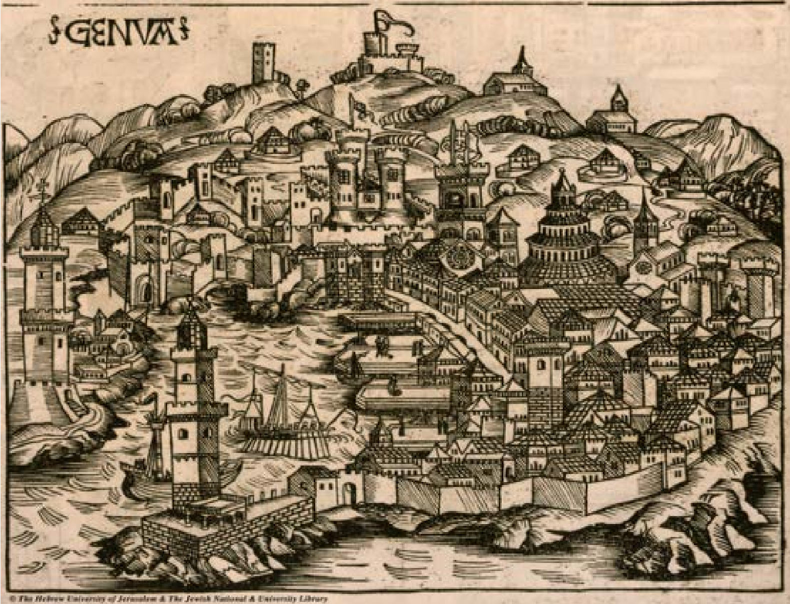



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Energy Systems

Lectures on energy sources, conversion techniques and environmental issues.

Ing. Mattia De Rosa

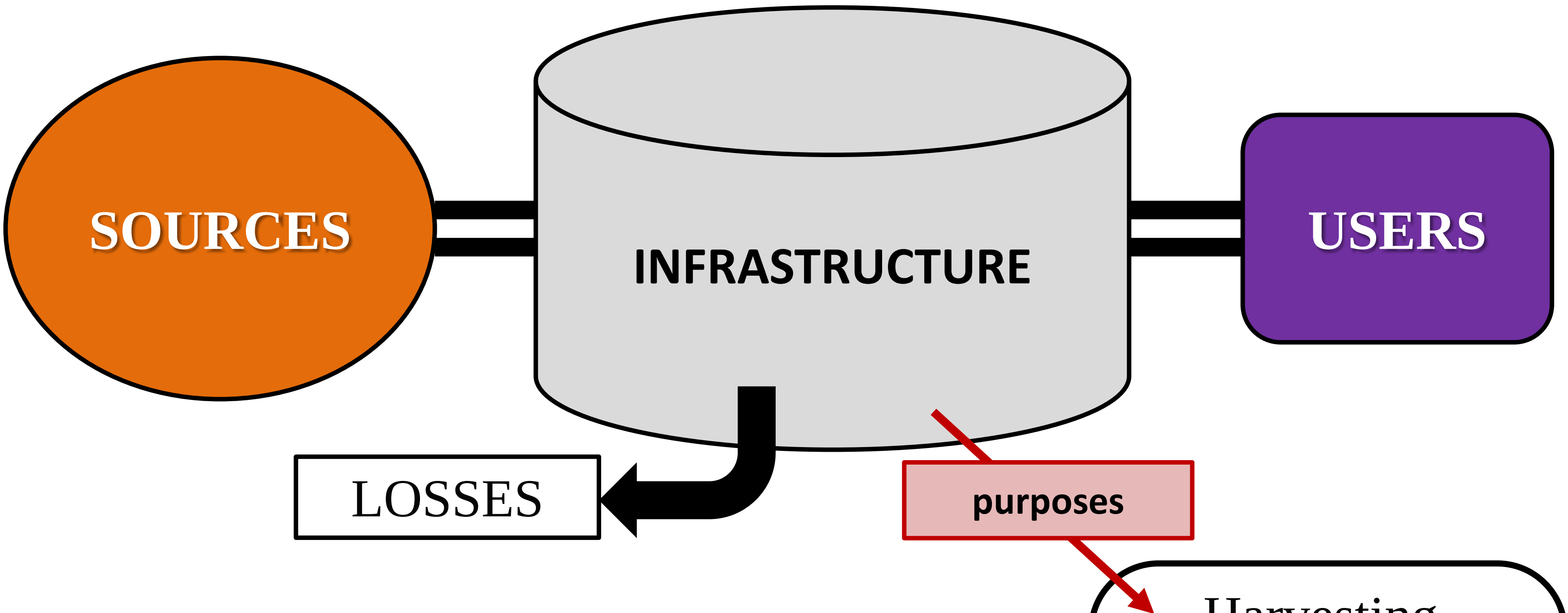
Tambov State Technical University (ТГТУ)
20th October 2014

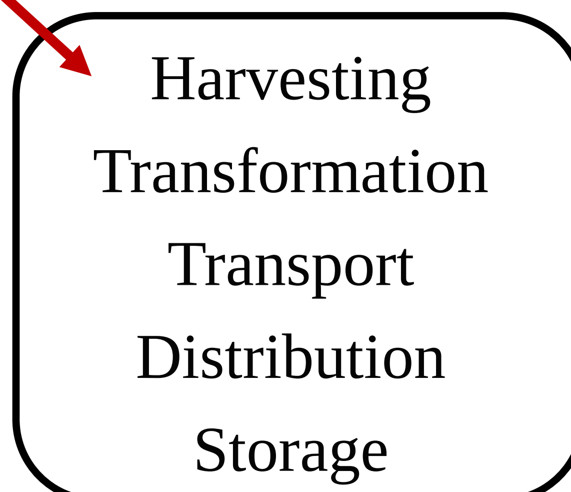
Contents

COURSE SCHEDULE

- Introduction on the energy context
  - Energy demand, user sectors and environmental issues.
  - Energy sources and carriers
  - Non-renewable sources (fossil fuels)
  - Renewable sources (solar, hydroelectric, wind, biomass, geothermic, ...)
- Energy conversion
  - Thermodynamic power cycles
  - Thermal power systems (fossil fuels, nuclear, combined cycles)
  - Renewable power systems (photovoltaic and concentrated thermal solar plant, hydroelectric, wind, biomass, geothermic, etc.)
- Energy systems modeling
  - Global regional energy demand for different sectors, types of users, etc.
  - Tools for modeling energy systems
  - Introduction on EnergyPlan
  - Training on the use of EnergyPlan using simple tutorials.
  - Modeling an energy system – practice.

Energy System





The term <u>ENERGY SYSTEM</u> is usually adopted to denote the whole processes of production, transport, conversion and distribution of energy sources.

Energy source

When should a physical system be considered an energy source ?

Generally, a physical system contains energy if, potentially, it is able to do work (in a physical sense).

Moreover, a physical system containing energy can be considered a **SOURCE** if it is possible to make, at least, part of this energy available in quantity and with characteristics useful for the utilization by the human being.

