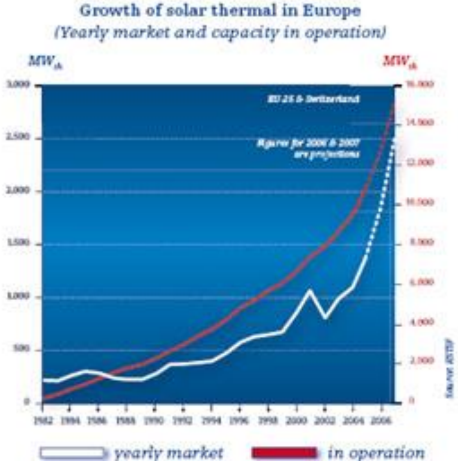
B. O'Regan, M. Grätzel, Nature 353, 737 (1991)
T.Torres et co. JACS 129, 2007, 9251.

Solar Thermal: Active Solar Heating.

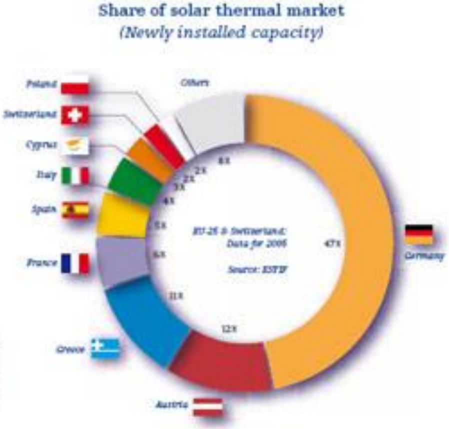
- Enough solar energy hits the earth in 60 seconds to power all of its energy needs for a full year.
- 72 hours of solar energy is equal to all of the stored up energy in all fossil fuel reserves of oil, coal, and NG.

- 1767. Horace DeSaussure built the first solar water heater
- 1891. First patent for solar water heater.
- 1899. Solar heaters installed in 2/3 of homes in Pasadena.
- Solar energy represents a huge resource for the generation of electricity (market on the right).




Growth of solar thermal in Europe
(Yearly market and capacity in operation)

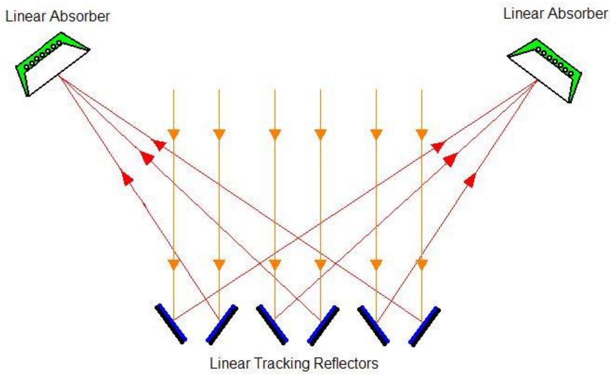
Source: ESTIF

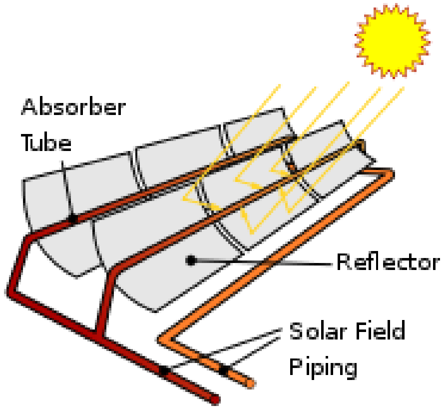

Share of solar thermal market
(Newly installed capacity)

Source: ESTIF

Solar Thermal: Alternatives.

1. **Low-temperature solar heating and cooling systems**
    - 1.1 Low-temperature collectors
    - 1.2 Heat storage in low-temperature solar thermal systems
    - 1.3 Solar-driven cooling
    - 1.4 Solar heat-driven ventilation
    - 1.5 Process heat
2. **Medium-temperature collectors**
    - 2.1 Solar drying
    - 2.2 Cooking
    - 2.3 Distillation
3. **High-temperature collectors**
    - 3.1 System designs
        - 3.1.1 Parabolic trough designs
        - 3.1.2 Power tower designs
        - 3.1.3 Dish designs
        - 3.1.4 Fresnel technologies
        - 3.1.5 MicroCSP
        - 3.1.6 Enclosed parabolic trough





Geothermal Energy.

It is a non-renewable source of energy

- Energy withdrawn is much faster than it is being replenished.
- If considering energies from hot dry rocks, geothermal energy can be considered as renewable.

Average outflow of 0.06 *W/m²* (500 times less than incoming solar flux)
Each dept. Km temperature grown 30°. Local concentrations could be order of magnitudes higher.

Geothermic Zones : Iceland and New Zeeland (geyser) …….

In Italy at *Larderello* (power plant 3000 t steam/h – pressure: 4-8 *atm* and temperature: 180-250°C - installed power 380 MW).

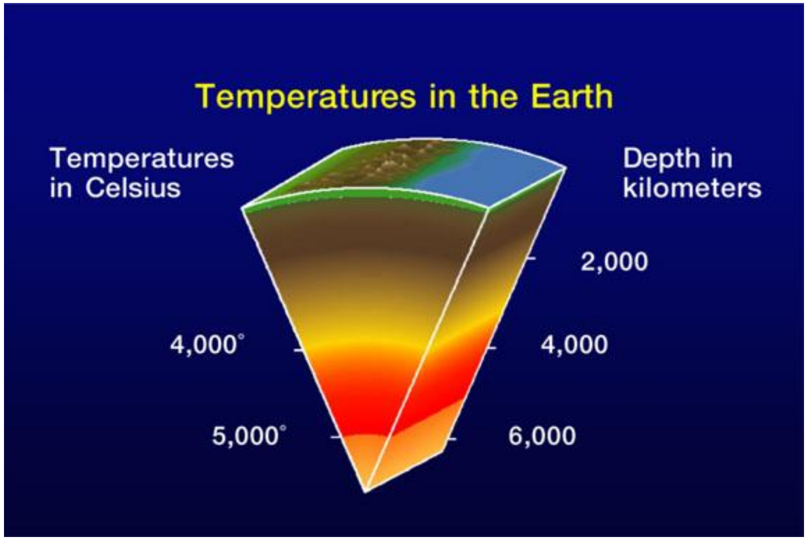
Used with fluids at T<150°C as *thermal energy* for heating (France, Russia, Hungary, Amiata M.).

Electric Energy : Fluids at T>200°C go to a turbine, expansion of steam in turbine (mechanical energy – electricity), problems of presence of liquid – vapor in turbine.

Geothermal Energy.

- Heat generated by natural processes occurring within the earth
- Fumaroles, hot springs and mud pots are natural phenomena that result from geothermal activity

- Different areas have different thermal gradients and thus different utilization potentials
- Higher thermal gradients correspond to areas containing more geothermal energy



Distribution of Major Geothermal Energy Reserves.

