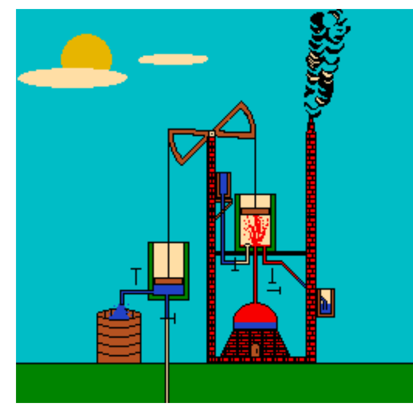
2017 ICFA School on Instrumentation

Alternative eco-friendly energy sources

G.Alimonti INFN & Università degli Studi, Milano

- Energy & Development
- Current production and its limits
- RES as a possible solution



The history of energy, evolution and discoveries in transforming energy, is the history of mankind (from Prometheus to Newcomen&Cawley…)

Human Development Index

The Human Development Index (HDI) was created to emphasize that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone.

UNITED NATIONS DEVELOPMENT PROGRAMME
Human Development Reports

HDI is a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and have a decent standard of living. The HDI is the geometric mean of normalized indices for each of the three dimensions.

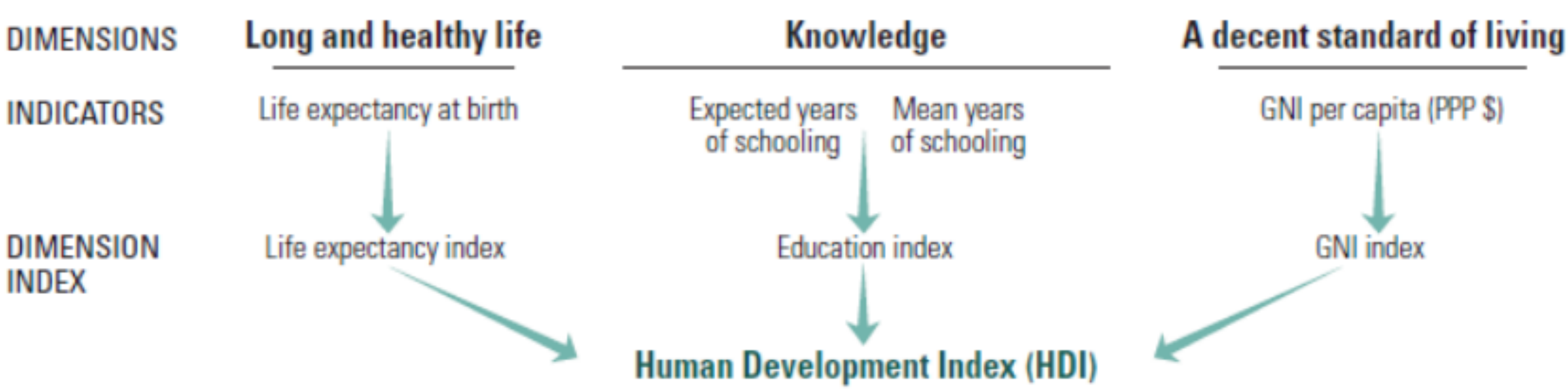
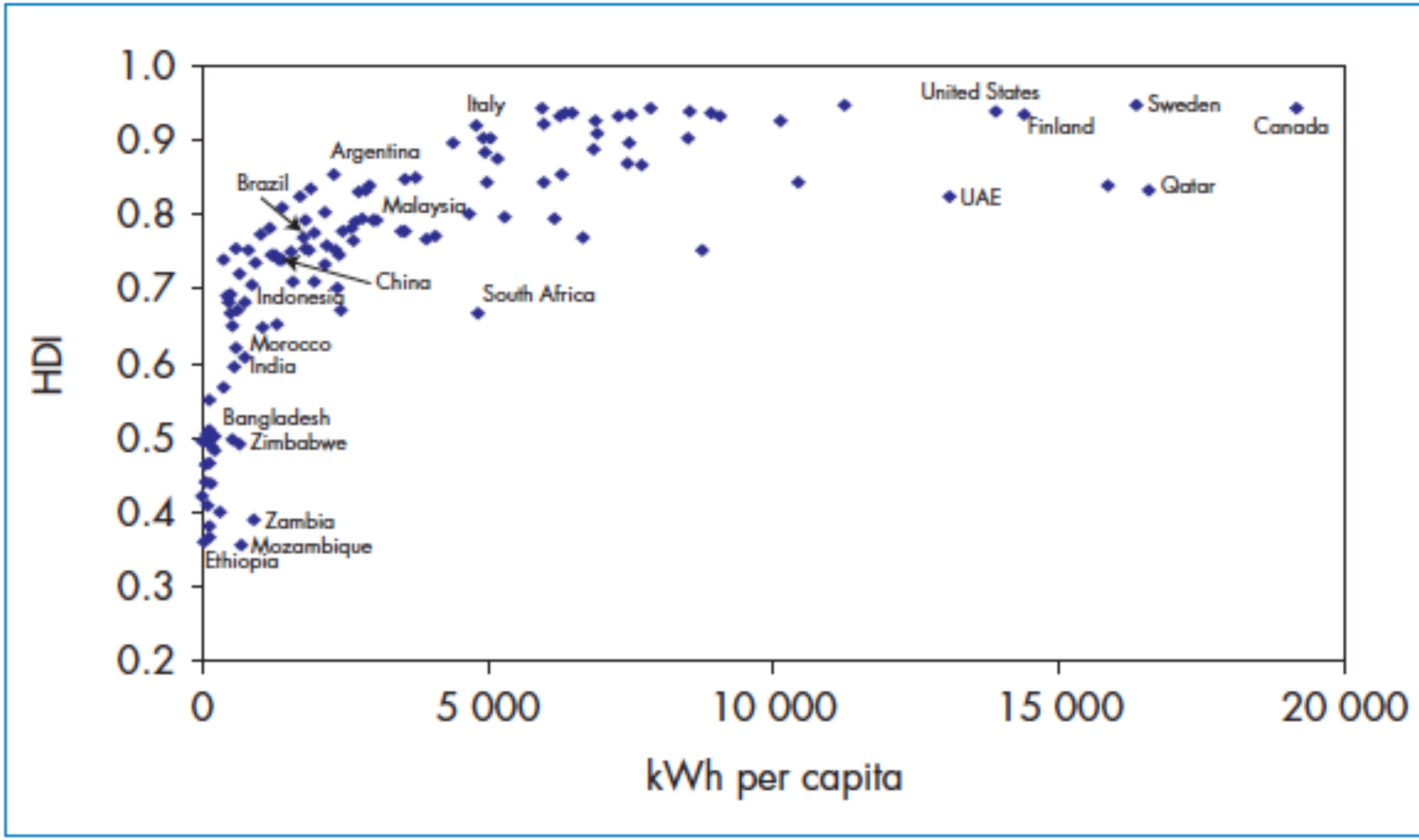


Figure 10.4: **HDI and Electricity Consumption per Capita, 2002**



Sources: IEA analysis; UNDP (2004).

HDI does not appear to increase much once you hit European levels of per-capita electricity consumption. But lower electricity consumption has an impact.

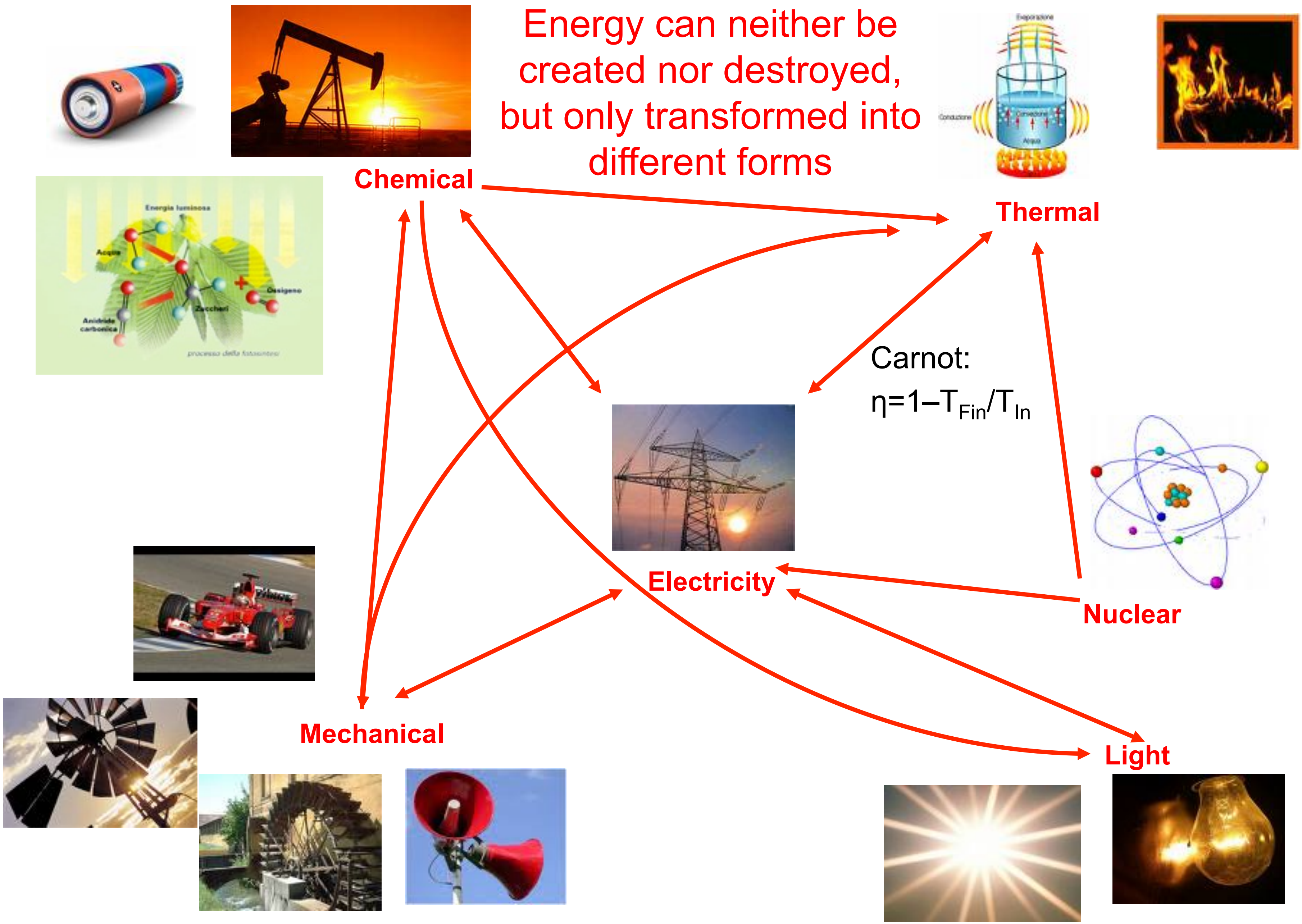
What is Energy?

Energy is defined as the ability of a body or system to do work.

Energy = Work (same unit is used)

The Joule is the SI unit of energy: it is the transferred amount of energy moving an object by a force of 1 Newton.

Very small amount of energy:
more intuitive saying that 4,1868 Joule=1 Calory, that is…
the energy needed to increase 1g of distilled water by 1°C



Energy can neither be created nor destroyed, but only transformed into different forms
Chemical
Thermal
Carnot:
$\eta=1-T_{Fin}/T_{In}$
Electricity
Nuclear
Mechanical
Light
Energia luminosa
Acqua
Ossigeno
Zuccheri
Anidride carbonica

General conversion factors for energy

To:	TJ	Gcal	Mtoe	MBtu	GWh
From:	multiply by:				
TJ	1	2.388×10^{2}	2.388×10^{-5}	9.478×10^{2}	2.778×10^{-1}
Gcal	4.187×10^{-3}	1	1.000×10^{-7}	3.968	1.163×10^{-3}
Mtoe	4.187×10^{4}	1.000×10^{7}	1	3.968×10^{7}	1.163×10^{4}
MBtu	1.055×10^{-3}	2.520×10^{-1}	2.520×10^{-8}	1	2.931×10^{-4}
GWh	3.600	8.598×10^{2}	8.598×10^{-5}	3.412×10^{3}	1

1KWh=10^3Wh=10^3x3600Ws=3.6×10^6Joule
1 eV=1.6×10^{-19}Joule: (important for PV and nuclear energy)
1 Toe = 10^{10} Calories (by definition) “heat content of 1 Ton of oil”
about 1/3 of the italian per capita energy use; allows a car to run for about 15000 Km.

http://www.iea.org/statistics/resources/unitconverter/

Energy/Power

Never mix energy with power
Power = Energy/Time

Energy is related to Power the same way Lenght is related to Velocity
or
the amount of water in a dam with the incoming/outgoing water flux
or
money in a bank account is related with salary and expenses!

(a FIAT 500 with the same weight of a Ferrari has the same energy when travelling at the same speed…even if, given the different power they have, they may need different time to reach the same velocity)

The Watt is the SI unit for Power: 1Watt=1Joule/1Second

Some examples: light bulb, oven, car, train…

Let's practice…

Evaluate "the mean power" of a human body:

We eat 2000 Kcal per day: $2x10^6$Cal~$8x10^6$Joule
and we assume we use them all (we would rather doing this!...)
$8x10^6$Joule/10^5sec = 80Watt

Evaluate how much water has to drop from what hight to produce 1 KWh
(let's assume an hydro plant tranforms potential energy to EE with ε=1)

The potential energy is mgh:
1KWh=$3.6x10^6$Joule=mgh [Kg][Meter/Sec^2][Meter]=mx9.8xh~10mh
1KWh is about 1ton of water falling from 360 meters...

Burning 10g of wood may lift a man by >100 meters
Energy content of 100g chocolate would lift a man by ≈2000 meters

Primary Energy

Primary energy is the energy directly available in nature

Renewables (directly or inderectly coming from the Sun)

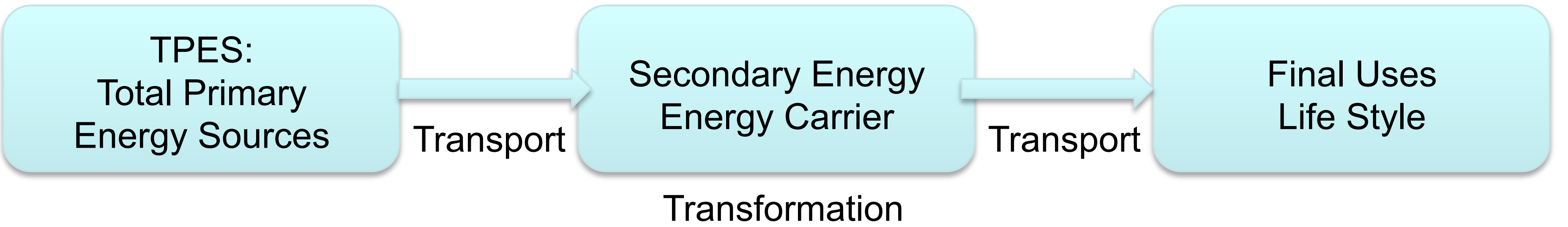
- Hydro (and ocean)
- Wind
- Solar
- Geothermal
- Biomass
  - Waste

Not Renewables

- Fossil fuels
  - Coal
  - Oil
  - Natural gas
- Nuclear fission (fusion?)

Secondary Energy/Energy Carriers

Secondary Energy: Primary Energy Sources transformed in a different form more suited to transport and/or final use



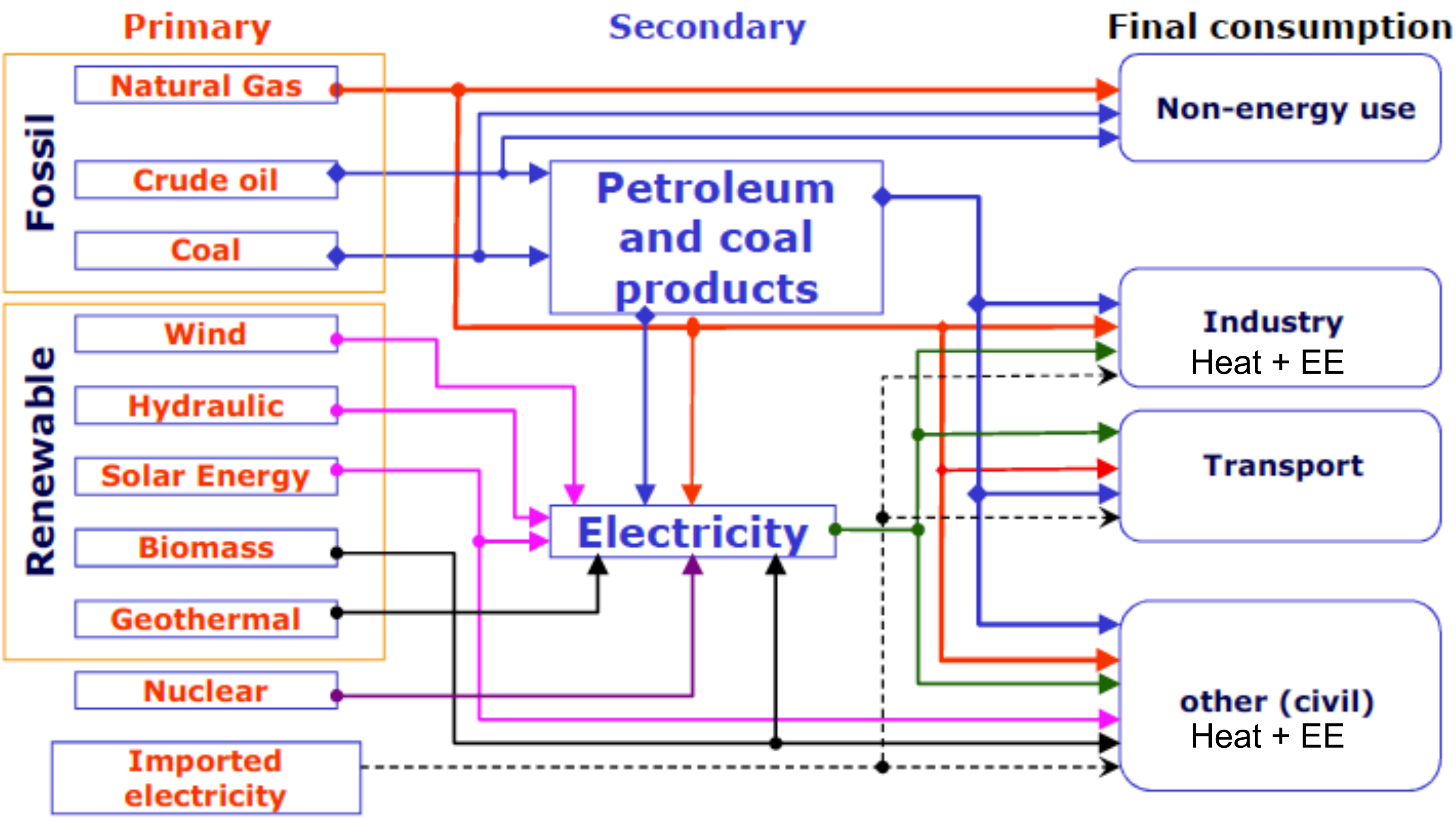
A fundamental step for the energy use is the transformation (losses) from an available form to an easily usable/transportable form

An example of secondary energy is the electricity: it can not be stored and therefore must be produced at the same time of the request, but has the advantage of being easily transportable over great distance to the final user, who can very easily convert it with very high efficiency into mechanical energy, heat, or use it as light source.

How would you consider the food?...

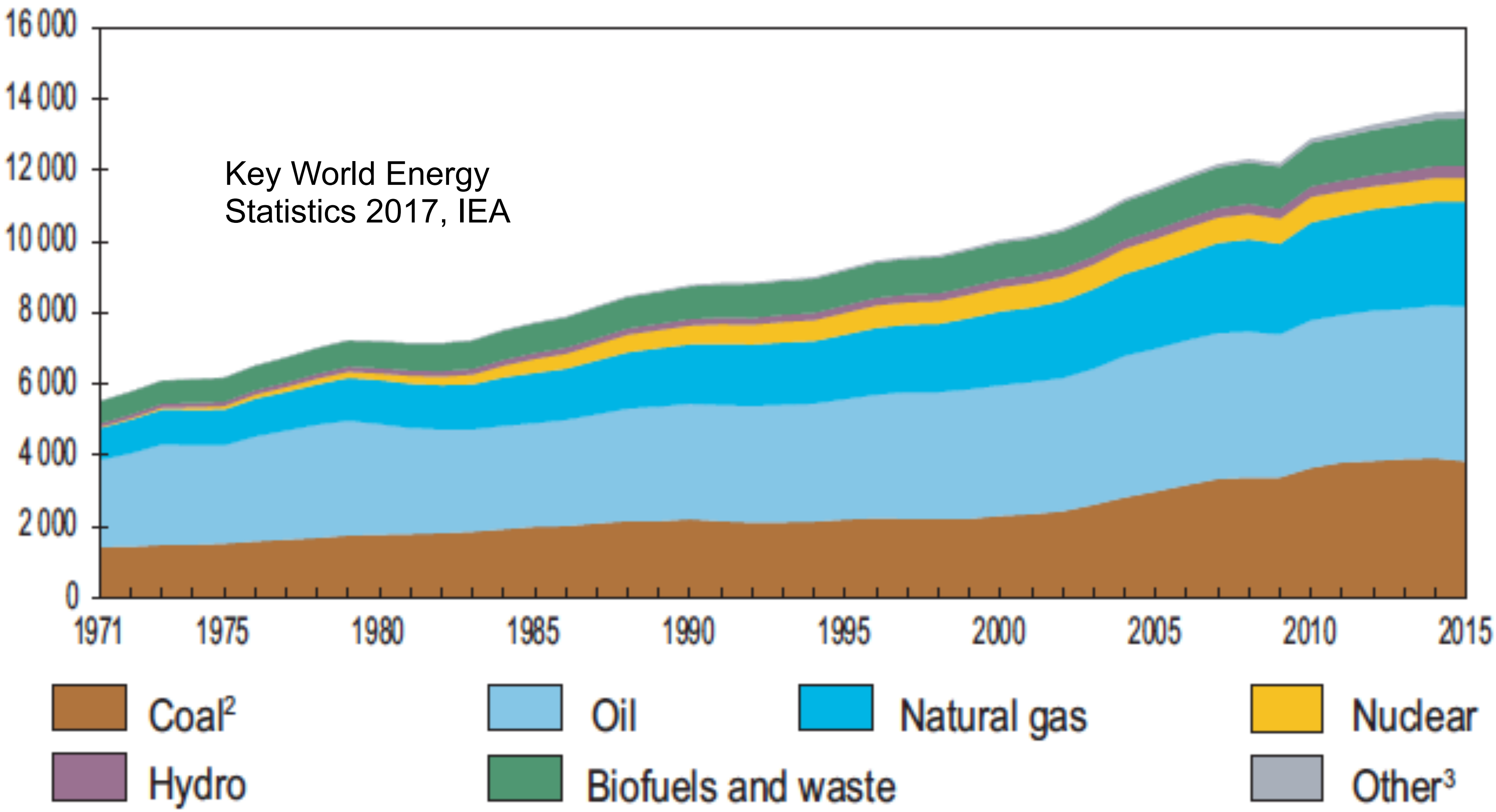
G.Alimonti

From Primary Energy Sources to final consumption



Non-energy use: fuels not used as raw materials or consumed as fuels. Ex: petrochemical feedstocks.
Other (civil): residential, commercial or public services, agriculture, forestry and not specified consumption.

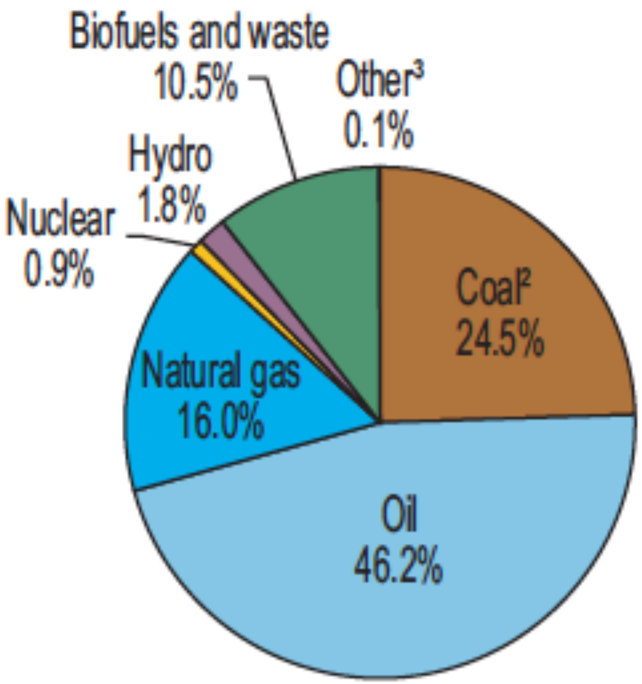
World[1] TPES from 1971 to 2015 by fuel (Mtoe)



1. World includes international aviation and international marine bunkers.
2. In these graphs, peat and oil shale are aggregated with coal.
3. Includes geothermal, solar, wind, tide/wave/ocean, heat and other.

1973 and 2015 fuel shares of TPES

1973

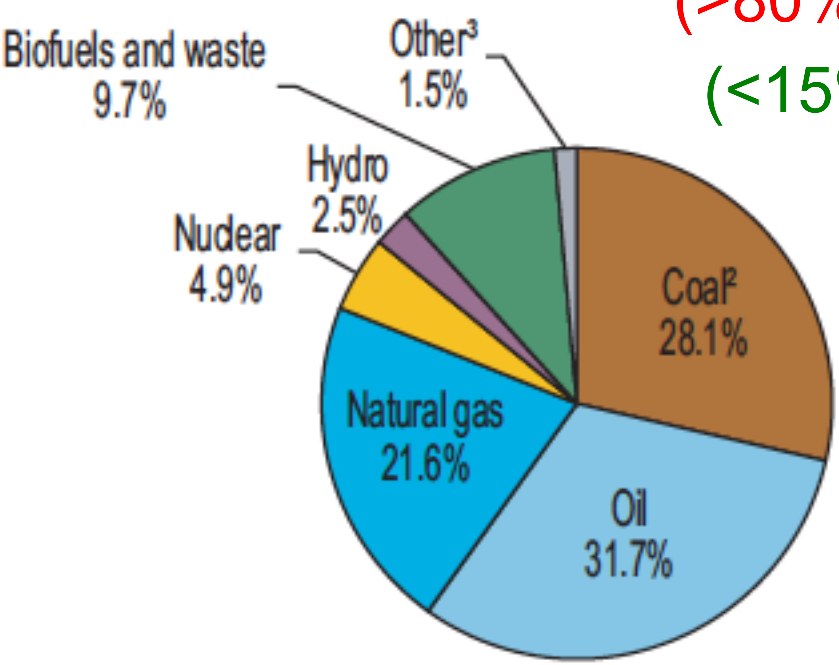


6 101 Mtoe

2015

(>80% FF)

(<15% RES)



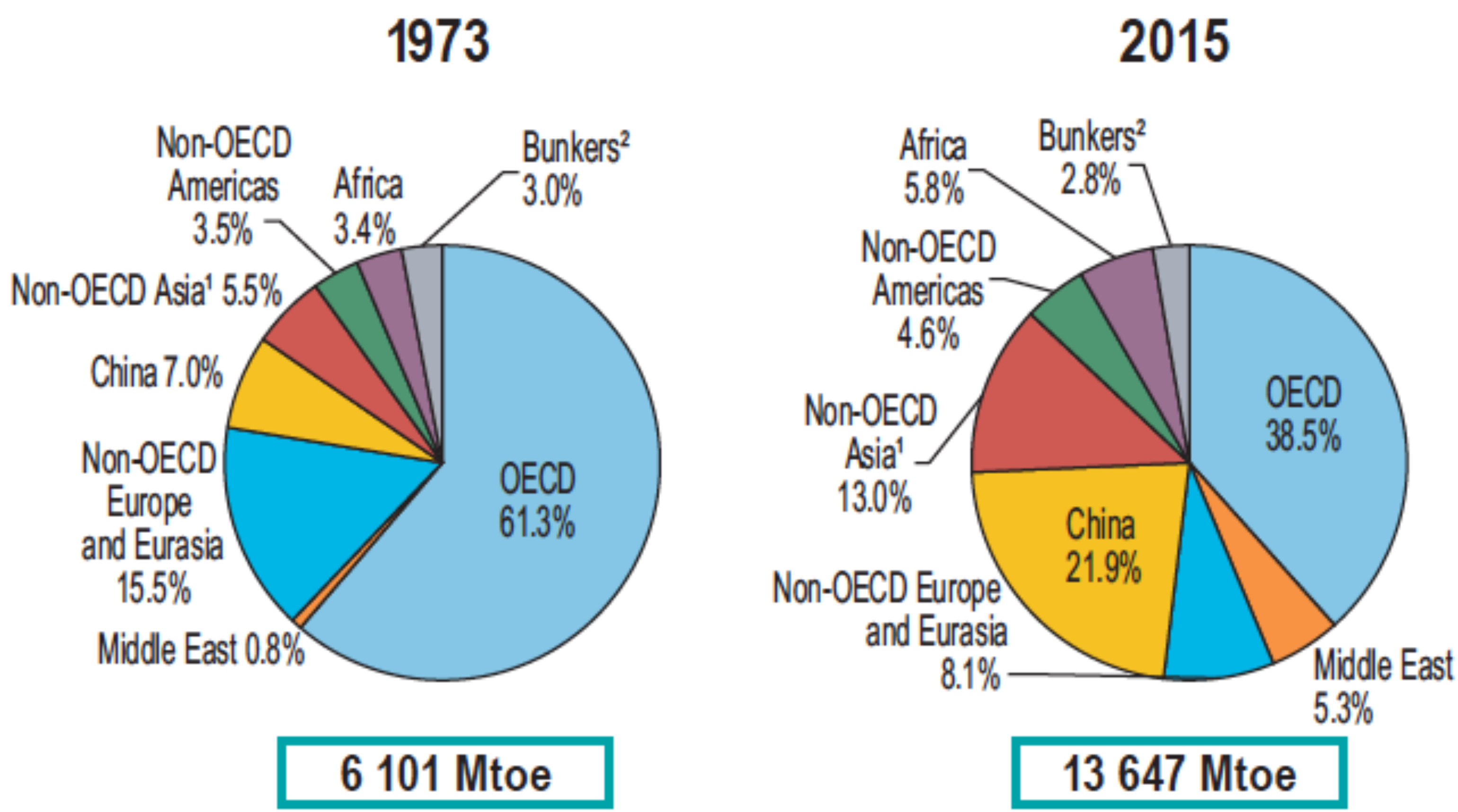
13 647 Mtoe

1. World includes international aviation and international marine bunkers.
2. In these graphs, peat and oil shale are aggregated with coal.
3. Includes geothermal, solar, wind, tide/wave/ocean, heat and other.

Key World Energy Statistics 2017, IEA

G.Alimonti

1973 and 2015 regional shares of TPES



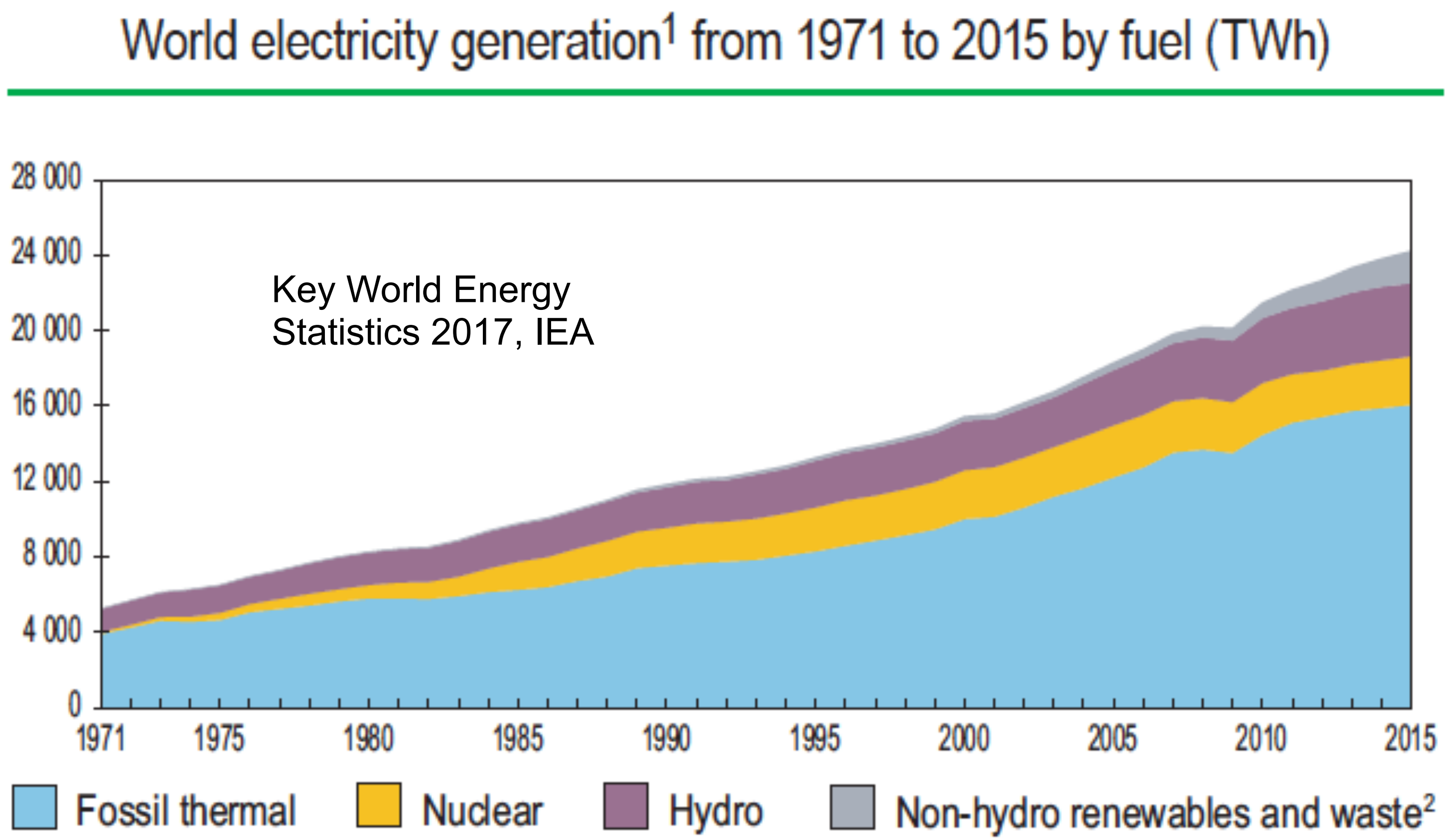
1. Non-OECD Asia excludes China.
2. Includes international aviation and international marine bunkers.

Key World Energy Statistics 2017, IEA

OECD (Organisation for Economic Co-operation and Development): Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.