In other words, if:

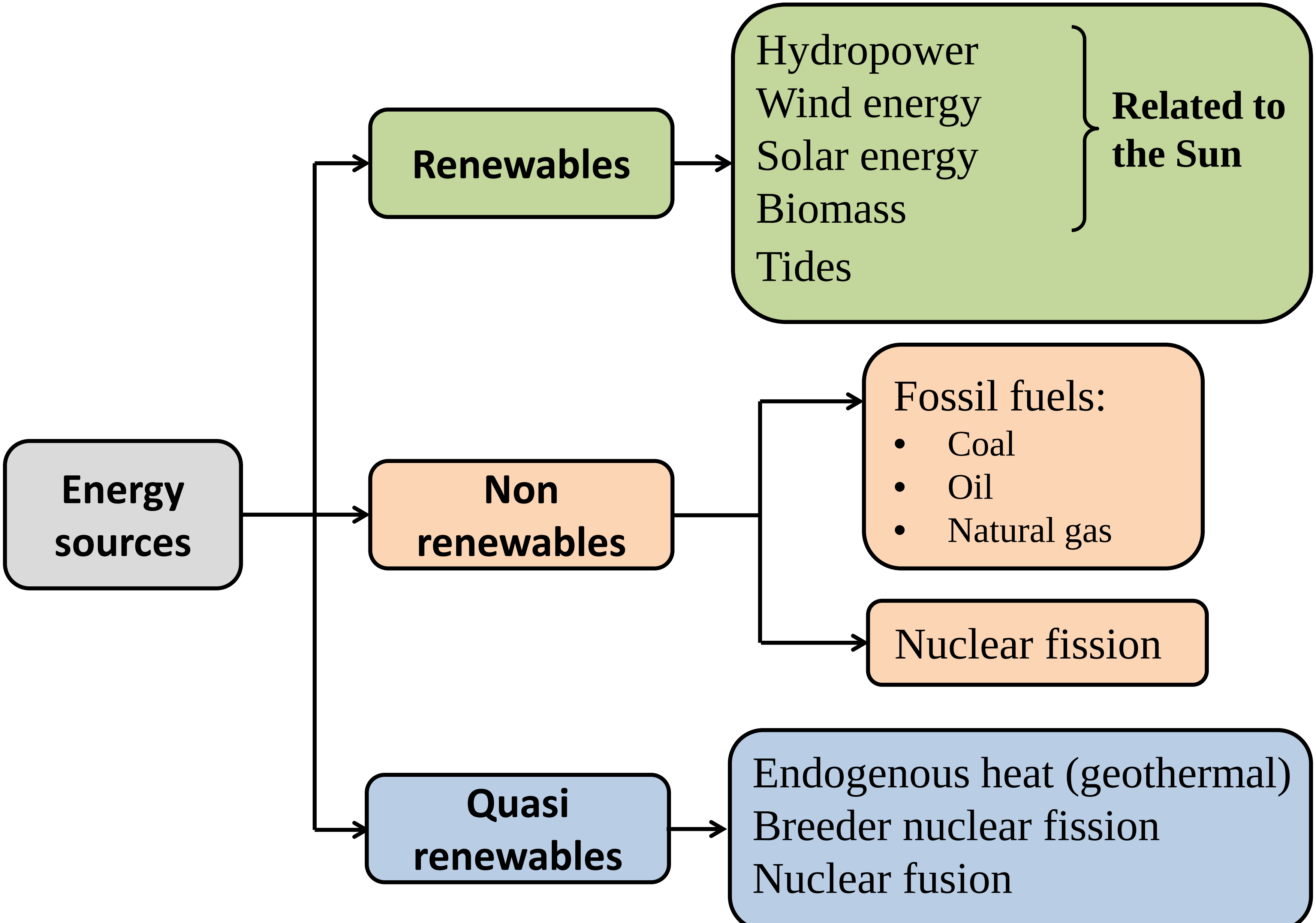
- it can be controlled
- it is economically viable

Energy source

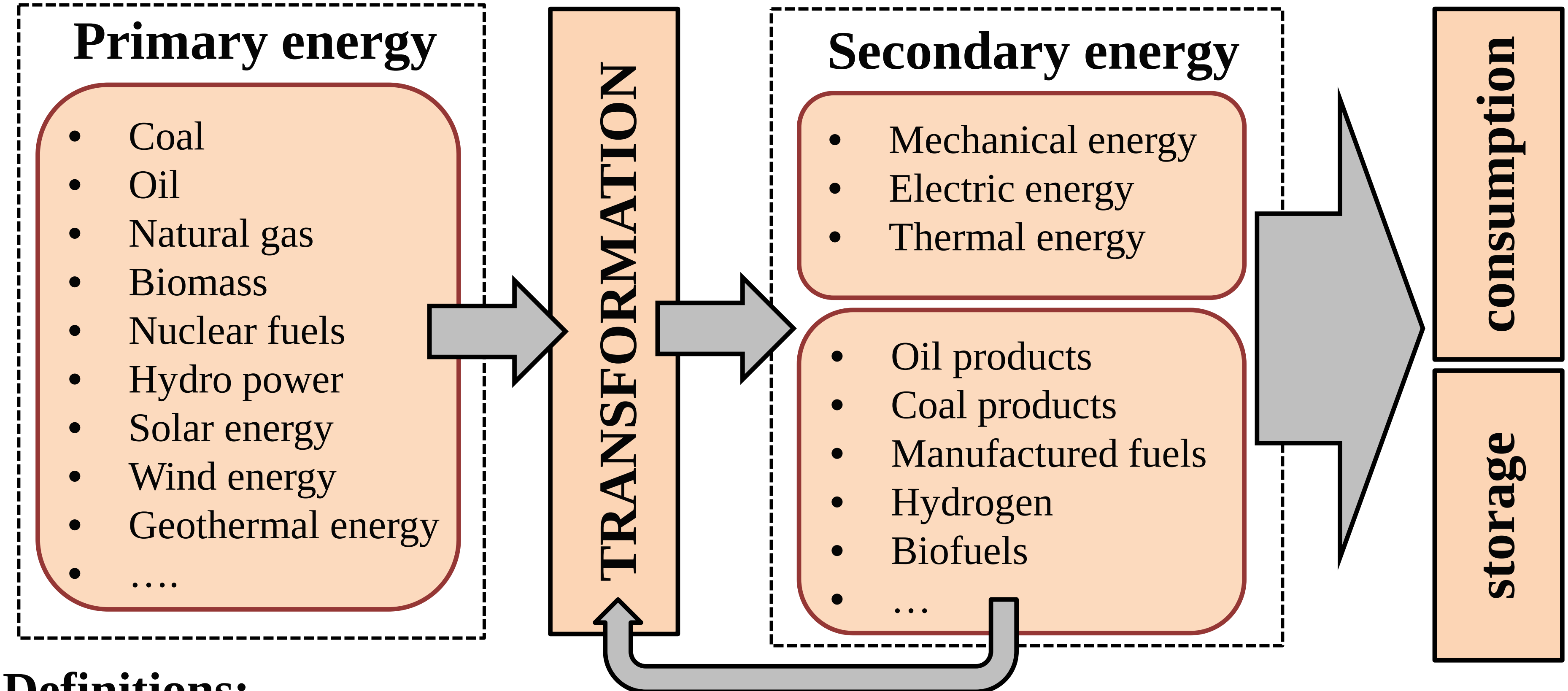
The energy sources owns different intrinsic characteristics, which regard:

- **Availability** (constant, periodical, aleatory)
- **Type** of energy which can be produced (thermal, mechanical, electric)
- **Costs** for supply, plants and maintenances
- **Environmental impact** (depending also on the adopted standards of each country)
- **Specific power** (energy per unit of mass/volume, surface area required by plants, etc.)
- Power plant **scale** (in terms of economies of scale)
- Power plant conversion **efficiencies**
- **Security** and related risks
- **Storage** options

Renewable and non-renewable energies



Primary and secondary energies



<u>Definitions:</u>

Primary energy: energy forms which can be found in nature directly without any conversion or transformation process.

Transformation: any process aimed to transform one form of energy to another.

Secondary energy: all sources of energy that result from transformation of primary sources.

Energy carrier

The primary energy sources need to be converted into more useful energy forms permitting their transfers and movements.

This "middle" energy forms are defined **ENERGY CARRIER**.

<u>Definition according to ISO</u> :

"A substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes".