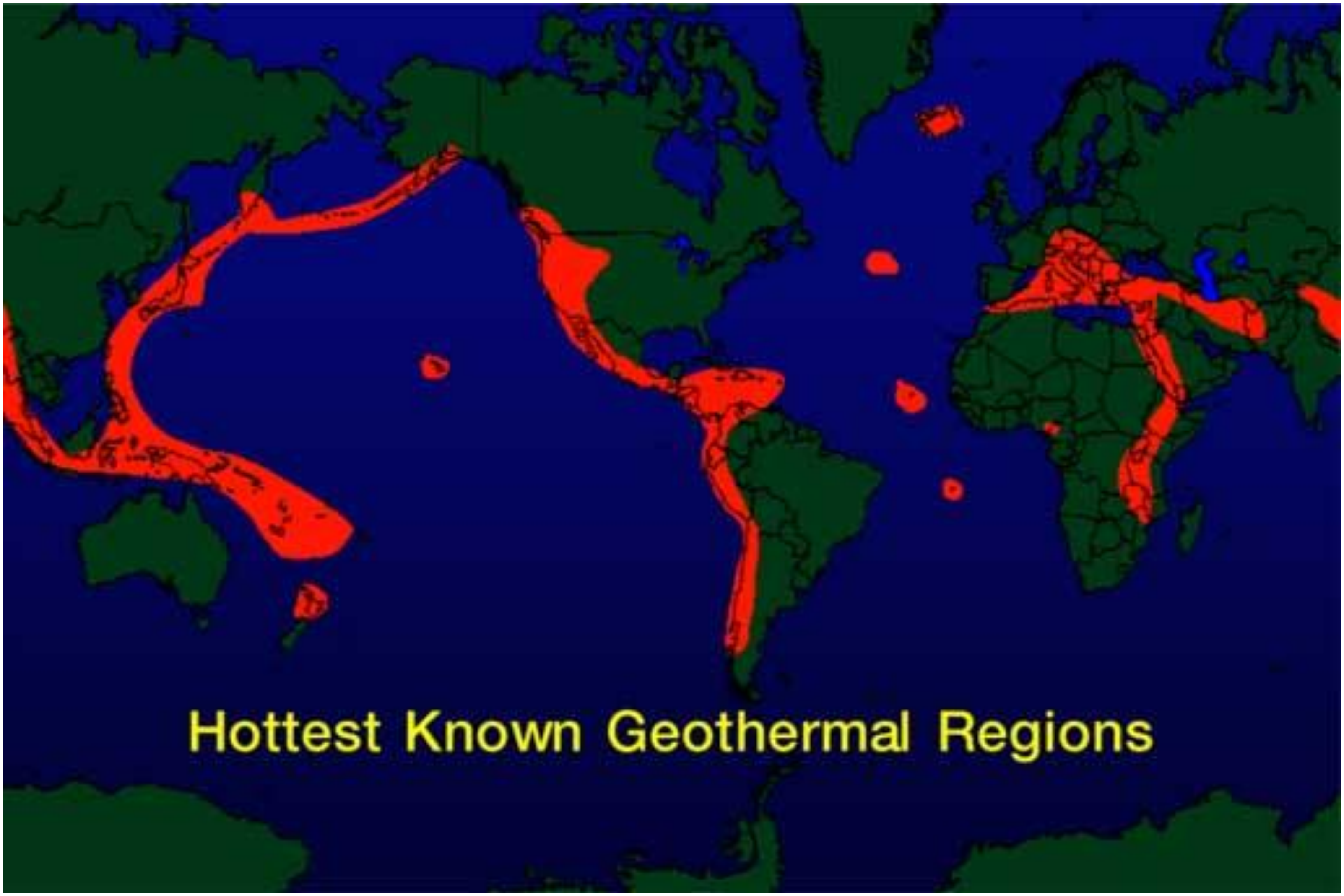


Photo: www.geothermal.marin.org/

Distribution of Geothermal Reservoirs.

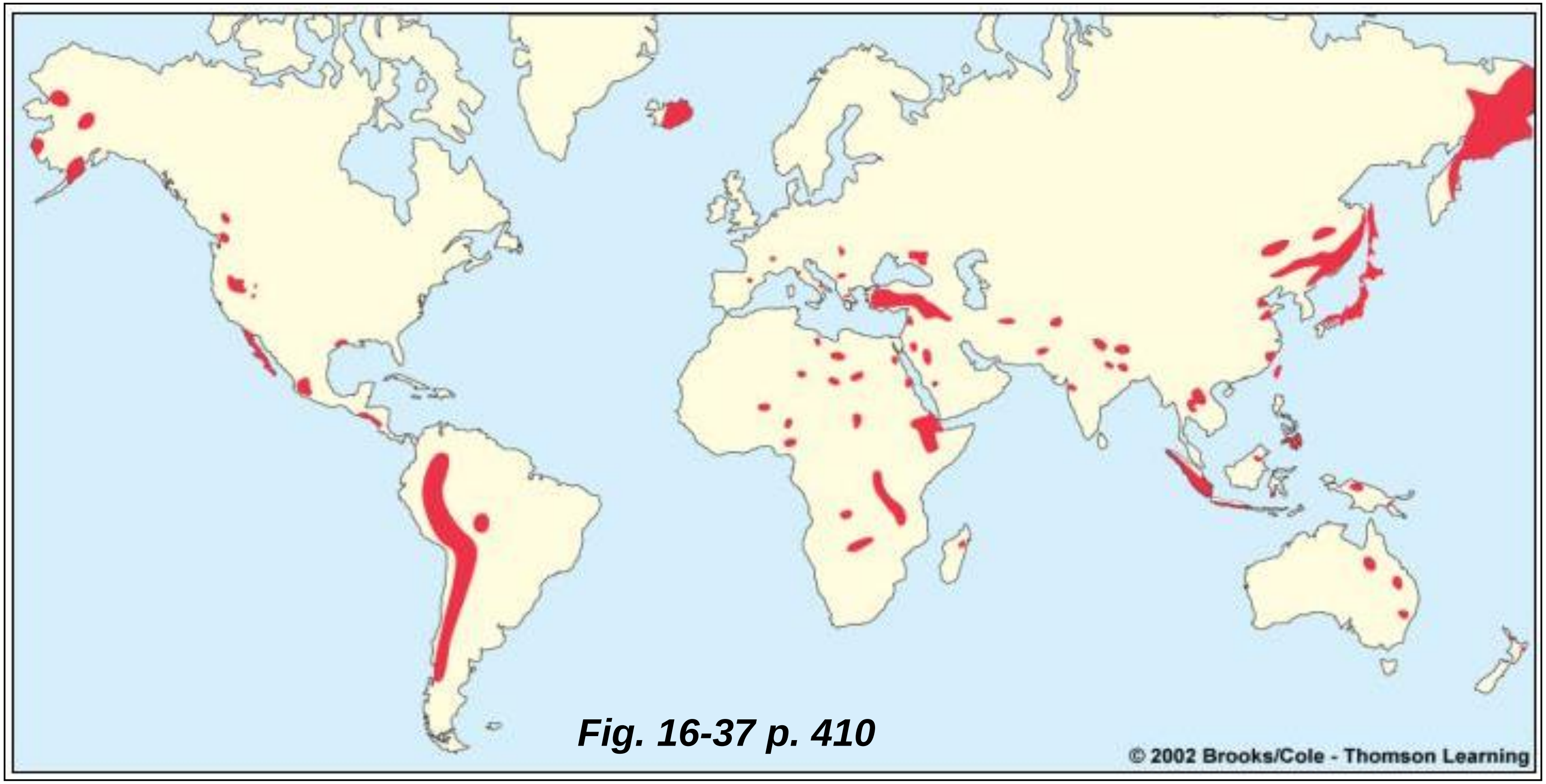


Fig. 16-37 p. 410

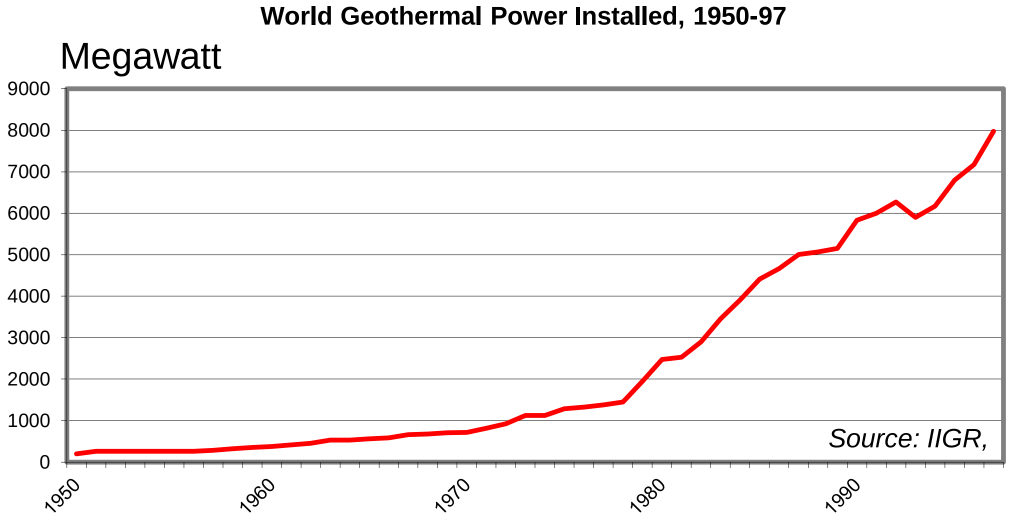
© 2002 Brooks/Cole - Thomson Learning

Appropriate detailed information can be obtained at:

http://geothermal.marin.org/geomap_1.html

World Sources of Geothermal Energy.