Electricity generation by source

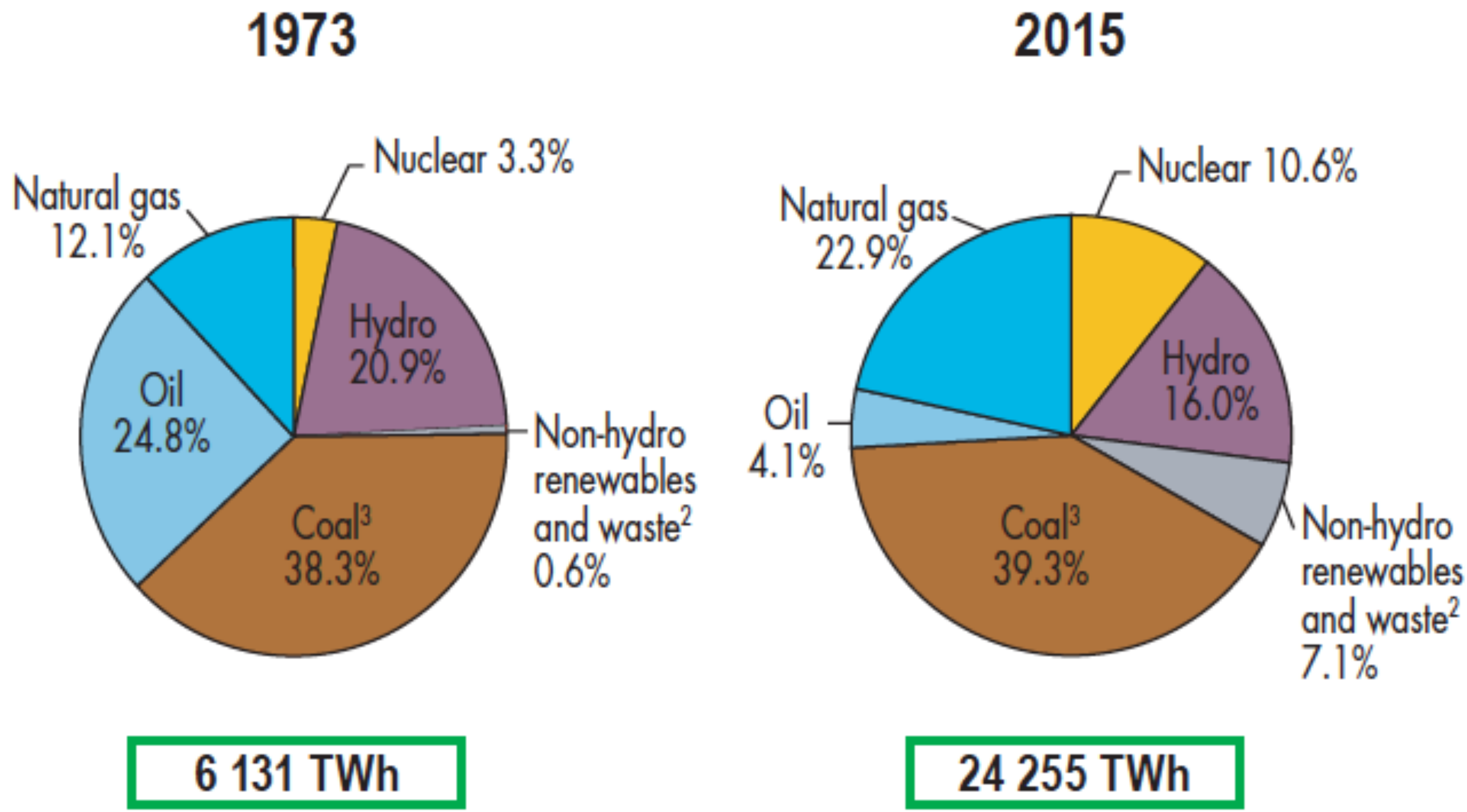
…not just by by fuel…



1. Excludes electricity generation from pumped storage.

2. Includes geothermal, solar, wind, tide/wave/ocean, biofuels, waste, heat and other.

1973 and 2015 source shares of electricity generation[1]



Key World Energy Statistics 2017, IEA

1. Excludes electricity generation from pumped storage.
2. Includes geothermal, solar, wind, tide/wave/ocean, biofuels, waste, heat and other.
3. In these graphs, peat and oil shale are aggregated with coal.

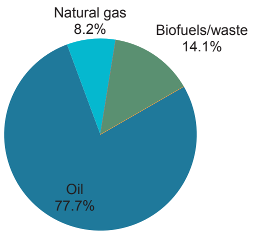
Energy in Cuba

IEA Energy Statistics

Statistics on the web: http://www.iea.org/statistics/

Share of total primary energy supply* in 2015

Cuba



12 048 ktoe

* Share of TPES excludes electricity trade.

** In this graph, peat and oil shale are aggregated with coal, when relevant.

Note: For presentational purposes, shares of under 0.1% are not included and consequently the total may not add up to 100%.

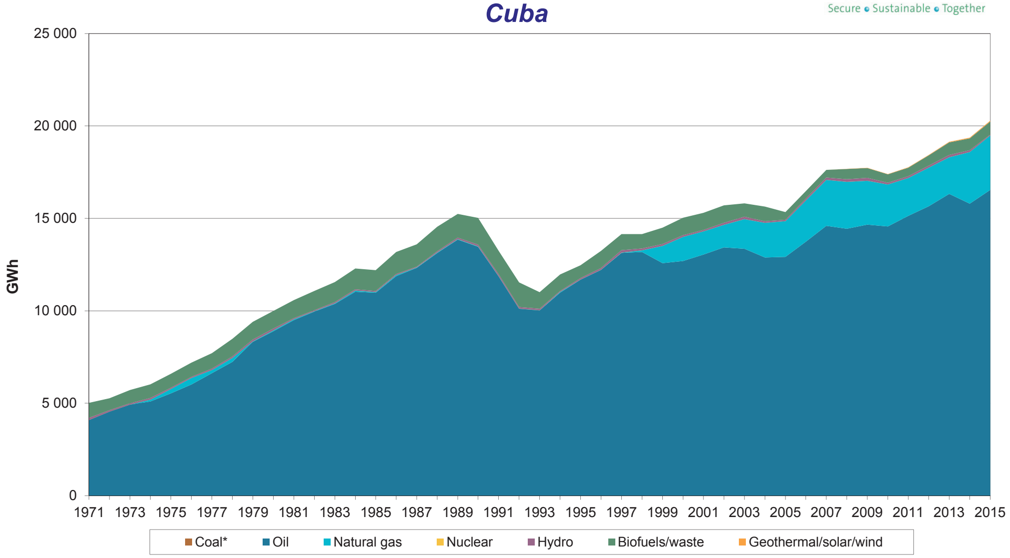
For more detailed data, please consult our on-line data service at http://data.iea.org.

IEA Energy Statistics

Statistics on the web: http://www.iea.org/statistics/

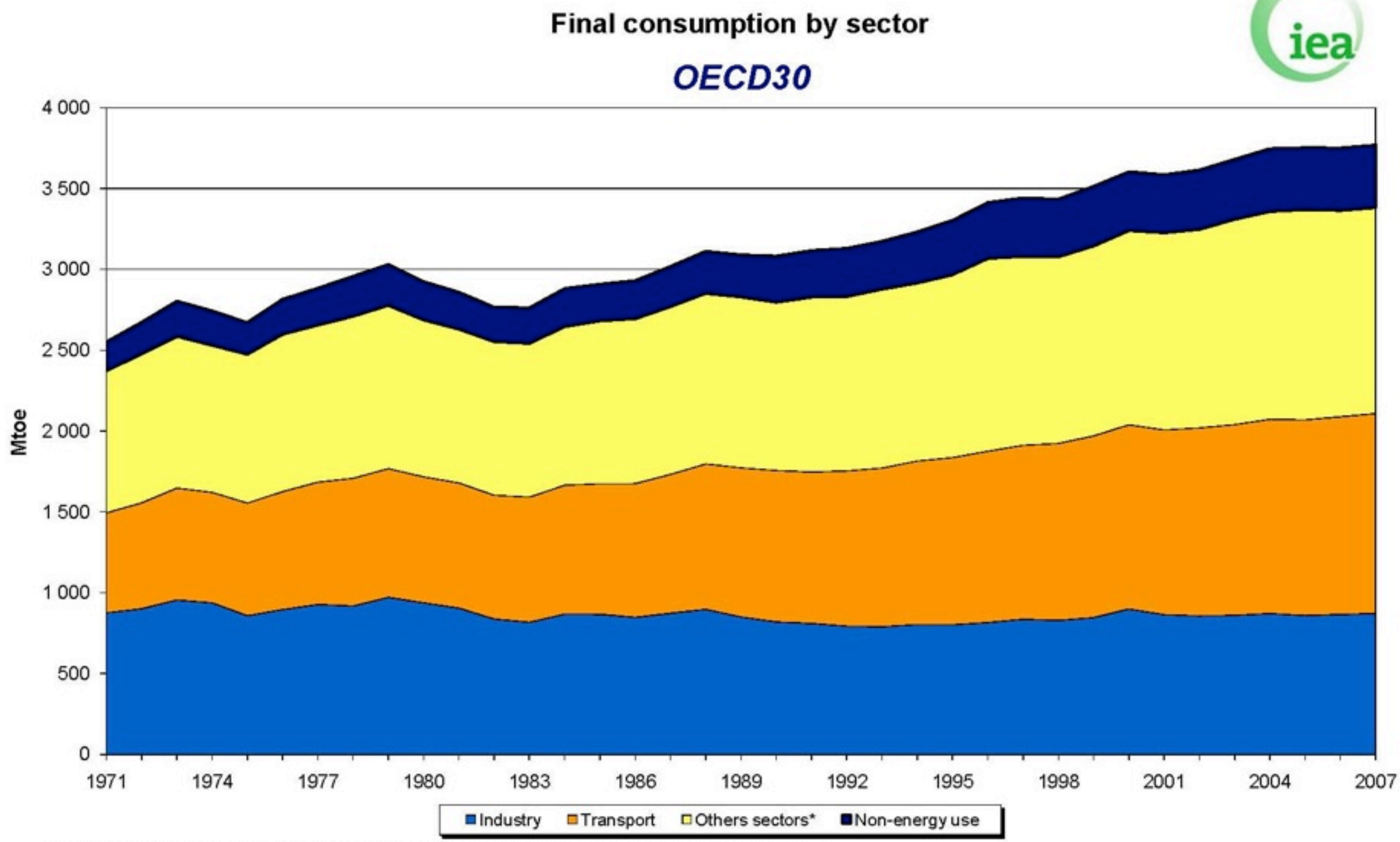
Electricity generation by fuel

Cuba



* In this graph, peat and oil shale are aggregated with coal, when relevant.

For more detailed data, please consult our on-line data service at http://data.iea.org.



* Includes residential, commercial and public services, agriculture/forestry, fishing and non-specified.

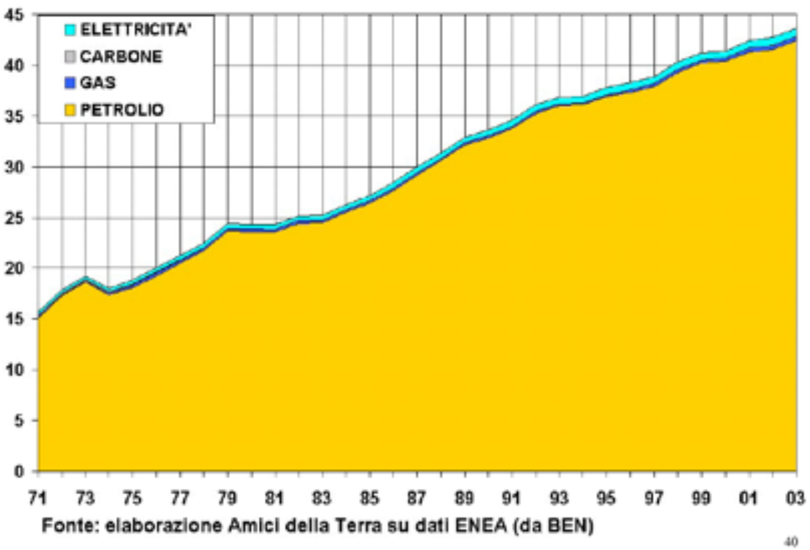
For more detailed data, please consult our on-line data service at http://data.iea.org.

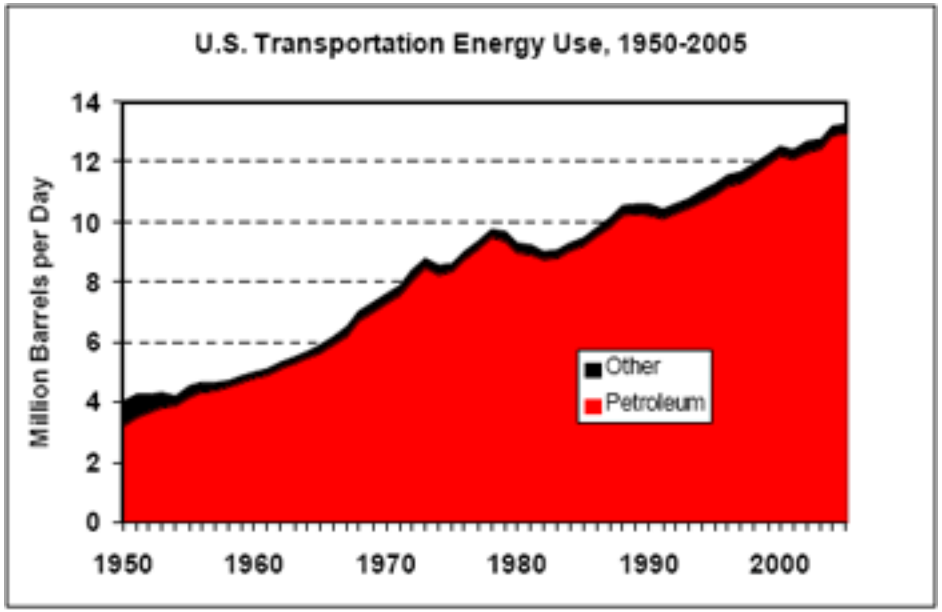
Non-energy use covers those fuels that are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel. Non-energy use also includes petrochemical feedstocks.

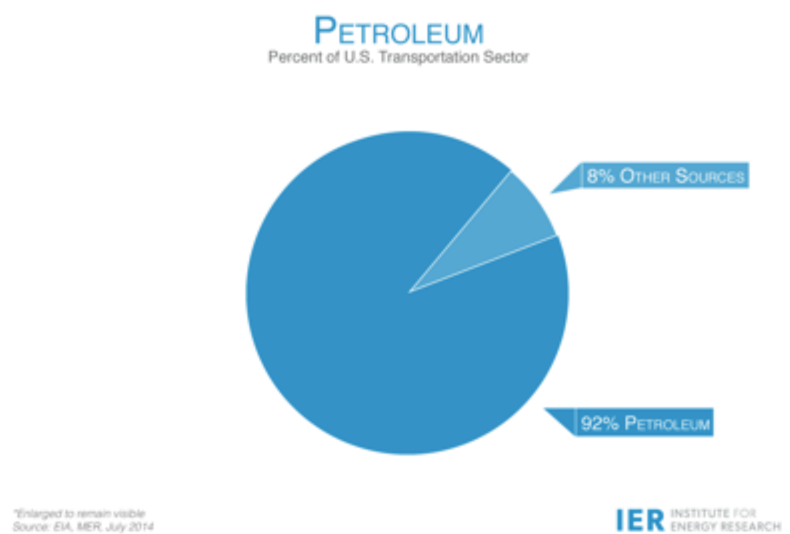
G.Alimonti

Transportation depends on oil…

Final energy consumption for transportation in Italy from 1971 to 2003 (Mtoe)

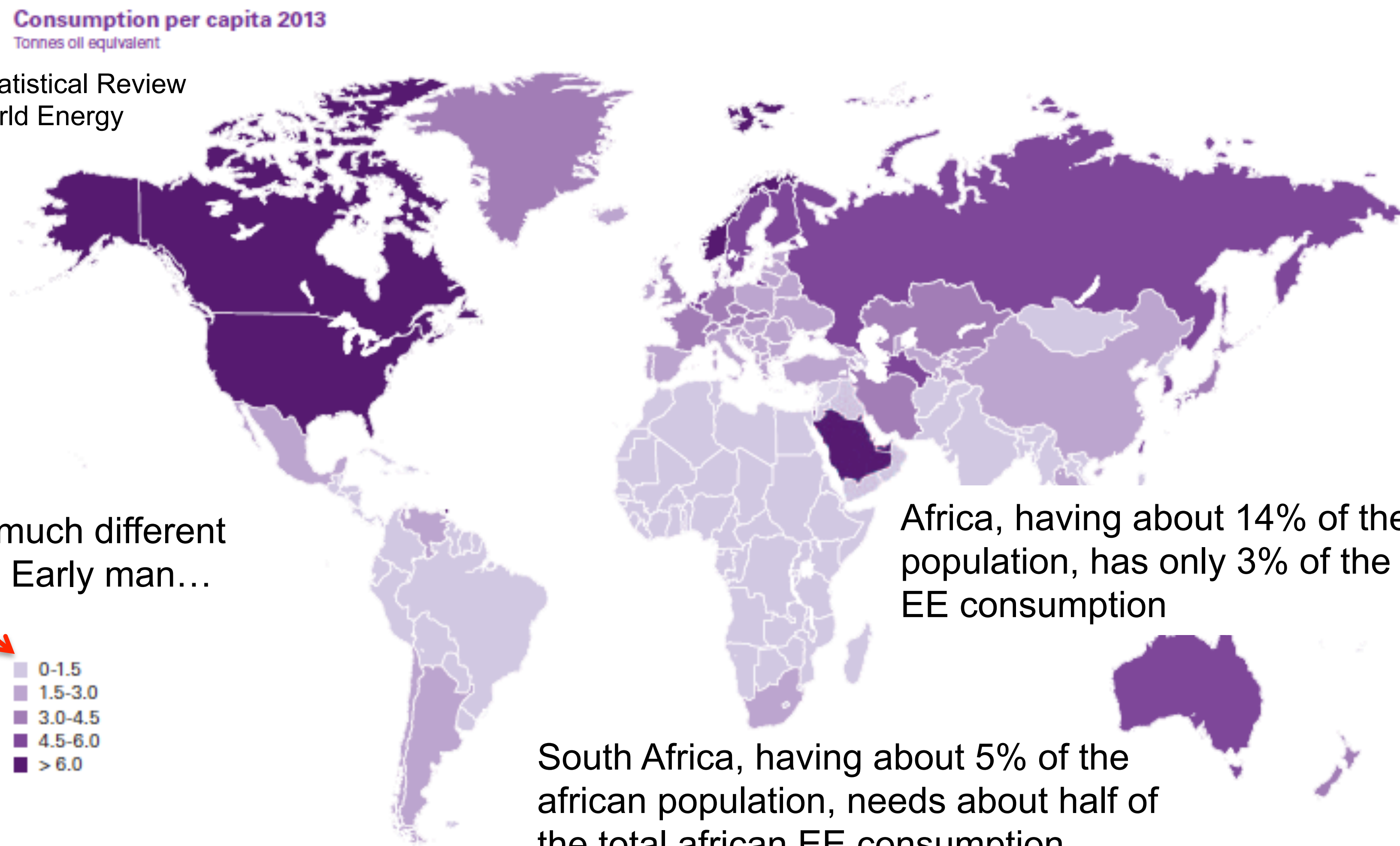






Per capita consumption (Primary Energy)

BP Statistical Review of World Energy



Not much different from Early man…

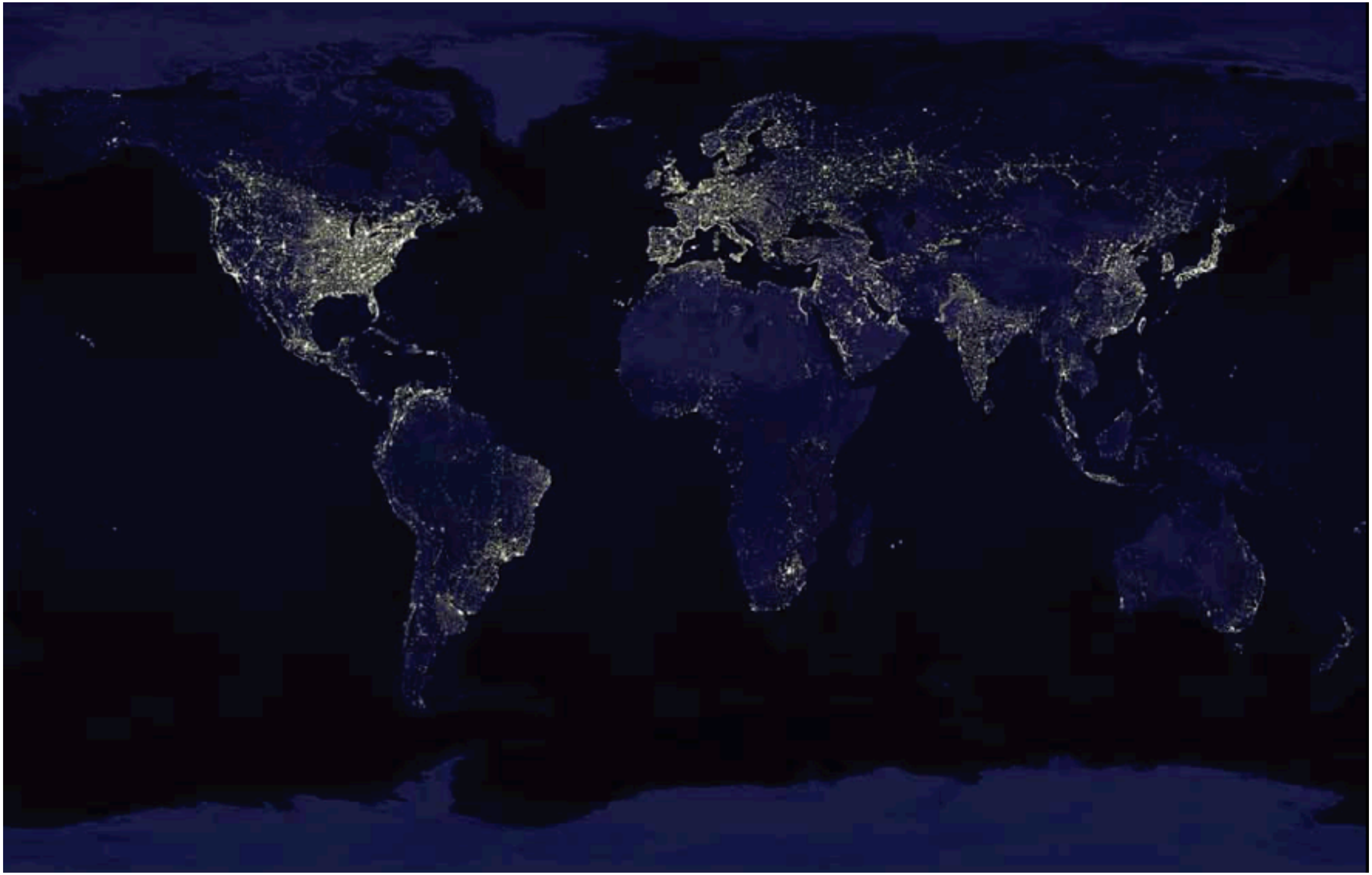
Africa, having about 14% of the world population, has only 3% of the world EE consumption

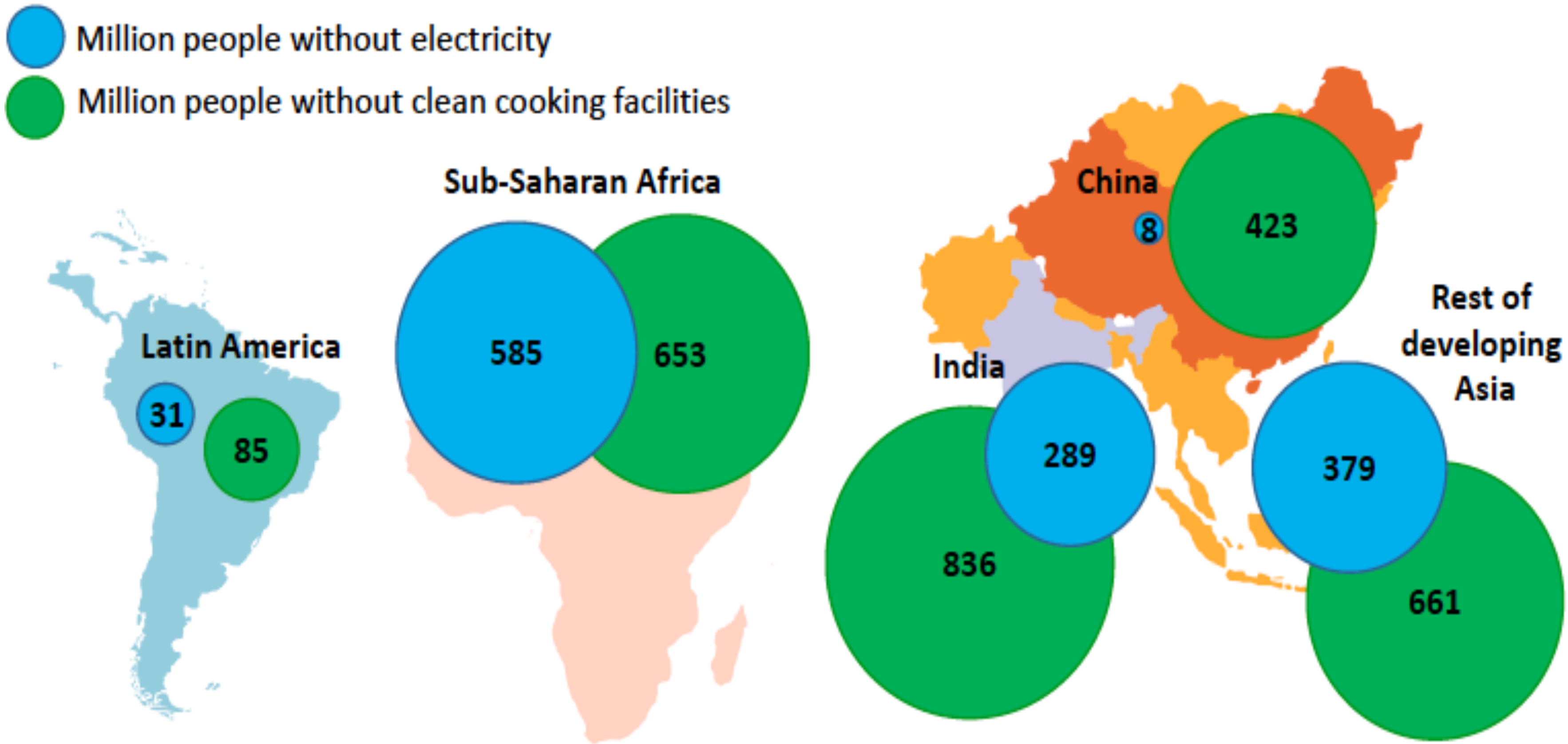
South Africa, having about 5% of the african population, needs about half of the total african EE consumption

Excluding northern and southern african countries, the main energy source for the remaining african population is wood (>85%)

G.Alimonti

Per capita consumption …





1.3 billion people in the world live without electricity
and 2.7 billion live without clean cooking facilities

WEO 2011, IEA

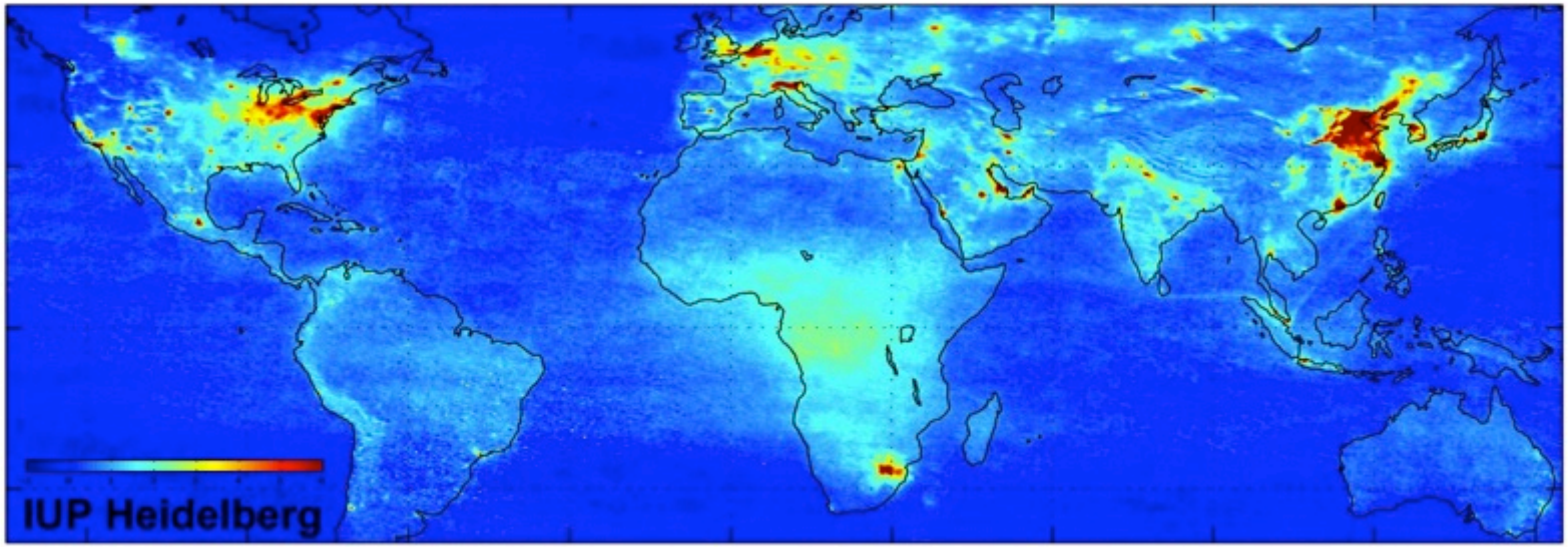
Access to electricity and to energy in general, is considered to be an essential requirement for human development. IEA evaluates that investments of about 35 $ billion/year would bring energy access to the whole world population.

Current Energy production (>80% FF) limits

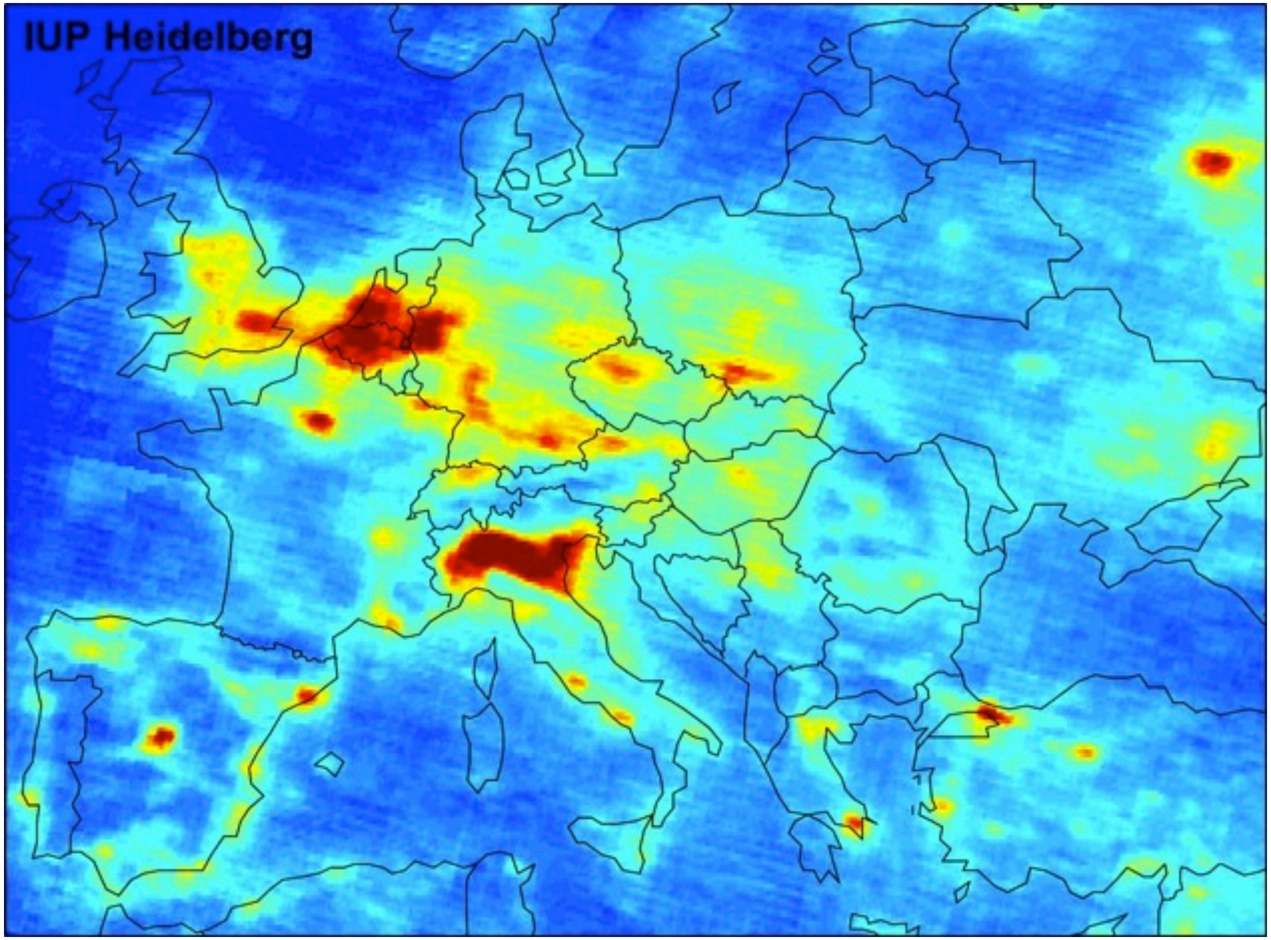
Three main limits of the actual energy production:
(other then the non uniform energy distribution)

- Polluting emissions→ Health&Environment impact
  (NO_x, SO_x, Particulate, Ozone, CO, VOC, NH_3)
- Limited resources→ What's next?
- GHG emissions→ Climate Change?

Polluting emissions (NO_2)



Global mean tropospheric nitrogen dioxide (NO_2) vertical column density (VCD) between January 2003 and June 2004, as measured by the SCIAMACHY instrument on ESA's Envisat. Image produced by S. Beirle, U. Platt and T. Wagner of the University of Heidelberg's Institute for Environmental Physics.



A detail from a global image shows the European mean tropospheric nitrogen dioxide (NO_2) vertical column density (VCD) between January 2003 and June 2004, as measured by the SCIAMACHY instrument on ESA's Envisat. Image produced by S. Beirle, U. Platt and T. Wagner of the University of Heidelberg's Institute for Environmental Physics.