Generally, it is possible to define an energy carrier as a medium to transfer an energy form to another one.

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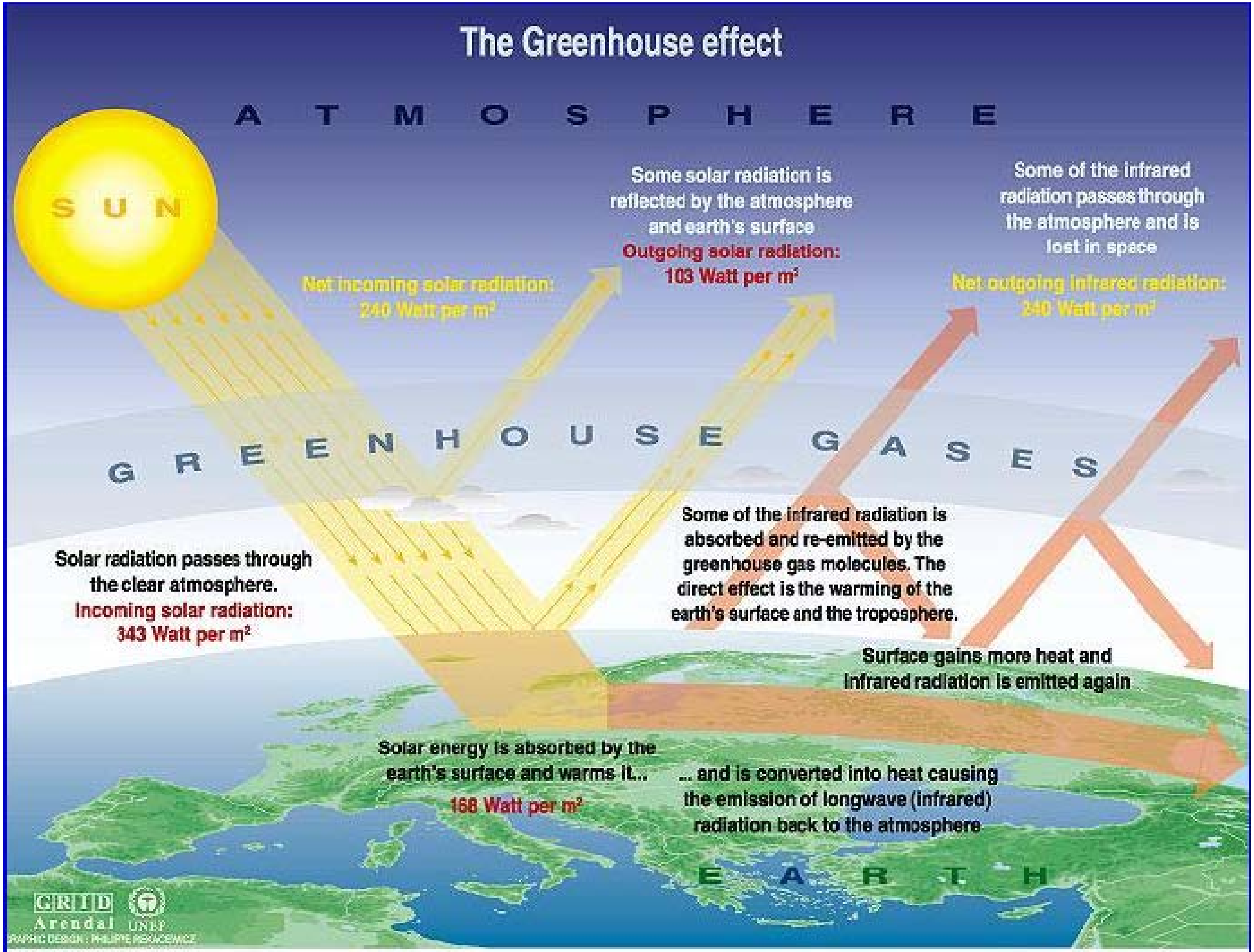
Common units

To:	TJ	Gcal	Mtoe	MBtu	GWh
From:	multiply by:				
TJ	1	238.8	2.388×10^{-5}	947.8	0.2778
Gcal	4.1868×10^{-3}	1	10^{-7}	3.968	1.163×10^{-3}
Mtoe	4.1868×10^{4}	10^{7}	1	3.968×10^{7}	11630
MBtu	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
GWh	3.6	860	8.6×10^{-5}	3412	1