- World (7000 MW_e)
- US (3000 MW_e)
- Philippine (1100 MW_e)
- Mexico (800 MW_e)
- Italy (600 MW_e)
- Indonesia (300 MW_e)


World Geothermal Power Installed, 1950-97

Source: IIGR,

Flow

- Volcanoes (molten magma – 2000 °C)
- Hot springs (water reservoirs of about 200 °C)
- Geysers (natural steam reservoirs)

Non-Flow

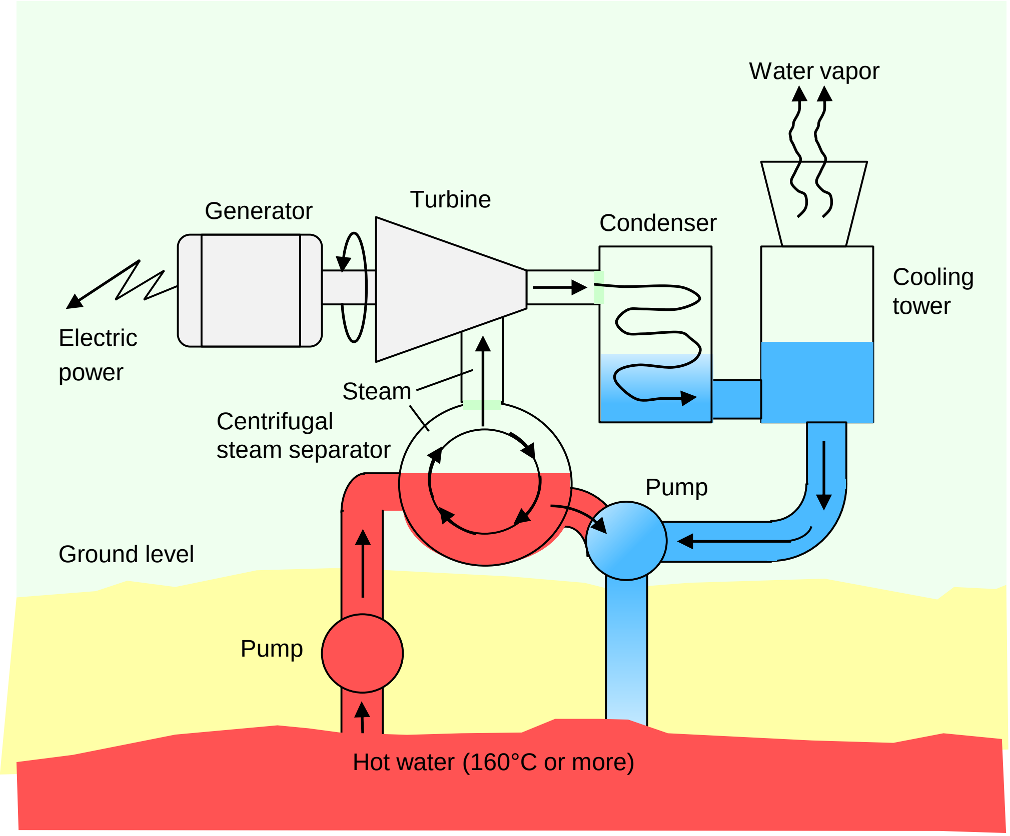
- Hot dry rock (40-70 °C/km depth)
  - About 5% of Italy land area

Geothermal Energy – Problems.

- Many sites are difficult to access.
- Technology exists only for hot water & steam reservoirs
- Subsidence risk
- Pollution (H_2S, sludge, CO_2)
- Induced seismicity by water injection (to prevent soil salination) or nuclear explosions (normally used to fracture impermeable rocks)
- Corrosion and plant problems.

Conventional Uses of Geothermal Energy.

- Health spas
- Direct use for space heating
- Steam for electricity production



Direct Flash Design

Wind Energy.

Arising from solar energy depends on motion of air mass.

- Windmills exploit the wind action to transform *mechanical energy into electricity*.
- The first known use of wind energy was around 5000 BC as the ancient Egyptians used sails to drive boats on the Nile river.
- 900 AD. Persians used windmills to pump water and mill grain.
- 16th Century. 10,000 windmills in use in the Netherlands to pump water. Dutch developed wide range of use.

- 19th Century. Wood blades replaced by steel and metals.
- First commercial electrical plant. 12KW.
- Today: 70 – 100 KW turbines. (5–10 KW for one home).

Wind Power: Advantages and Disadvantages.

Advantages

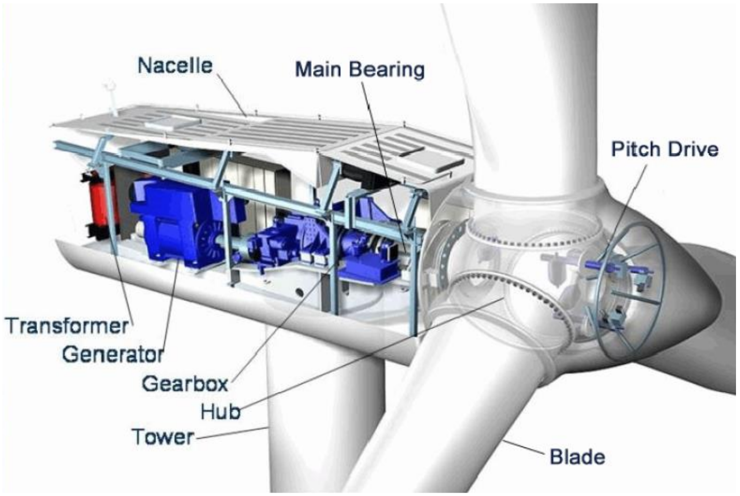
- Clean renewable energy
- Cost effective already
- Wind’s generation profile matches well with solar
- Abundantly available in some states at proper power densities (off shore preferred)
- Low Maintenance costs of “Plant” because requires few personnel.
- Power is decentralized. Made available to remote farms and communities, underdeveloped nations
- Can be used to make clean hydrogen via electrolysis or stored with other systems.

Disadvantages

- Turbines only work in breezy areas and suffers from transmission losses & maintenance costs.
- Peak power problem; power capacity based on peak demand
- Wind is not storable
- Low energy-density. Turbines generate single-digit KW instead of three-digit MW of fossil and nuclear plants.
- Noise and sight pollution
- Bird mortality hitting turbine blades
- Net metering and control the connect costs and grid required
- High initial capital cost. 5 - 10 y of production needed to reclaim.

Wind Energy.

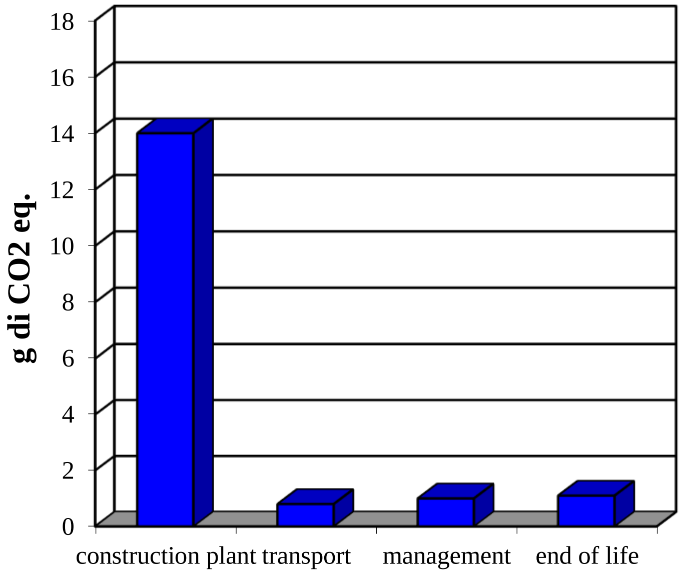
- To obtain evenness acid storage batteries (NaS) or fly-wheel are used. Paddles can be 50 m long with a power of 1.75 MW.
- In Italy, after 2010–2012 development, now eolic energy is 7%. Being intermittent eolic plants are near to thermal plants.