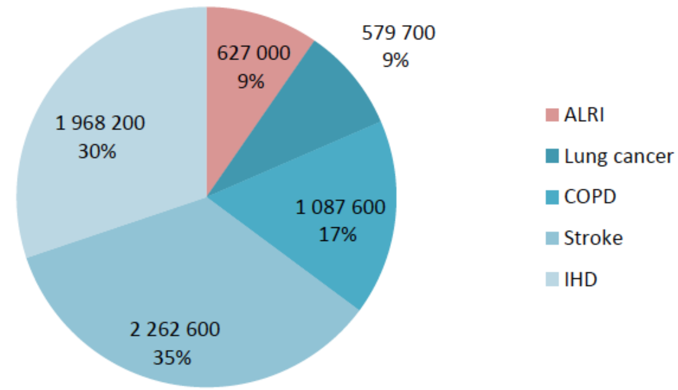
Polluting emissions (PM)

Beijing, China

Courtesy of dr. Lazzarini, ARPA Lombardia

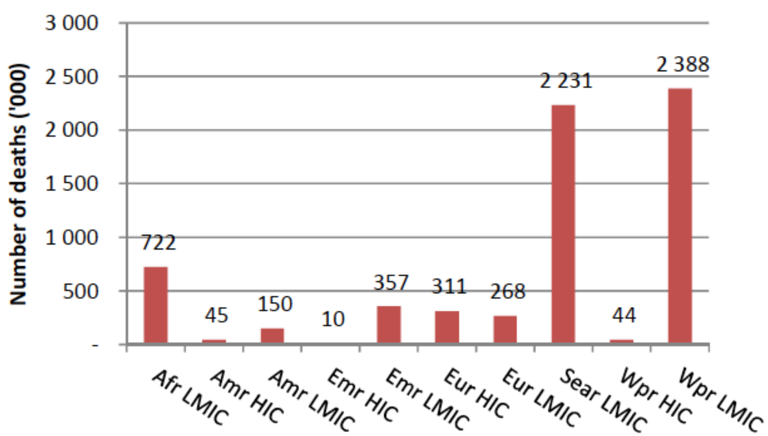
Globally, almost 7 million deaths were attributable to the joint effects of household (HAP) and ambient air pollution (AAP) in 2012.
Fonte: WHO 2016

***Figure 4**. Deaths attributable to the joint effects of HAP and AAP in 2012, by disease*



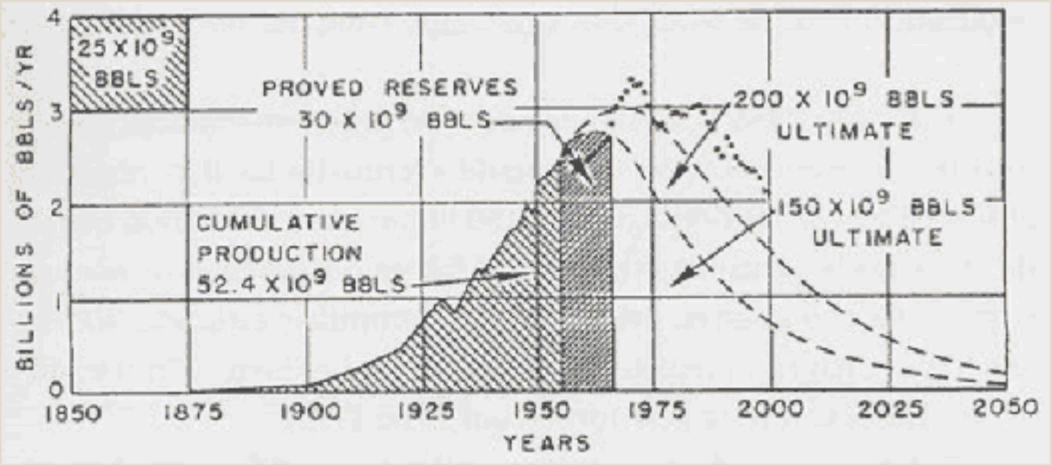
Percentage represents percent of total HAP burden (add up to 100%).
HAP: Household air pollution; AAP: Ambient air pollution; ALRI: Acute lower respiratory disease; COPD: Chronic obstructive pulmonary disease; IHD: Ischaemic heart disease.

***Figure 1**. Total deaths attributable to the joint effects of HAP and AAP in 2012, by region*



HAP: Household air pollution; AAP: Ambient air pollution; Amr: America, Afr: Africa; Emr: Eastern Mediterranean, Sear: South-East Asia, Wpr: Western Pacific; LMIC: Low- and middle-income countries; HIC: High-income countries.

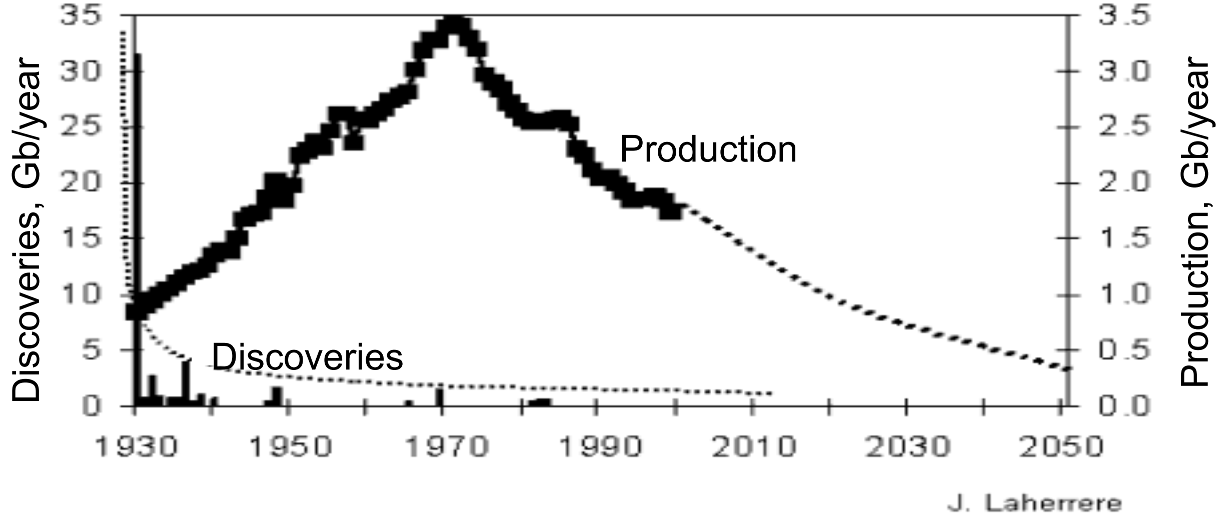
Limited resources



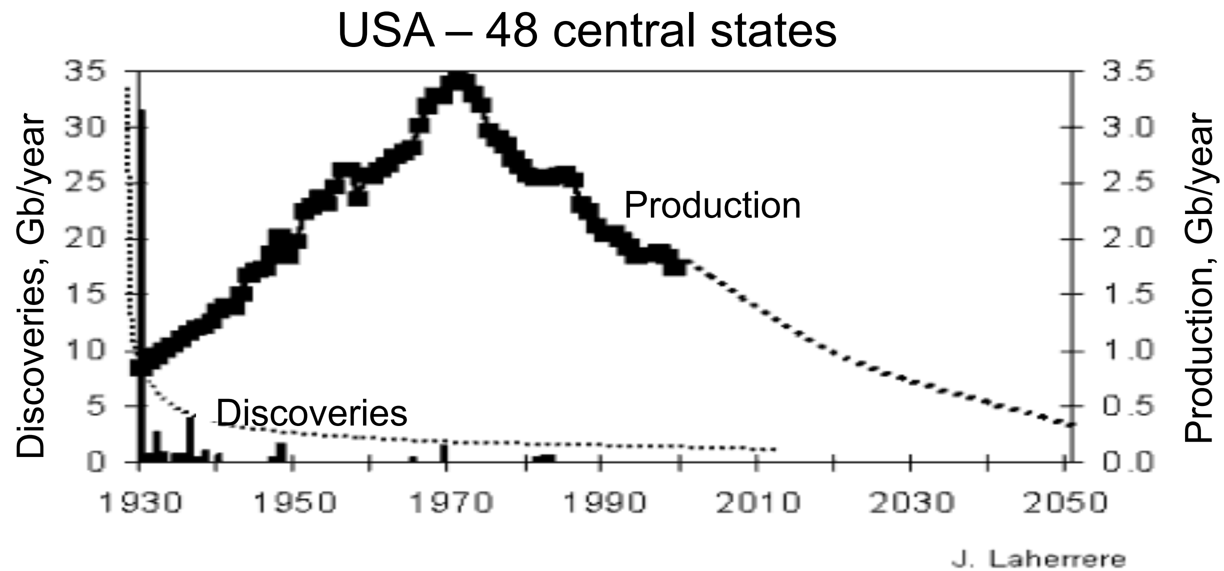
"Nuclear energy and the fossil fuels", M.King Hubbert, June 1956

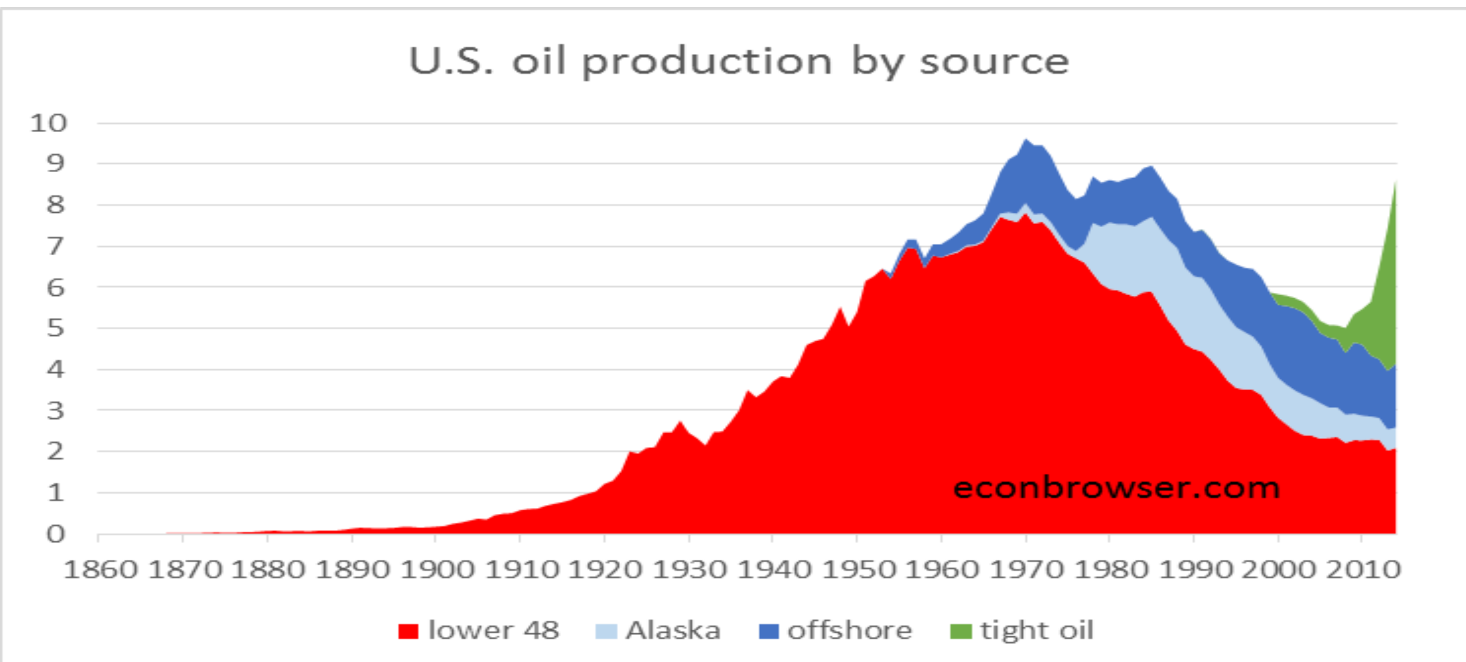
Hubbert is best known for his studies on the size of oil fields. He predicted that, for any given geographical area, from an individual oil field to the planet as a whole, the rate of petroleum production of the reserve over time would resemble a bell curve. Based on his theory, he presented a paper to the 1956 meeting of the American Petroleum Institute in San Antonio, Texas, which predicted that overall petroleum production would peak in the United States between 1965 and 1970. At first his prediction received much criticism; Hubbert became famous when his prediction proved correct in 1970.

USA – 48 central states



In 1974, Hubbert projected that global oil production would peak in 1995 "if current trends continue". Various subsequent predictions have been made by others as trends have fluctuated in the intervening years. But technologies evolve and new oil reserves can be exploited….





We are using limited resources that will not finish tomorrow…

GHG emissions

The oxidation of C-H bonds generates carbon dioxide and water

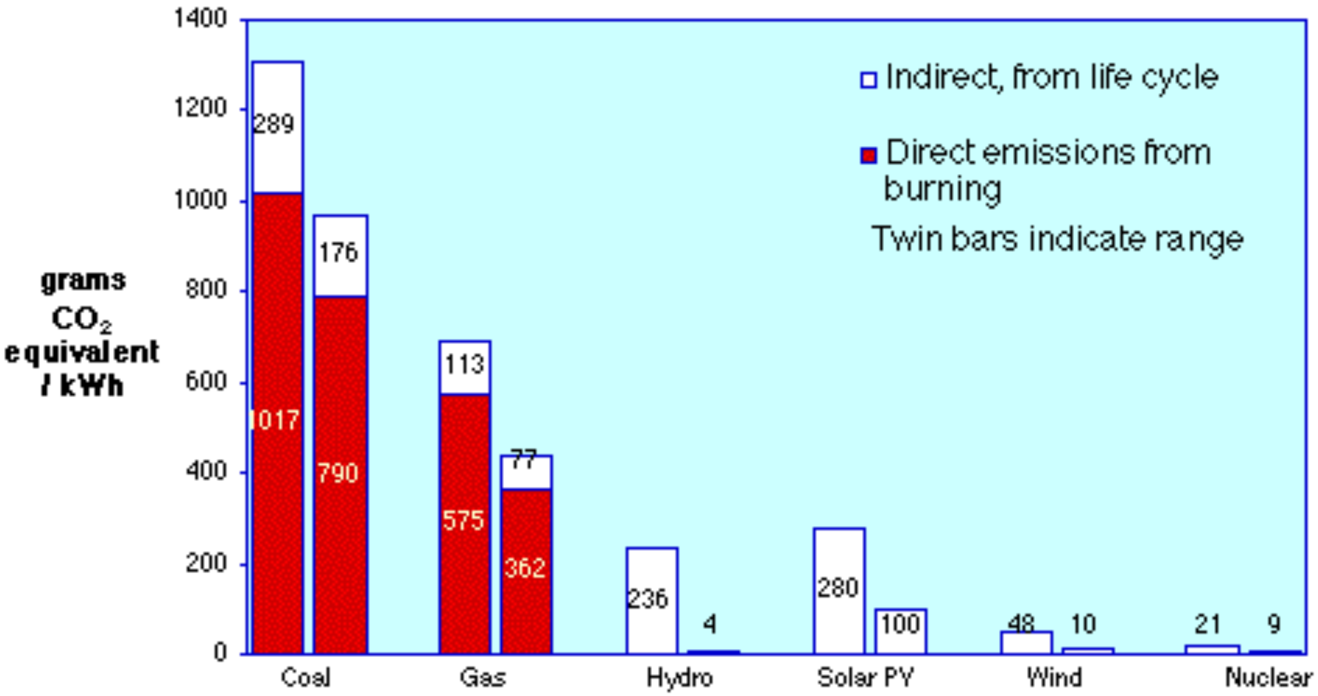
Natural Gas: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ [+ 891 kJ]

1 + 2 = 3

1 Kg Natural Gas

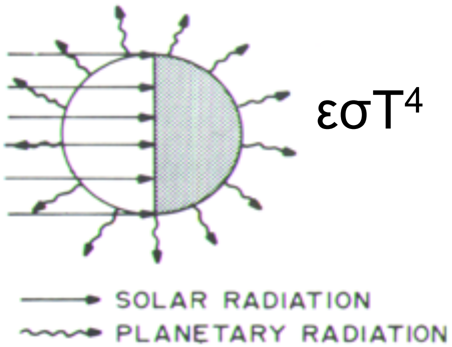
~3 Kg CO_2

Greenhouse Gas Emissions from Electricity Production

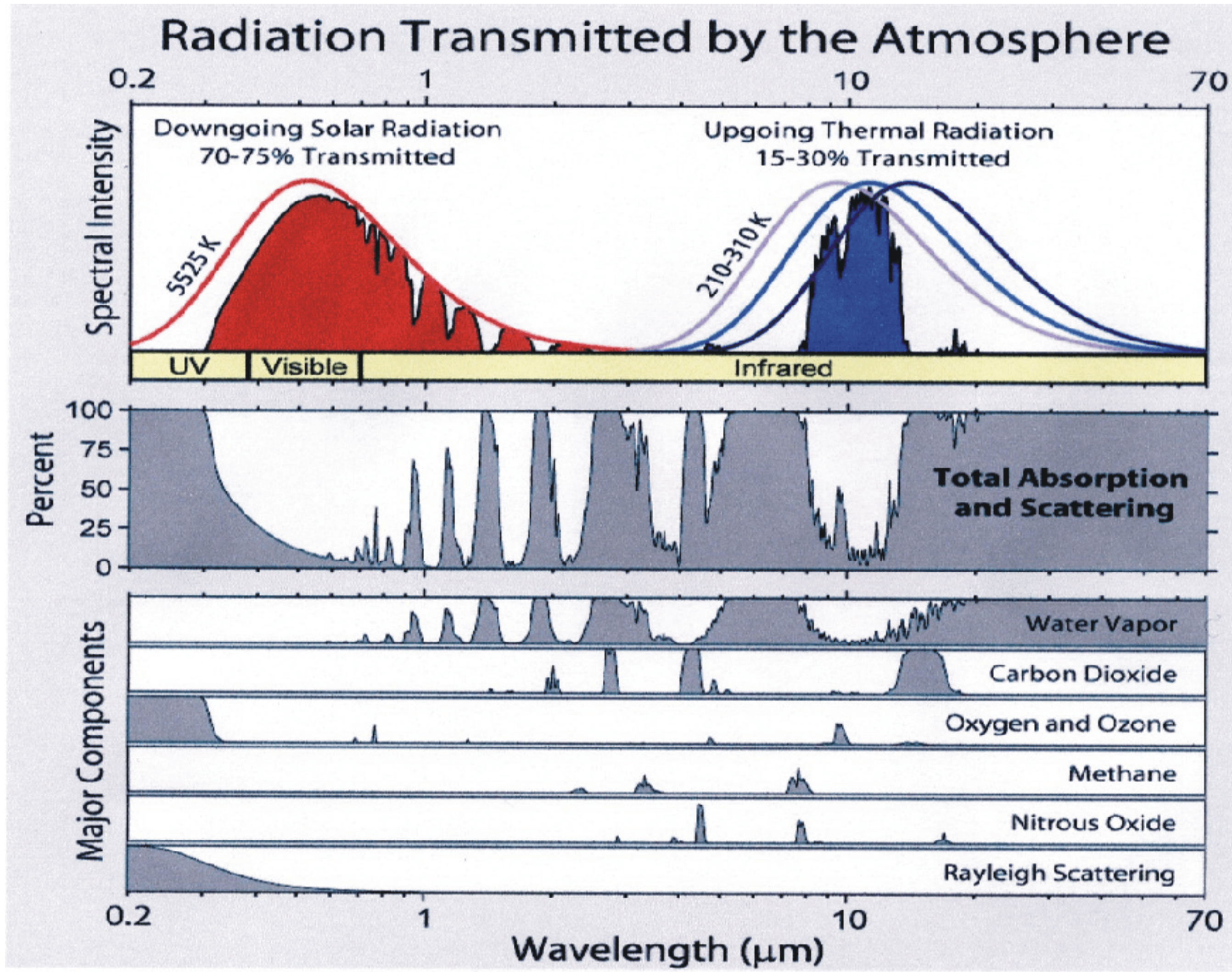


Source: IAEA 2000

GHG contribution



$\varepsilon\sigma T^4$

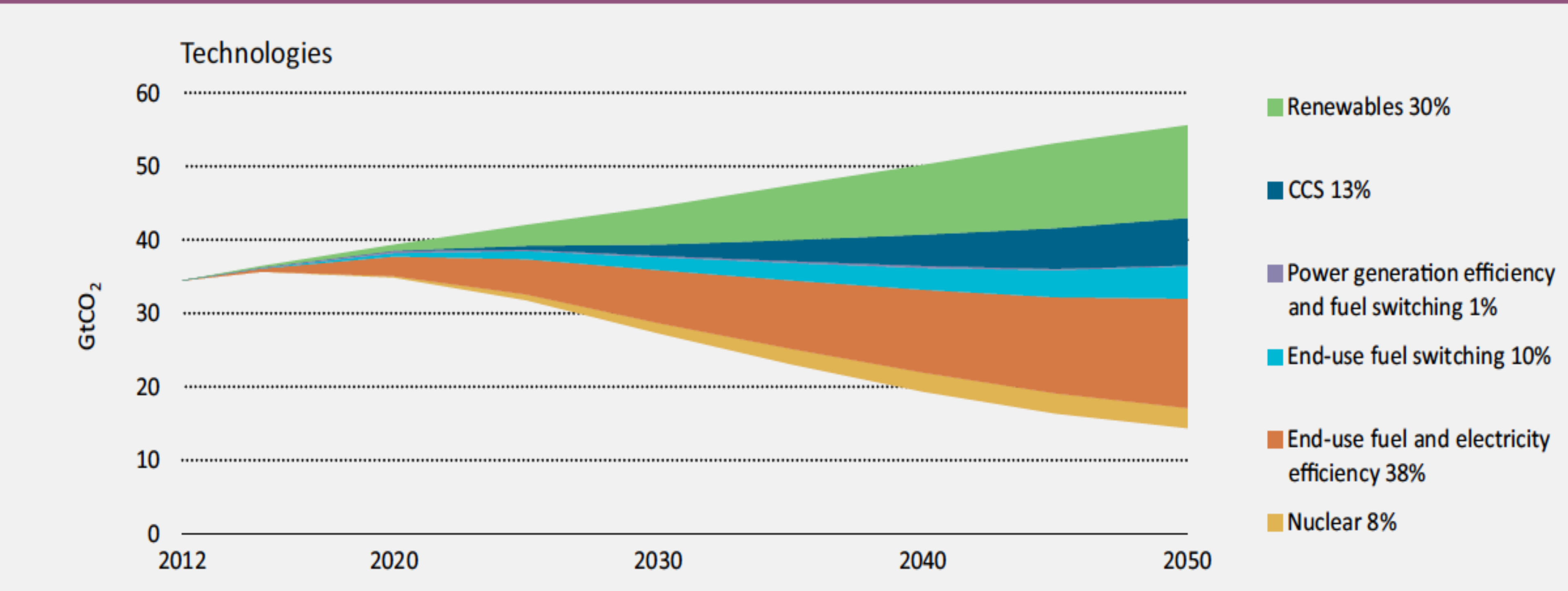


$\Delta F(W/m^2)=5,35 \ln C/C_0$

$\Delta T\ (K) = 0,3\ \Delta FCO_2$

What solutions?

Figure 1.6 Contribution of technology area and sector to global cumulative CO_2 reductions between 6DS and 2DS



Source: Energy Technology Perspectives, 2015, IEA

Renewable Energy Sources (RES)

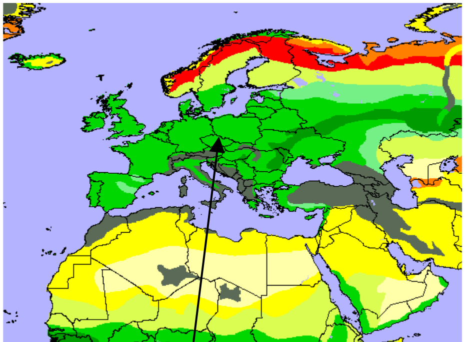
- Solar Radiation (~90000 Gtoe/year)
  - Photovoltaic → Electric Energy
  - Solar thermal/CSP → Heat/EE
  - Photosynthesis → Biomass → Heat/EE/Biofuel
  - Atmosphere int. → Wind → EE
  - Evaporation → Hydro → EE
- Geothermal energy (~25 Gtoe/year)

World primary energy supply ≈13 Gtoe/year
(one Sun hour ≈ world annual energy consumption!)

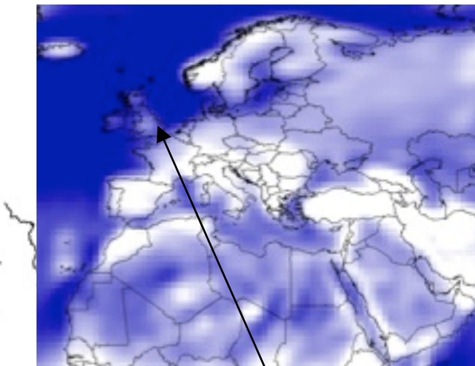
RES in EU-MENA

(Maximal production in $GWh_{el}/km^2/y$)

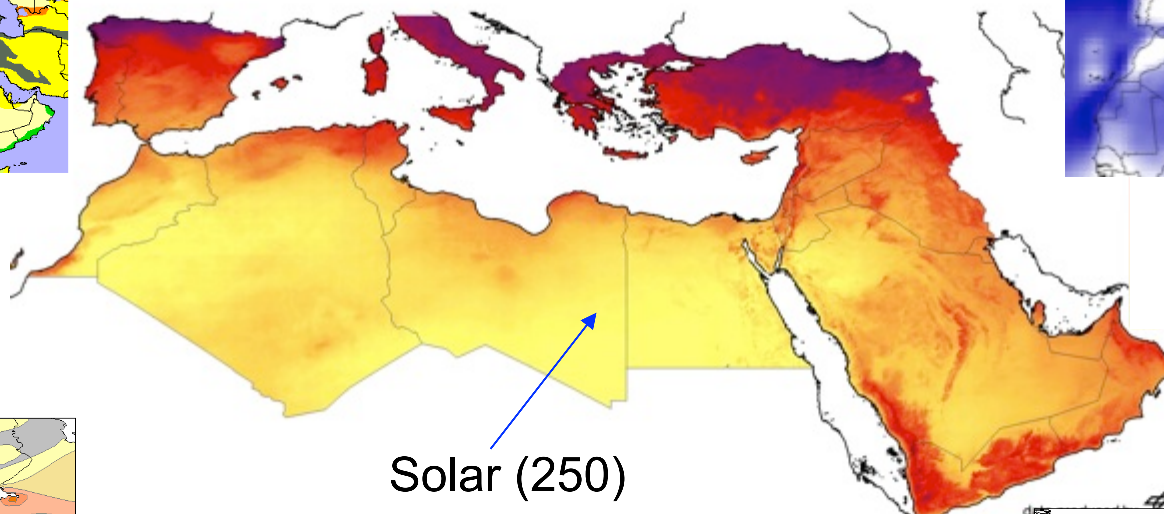
(Fonte: TRANS-CSP, DLR)



Biomass (1)

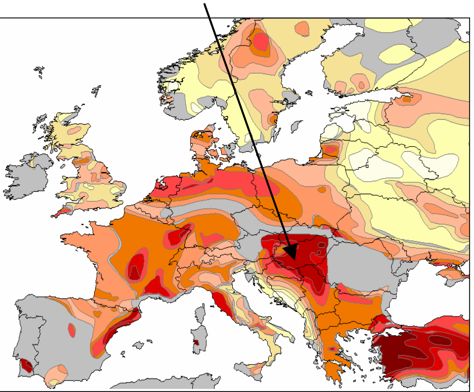


Wind (30)

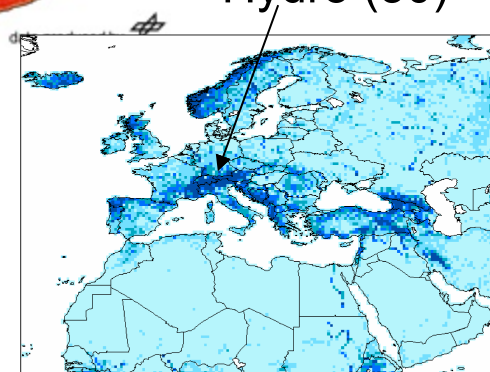


Solar (250)

Geothermal (1)



Hydro (30)

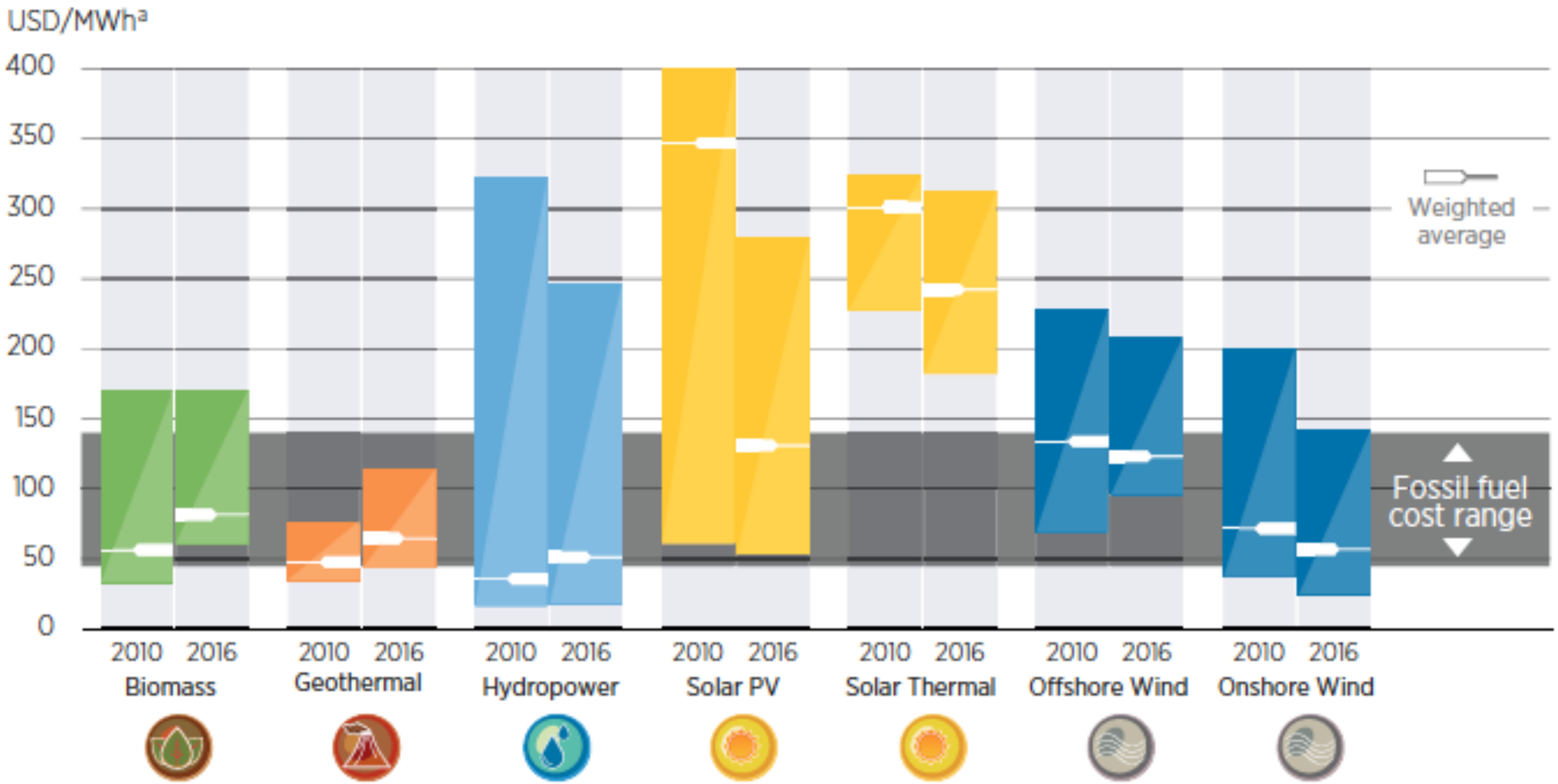


Diluted RES and low efficiency technologies yield to high production costs

1 day italian oil production ≈

1 year solar desert irradiation/Km²

Figure 1.6 Levelised cost of electricity for utility-scale power (ranges and averages), 2010 and 2016



Note: a) MWh: megawatt-hour

b) All costs are in 2016 USD. Weighted Average Cost of Capital is 7.5% for OECD and China and 10% for Rest of World

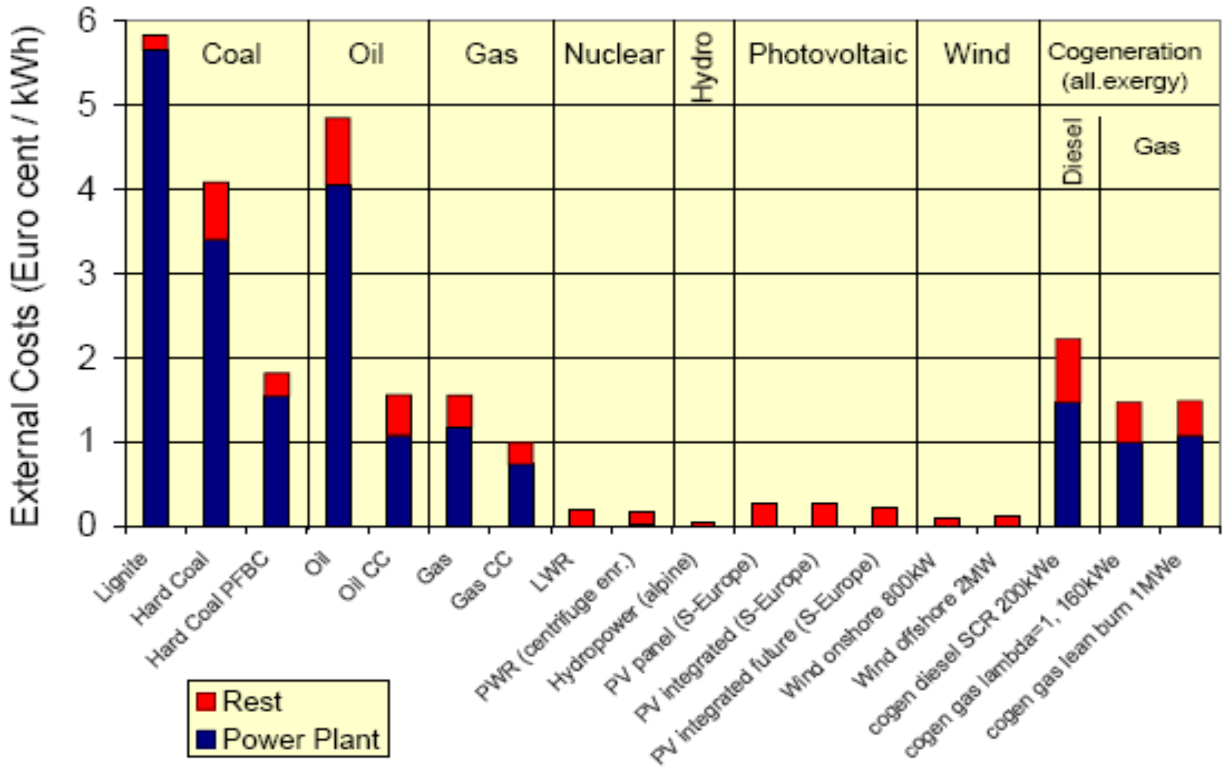
Source: Rethinking Energy 2017, IRENA (International Renewable Energy Agency)

External energy production costs

The external costs are defined as those incurred in relation to health and the environment and quantifiable but not built into the cost of the electricity to the consumer and therefore which are borne by society at large. They include particularly the effects of air pollution on human health, crop yields, as well as occupational disease and accidents

Fig.9. External costs of current and advanced electricity systems, associated with emissions from the operation of power plant and with the rest of energy chain.