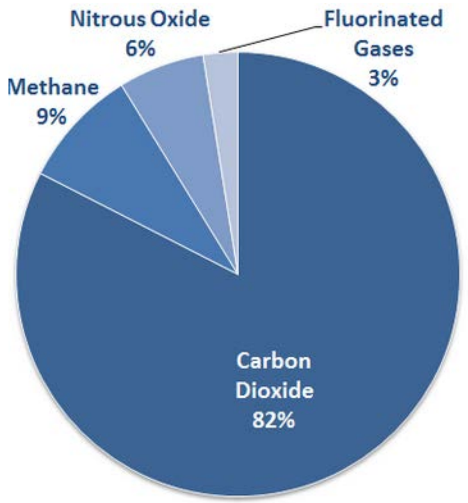
Environmental issues

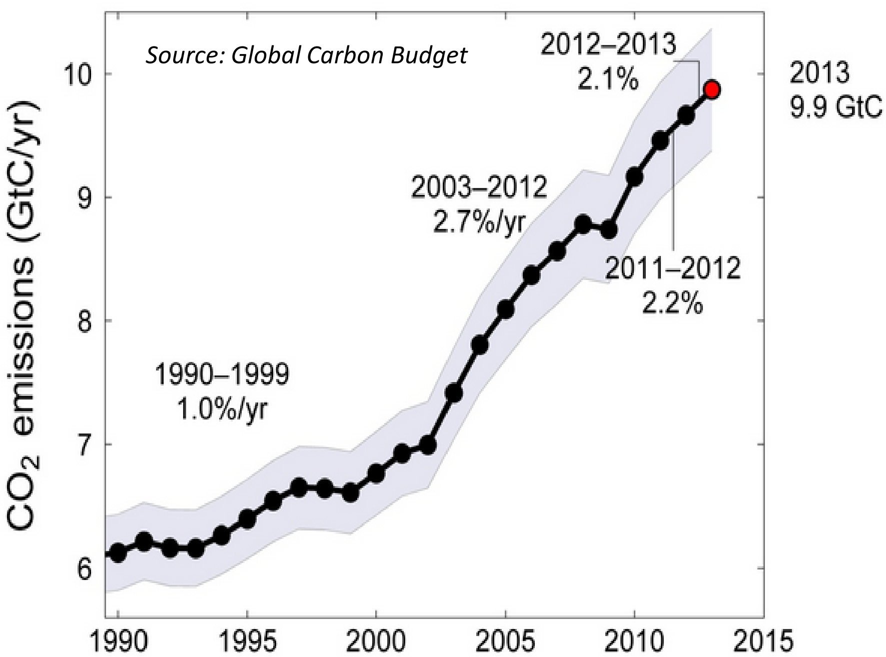


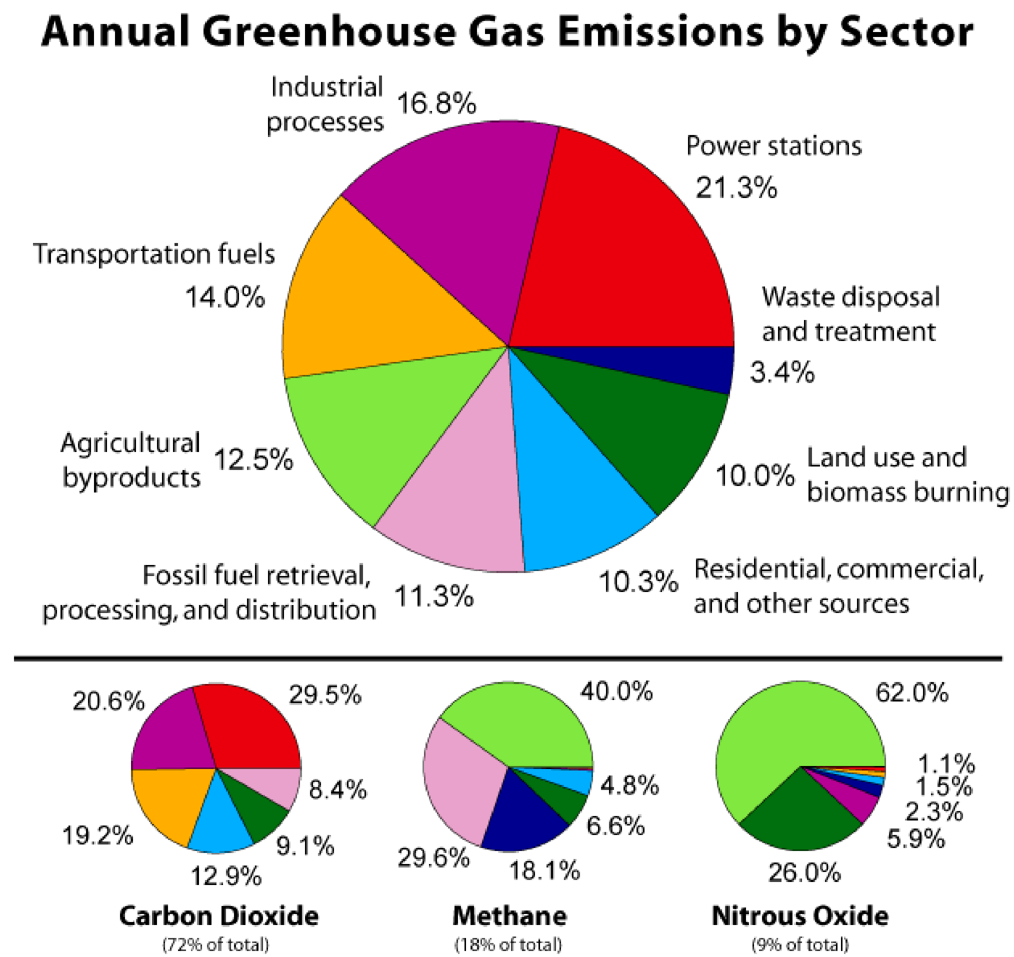
Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

Environmental issues

Main greenhouse gases







Main pollutants related to combustion

Type	Effect	Residence times
CO_2 – Carbon dioxide	Greenhouse gas	High global effects
CO - Carbon monoxide	Toxic	Low local effects
HC - Hydrocarbon	Toxic, acid deposits, carcinogen, greehouse gas (CH4)	Low, local effects (CH4: high, global effects)
NO_x – Nitrogen oxides	Toxic, acid deposits	Low, local effects
SO_x – Sulfur oxides	Toxic, acid deposits	Low, local effects
PM - Particulates	Toxic	Low, local effects

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Understanding the value of energy

- Turn on a 100W lamp for 7 minutes
- Heat 10 liters of water increasing its temperature of 1°C
- Lift a weight of 40 quintals

All these consumptions need the amount of energy owned by 1 gram of petrol (about 42kJ or 0.01kWh)