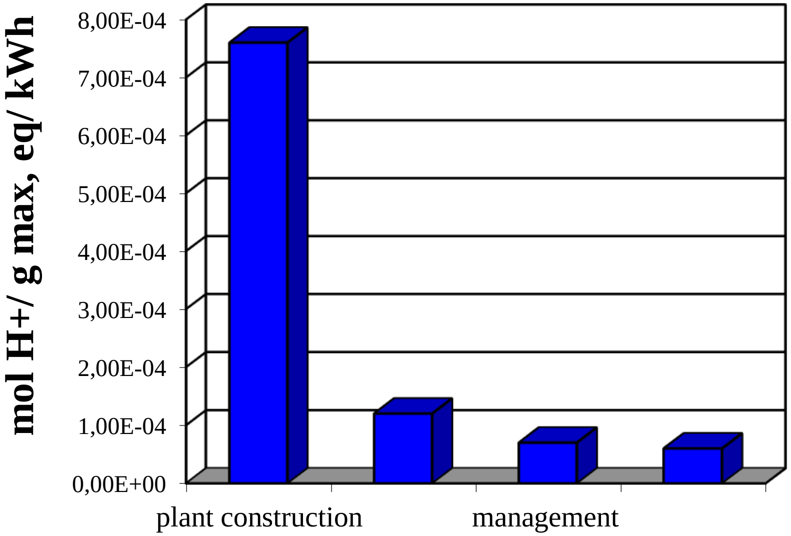


From Raw Material-to-Installation

Raw Material & Machinery Suppliers	Design & Development Services	Component Suppliers	Wind Turbine Companies	Construction & Installation Services	Wind Developers
•Steel •Carbon Fiber •Balsa Wood •Fiberglass •Other materials •Machinery •Tooling	•Design •Engineering •University Research •Machining •Automation •Assembly	•Gear Boxes •Bearing •Tower •Generators •Blades •Electronics	•OEMs •Large Utility Scale •Small Wind •New Wind Energy Designers •Turbine Mfg Licensees	•Engineering & Procurement (EPC) •Construction Companies •Transportation Services •Operation & Maintenance	•Feasibility Analysis Firms •Project Developers •Utilities

GHG Emissions and AP Potential in Different Stages of Life Cycle of Eolic Plants.





Life cycle emissions:

16.9 g of CO_2/kWh

Acidification potential:

1.01 10^{-3} mol H^+/g, max eq./kWh

Biomass Energy.

Advantages:

renewable

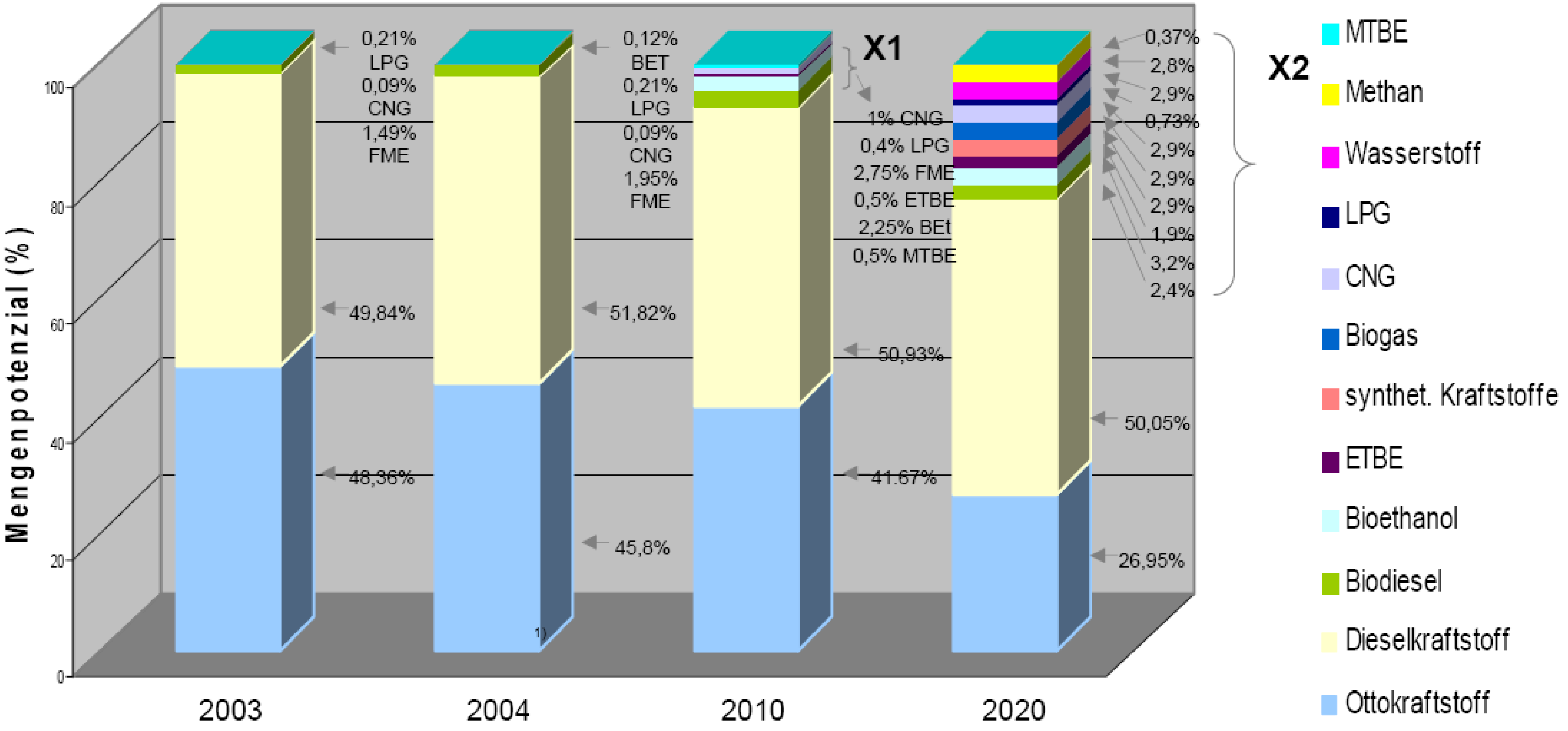
Disadvantages:

Local use

Possible environmental problems

- Lower foreign country dependence
- Lower CO_2 emission being used by plants through photosynthesis.
- Biogas from digestion of organic residues with anaerobic bacteria - appropriate for small plants but also for depuration
- From organic residues by cogeneration (electricity and heat)
- Biodiesel from oil seeds, in extensive cultivations, i.e. palm oil)
- Biodiesel BfL from pyrolysis, hydrogenation, etc.
- Ethanol (from sugar, starch, cellulose), by using several plants at high growth (poplar, willow, miscantus, etc.), but also agricultural and forestry residues.

Relative Potential of Fuel Market
(German Expert Group).



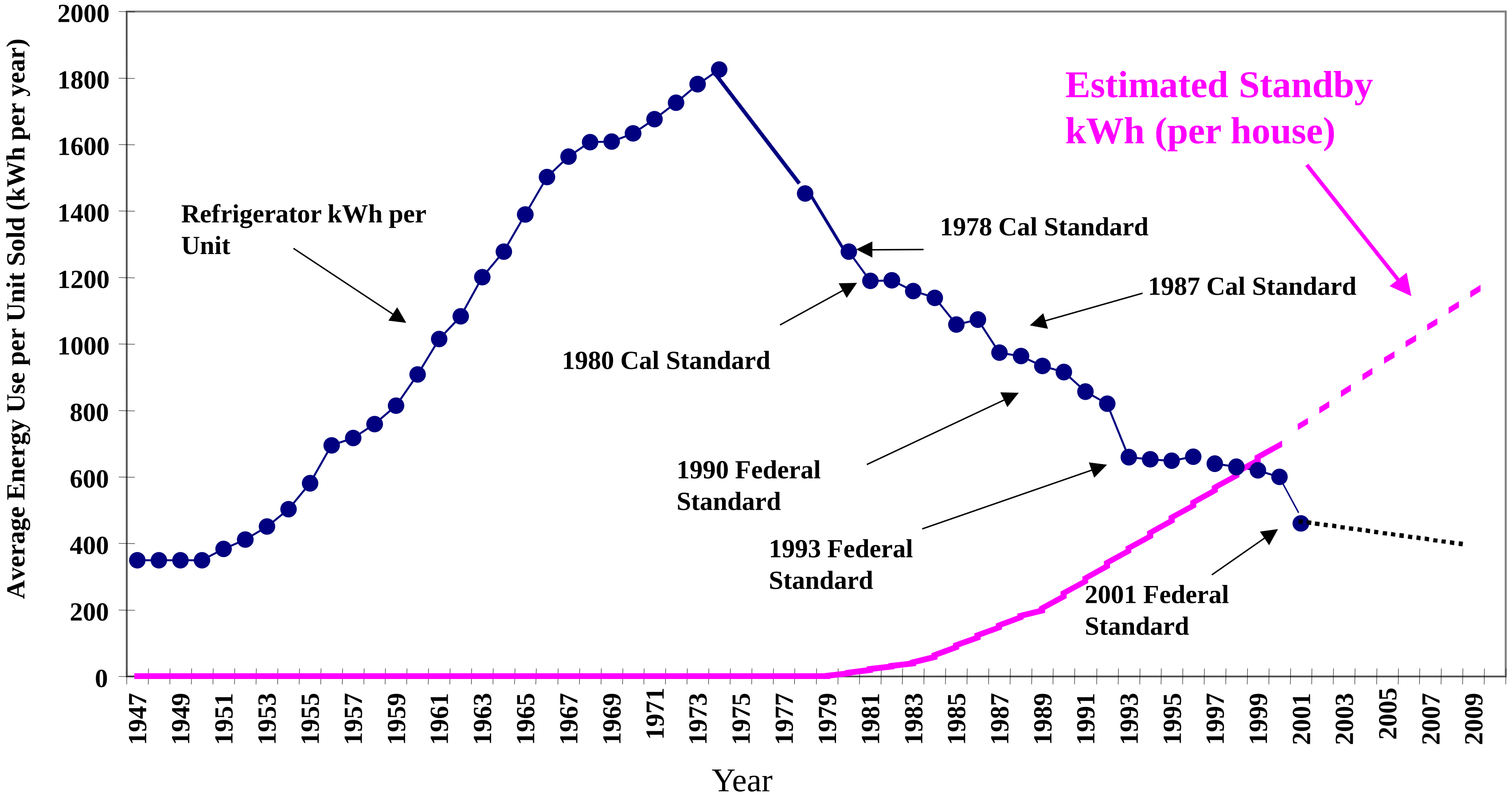
X_1 : According to report there is a theoretical potential for biofuels of up to 9%.