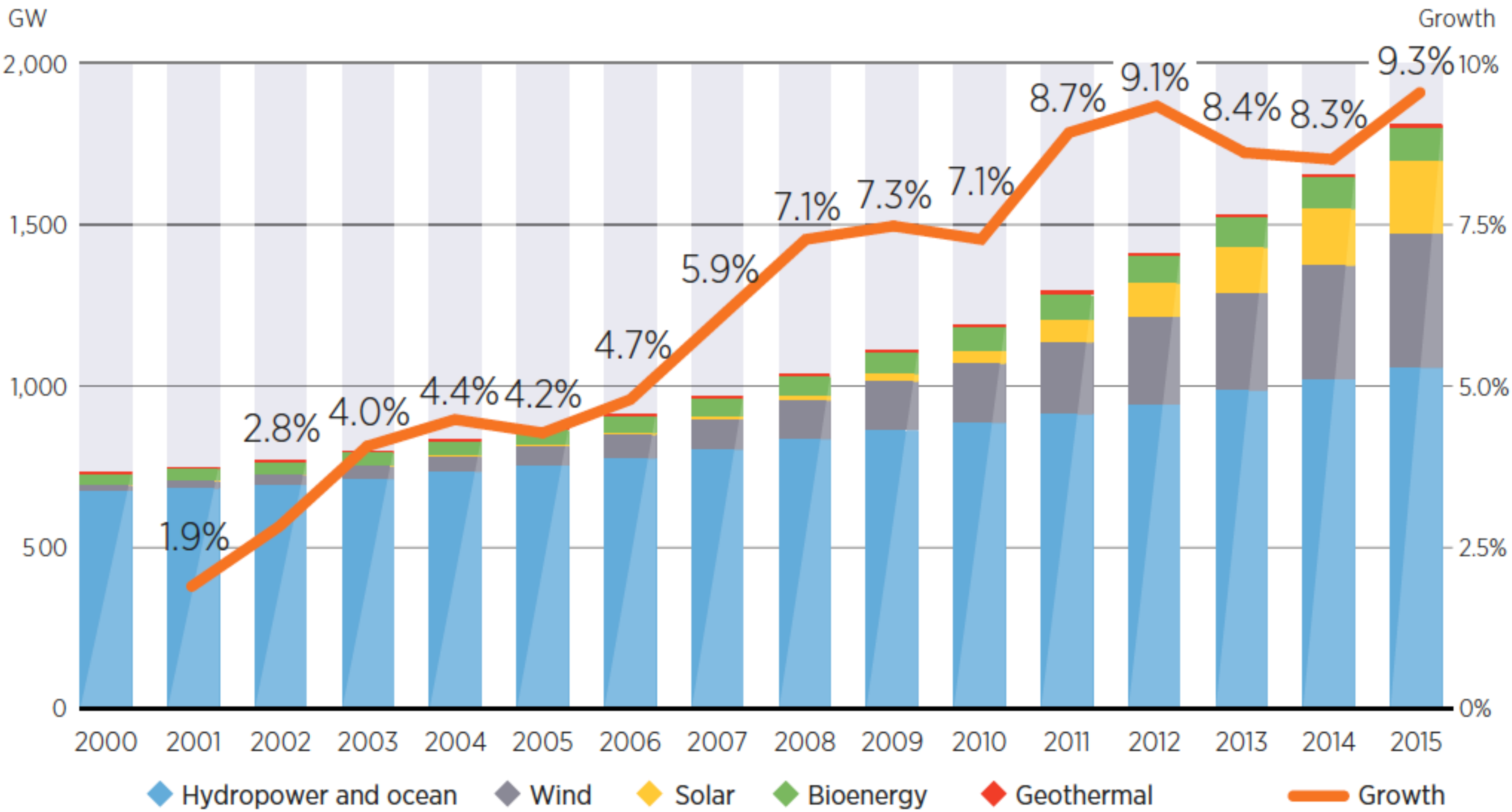
a) the costs in €cent/kWh



Externalities of Energy: Extension of accounting framework and Policy Applications

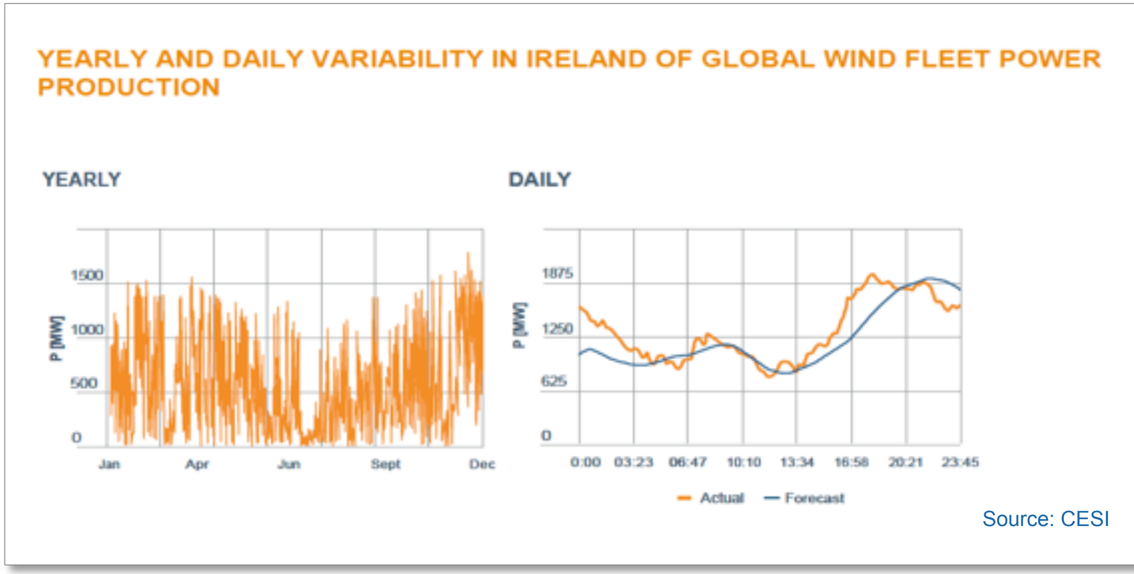
Externalities of Energy: Extension of Accounting Framework and Policy Applications – Final Technical Report – Version 2, August 2005. European Commission (2005).

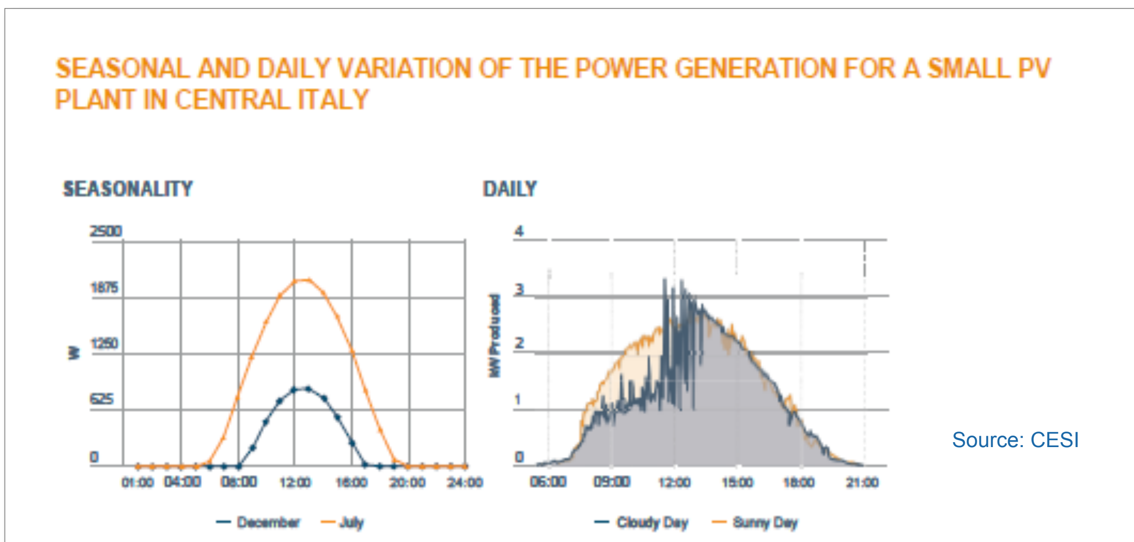
Figure 1.2 Renewable power capacity and annual growth rate, 2000-2015



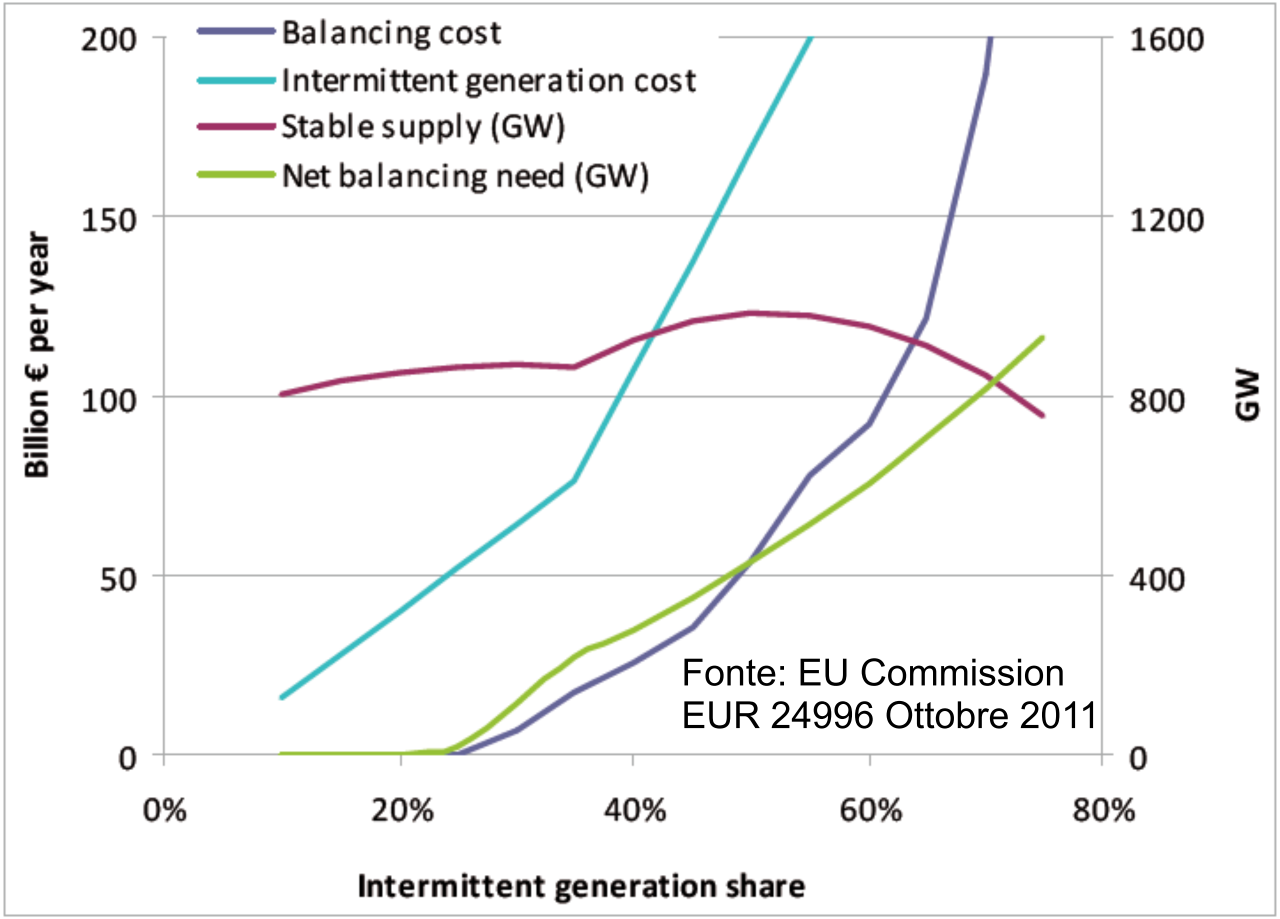
Source: IRENA, 2016b

RES impact (costs) on transmission grids
(variable nature of wind and sun)





Credits to:
A.Clerici, CESI



The policy implication of this analysis is that there are clear limits to the deployment of intermittent generation technologies in the EU-27. Furthermore, a corresponding upper threshold is estimated to be around 40% for the share of intermittent generation capacity in both a 2030 and 2050. Beyond this share, costly additional preventive measures will have to be taken in order to guarantee power system stability.

Overall, the abatement (balancing) costs are relatively low until 40% of intermittent generation, where the abatement costs are estimated to be 25 billion Euros per year. This is equivalent to a 23% cost increase on top of the "levelised costs" of intermittent generation. Once the share of intermittent generation goes up further, the abatement costs begin to increase exponentially. The abatement costs become significantly high beyond a share of 62% intermittent generation. At this point the abatement costs are estimated to be over 100 billion Euros per year, which is equivalent to a 42% cost increase on top of the "levelised costs" of intermittent generation.

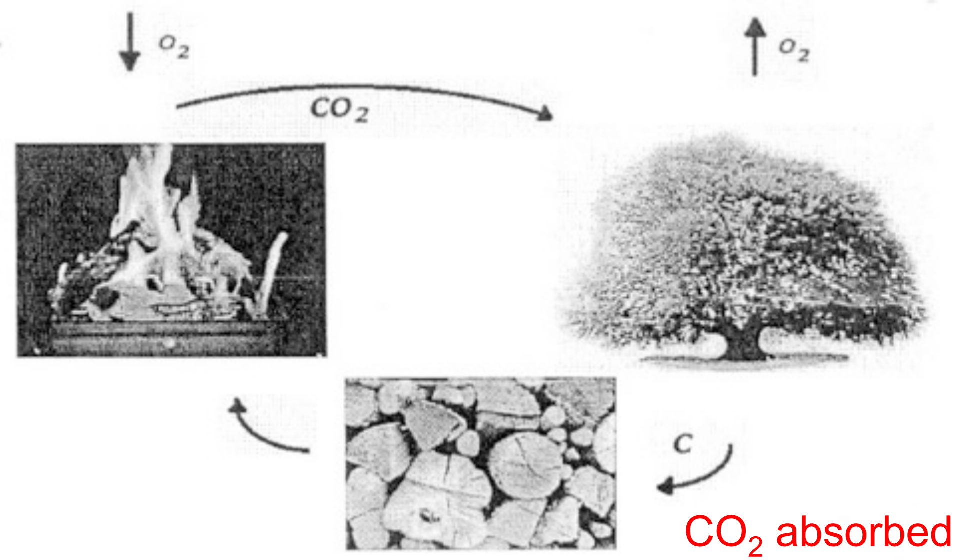
Biomass

"Organic matter from animal or vegetable origin, excluding the organic matter of fossil origin"

Closed CO_2 loop with photosyntesis:

Carbon dioxide ($6CO_2$) + Light + Water ($6H_20$) =

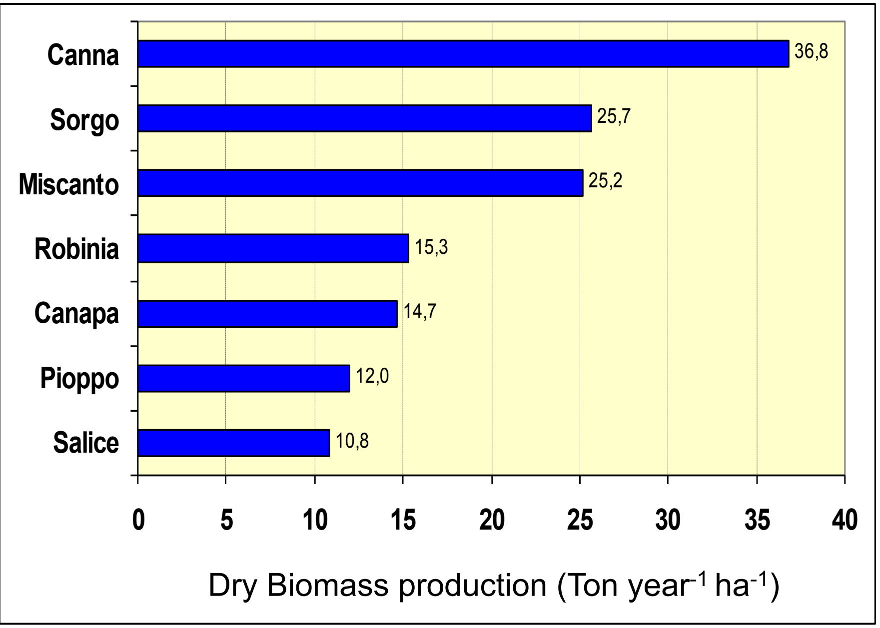
= Sugars ($C_6H_{12}O_6$, Energia) + Oxigen ($6O_2$)

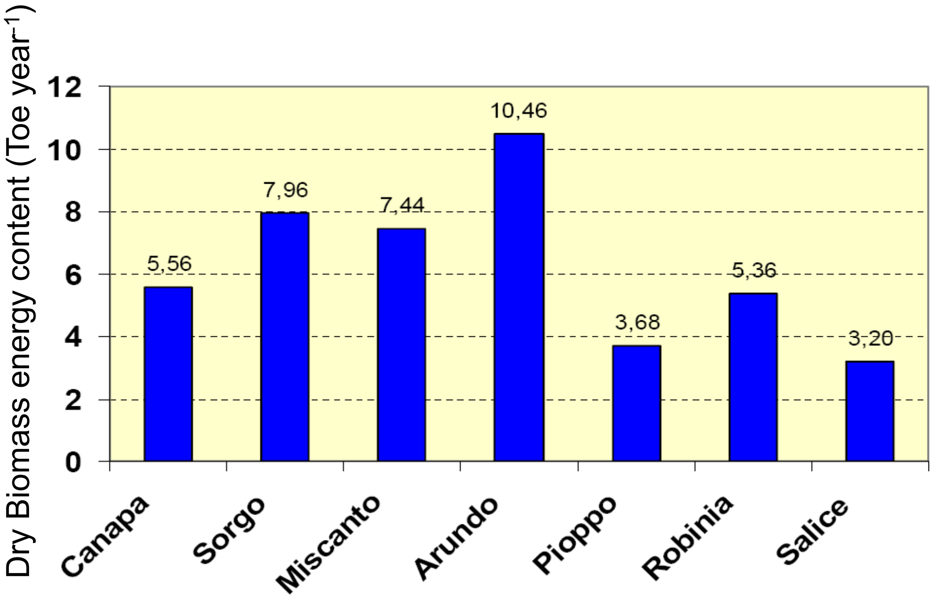


CO_2 absorbed by a forest...

Biomass "conversion efficiency"

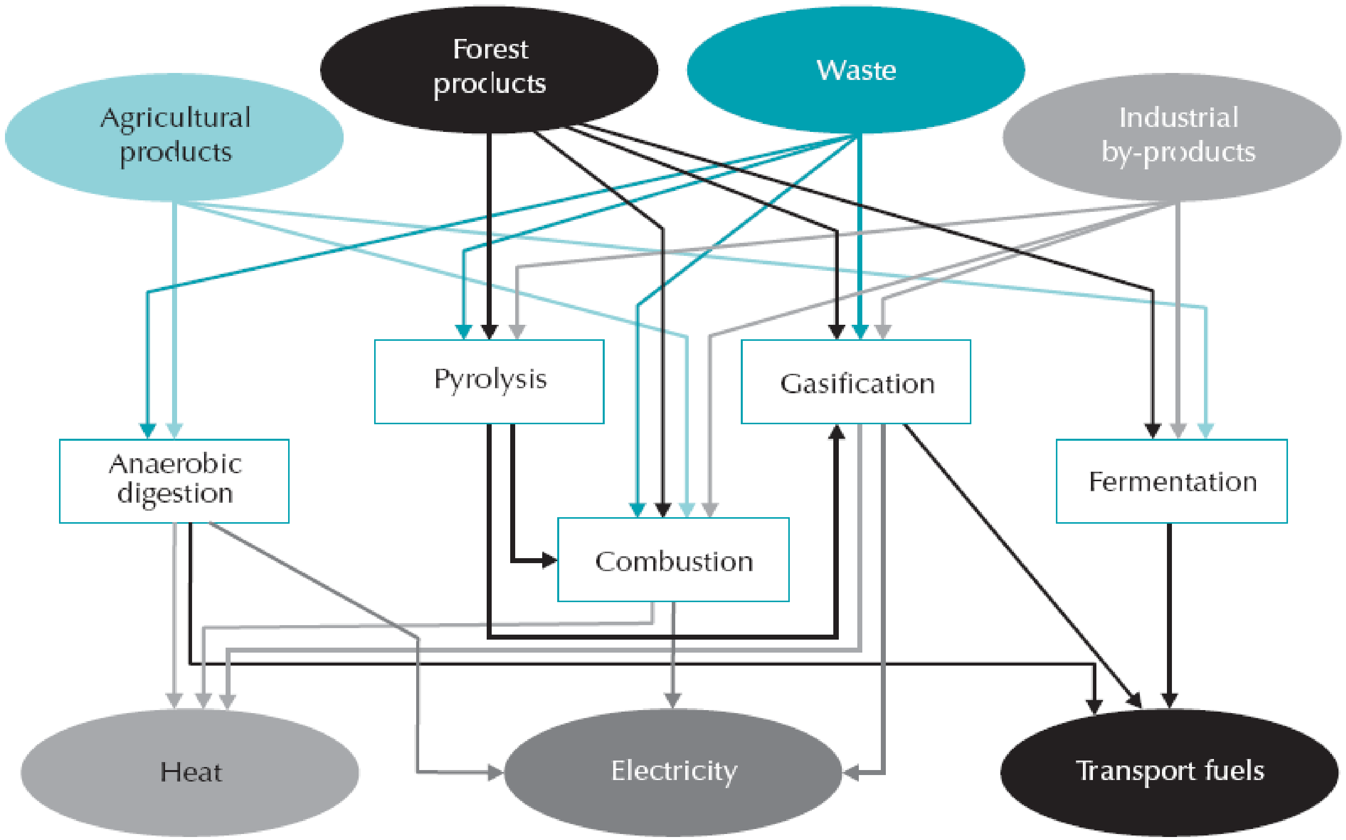
The global radiation power from the Sun averaged over 24h is about 250 W/m^2: evaluate the biomass "conversion efficiency"



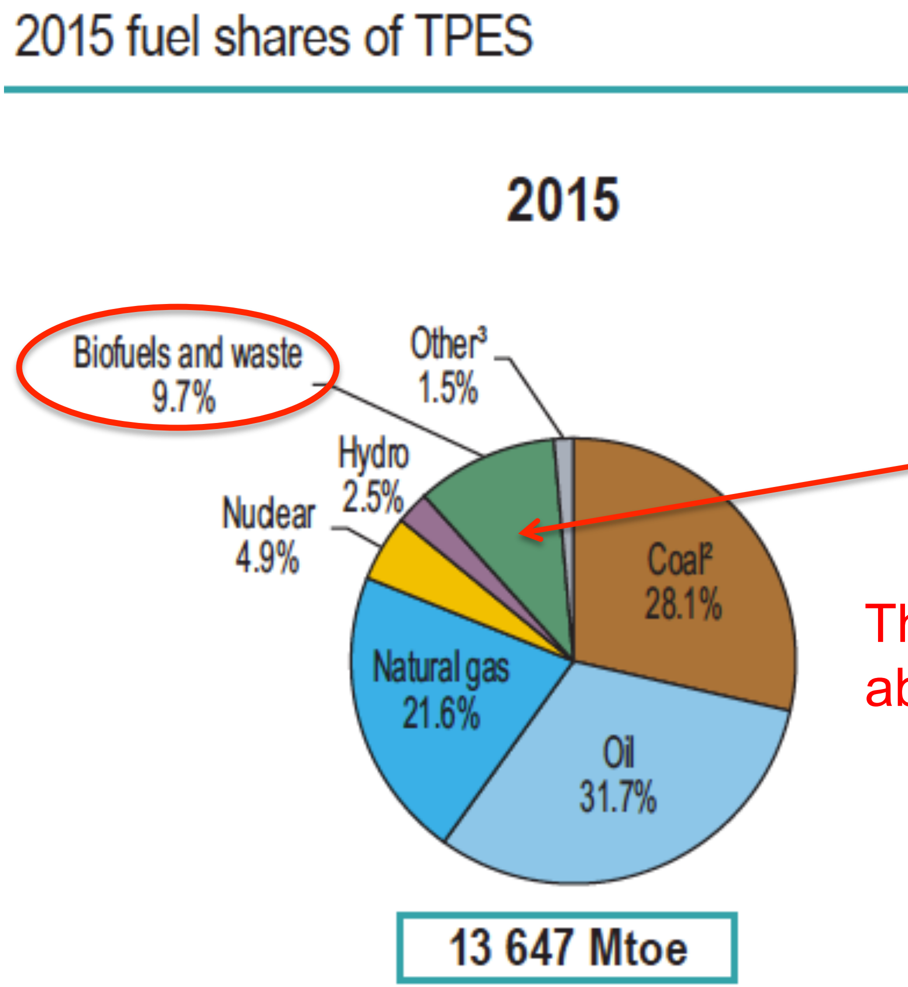


Energy from Biomass

A family of very different substances that need very different technologies for their conversion, giving very different products.



Biomass

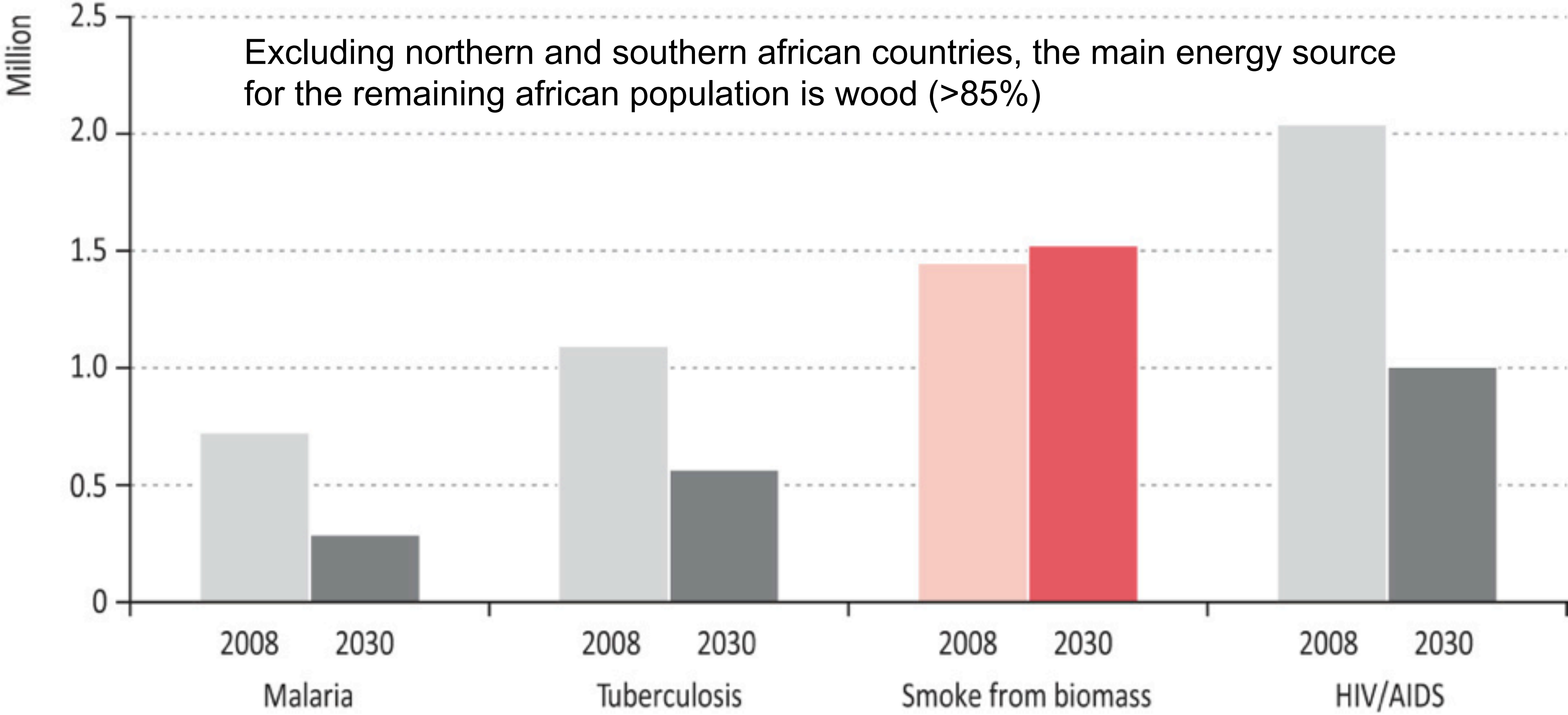


Less than 100 Mtoe are biofuels and about 40 Mtoe of electricity are produced from biomass

The main part of biomass in the world, about 9% of TPES, is used for heating

Excluding northern and southern african countries, the main energy source for the remaining african population is wood (>85%)…

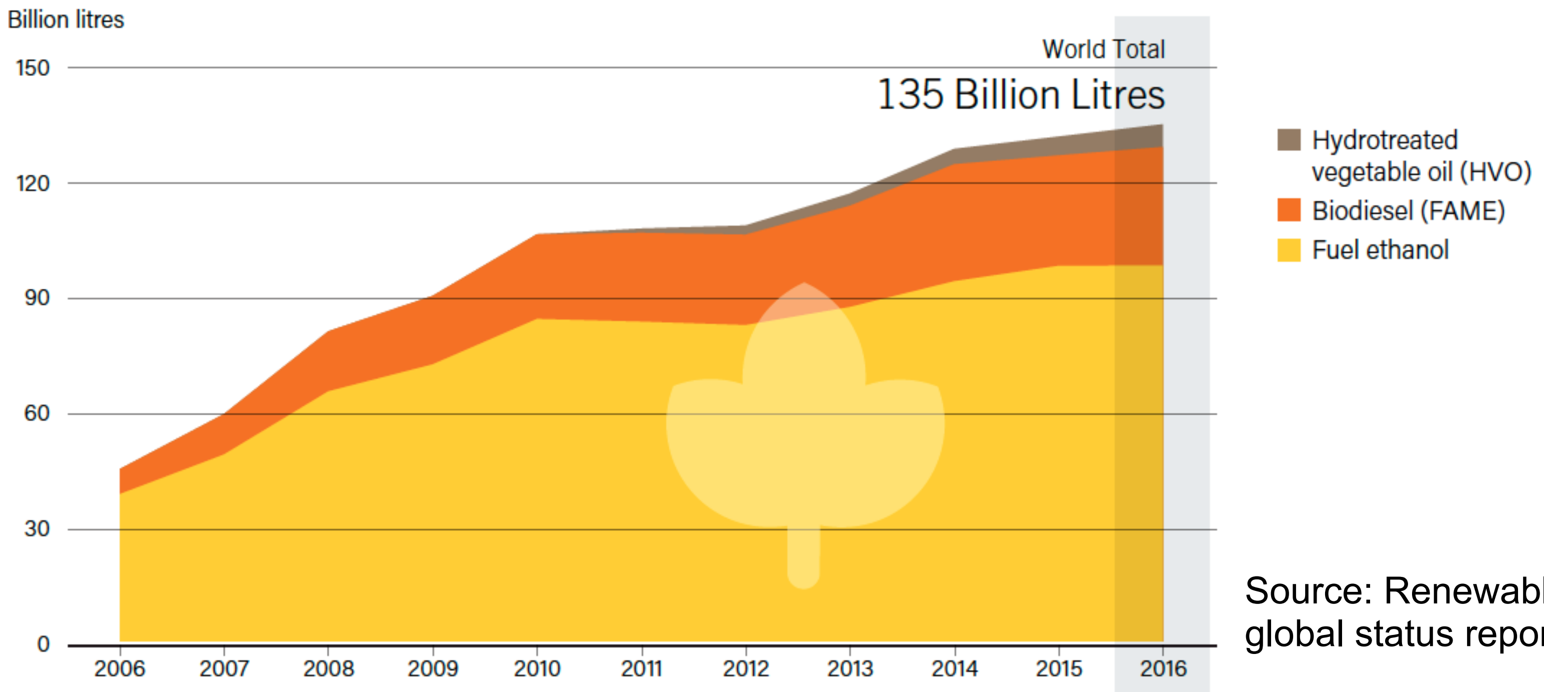
Premature annual deaths from household air pollution and selected diseases in the New Policies Scenario, 2008 and 2030



Source: IEA WEO 2011

Biofuels

Figure 9. Global Trends in Ethanol, Biodiesel and HVO Production, 2006-2016

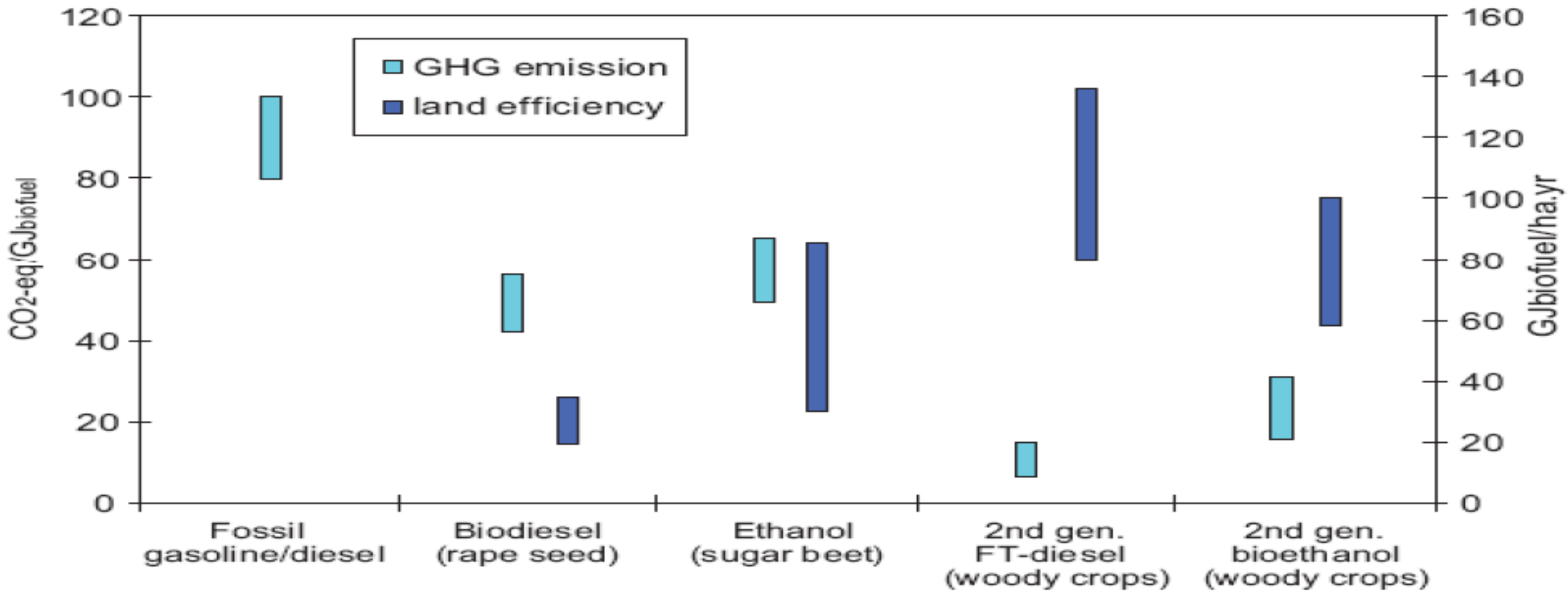


Source: Renewables 2017 global status report, REN21

One important limit is the conflict with food crops and their dedicated resources (fertile soil and water): to increase volumes, it is essential the introduction of the so-called second-generation technologies, able to produce biofuels from non-food biomasses and available in much larger quantities.

Second generation biofuels

A class of these biomass is represented by ligno-cellulosic biomasses: they are the carrier structures of the plant cells and are formed up to 50% by cellulose. By creating barriers to the external environment, these structures are unlikely to be attacked by microbiological agents: studies on their "digestion" are fundamental.



Source: REFUEL project, 2008

Biomass energy convertion efficiency~1%, biofuels ~0,1%...algae ~10%

Third generation biofuels (from algae)

As an alternative to ligno-cellulosic biomass, production processes of algae-based biofuels are currently being studied. The interest for algae is at their very high growth and reproduction speed, which results in an high productivity. Some studies report that some types of algae can produce from 30 to 50 times the biodiesel that can be obtained from a plantation of oilseeds. An important role in the search for advanced solutions for the production of biofuels can be played by genetic engineering technologies.