The cost depends on the type of fuel and on the Country

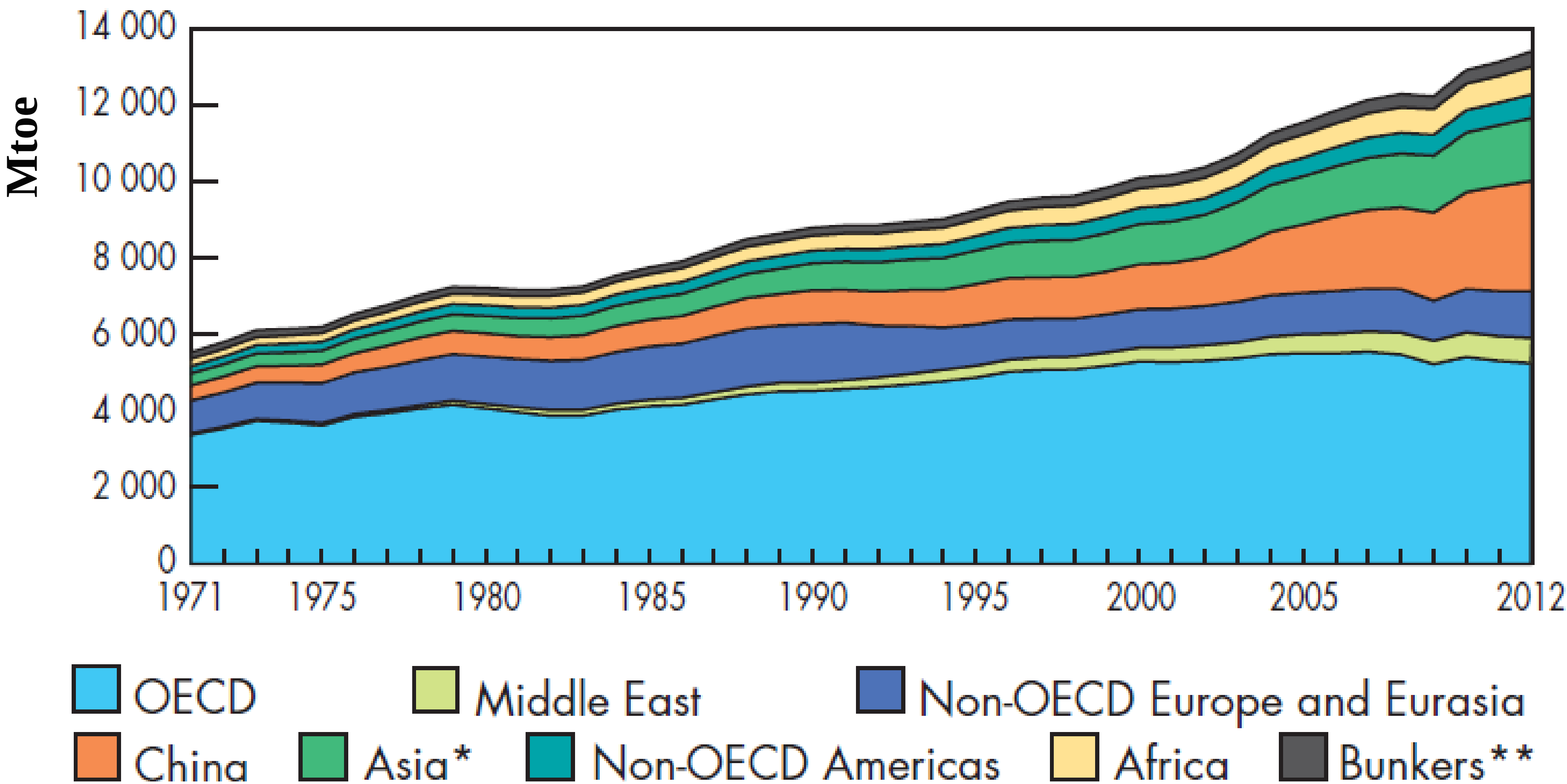
World Energy Consumption

Tambov State Technical University (ТГТУ)
20th October 2014

Ing. Mattia De Rosa

World energy demand

World primary energy consumption (in Mtoe) by region

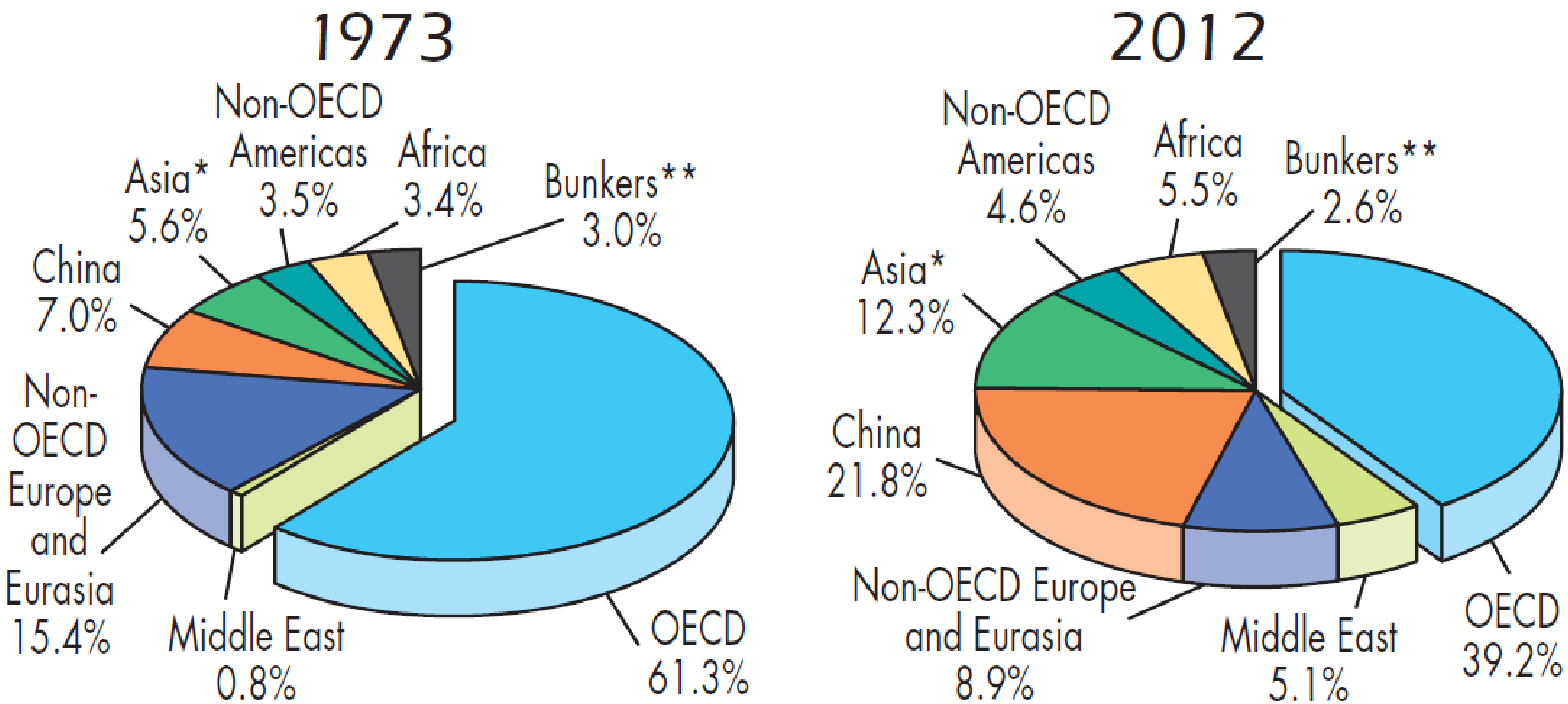


Source: IEA 2014

**Asia excludes China.

World energy demand

1973 and 2012 regional shares of TPES



6 106 Mtoe

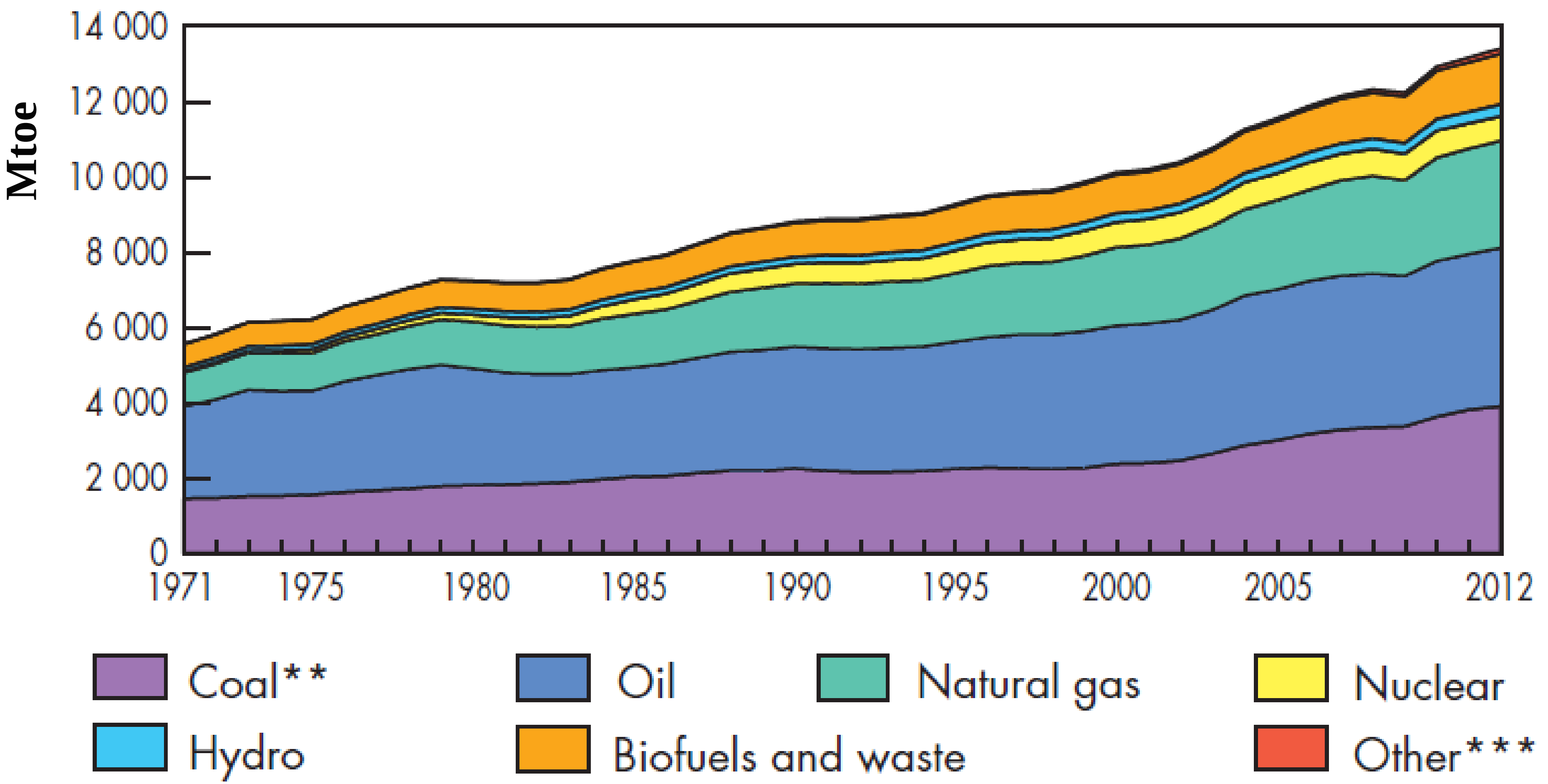
13 371 Mtoe

Source: IEA 2014

*Asia excludes China.