X_2 : According to report there is a theoretical potential for biofuels of up to 1/3 of the present fuels market.

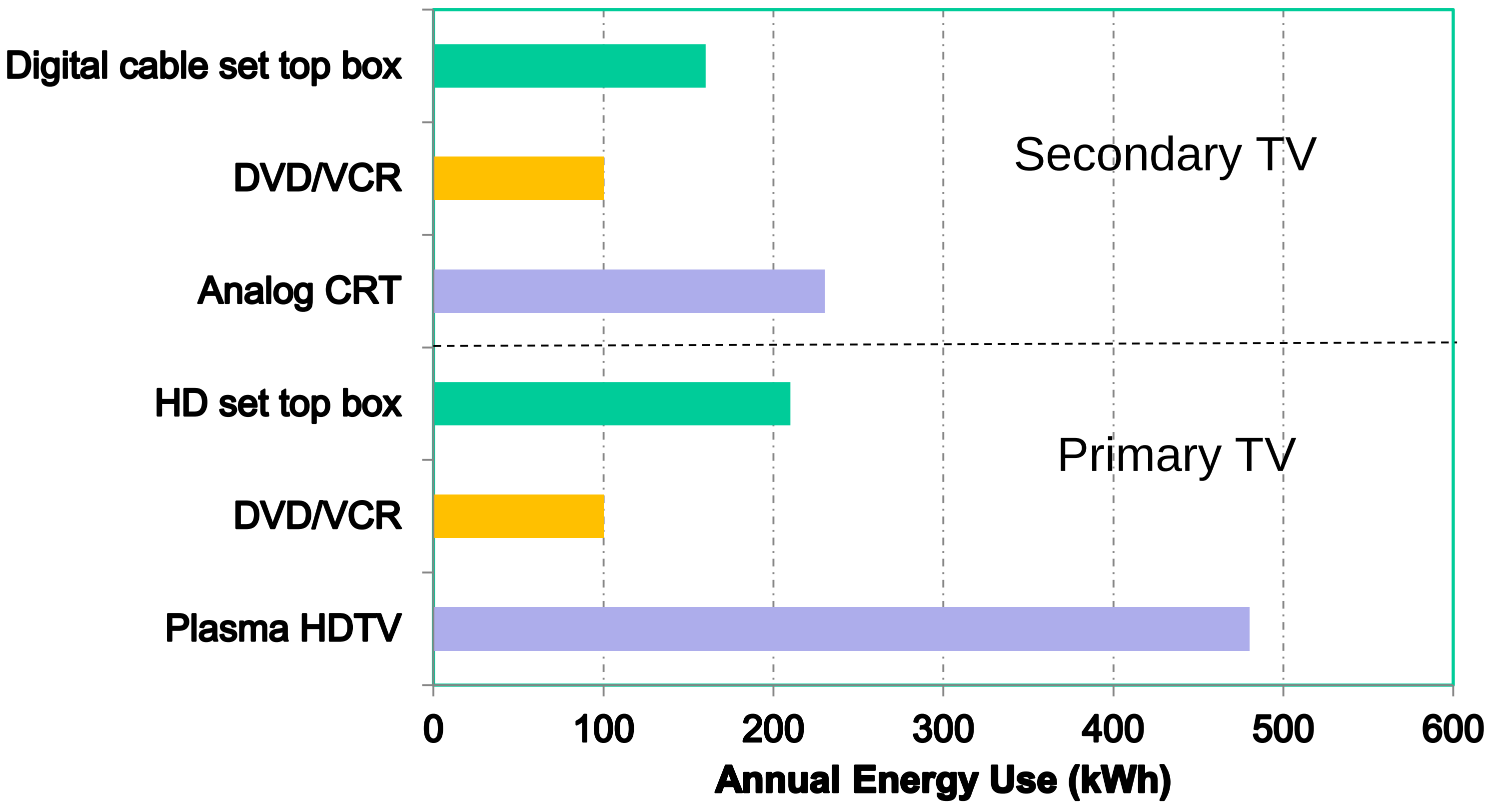
Energy Conservation.

A Major Part of the Solution to Energy Generation and Global Warming.

Average Energy Use per Refrigerator, 1947 to 2009.



Household Energy Use for Entertainment Electronics.



Combined energy use
~ 1200 kWh per year

NRDC, "Tuning in to Energy Efficiency: Prospects for Saving Energy in Televisions," January 2005.

“Zero Energy” New Homes.

- Goals:
  - 70% less electricity => down to ~2,000 kWh/yr
  - 1 kW on peak
- Electronics are a problem!
  - 1,200 kWh/ yr for TVs, etc.
  - 100-200 W for standby
- TV Power

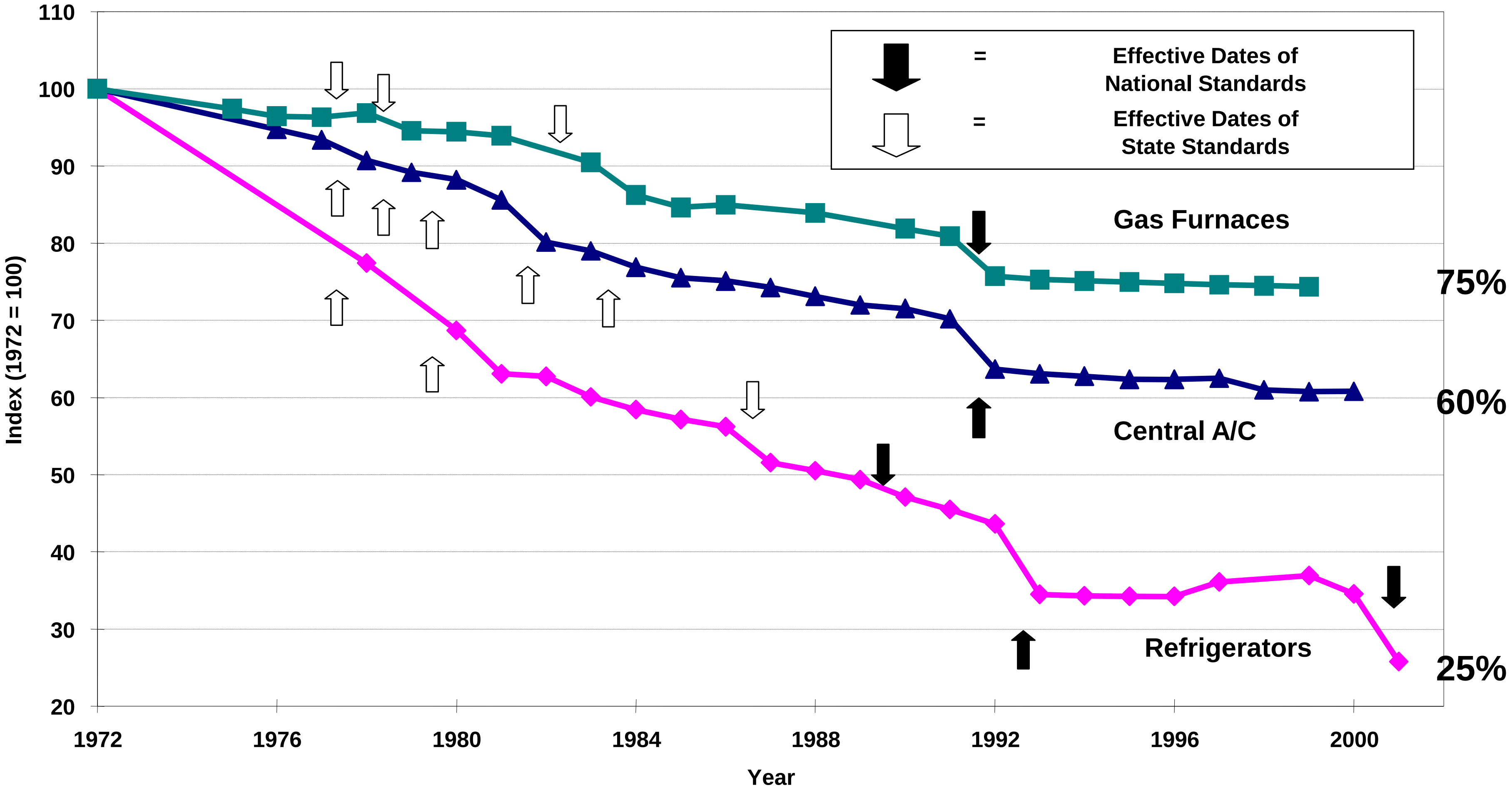
Plasma TV (50”)	400 W
Rear Projection TV (60”)	200 W
Large CRT (34”)	200 W
LCD (32”)	100 W