Open ponds

COMPARISON BETWEEN CROP EFFICIENCIES: THE BIODIESEL EXAMPLE

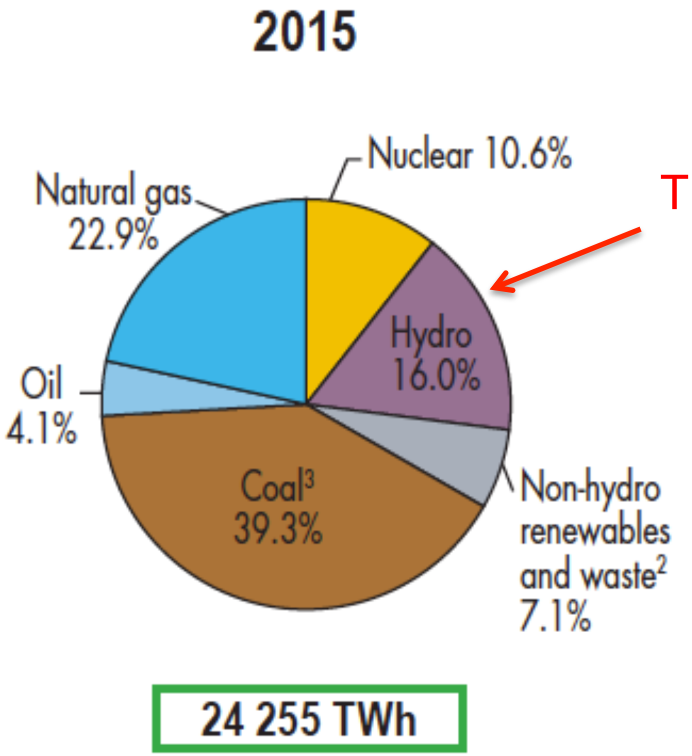
Plant Source	Biodiesel L/Hect/Year	Area required to match current global oil demand million hectares
Soybean	446	10932
Rapeseed	1190	4097
Mustard	1300	3750
Jatropha	1892	2577
Palm Oil	5950	819
Algae Low 1%	45000	108
Algae High 4%	137000	36

Closed bio-reactors

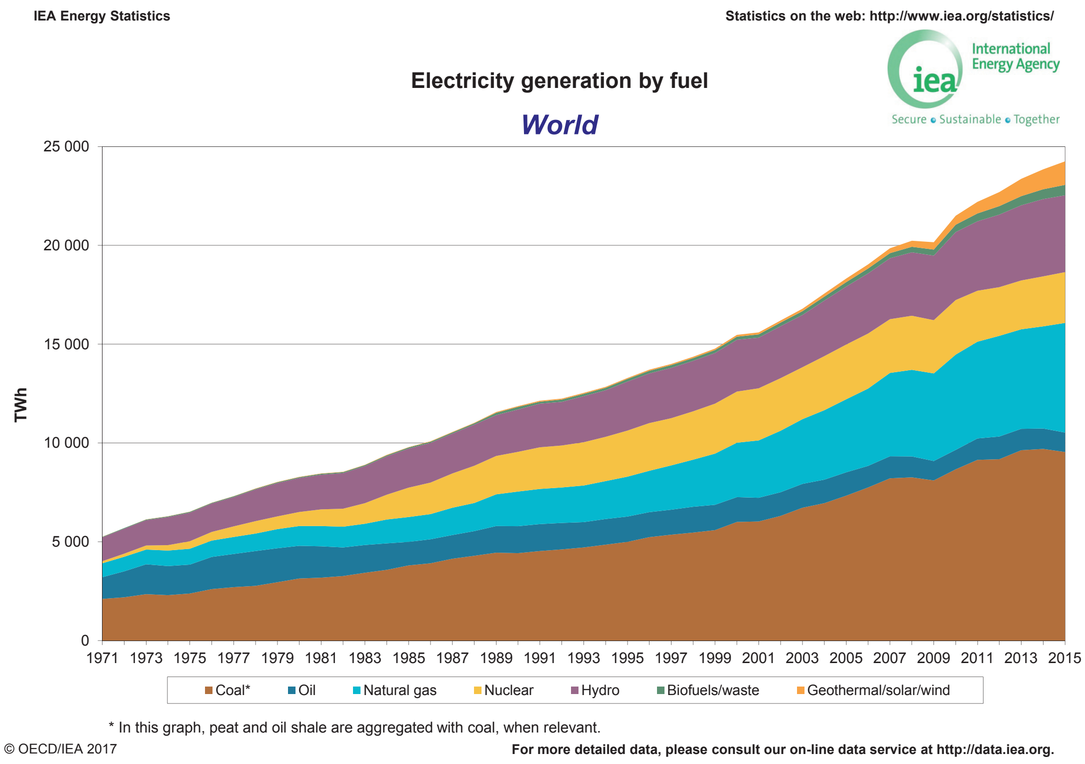
Problem: price for cultivation is currently too high

G.Alimonti

Hydroelectric energy



The most important RES for electricity production



Hydroelectric energy

The water potential energy, mgh, is directly converted to EE

$1kWh = 3.6x10^6 J = mgh(\varepsilon=100\%) = 10^3 Kg \times 9,8 m/sec^2 \times 367 m$

Water flow or hydroelectric jump

The use of water is one of the oldest forms of exploitation of natural energy, originally developed by transforming the energy of the water flow into mechanical energy. With the rapid spread of electricity at the end of the XIX century, an even more intensive exploitation of this resource started; transformation into electricity replaced the conversion into mechanical energy.

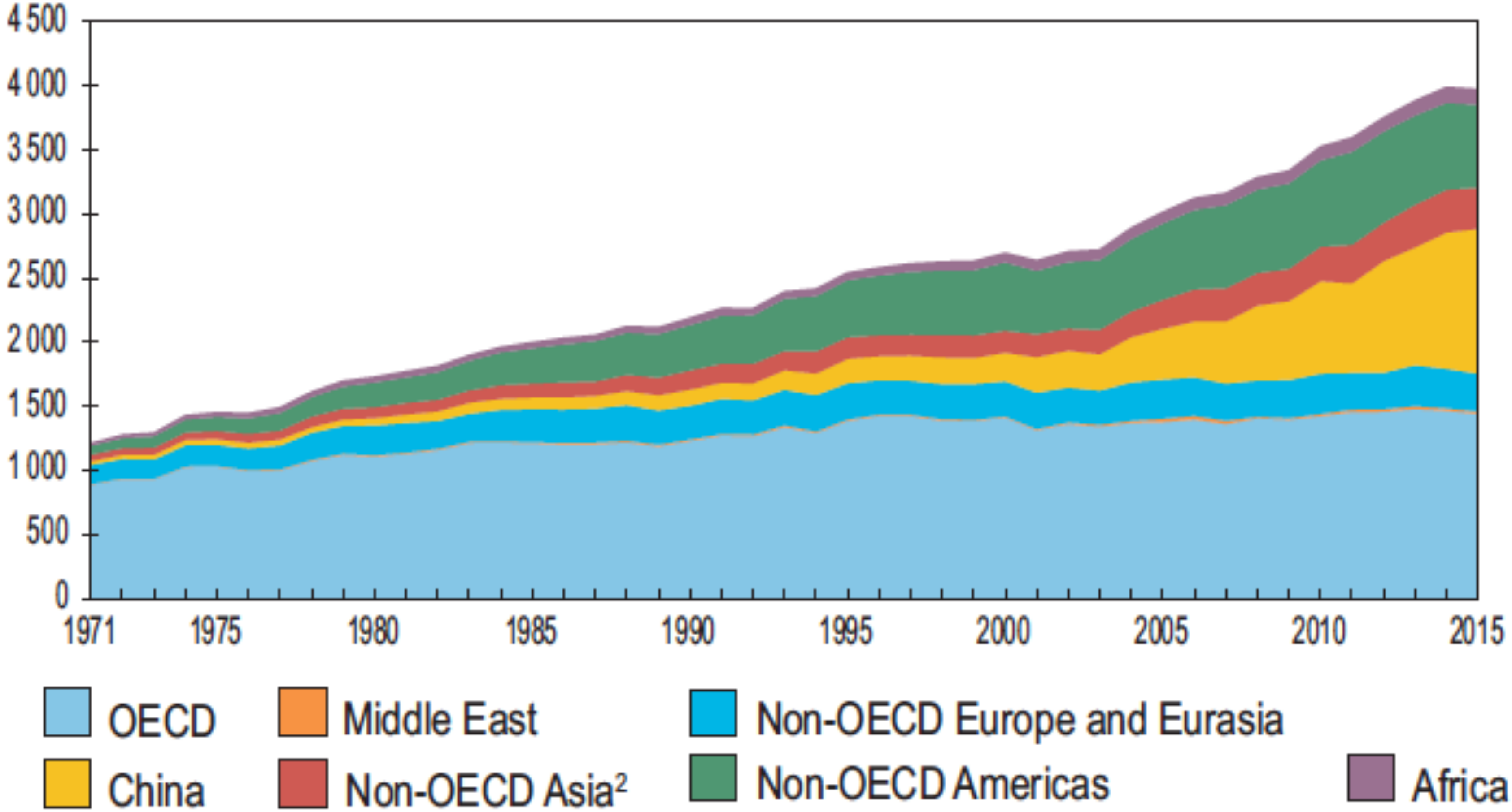
Three Gorges Dam

Lake surface	108.400 ha
Dam hight	175 m
Power	18.200 MW (!!)
Annual production	84.7 TWh

Assuan Dam, 1970.

Lake surface	650 000 ha
Dam hight	111 m
Power	2100 MW
Annual production	10 TWh
Irrigated area	700 000 ha

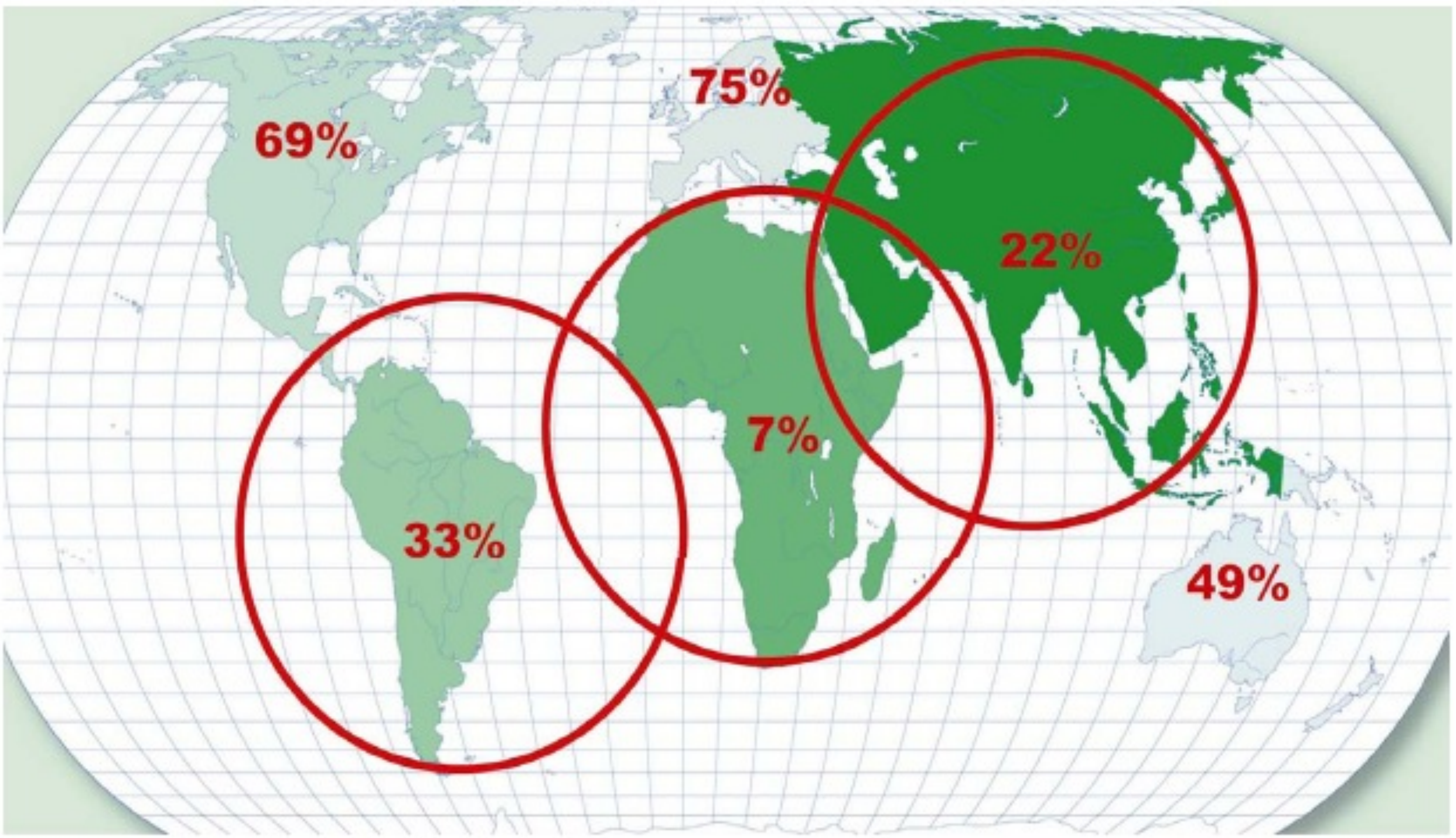
World hydro electricity production[1] from 1971 to 2015 by region (TWh)



1. Includes electricity production from pumped storage.

2. Non-OECD Asia excludes China.

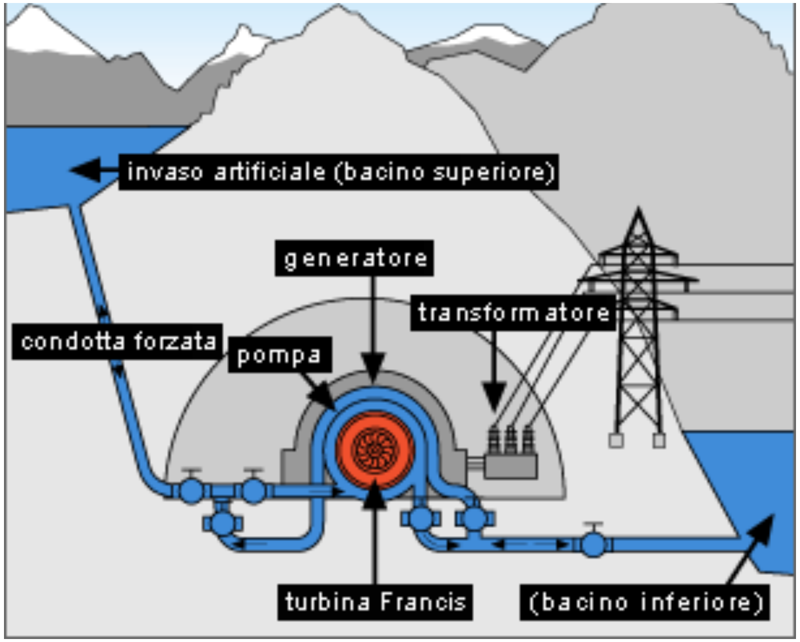
Hydropower: Usage / Potential



Energy storage

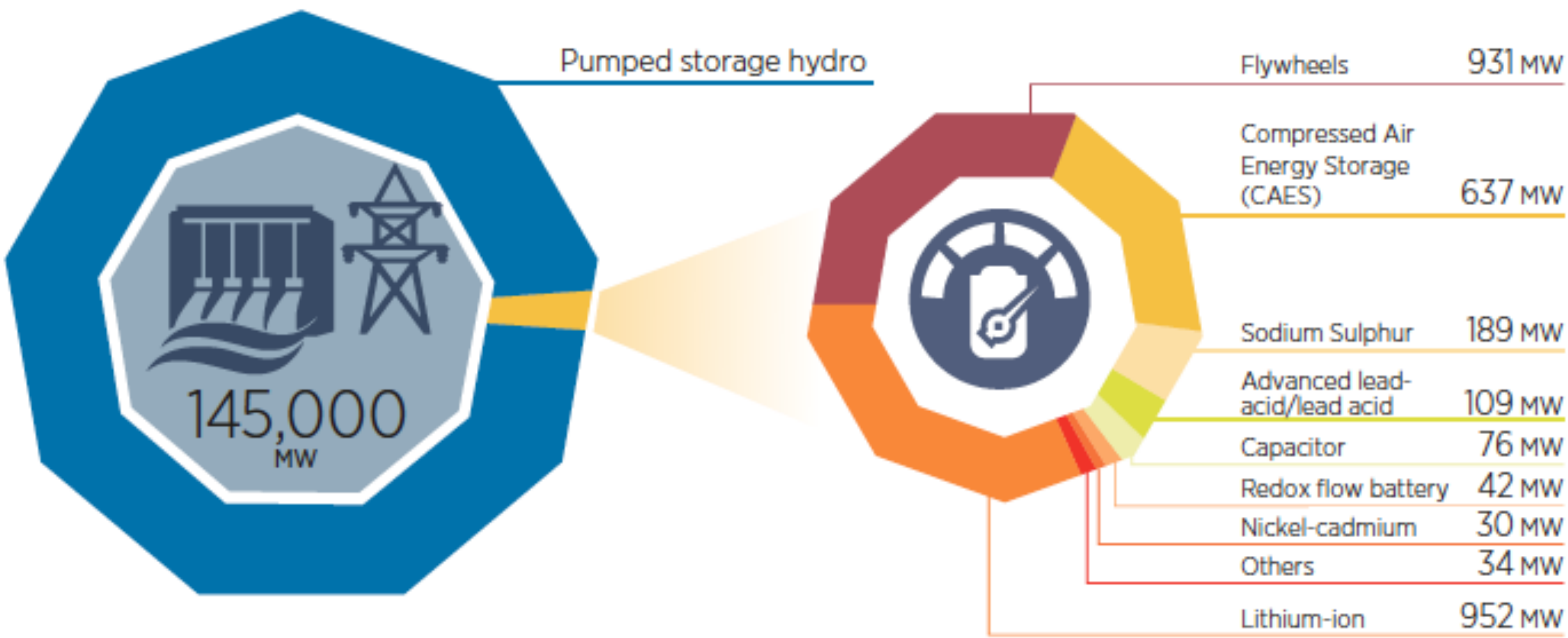
Hydroelectric plants are characterized by reliability and flexibility of operation, by a starting and stopping time limited to a few minutes. The technology is mature, extensively tested, the components have a long life and malfunctions are normally rare. Plant management generally requires little personal, because you can make it work entirely via remote control.

Hydro plant with pumped storage



They also offer the ability to store energy when not required by the network and to return EE in times of high demand.
The efficiency of the process is around 75%

Figure 4.5 Share of various storage technologies in global electricity storage system (MW)



Note: Pumped storage data are for 2016; other data are for 2014.
Source: IRENA, 2015h; pumped storage data from IHA, 2016

30 MW pilot pant.
Okinawa, Japan

Wind energy

About 2% of the solar energy falling on Earth is transformed into wind energy: this is about 200 times the global energy consumption.

Wind energy

About 2% of the solar energy falling on Earth is transformed into wind energy: this is about 200 times the global energy consumption.

The evolution of the wind turbines has led over the past 30 years to a cost reduction per installed power in the order of 75% favoring its strong development.

5MW wind turbine with a rotor diameter of more than 120 m.

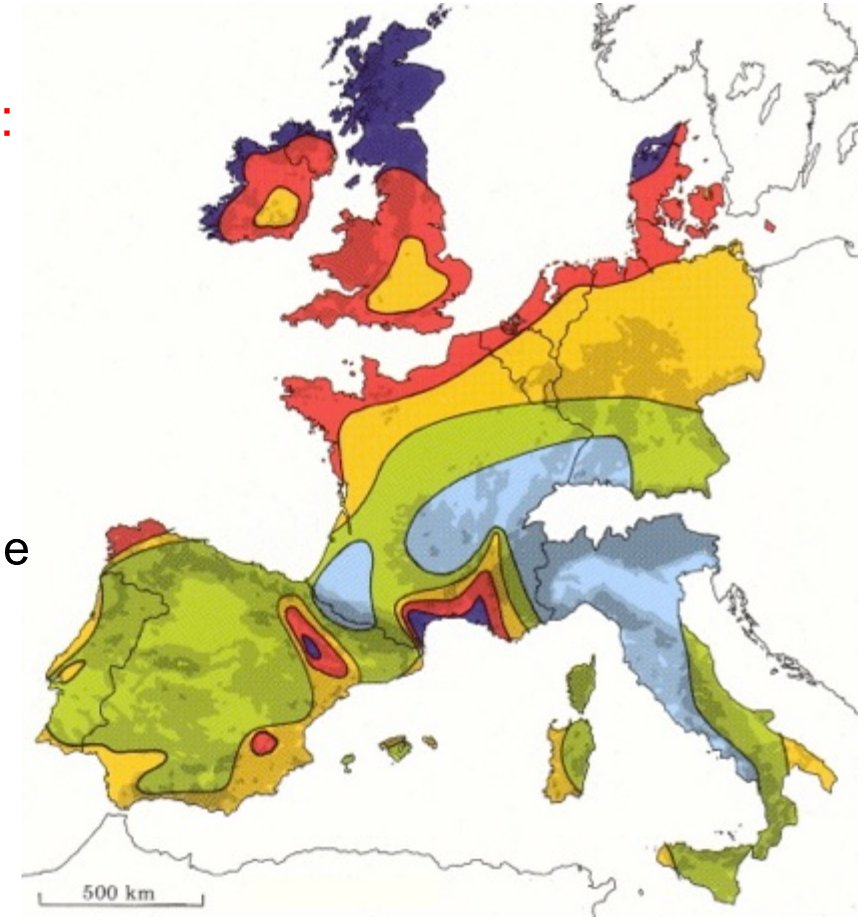
Wind KWh cost

Wind is fairly intense and regular only in few places on Earth to produce EE: it is estimated that only about 5% of wind energy potential may be exploited, but this is still about 10 times the global energy demand.

It's production cost depends heavily on operating hours and average wind speed:

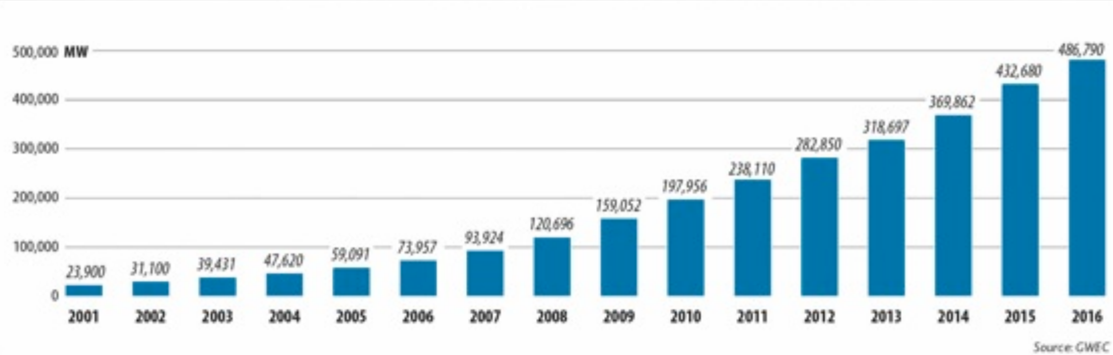
$$P = 0{,}593 \cdot \frac{\rho}{2} \cdot \pi \cdot V^3 \cdot \frac{D^2}{4}$$

In particularly favorable conditions (sites have been identified in Ireland where the equivalent operating time reaches 3500 hours per year) the energy cost may be less than 35 € / MWh.



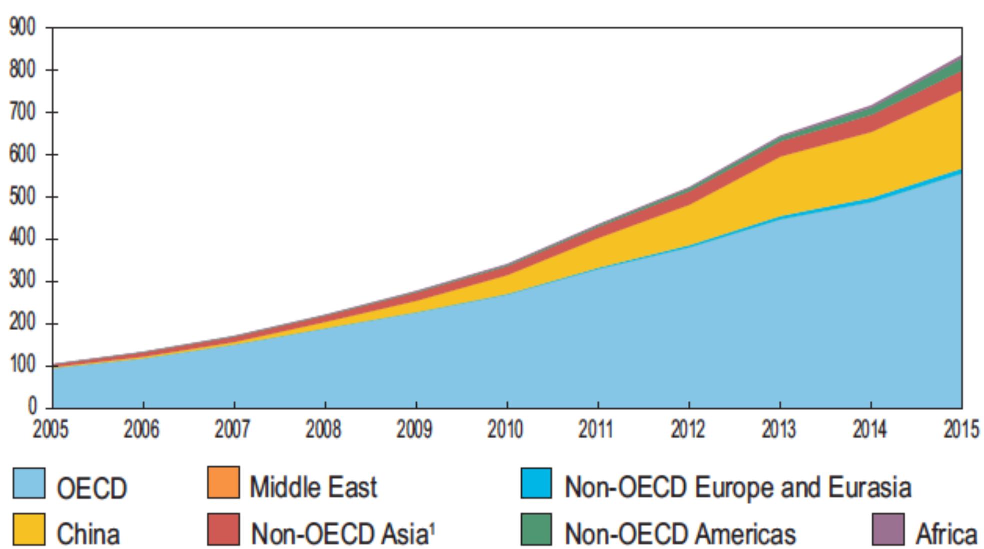
Wind global installed power

GLOBAL CUMULATIVE INSTALLED WIND CAPACITY 2001-2016

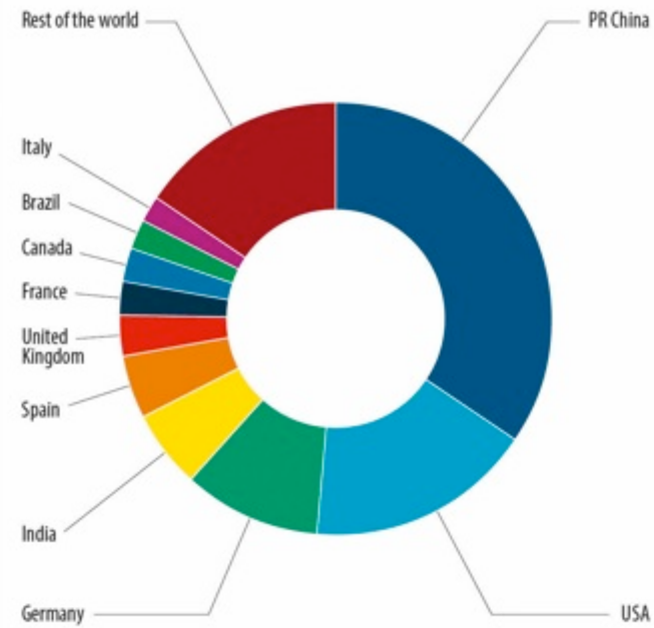


Source: GWEC

World wind electricity production from 2005 to 2015 by region (TWh)



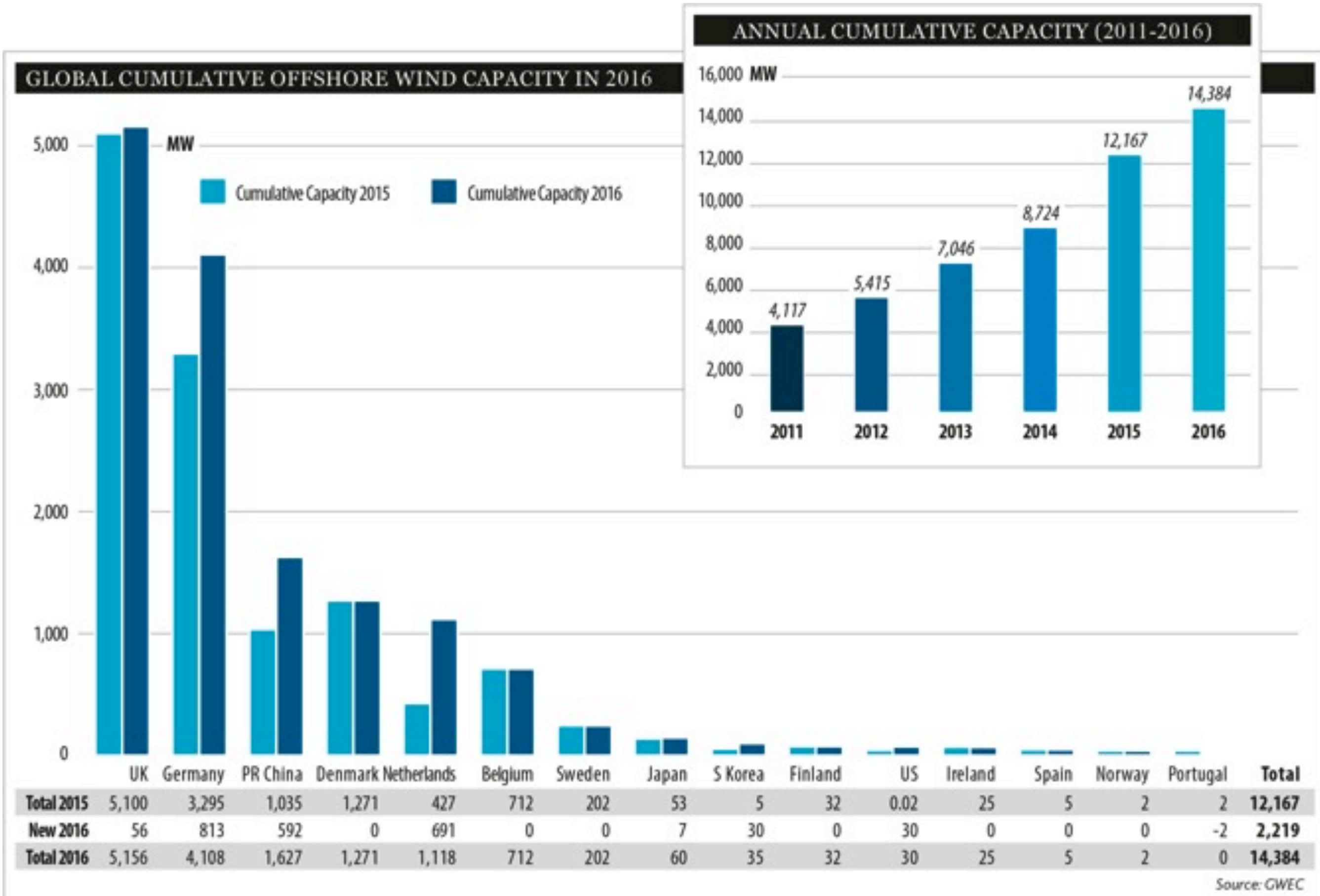
TOP 10 CUMULATIVE CAPACITY DEC 2016



Country	MW	% Share
PR China	168,732	34.7
USA	82,184	16.9
Germany	50,018	10.3
India	28,700	5.9
Spain	23,074	4.7
United Kingdom	14,543	3.0
France	12,066	2.5
Canada	11,900	2.4
Brazil*	10,740	2.2
Italy	9,257	1.9
Rest of the world	75,576	15.5
Total TOP 10	**411,214**	**84**
World Total	**486,790**	**100**

Source: GWEC

Off-shore Wind Energy

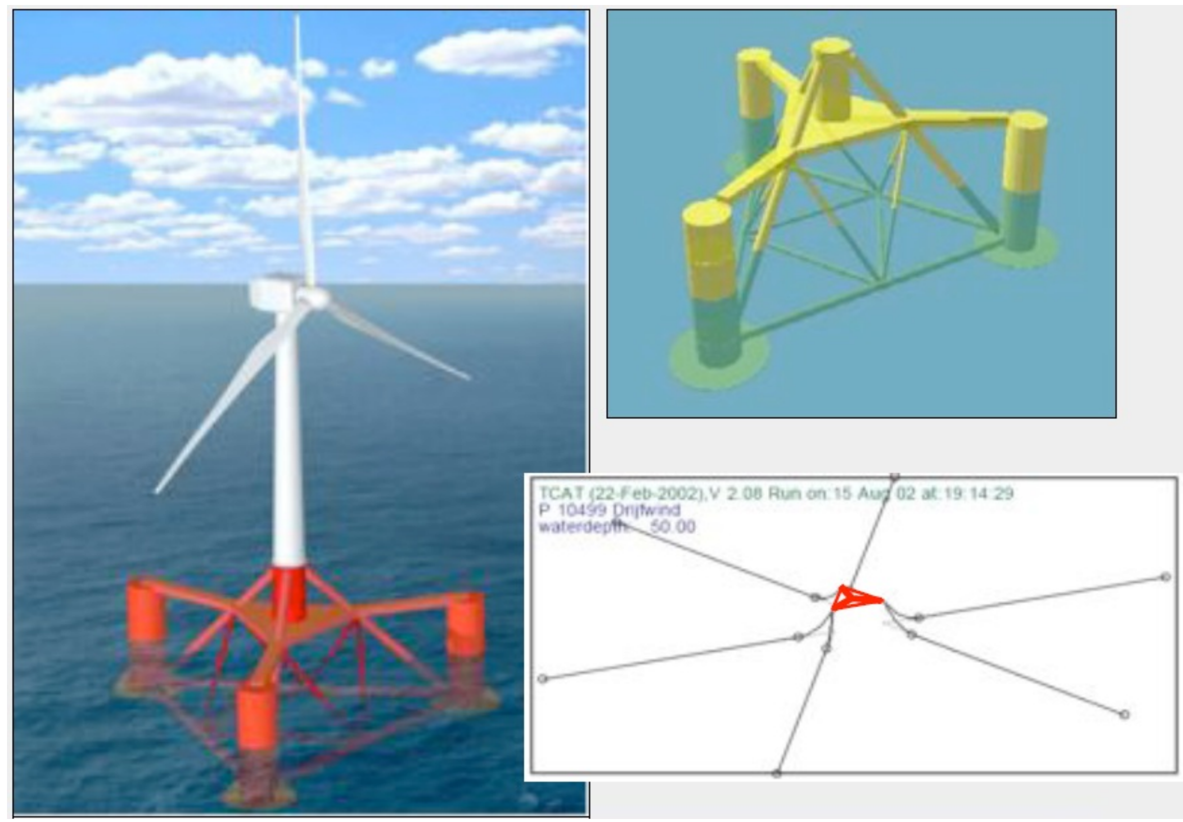


Limited by the sea bottom depth

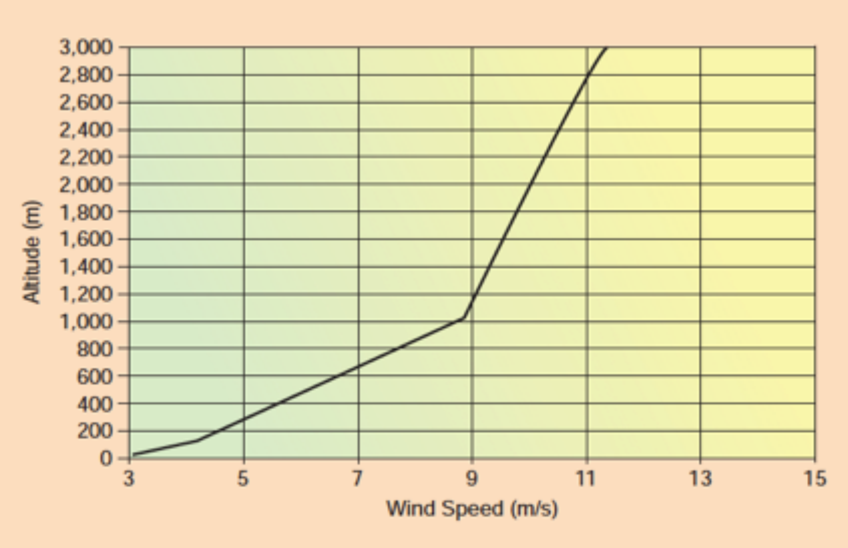
Wind off-shore… tomorrow?