World energy demand

World primary energy consumption (in Mtoe) by fuel

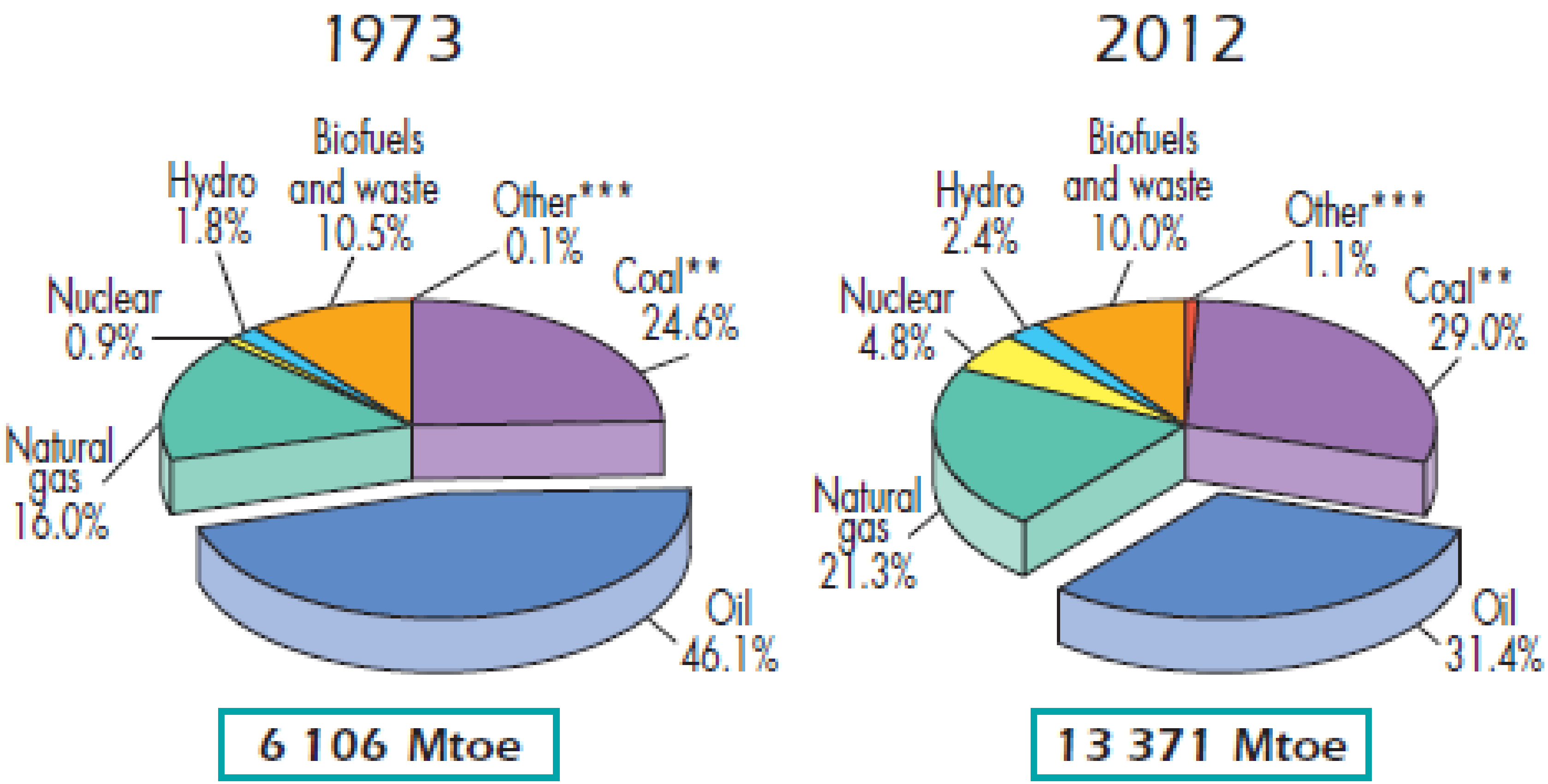


Source: IEA 2014

***Includes geothermal, solar, wind, heat, etc.

World energy demand

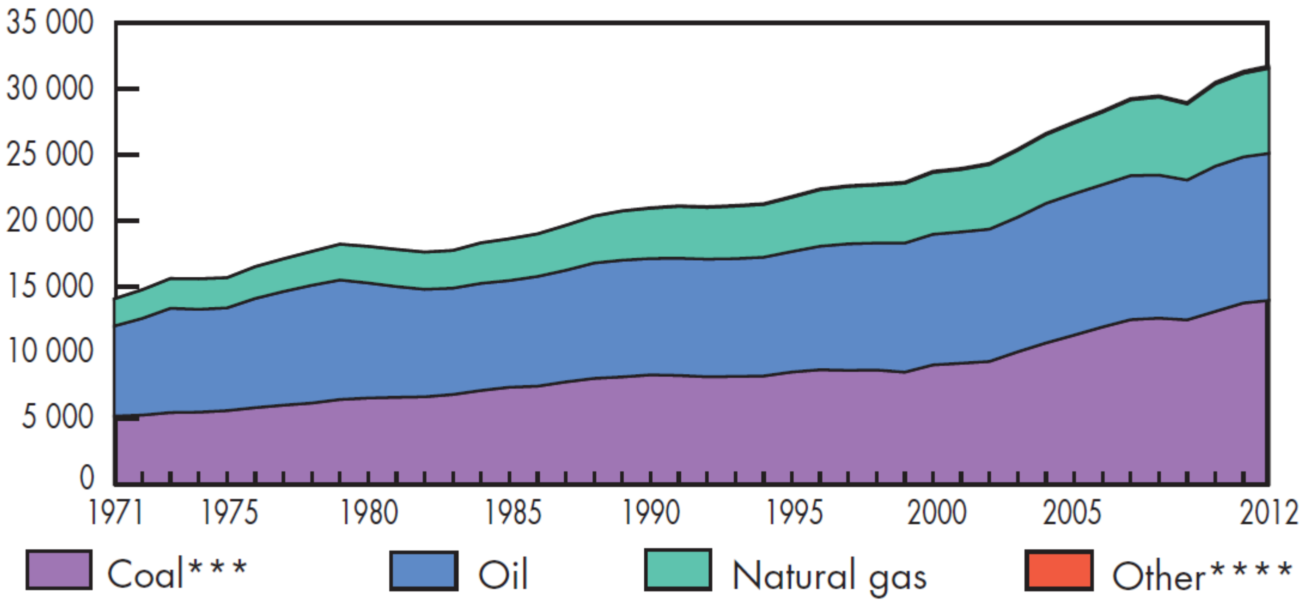
1973 and 2012 fuel hares of TPES



Source: IEA 2014

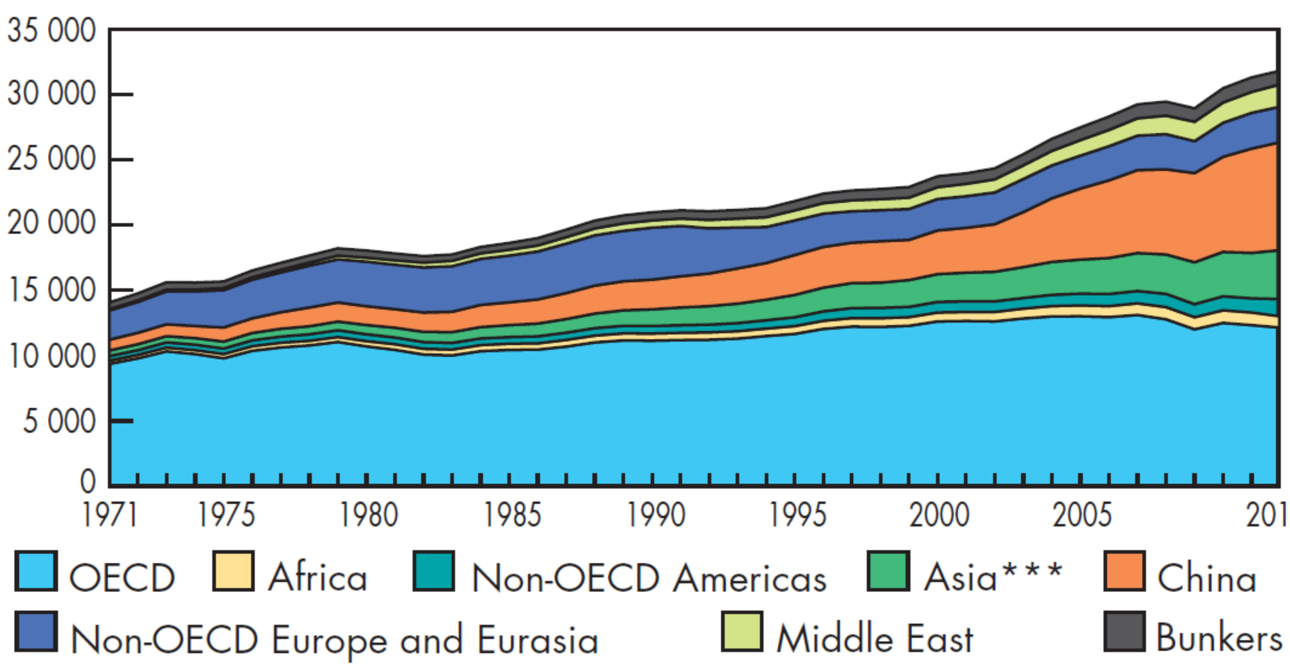
***Includes geothermal, solar, wind, heat, etc.