Heading and Cooling in the Home.

- Accounts for 45% of energy bill or € 1,000 per year
- HVAC – Heating, Ventilating and Air Conditioning
- SEER efficiency rating of AC
- Before 1992, typically 6.0
- After 1992 required 10.0
- Jan. 2006, required minimum 13.0
- Jan, 2015, required minimum 21.0

SEER = acronym for Seasonal Energy Efficiency Ratio

Impact of Standards on Efficiency of 3 Appliances.



Recent Issues and Perspectives in Italy (POLIMI - 2013).

es

Il quadro normativo italiano
per l'efficienza energetica

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DIPARTIMENTO
DI INGEGNERIA
GESTIONALE

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MIP

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www.energystrategy.it

Regulatory Framework in Italy.

L'evoluzione del quadro normativo nazionale:

il recepimento della Direttiva europea 2012/27/UE

Rispetto al quadro normativo ad oggi vigente in Italia, si nota come la Direttiva europea intenda:

- **colmare i «gap»**, soprattutto con riferimento all'**assenza di obblighi nell'industria;**
- **rafforzare**:
  - **il sistema di obblighi**, introducendone di nuovi **a carico della Pubblica Amministrazione;**
  - **il sistema di incentivi diretti ed indiretti**, favorendo la **consapevolezza dei consumi energetici** da parte degli utenti finali.

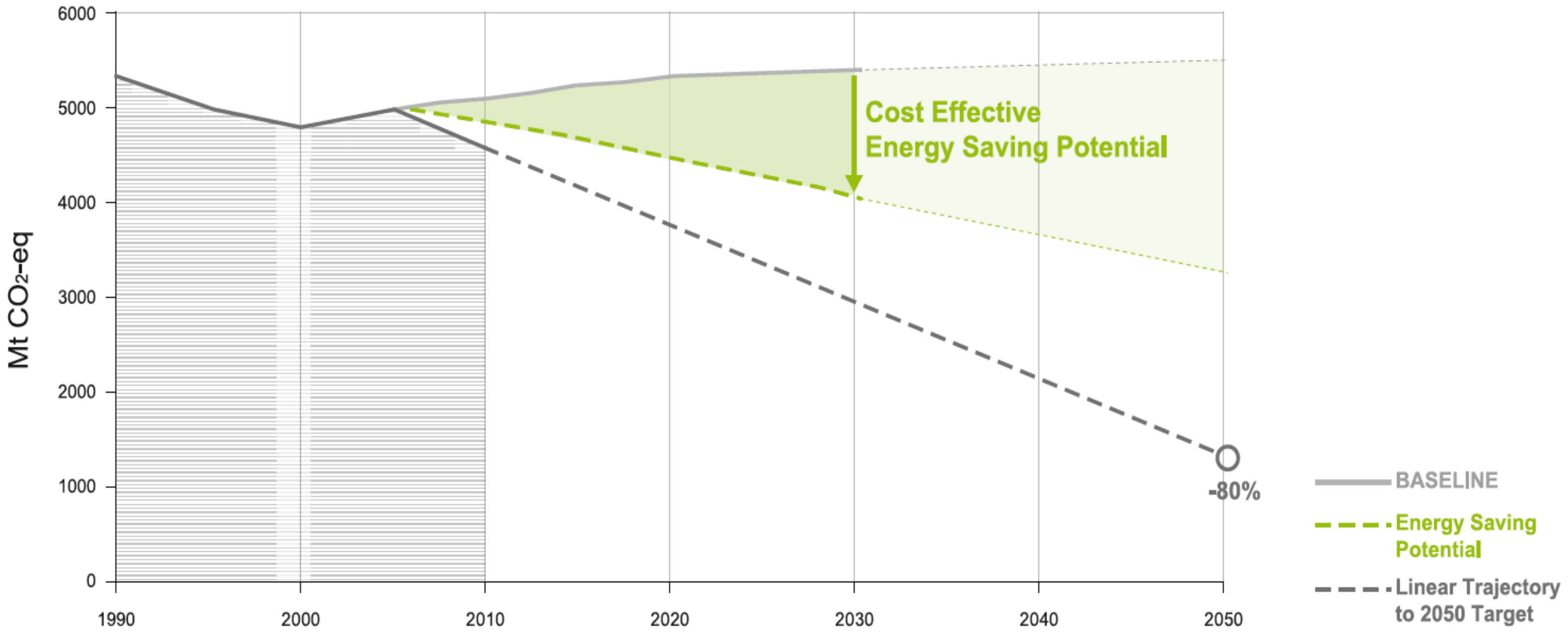
		AMBITO D'APPLICAZIONE			
		PROCESSO PRODUTTIVO		BUILDING	
		Industria	Servizi	Residenziale	Non Residenziale *
TIPO DI PROVVEDIMENTO	OBBLIGHI	Legge 10/91 e s.m.i.			
				D.L. 192/2005 e s.m.i. *(D.L. 22/11/12 – abrogazione autocertificazione energetica e D.L. 4/06/13 – Attestato di Prestazione Energetica)*	
				D.L. 3/03/11	
	INCENTIVI DIRETTI ED INDIRETTI	D.M. 20/7/04 e s.m.i. *(DM 28/12/2012 – Titoli di Efficienza Energetica)*			
			DM 28/12/2012 – Conto Energia Termico		
			Legge n. 296/06 e s.m.i. *(D.L. 4/06/2013 – Detrazioni fiscali riqualificazione energetica)*		
		D.L. 83/2012 e s.m.i. – Decreto «energivori»			