Project for a 5 MW unit for sea depth > 50 m: weight 700 t.

Platform with 3 cylindrical floats (diameter 8 m, height 24 m) arranged at the vertex of a 68 m side triangle, 6 mooring lines.
Total weigh 2430 tons

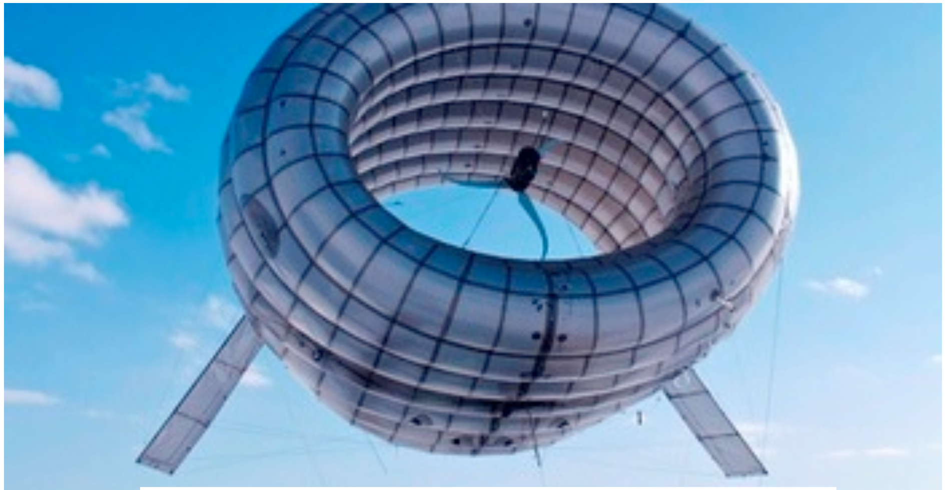


High-altitude wind power…



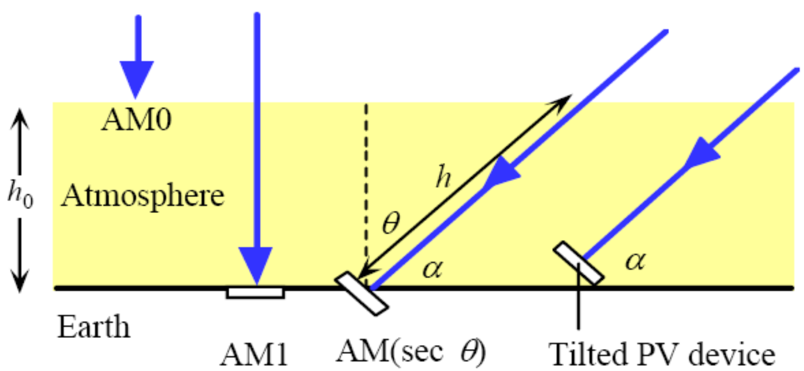
Wind velocity Vs altitude: data based on average Europe ground wind speed of 3 m/s

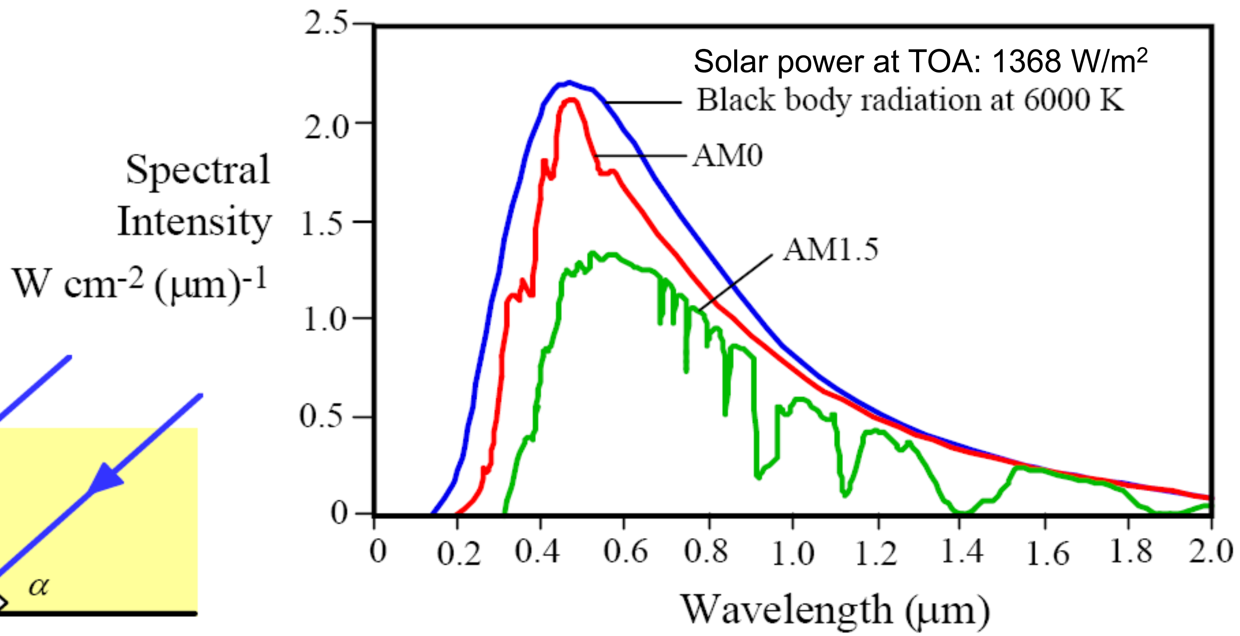
http://www.kitegen.com/en/



http://www.altaerosenergies.com/

Solar energy: solar radiation

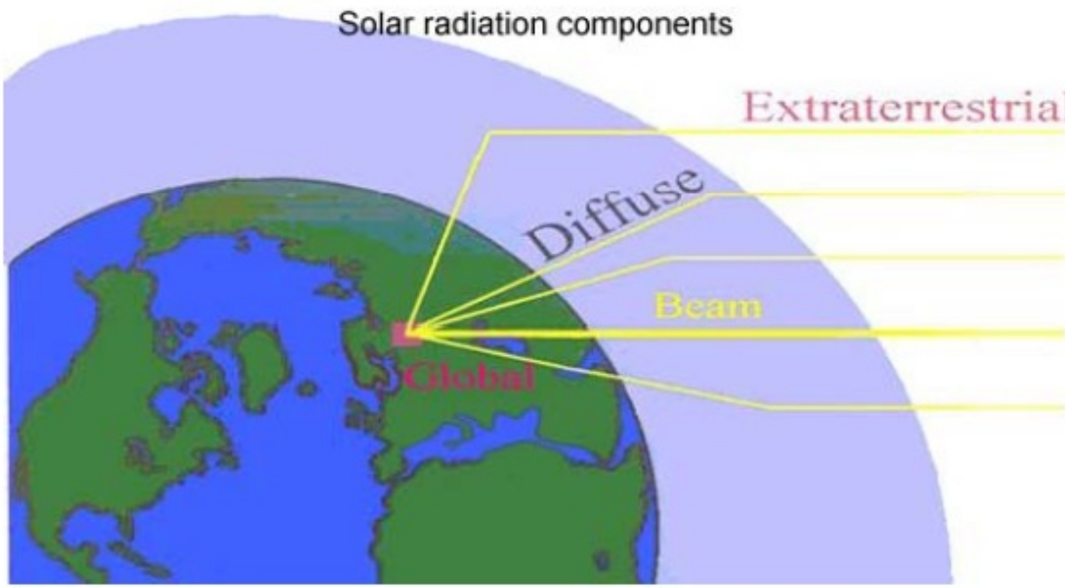




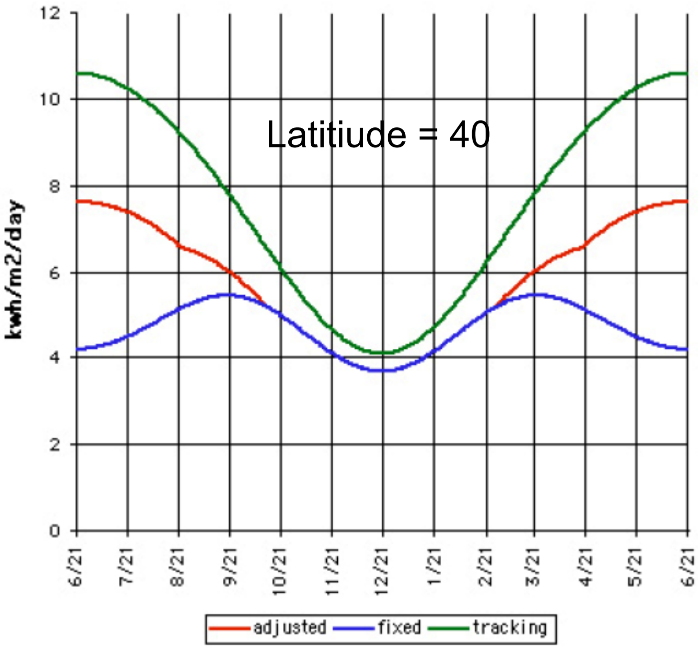
Air mass m (AMm) is defined as the ratio between the actual path into the atmosphere h and the shortest path h0: $m=h/h_0= 1/\cos\theta$ where θ is the zenith angle. With θ ≈45° m = 1.5 (AM1.5)

Solar radiation: direct/diffused

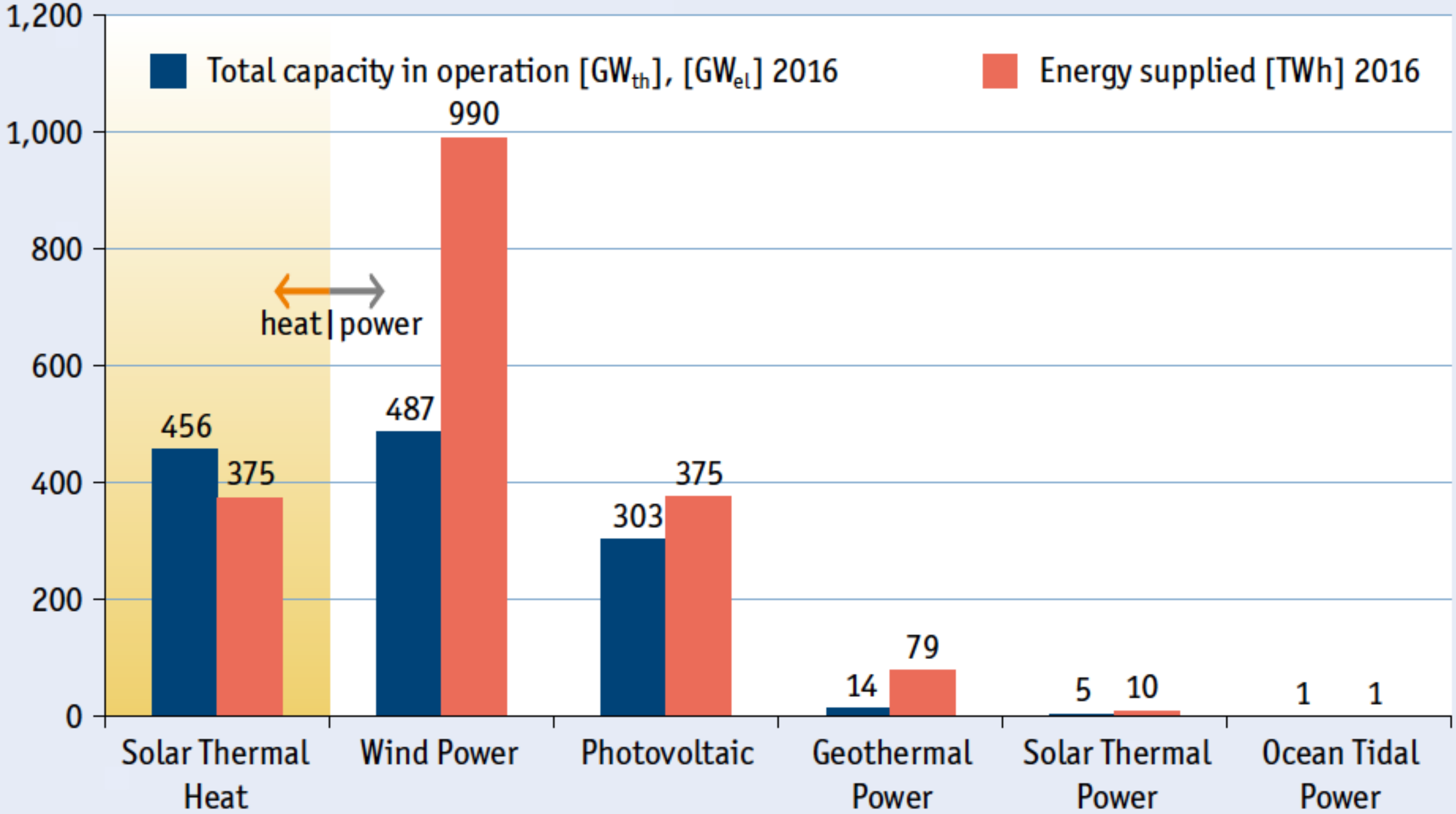
On average the solar irradiation at sea level (AM1.5G: Global=Direct+Diffused) is about 1 KW/m^2. The Direct contribution depends on clouds, humidity, dust... In a clean sunny day the Direct component can be very close to the Global one.



Focusing systems exploit only the Direct component



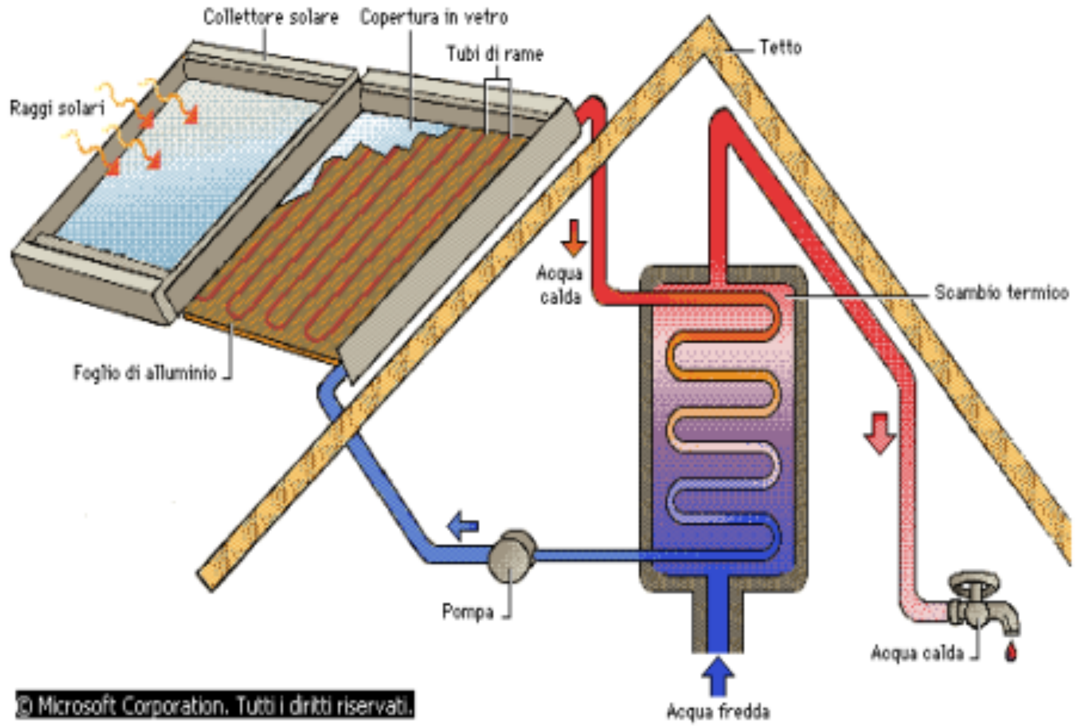
Global capacity in operation [GW_{el}], [GW_{th}], **and energy supplied** [TWh_{el}], [Twh_{th}], **2016**



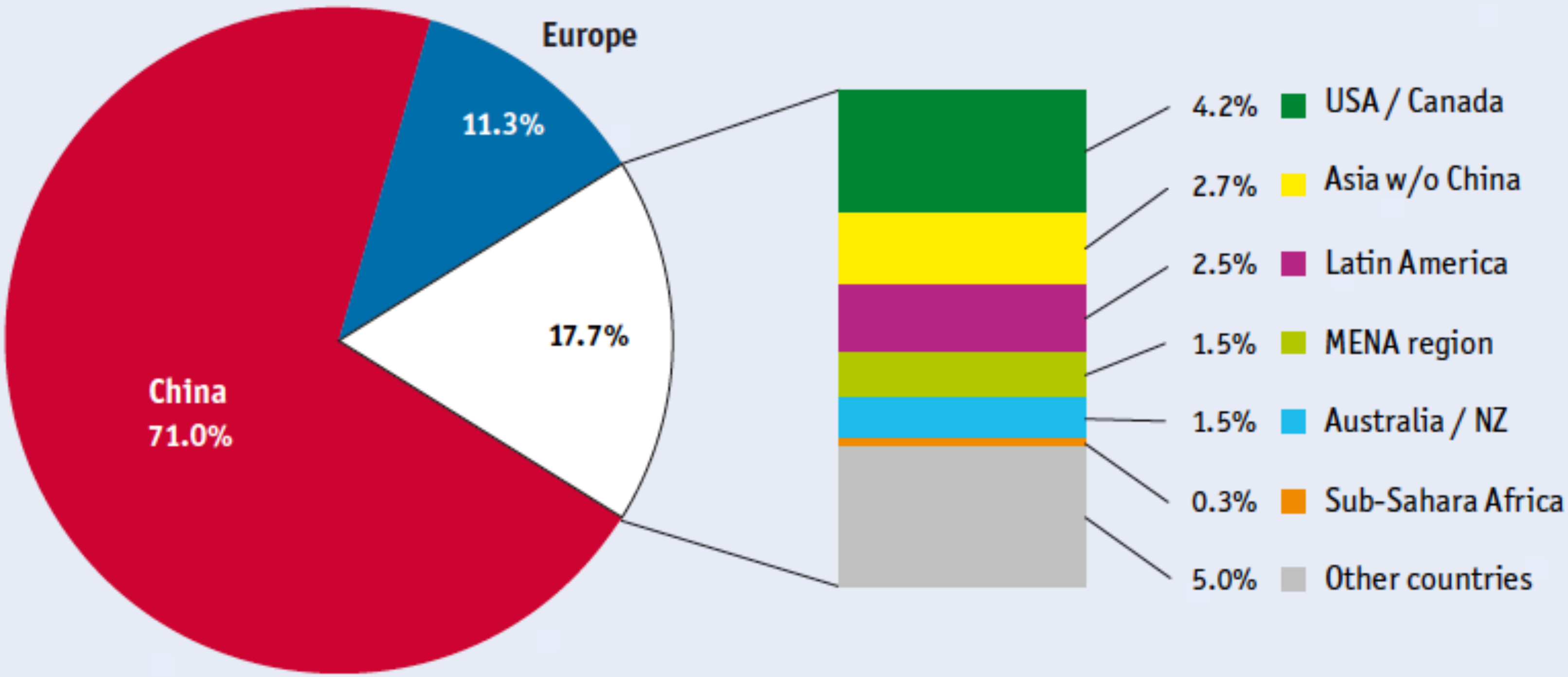
Global capacity in operation [GW_{el}], [GW_{th}] 2016 and annual energy yields [TWh_{el}], [TWh_{th}] (Sources: AEE INTEC, Global Wind Energy Council (GWEC), European PV Industry Association (EPIA), REN21 - Global Status Report 2017)

Solar thermal

Solar thermal technologies at low temperature (below 100 °C, seldom close to 120 °C) comprise systems that use a solar collector for heating a liquid or air. The goal is to capture solar energy to produce domestic hot water or to heat buildings. Classic solar collectors are usually installed on the house roofs.



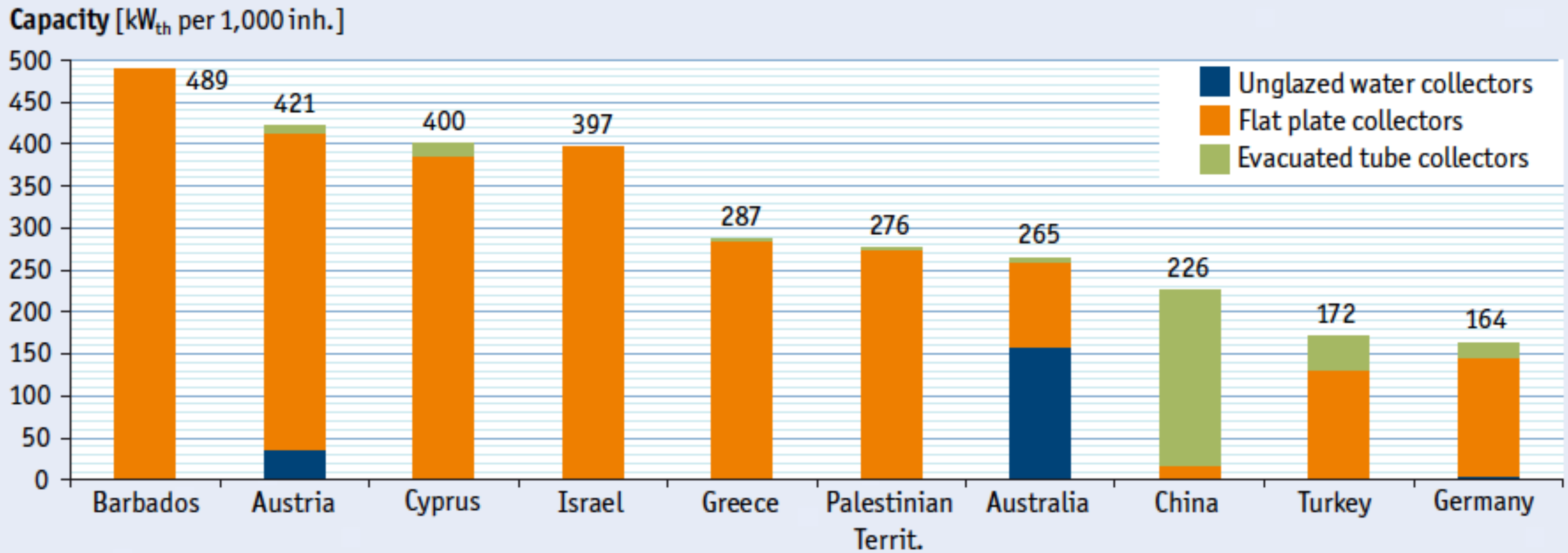
Solar Thermal in the world



Sub-Sahara Africa:	Botswana, Burkina Faso, Ghana, Lesotho, Mauritius, Mozambique, Namibia, Senegal, South Africa, Zimbabwe
Asia w/o China:	India, Japan, South Korea, Taiwan, Thailand
Latin America:	Barbados, Brazil, Chile, Mexico, Uruguay
Europe:	EU 28, Albania, Macedonia, Norway, Russia, Switzerland, Turkey
MENA region:	Israel, Jordan, Lebanon, Morocco, Palestine, Tunisia

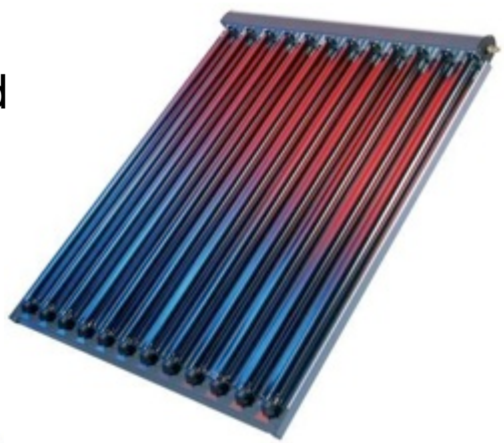
Fonte: Solar Heat Worldwide 2017

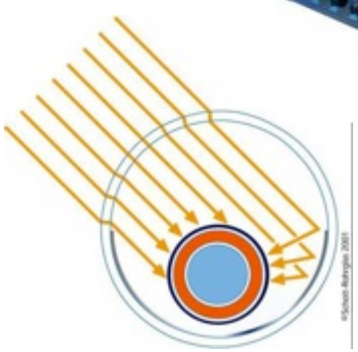
Share of the total installed capacity in operation (glazed and unglazed water and air collectors) by economic region in 2015



Top 10 countries of cumulated water collector installations (relative figures in kW_{th} per 1,000 inhabitants)

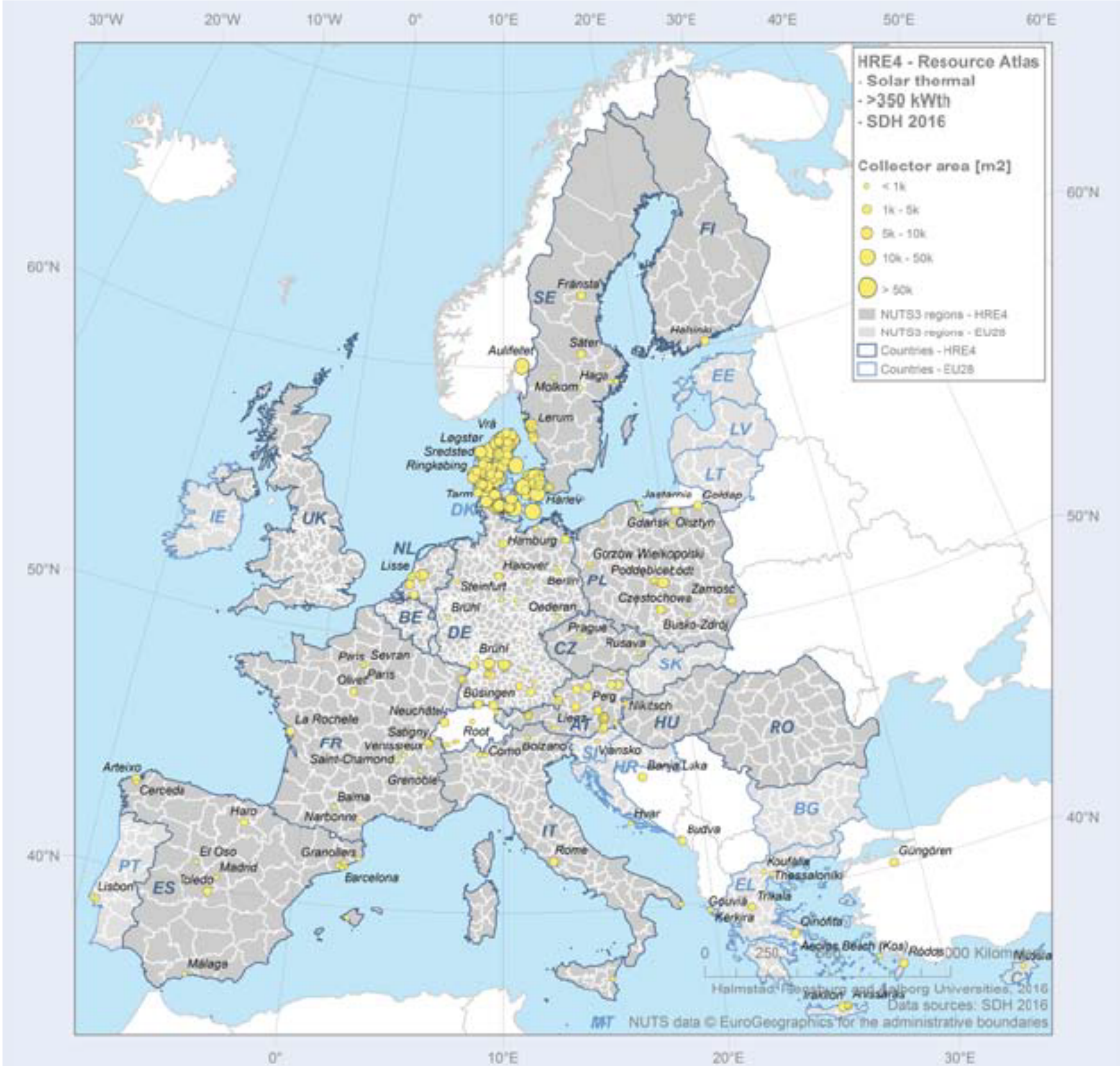
Evacuated tube collector





Conduction and convection losses are minimized

Flat plate collector



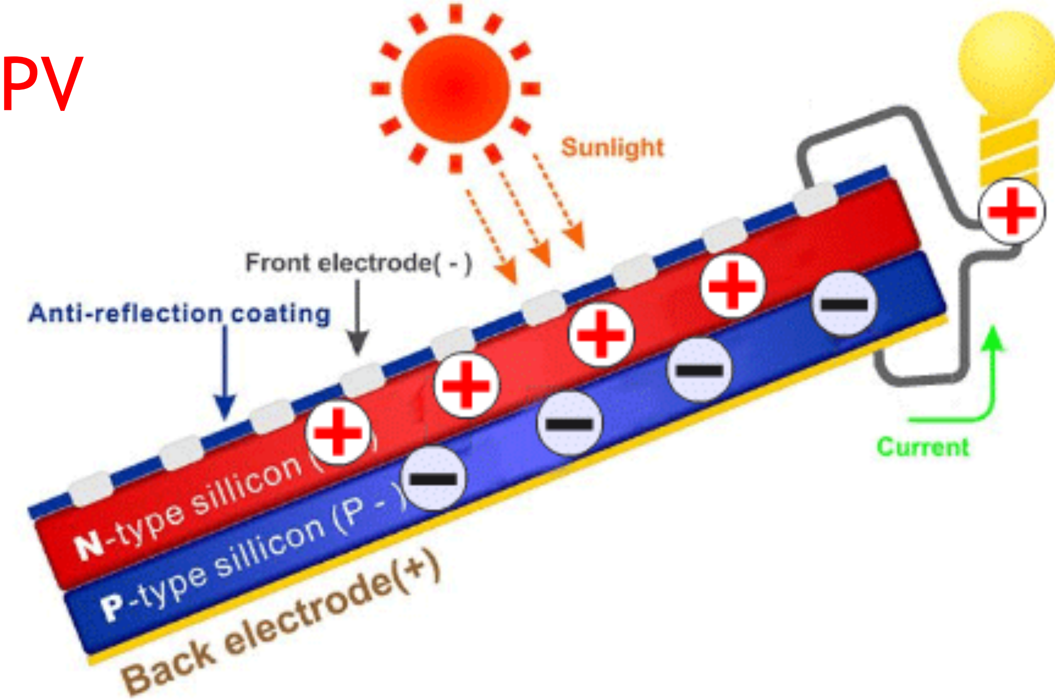
Solar district heating systems > 500 m² (> 350 kW$_{th}$) in Europe. (Source: EU-project Heat Roadmap Europe)

G.Alimonti

Solar thermal

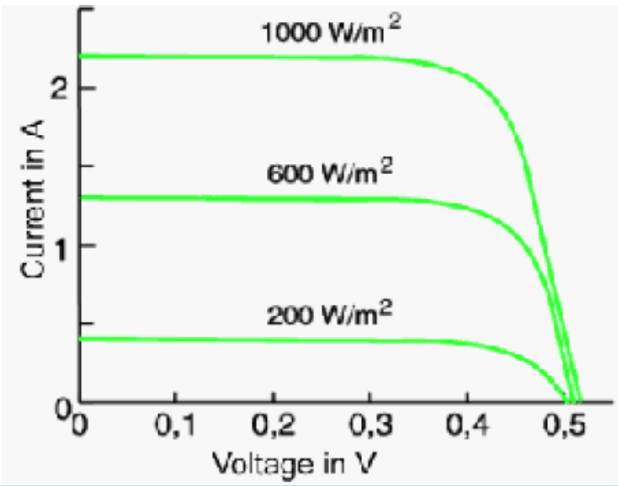
One of the largest solar thermal plant in Europe of 20 000 m^2 used to heat a district in Denmark.

Solar PV



PV cell behaves like a battery with an open-circuit voltage, which does not depend on the size and depends very little also on the irradiation. For silicon cells ΔV ~ 0,5 Volts.

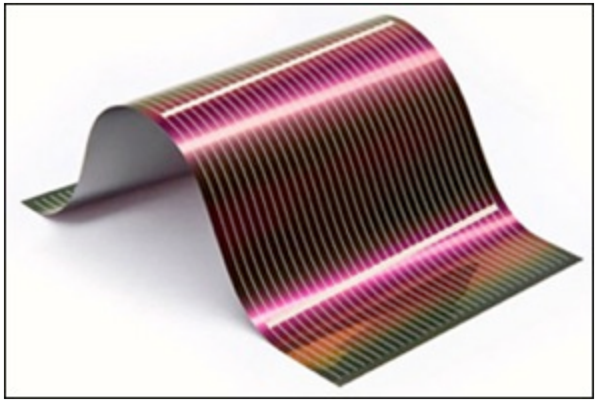
On the other end, the current strongly depends on irradiation and is proportional to the cell area. A 10 cm diameter silicon cell outputs a current of about 2 Ampère when exposed to a 1kw/ m² irradiation.