CO_2 Emissions

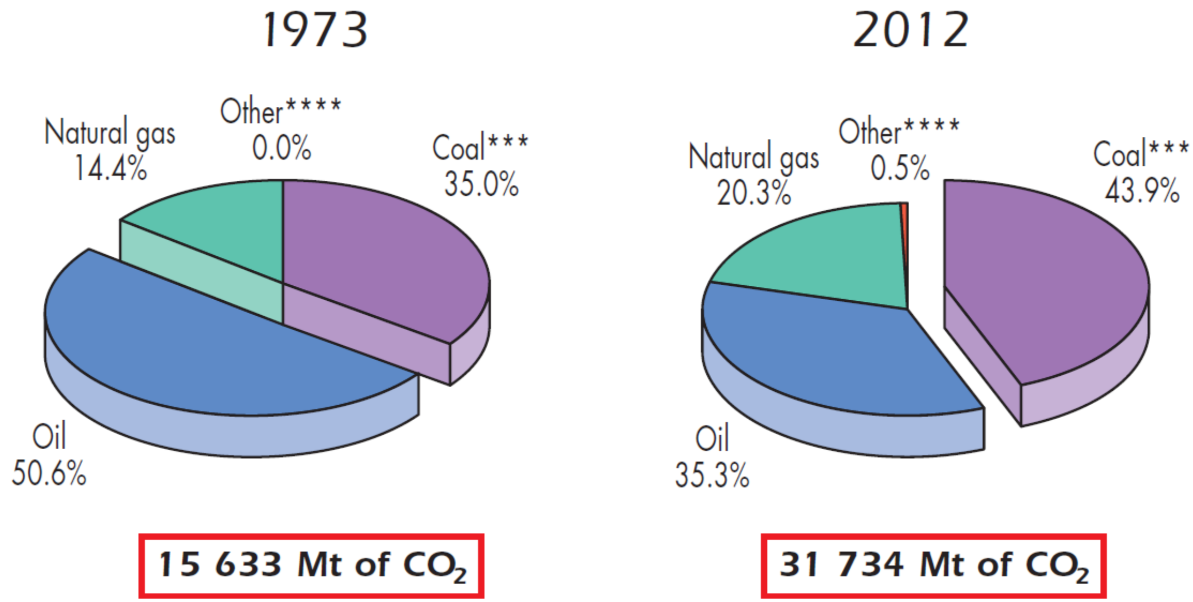


BY FUEL

BY REGION

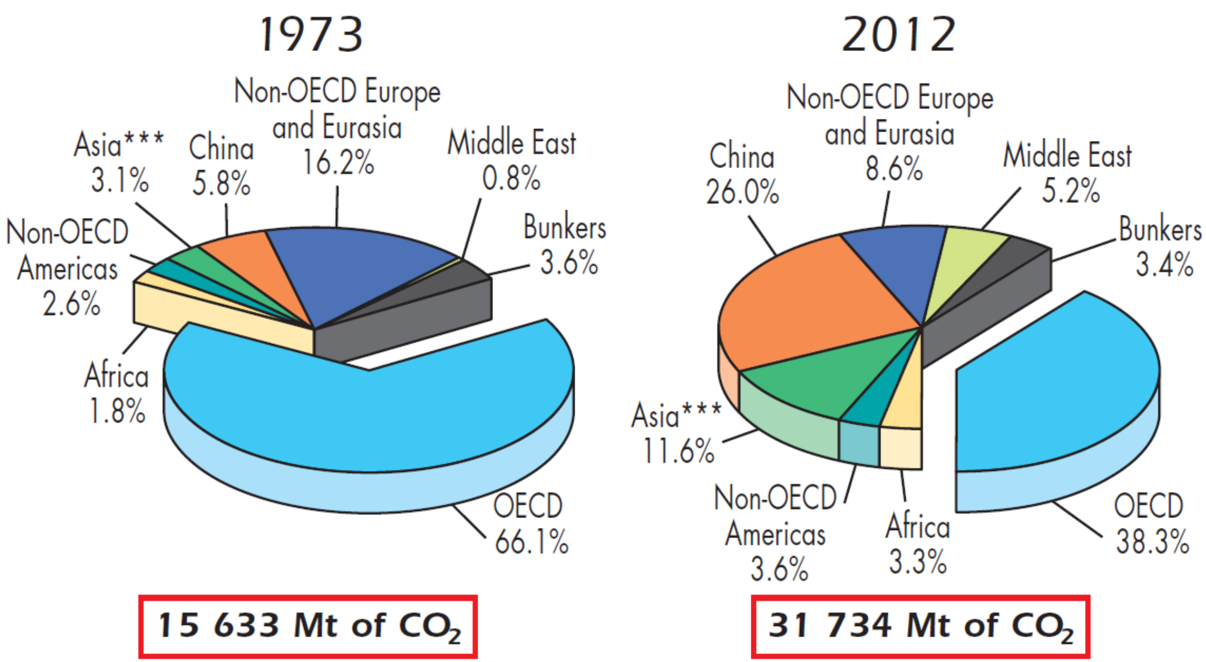


CO_2 Emissions



1973 and 2012 fuel shares of TPES

1973 and 2012 regional shares of TPES



Source: IEA 2014

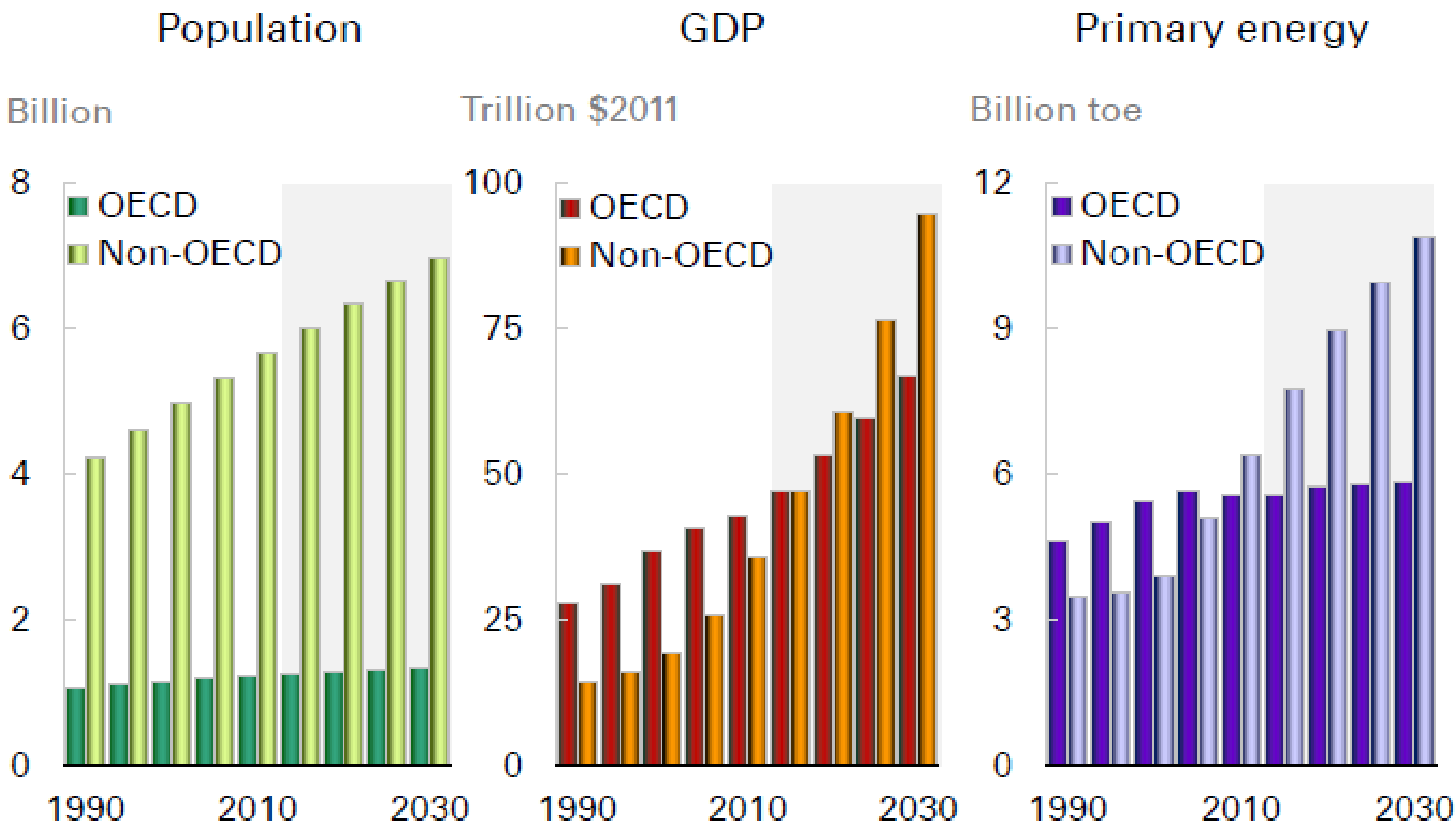
Population and income growth

- Population and income growth are the key drivers behind growing demand for energy. By 2030 world population is projected to reach 8.3 billion, which means an additional 1.3 billion people will need energy.
- Low and medium income economies account for over 90% of population growth to 2030. Due to their rapid