Il quadro normativo italiano per l'efficienza energetica

Dicembre 2013

www.energystrategy.it

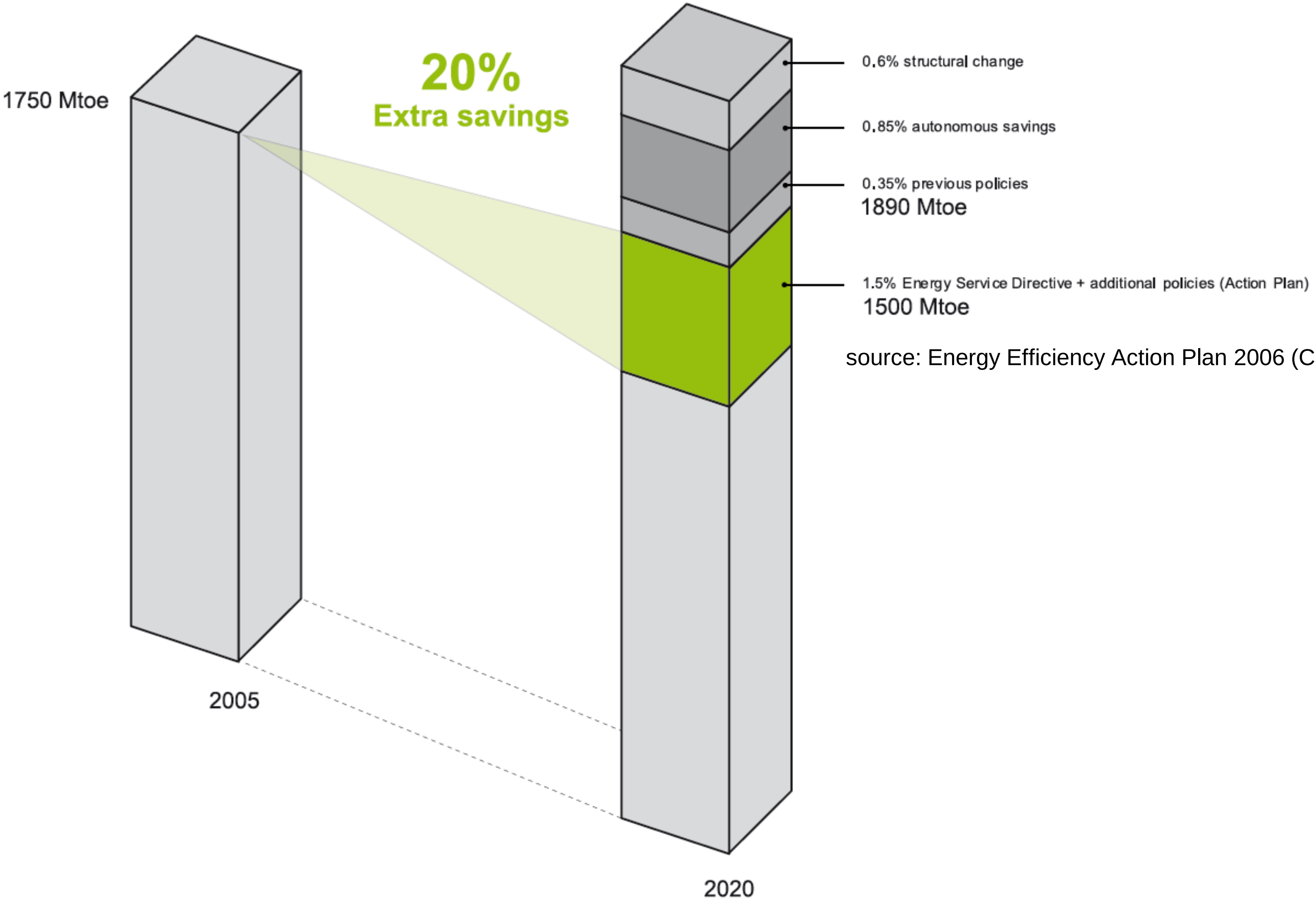
Expected Impact of Energy Saving on GHG Emissions in the EU 27.



Monitoring, baseline and linear trajectory towards the 2050 ambition of reducing emissions beyond -80% compared to 1990. The green wedge illustrates the impact of the cost-effective energy savings potential.

Fraunhofer Institute Energy saving 2020 (2010)

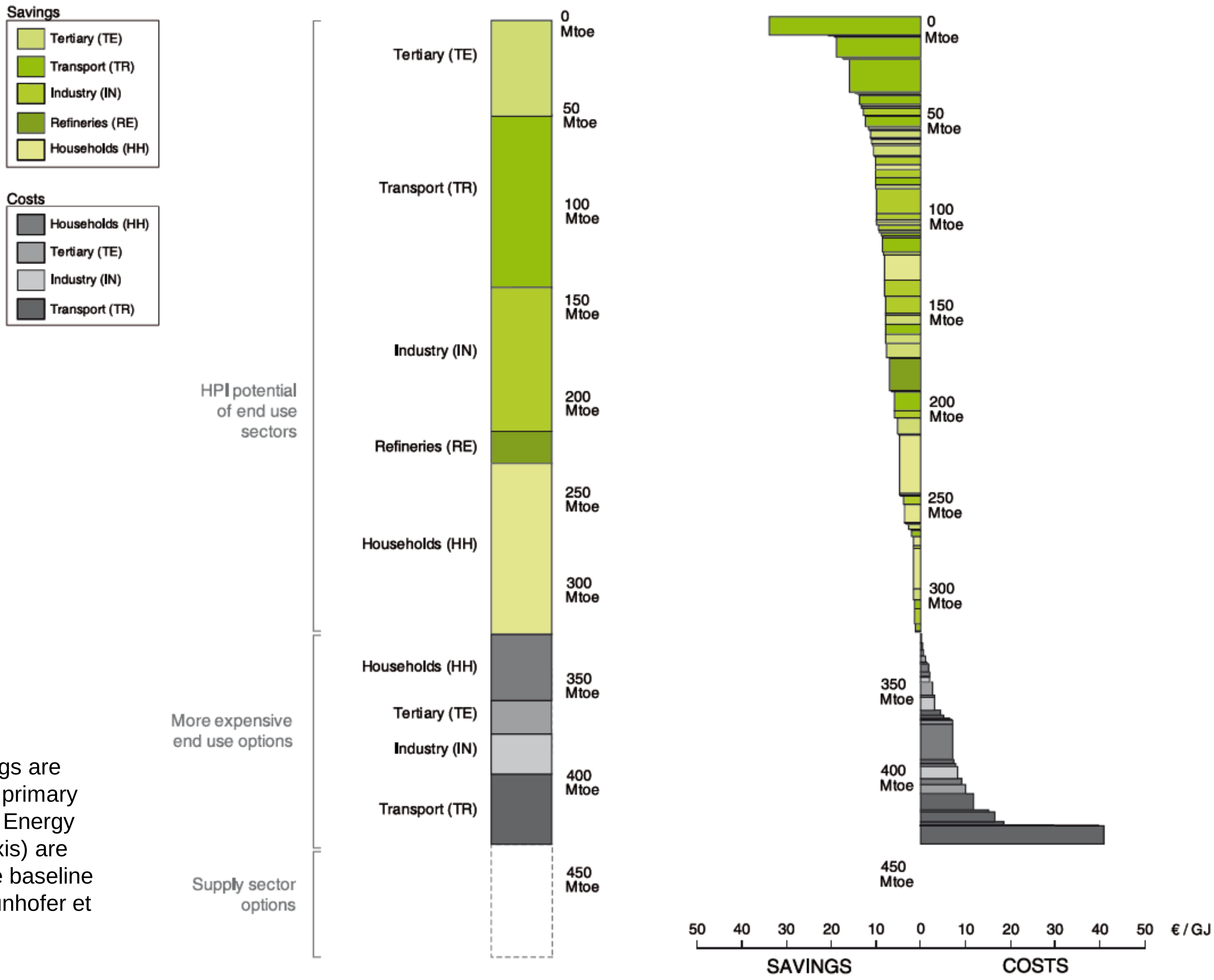
EU's 20% Energy Savings Target Compared to the Baseline.



source: Energy Efficiency Action Plan 2006 (COM(2006) 545 final

Fraunhofer Institute Energy saving 2020 (2010)

Overall MACC for energy efficiency options of end-use sectors in the EU 27 in 2020.



Energy savings are expressed in primary energy units. Energy savings (Y-axis) are relative to the baseline (source: Fraunhofer et al., 2009).