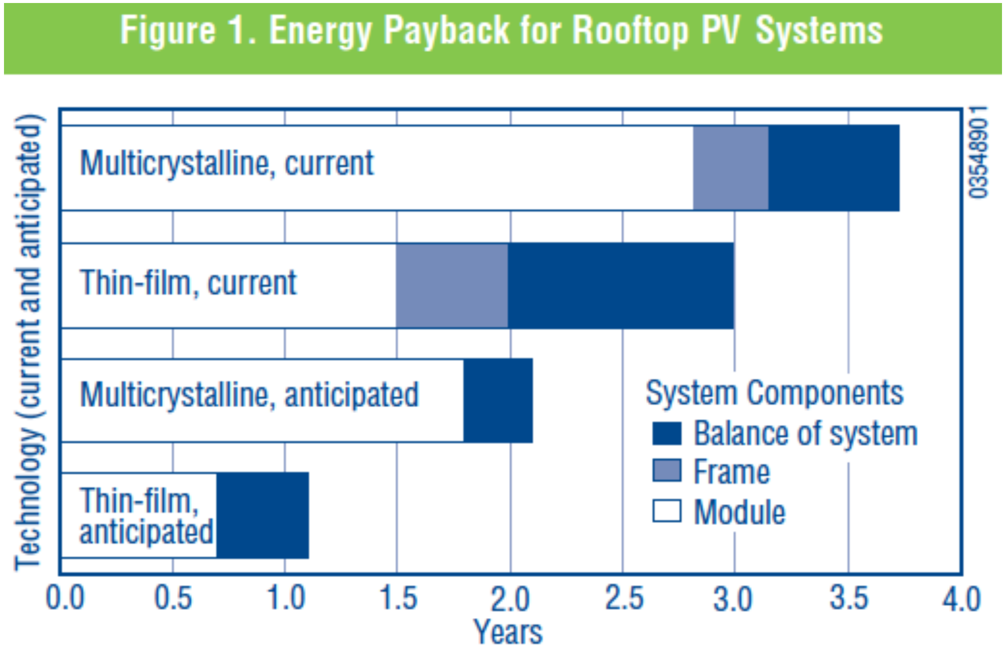


Main technologies on the market

Multi-Si

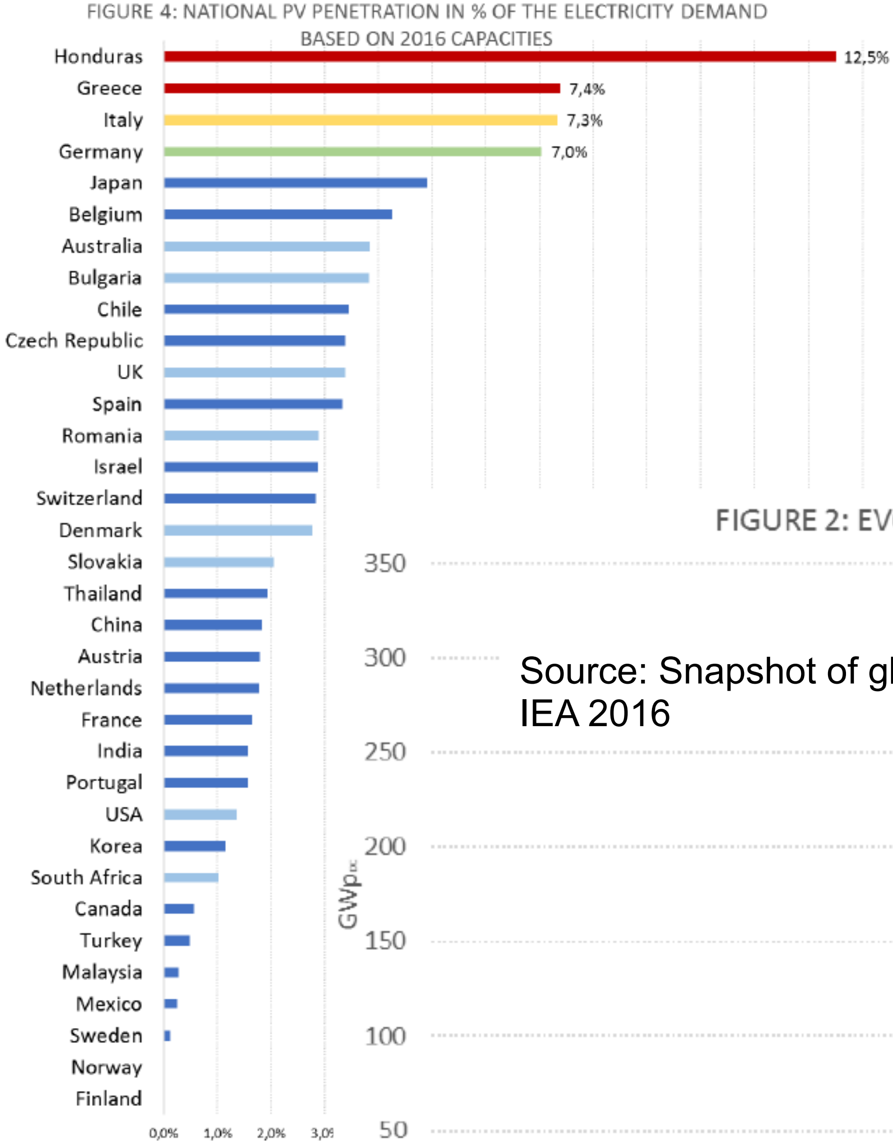
Thin film

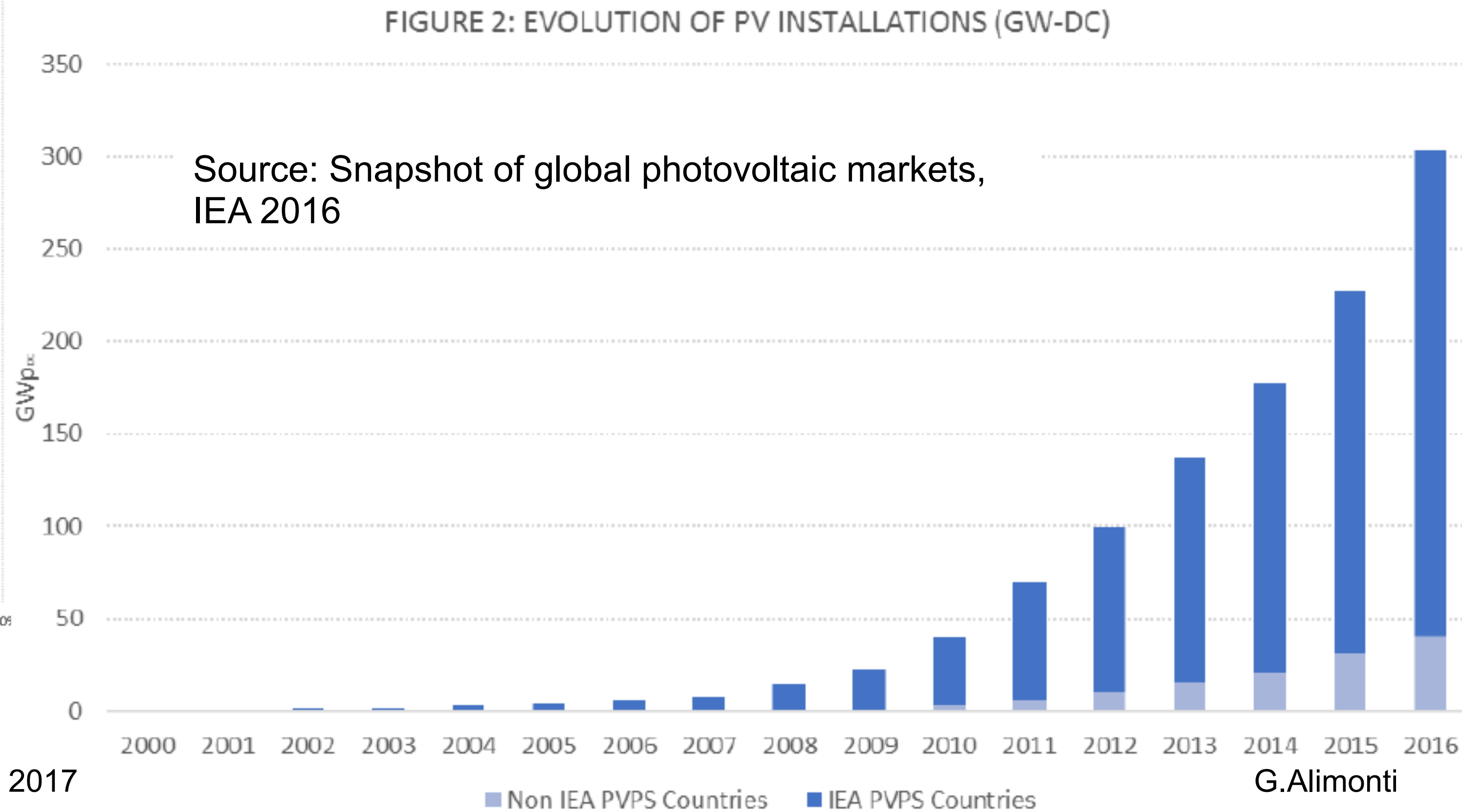




Source: NREL National Renewable Energy Laboratory

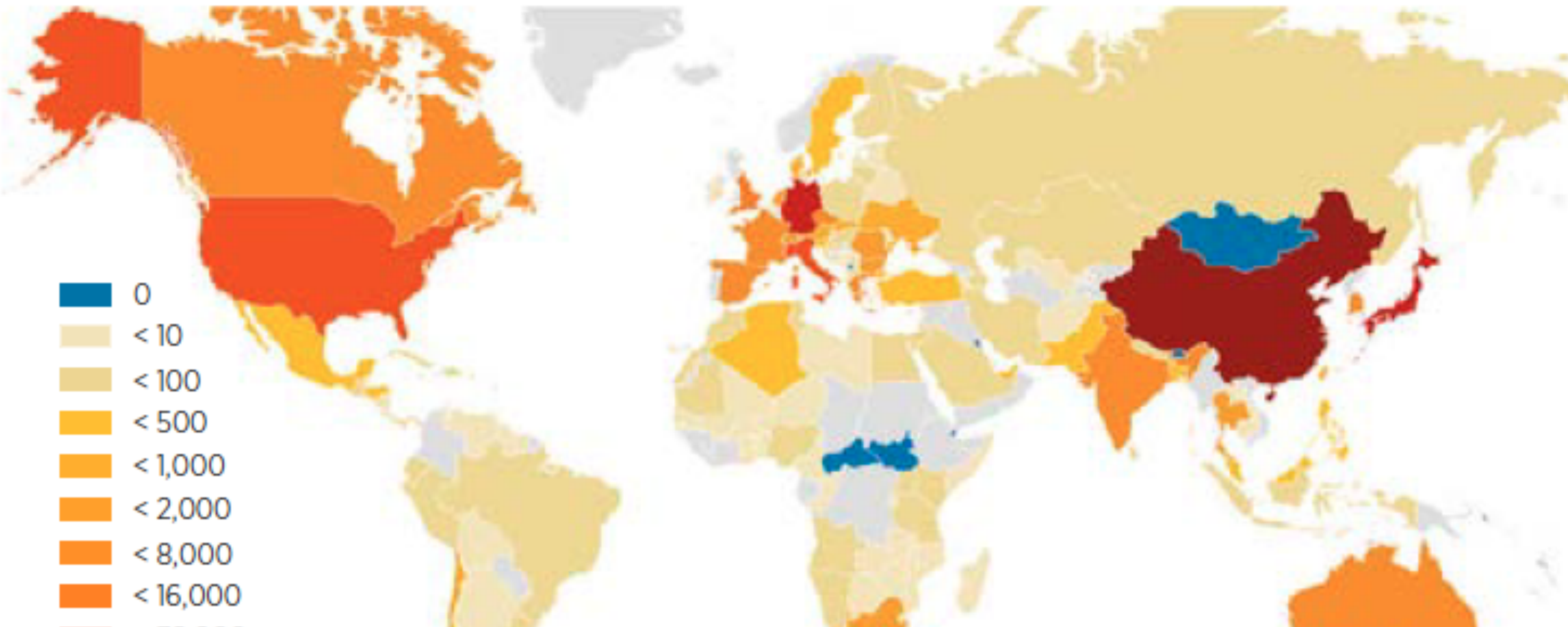
PV in the world





Source: Snapshot of global photovoltaic markets, IEA 2016

Figure 4.1 Global cumulative installed solar PV capacity by country, 2015



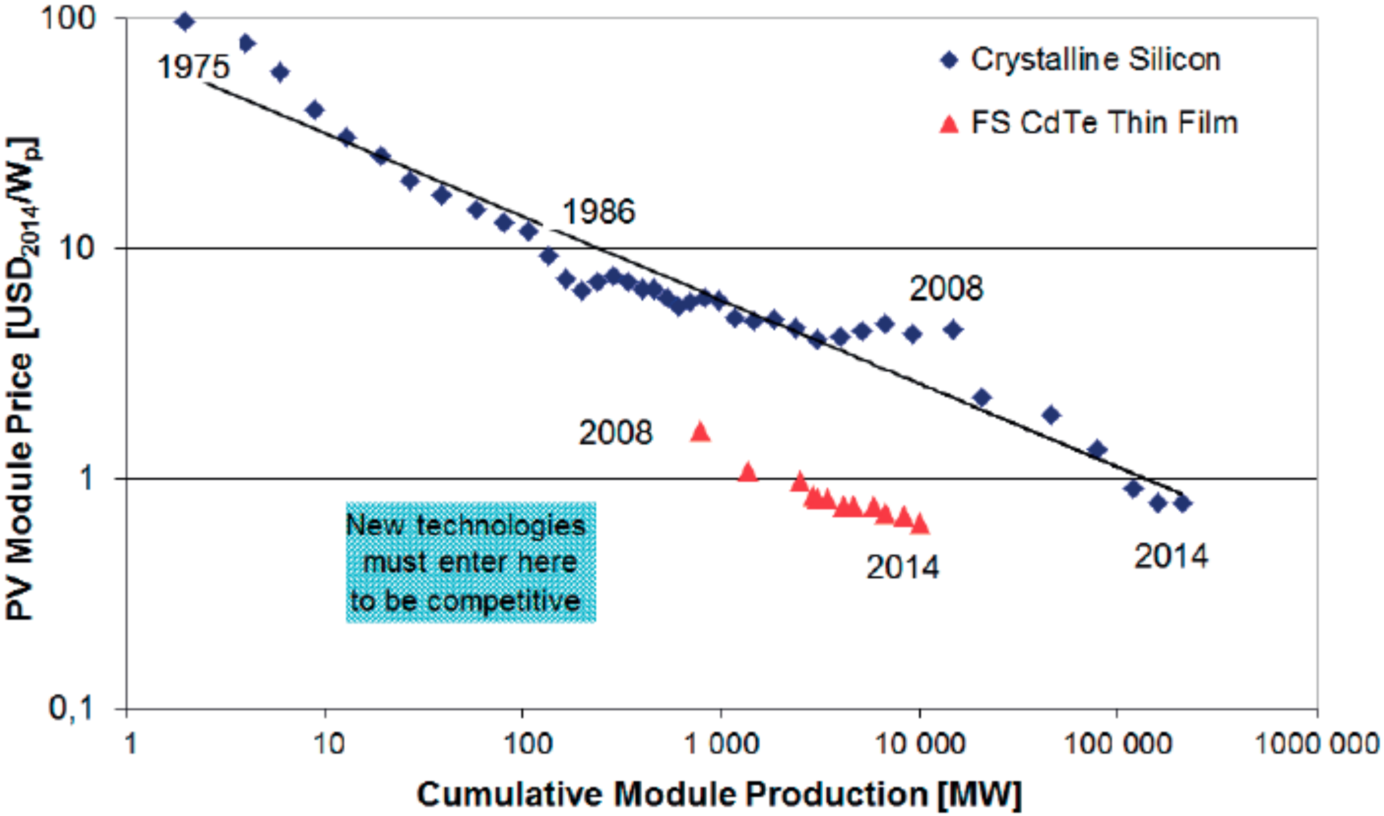
Source: IRENA, 2016j

TABLE 1: TOP 10 COUNTRIES FOR INSTALLATIONS AND TOTAL INSTALLED CAPACITY IN 2016

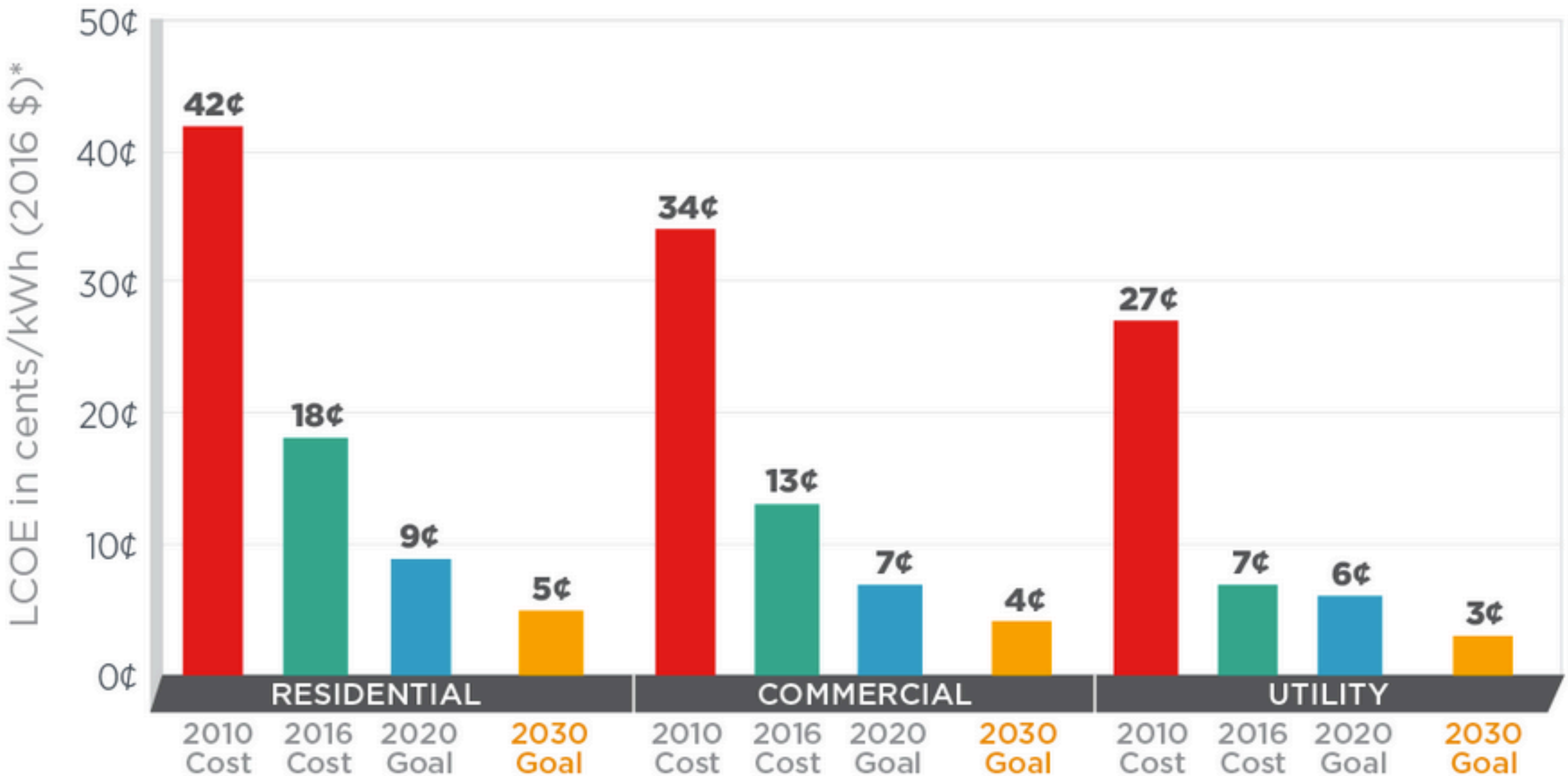
TOP 10 COUNTRIES IN 2016 FOR ANNUAL INSTALLED CAPACITY			TOP 10 COUNTRIES IN 2016 FOR CUMULATIVE INSTALLED CAPACITY		
1	China	34,5 GW	1	China	78,1 GW
2	USA	14,7 GW	2	Japan	42,8 GW
3	Japan	8,6 GW	3	Germany	41,2 GW
4	India	4 GW	4	USA	40,3 GW
5	UK	2 GW	5	Italy	19,3 GW
6	Germany	1,5 GW	6	UK	11,6 GW
7	Korea	0,9 GW	7	India	9 GW
8	Australia	0,8 GW	8	France	7,1 GW
9	Philippines	0,8 GW	9	Australia	5,9 GW
10	Chile	0,7 GW	10	Spain	5,5 GW

PV cost

Based on historical records, a 20% cost decrease has been observed every time an installed power doubling has been reached on a global level.



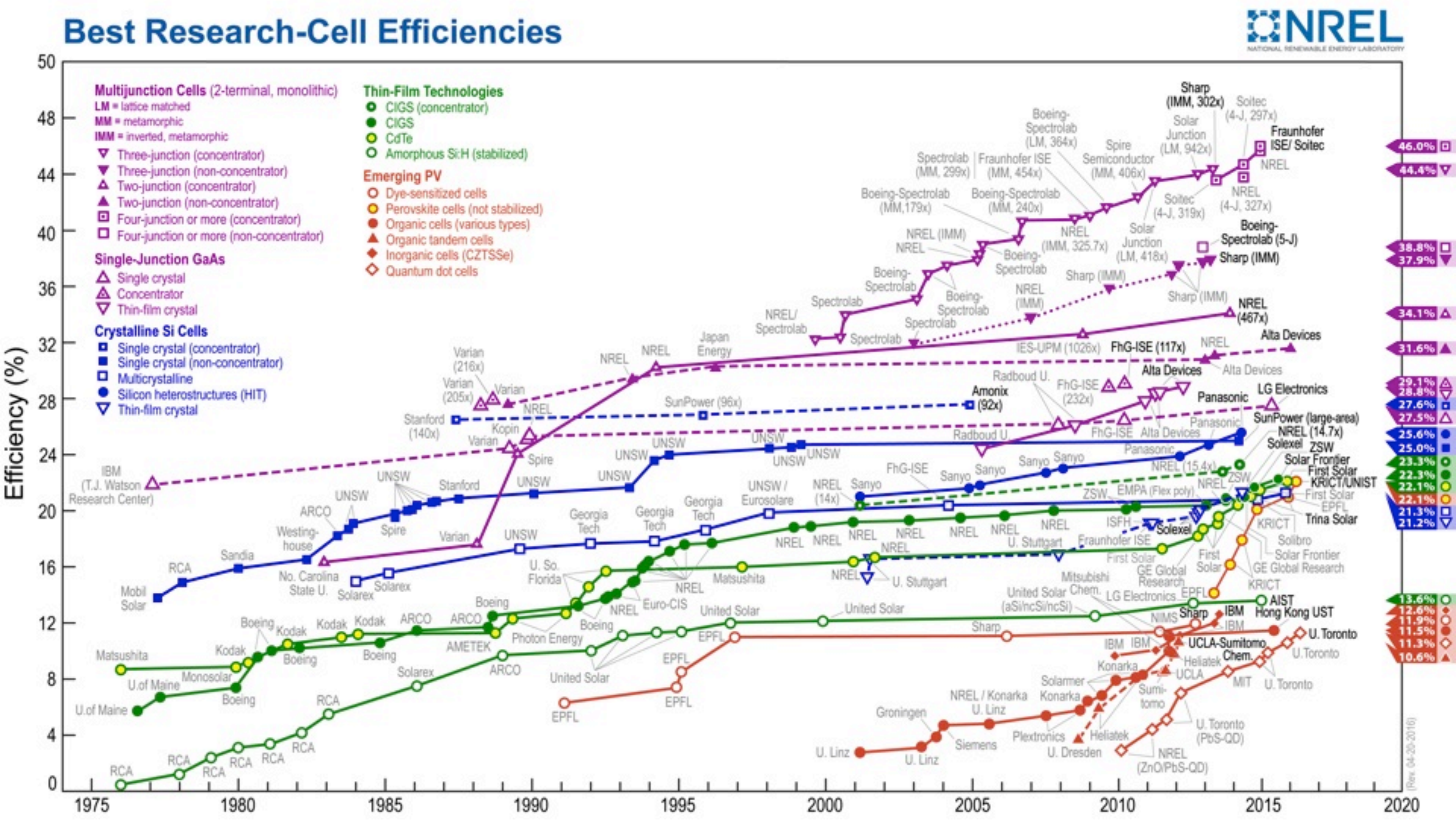
Source: Bloomberg New Energy Finance 2015



*Levelized cost of electricity (LCOE) progress and targets are calculated based on average U.S. climate and without the ITC or state/local incentives. Utility-scale PV uses one-axis tracking.

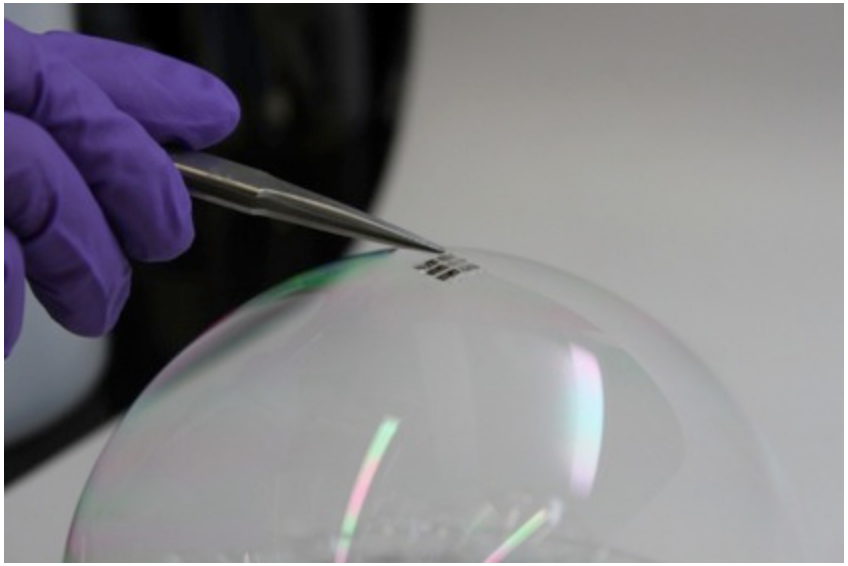
https://energy.gov/eere/solar/photovoltaics

PV: R&D



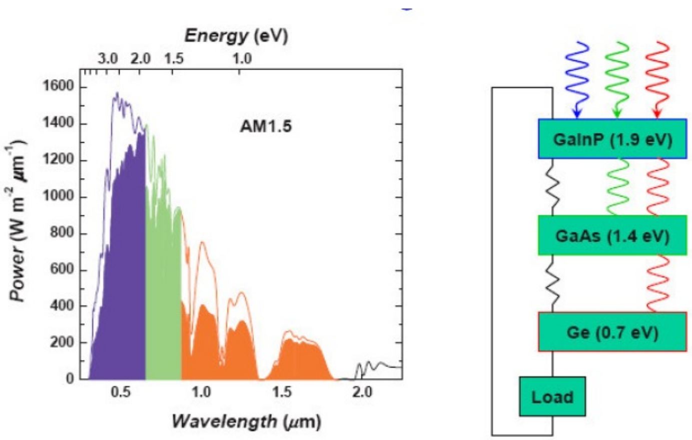
Best Research-Cell Efficiencies
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Multijunction Cells (2-terminal, monolithic)
LM = lattice matched
MM = metamorphic
IMM = inverted, metamorphic
Three-junction (concentrator)
Three-junction (non-concentrator)
Two-junction (concentrator)
Two-junction (non-concentrator)
Four-junction or more (concentrator)
Four-junction or more (non-concentrator)
Single-Junction GaAs
Single crystal
Concentrator
Thin-film crystal
Crystalline Si Cells
Single crystal (concentrator)
Single crystal (non-concentrator)
Multicrystalline
Silicon heterostructures (HIT)
Thin-film crystal
Thin-Film Technologies
CIGS (concentrator)
CIGS
CdTe
Amorphous Si:H (stabilized)
Emerging PV
Dye-sensitized cells
Perovskite cells (not stabilized)
Organic cells (various types)
Organic tandem cells
Inorganic cells (CZTSSe)
Quantum dot cells
Efficiency (%)
46.0%
44.4%
38.8%
37.9%
34.1%
31.6%
29.1%
28.8%
27.6%
27.5%
25.6%
25.0%
23.3%
22.3%
22.1%
22.1%
21.3%
21.2%
13.6%
12.6%
11.9%
11.5%
11.3%
10.6%

PV: R&D



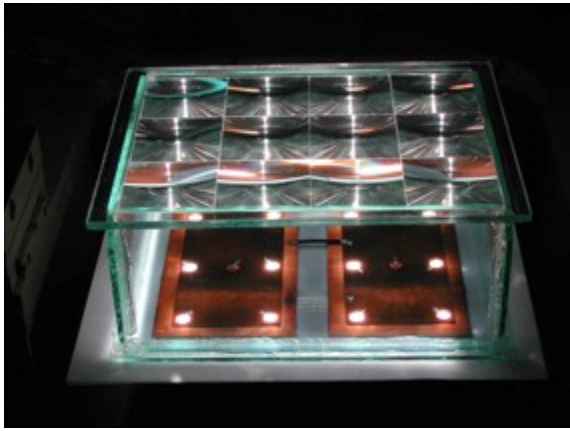
Solar cells as light as a soap bubble

Concentrated Solar Systems, Australia



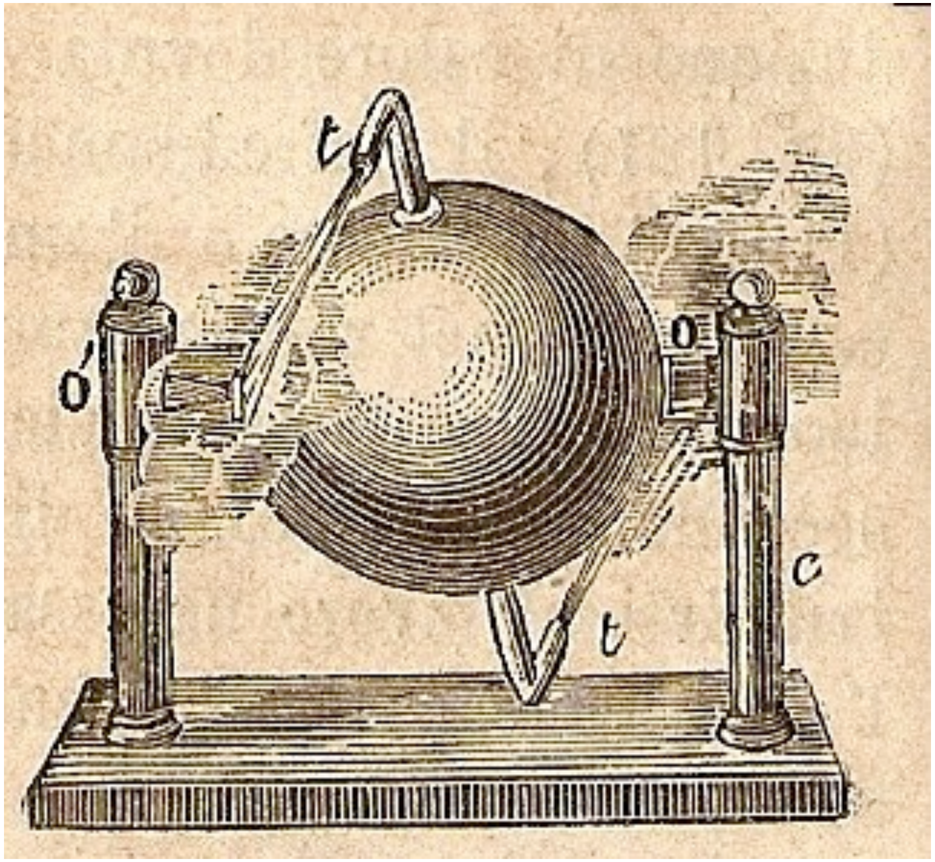
Multilayer solar cell

DSSC solar cells



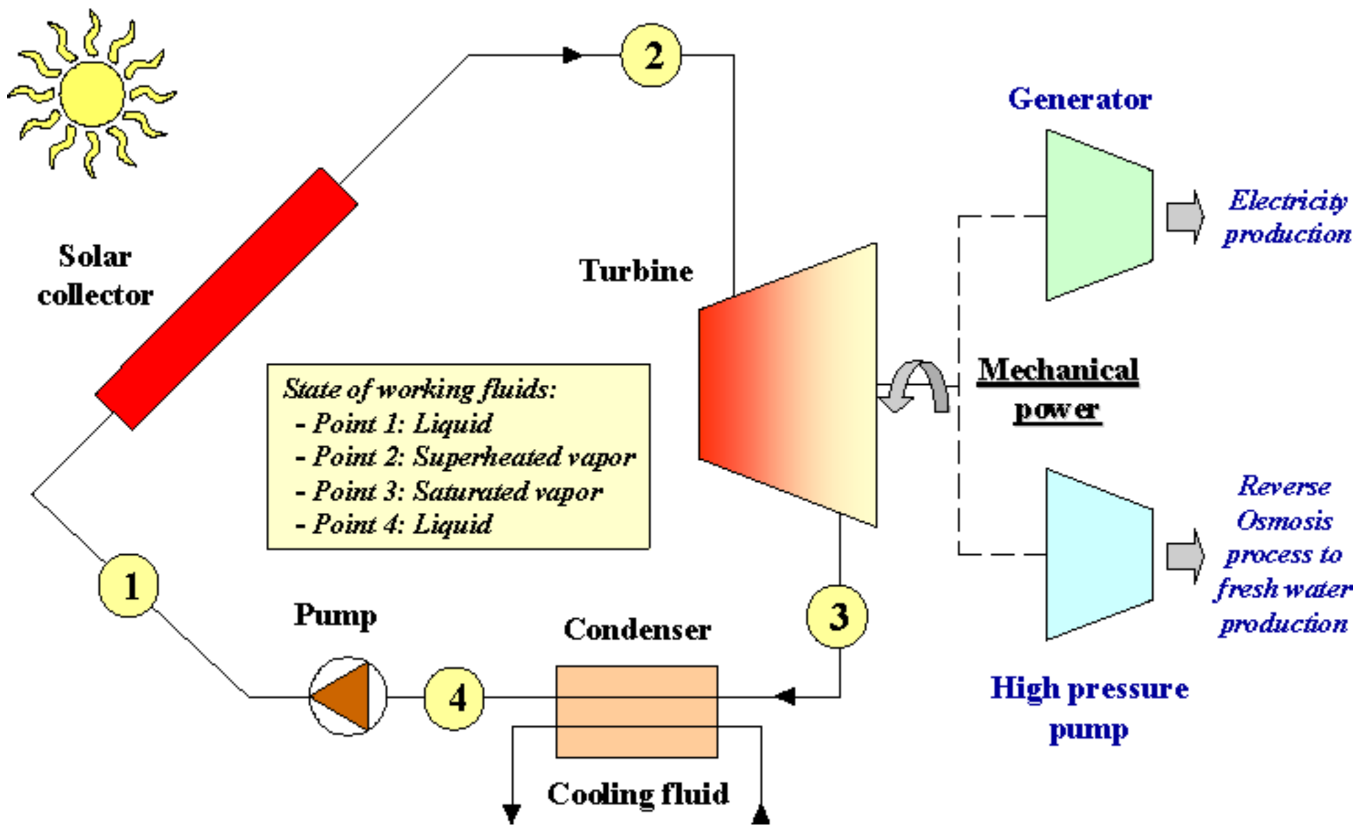
Fresnel lens, CESI, Italia

Concentrated Solar Power (CSP)



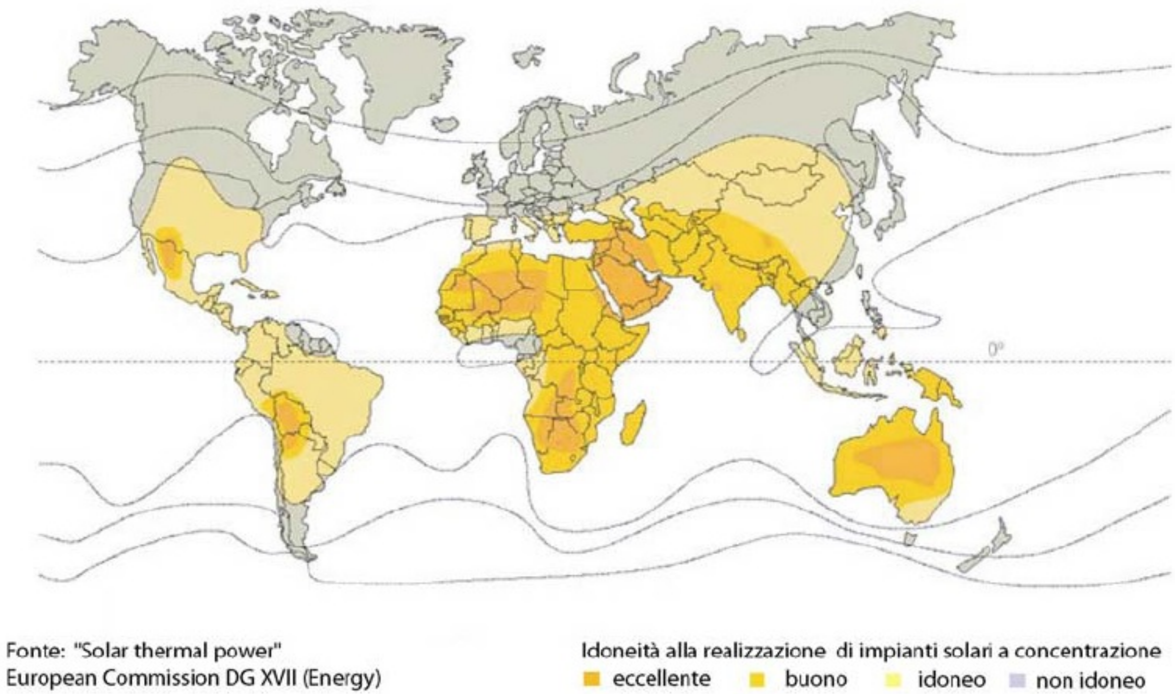
Aeolipile, steam turbine invented in the 1st century AD by Heron of Alexandria

Concentrated Solar Power (CSP)



Concentrated Solar Power (CSP)

CSP needs to reach higher Temperature and Pressure: solar concentration.
Only direct irradiation can be exploited: dry and clean air are needed.