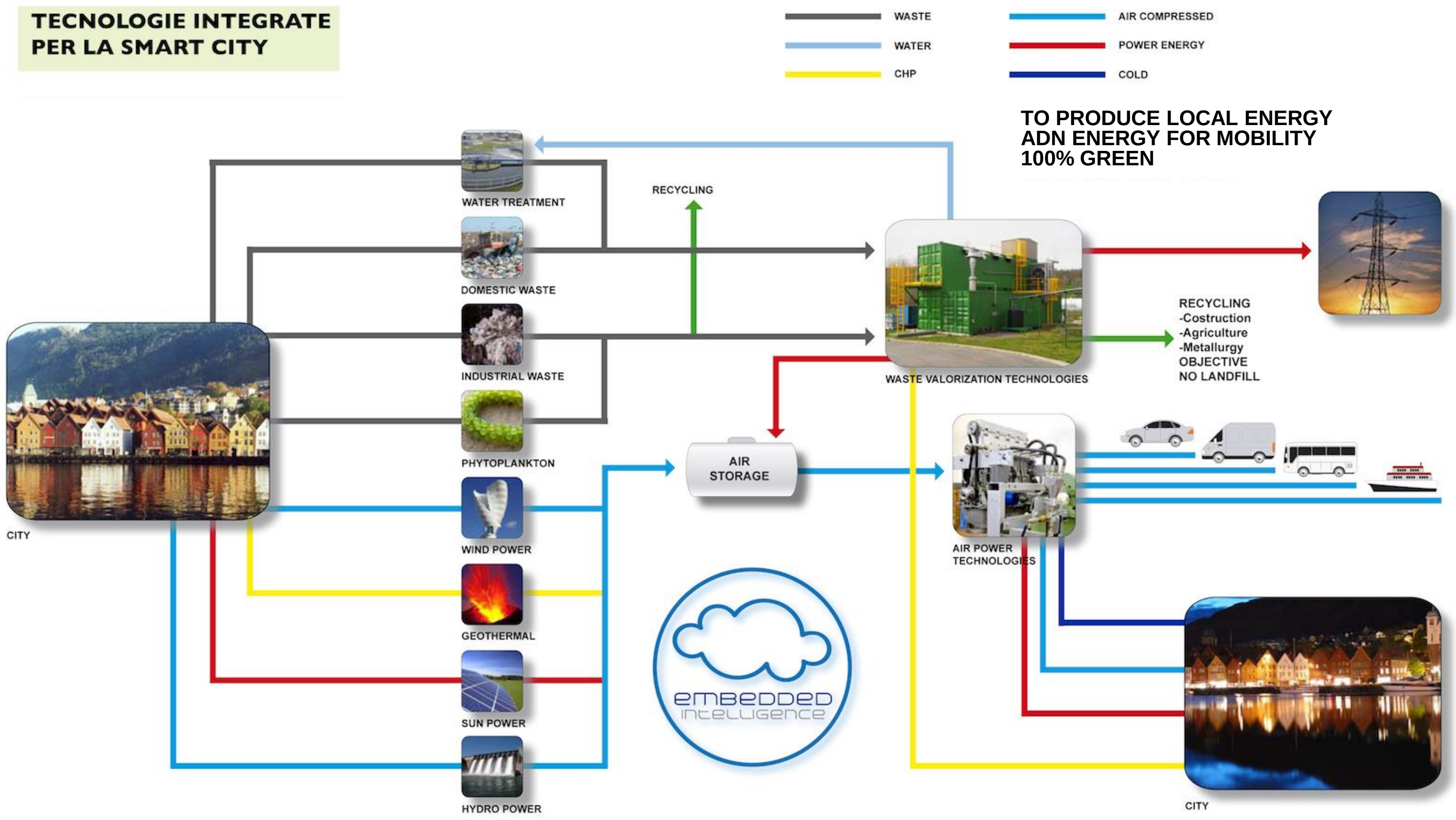
Areas of Potential Savings at Home.

- **thermal insulation** (insulated walls, pipes, roof, windows, double glazing, etc.).
- natural insulation
- energy meter to reduce consumptions
- lights off / no plasma TV
- fluorescent lamps and LED / appliances class A+ or A++
- fans instead of air conditioners
- domestic solar panels / domestic wind turbine
- limit the use of running water
- water recycle

Need for ecologic certification of houses (in Italy ≪Attestato di Prestazione Energetica≫ Decreto Legge 4 giugno 2013):

- ➢ determines incentives
- ➢ determines the price of an house

Integrated Technologies for Smart City.



TECNOLOGIE INTEGRATE PER LA SMART CITY

- WASTE
- WATER
- CHP
- AIR COMPRESSED
- POWER ENERGY
- COLD

TO PRODUCE LOCAL ENERGY
ADN ENERGY FOR MOBILITY
100% GREEN

CITY

WATER TREATMENT

DOMESTIC WASTE

INDUSTRIAL WASTE

PHYTOPLANKTON

WIND POWER

GEOTHERMAL

SUN POWER

HYDRO POWER

RECYCLING

WASTE VALORIZATION TECHNOLOGIES

RECYCLING
-Costruction
-Agriculture
-Metallurgy
OBJECTIVE
NO LANDFILL

AIR STORAGE

AIR POWER TECHNOLOGIES

embedded intelligence

CITY

CITY LOCAL RESOURCES

...per energia locale e mobilita' pulita in citta'

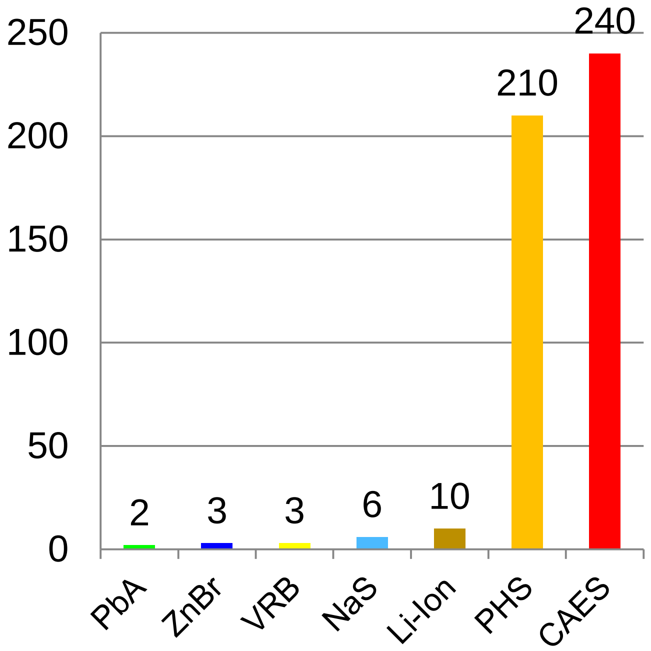
Source: SET ENERGY SERVICES

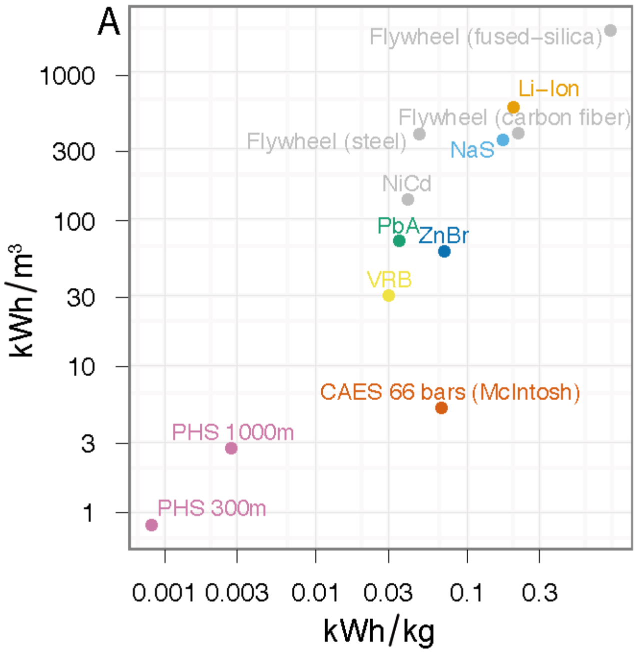
Energy Storage.

Six main approaches have been developed:

1. **Solid state batteries**, several different electrochemical devices for store energy as chemical compounds and release electric energy, include capacitors.
2. **Flow batteries**, el. devices storing energy directly in the electrolyte for long living cycles and quick response time.
3. **Flywheels**, mechanical devices that harness rotational energy to deliver instantaneous electricity
4. **Compressed Air Energy Storage**, utilizes compressed air as energy reserve
5. **Thermal**, capturing heat and cold to create energy on demand
6. **Pumped Hydro-Power**, creating large scale reservoirs of energy using water

Energy Stored on Invested (ESOI).





ESOI = The total energy stored over the life of a storage technology on the energy required for its construction

λ : cycle life

η: round – trip efficiency

D: depth of discharge

ε_{gate} : embodied energy

$$ESOI = \frac{\lambda \eta D}{\varepsilon_{gate}}$$

Barnhart & Benson
Energy Environ. Sci., 2013, **6**, 1083-1092.

References.

1. For an analysis of the potential energy savings, see the website http://energy.gov/eere/femp/energy-and-cost-savings-calculators-energy-efficient-products
2. For a report of software for energy savings available see the US website http://energy.gov/eere/femp/information-resources
3. For an overview of the Italian legislation on energy savings see www.energystrategy.it
4. For projections on energy savings in EU-27, see the study of Fraunhofer Institute *Energy saving 2020* (2010)
5. For comparisons on energy storage, see the work: Barnhart, Benson *Energy Environ. Sci.*, 2013, 6, 1083-1092.