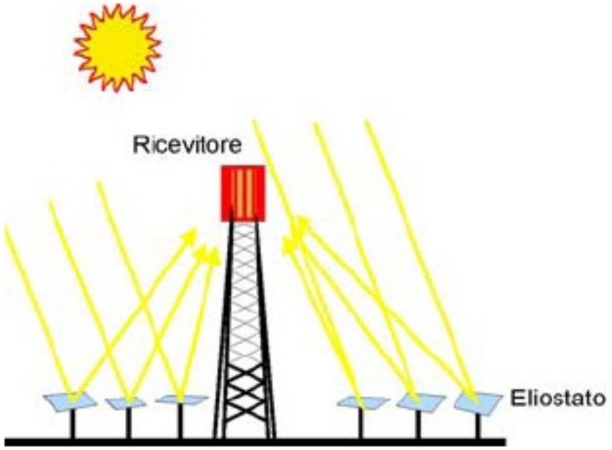


CSP technologies (1)

CSP comprises a plurality of technologies, divided into two large families.

Tower Systems, in which the solar radiation is concentrated on a special boiler set on top of a tower by a system of mirrors placed around its base

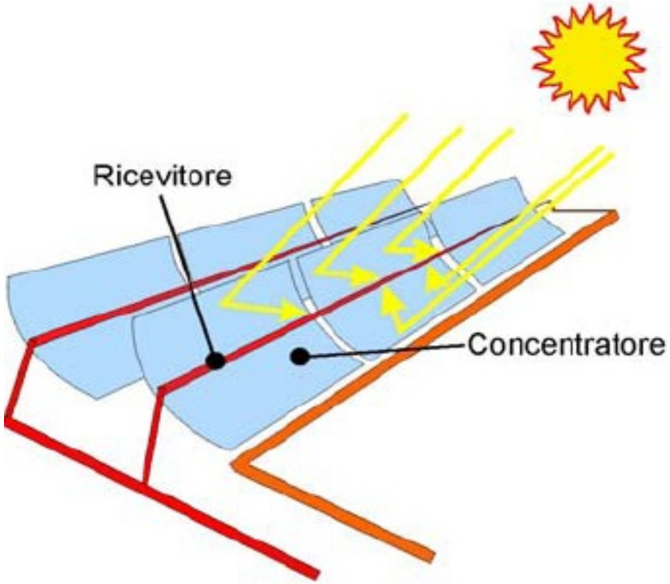
Planta Solar 10 (PS10) Siviglia



Nominal power: 11 MWe
Heliostats: 7,5 ha
Tower: 100 m
Heat receiver: 250 C°, 40 bar
Cost: 33 MEuro

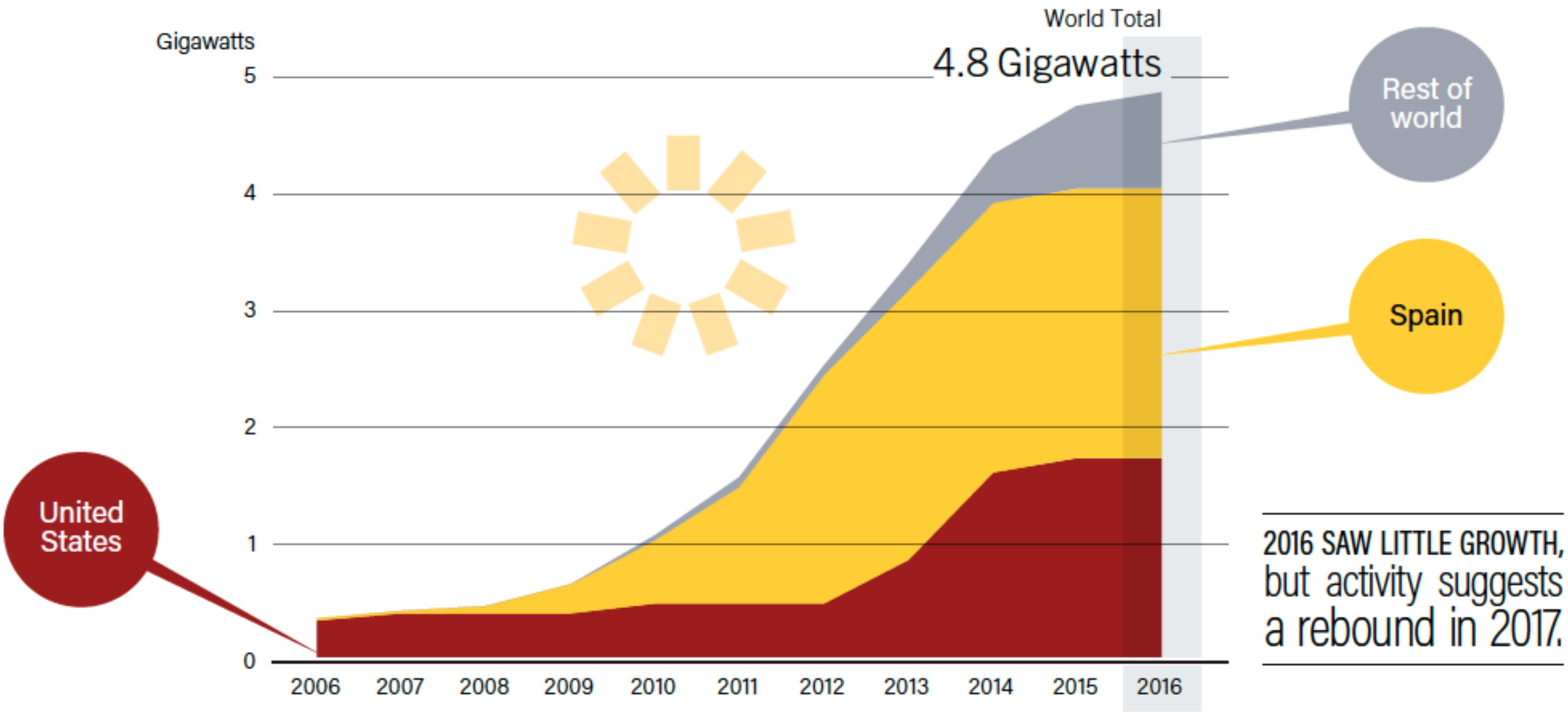
CSP technologies (2)

Collector systems, linear and parabolic, where the pipe containing the fluid runs along the focus of a large number of concentrating mirrors.



View of the SEGS plants (Solar Electric Generating Systems), built in the mid-eighties at Kramer Junction in the Mojave Desert (California), consisting of nine units with a total capacity of 354 MWe.

World installed CSP

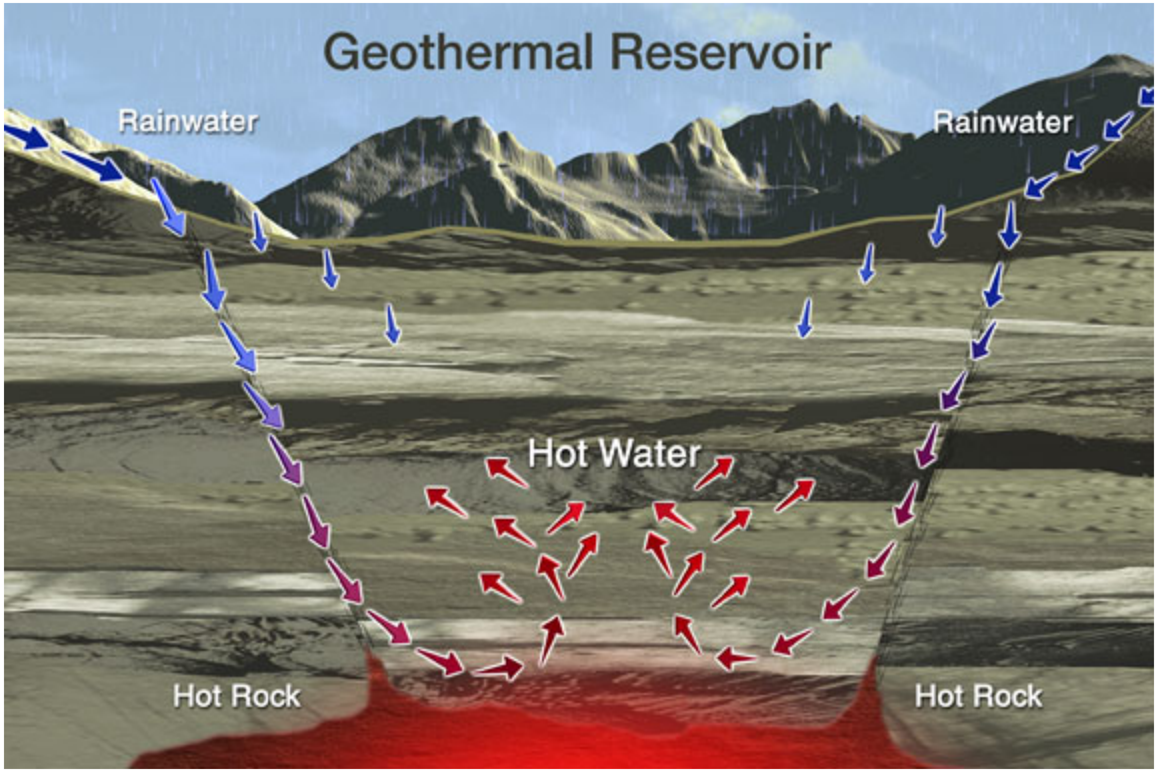


Source: RENEWABLES 2017
GLOBAL STATUS REPORT, REN21

Geothermal energy

Geothermal energy

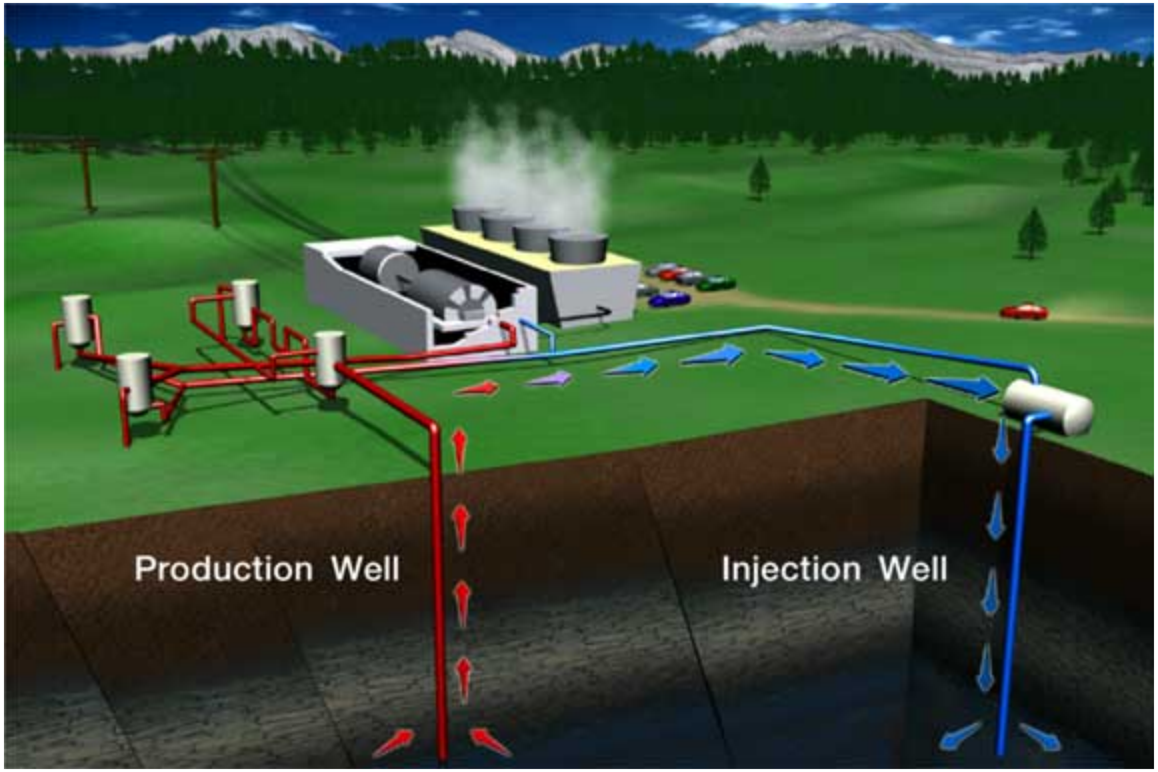
Geothermal energy is produced by nuclear reactions that take place in the heart of the Earth and partly comes from the original formation of the planet.
The medium flow of geothermal energy is about 0.06 W/m^2. Since the Earth surface is 5.2×10^{14} m^2 the geothermal potential of the Earth is 30 TW.



Geothermal energy

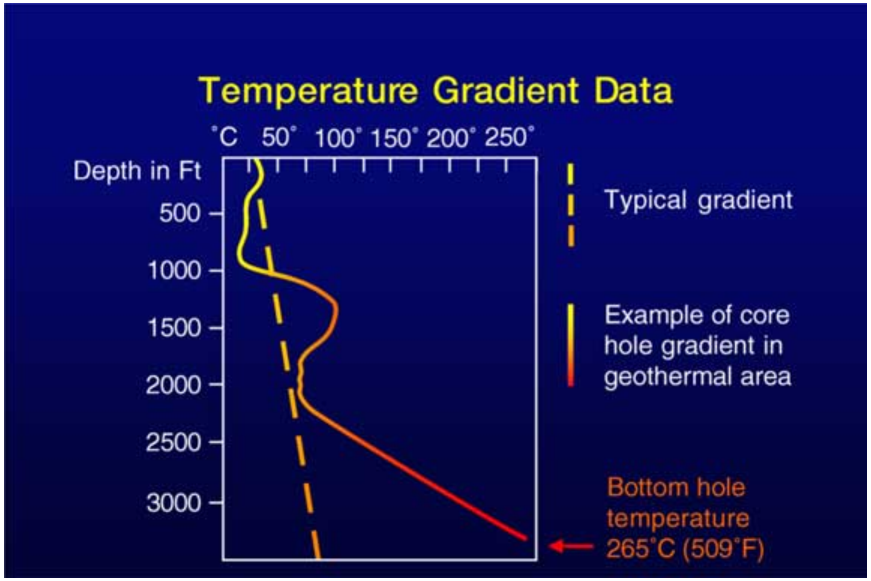
The production of electricity from geothermal plants consists in the conversion of heat coming from aquifers at high temperature (from 150 °C to 350 °C) through the use of turbo-generators.

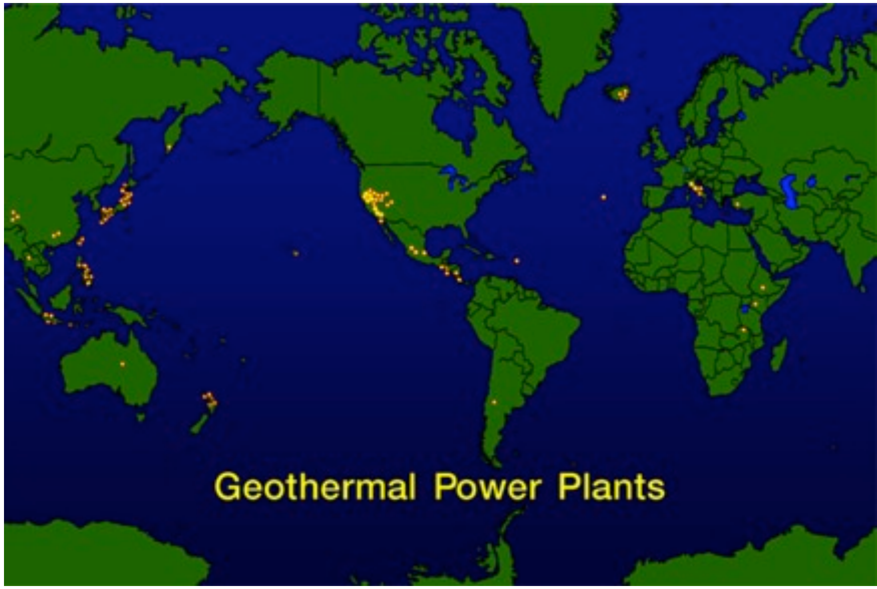
The technology is limited to drill a hole in a layer of hot rocks containing the hot fluid, which emerges on the surface and is then sent to a turbine after being purified by the corrosive compounds and harmful and debris of rock that are dragged.



Limits of hydrothermal geo-energy

Geothermal gradient
Earth has a thermal gradient of 30 °C/km: need to drill at least 6Km to produce electricity.
Only 1 out of 3-4 drillings is succesfull and the drilling cost is about 2M$/Km: exploitation of geothermal anomalies.





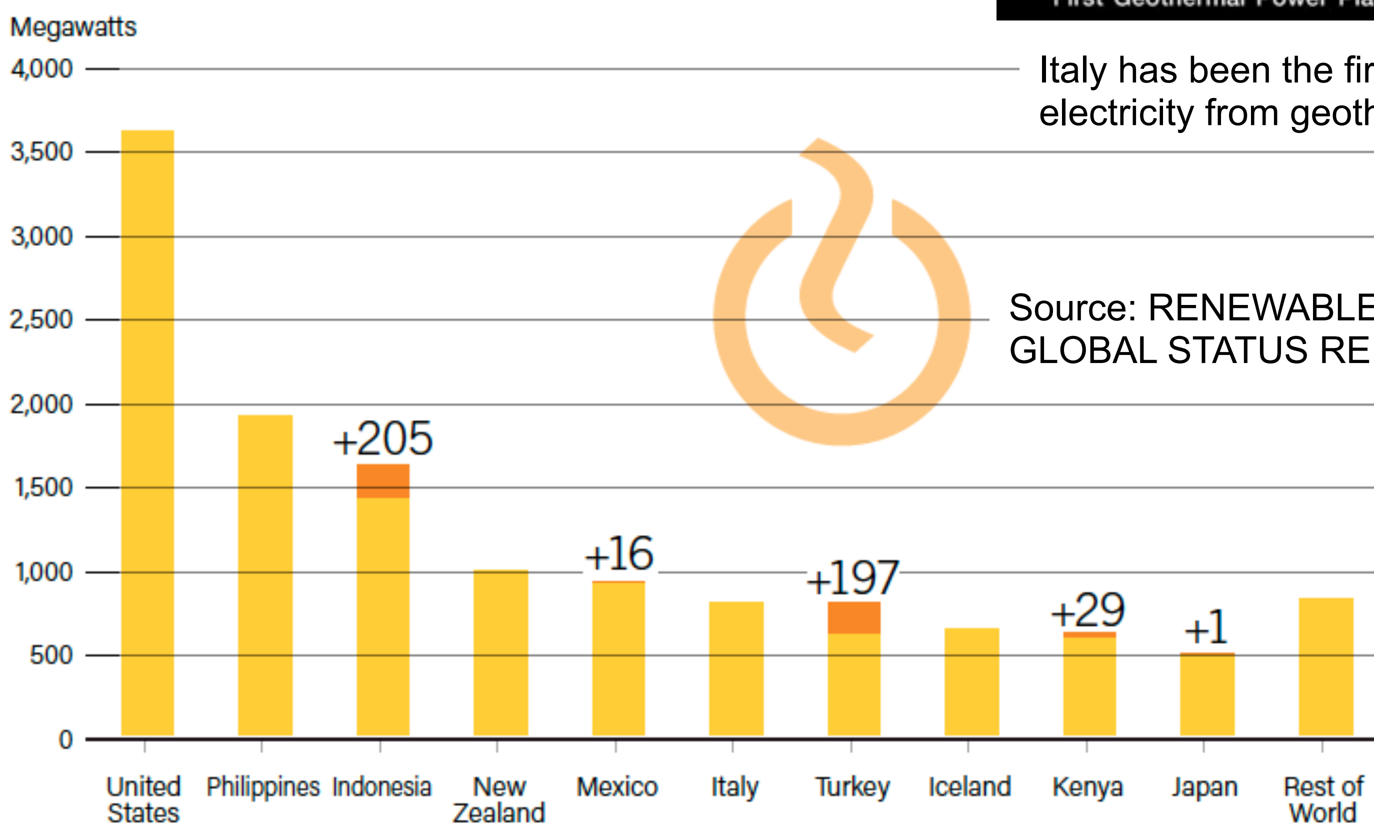
Unfortunately, these sources are a real miracle of nature, and usable only in a few cases.

Despite the high installation cost and the low conversion efficiency (≈15%), the EE cost is very competitive thanks to the high utilization factor.

First Geothermal Power Plant, 1904, Larderello, Italy

Italy has been the first country to produce electricity from geothermal fluids…

Figure 12. Geothermal Power Capacity and Additions, Top 10 Countries,



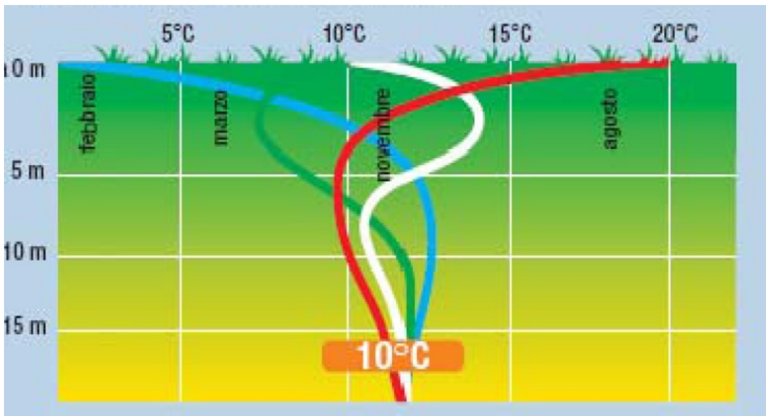
Source: See endnote 4 for this section.

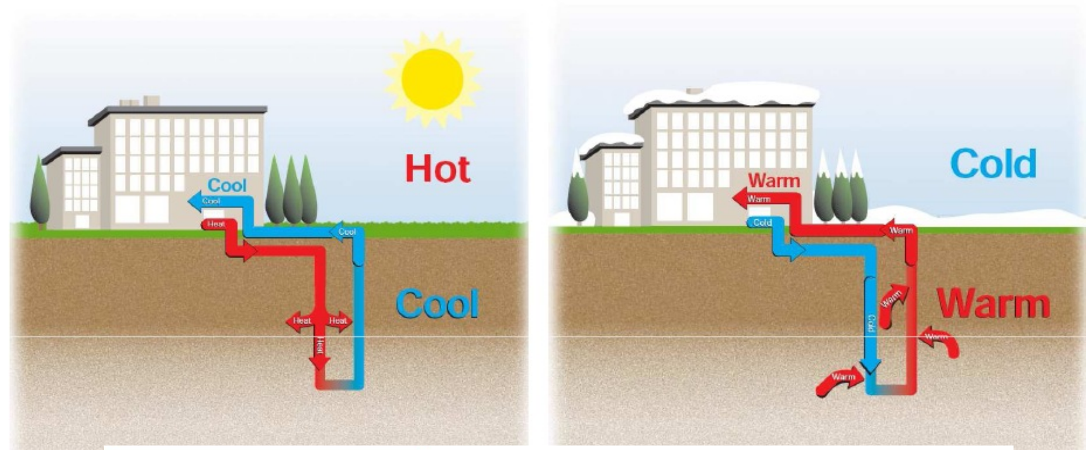
Source: RENEWABLES 2017 GLOBAL STATUS REPORT, REN21

G.Alimonti

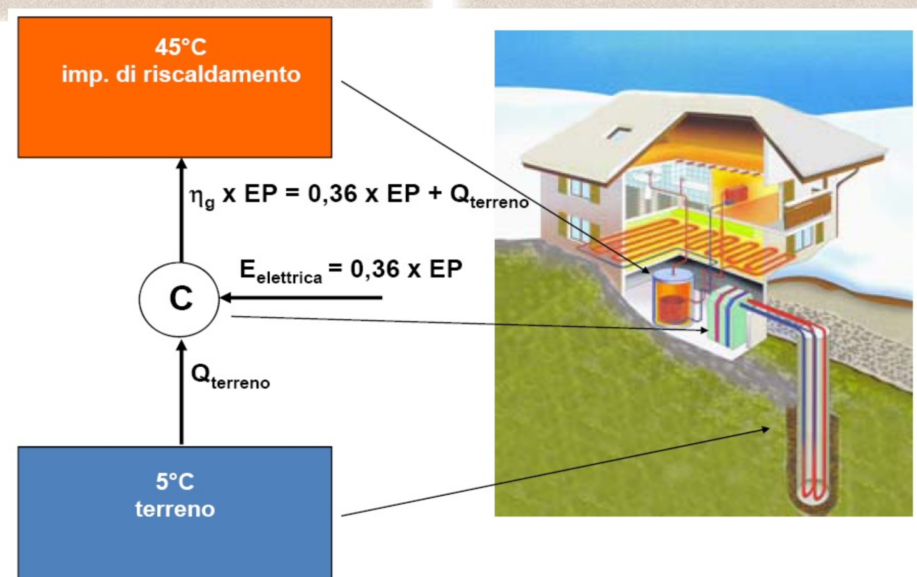
Heat pump

A heat pump nobilitates the heat taken from a cold source to the higher usefull temperature, at the expense of mechanical energy.



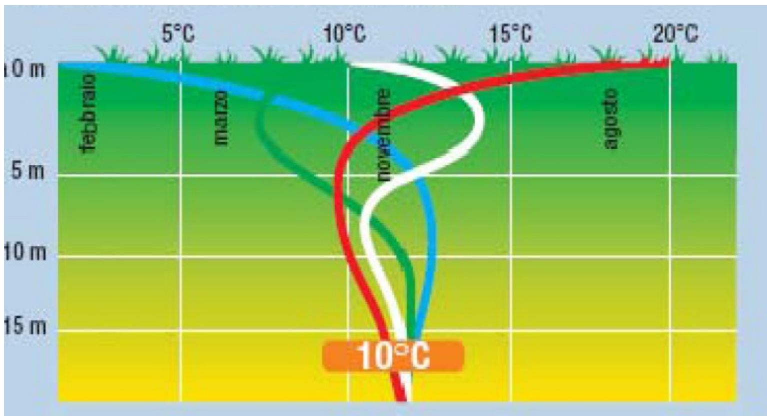


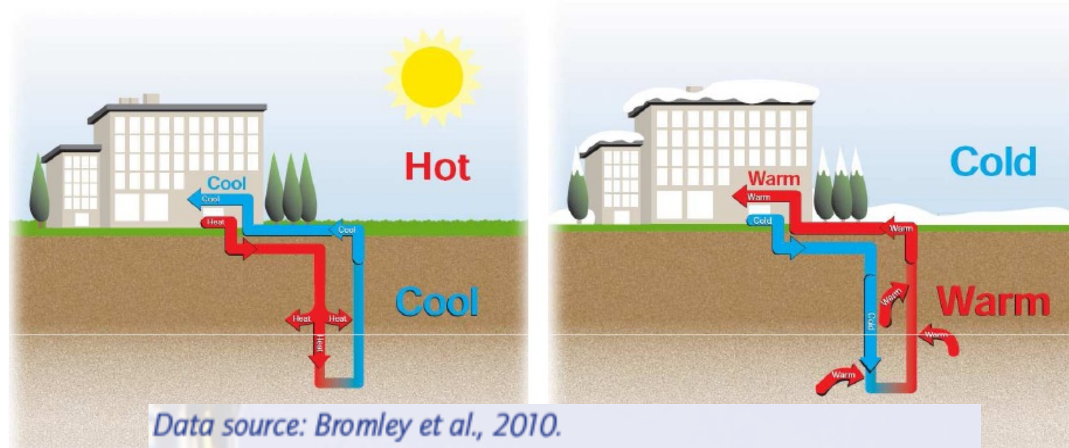
The geothermal heat pump exploits the few meters deep constant temperatures and the conductivity and heat capacity of the ground.



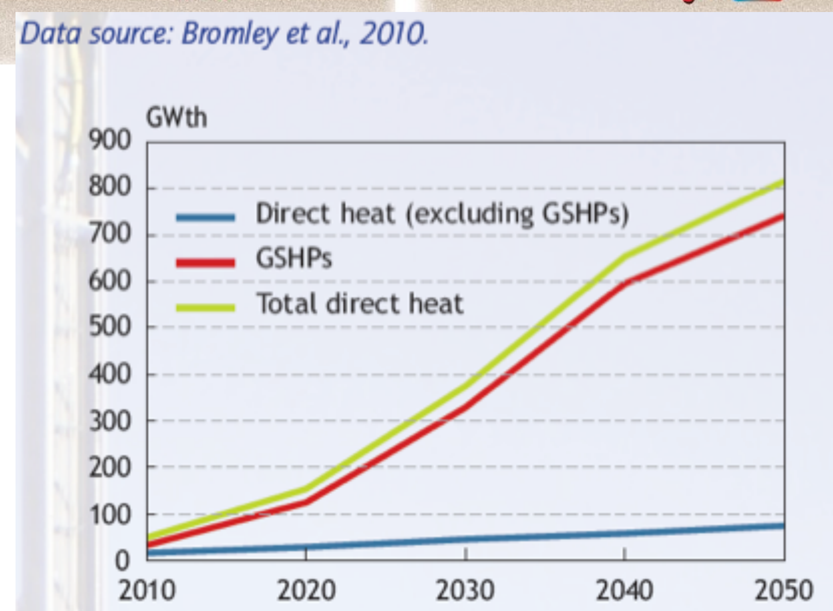
Heat pump

A heat pump nobilitates the heat taken from a cold source to the higher usefull temperature, at the expense of mechanical energy.

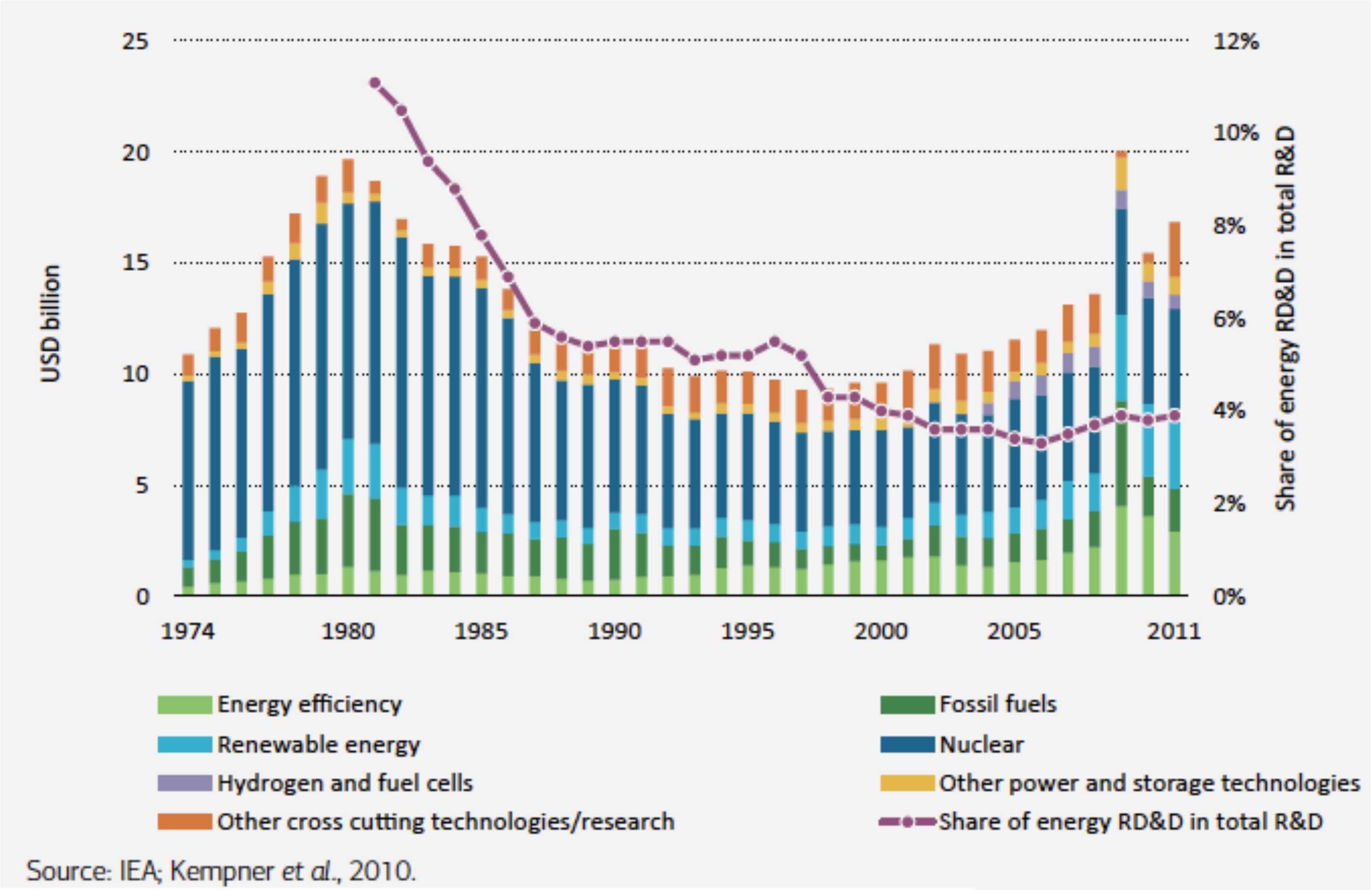




The geothermal heat pump exploits the few meters deep constant temperatures and the conductivity and heat capacity of the ground.

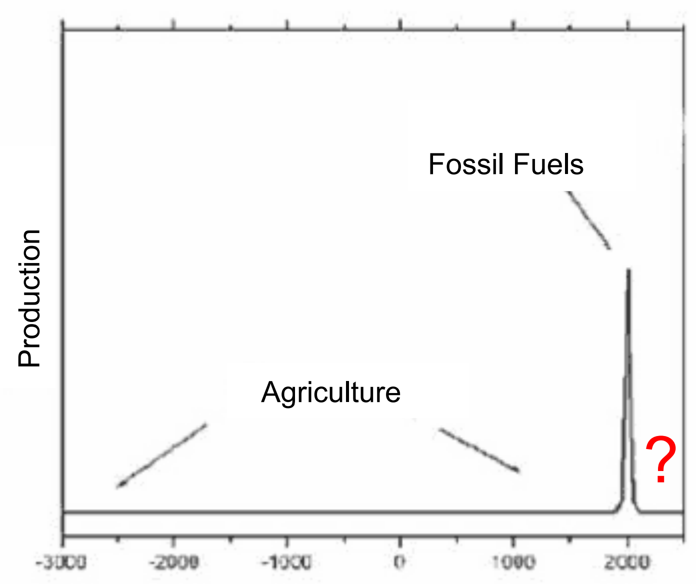


Government spending on R&D



Fonte: Tracking Clean Energy Progress 2013, IEA

Past & Future: what's next?



During the Roman empire, a slave eating about 2000 ÷ 2500 kcal/day, could produce a work output around 3-400 Wh/day, equal to about 100 grams of oil: every European citizen, who now consumes about 10 kg of oil a day, is exploiting the job of 100 to 150 slaves.

Energy is essential for all organic and inorganic activities: history of human evolution reflects history of mankind ability to control and transform Energy.
Hubbert, 1962

Thank you for your attention!

gianluca.alimonti@mi.infn.it