industrialization, urbanization and motorization, they also contribute 70% of the global GDP growth and over 90% of the global energy demand growth.

Source: BP Energy Outlook 2013

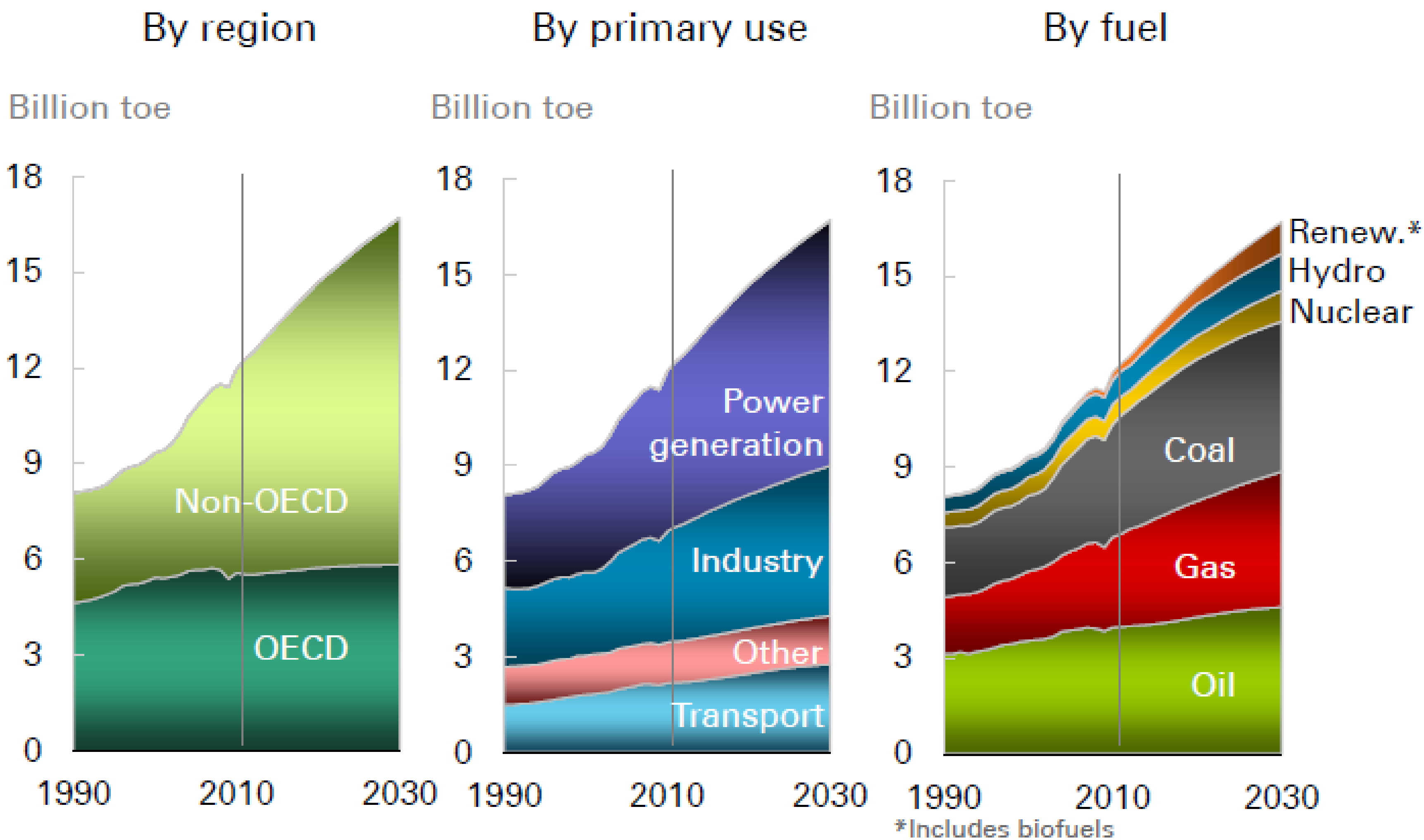
Future trends

Source: BP Energy Outlook 2013



OECD: Organization for Economic Co-operation and Development

Future trends



Adapted from BP Energy Outlook 2013

Future trends

Global energy trends to 2035

IEA (International Energy Agency) in its World Energy Outlook 2013 investigated 3 different scenarios:

Current Policies Scenario: takes into account only of policies already enacted.

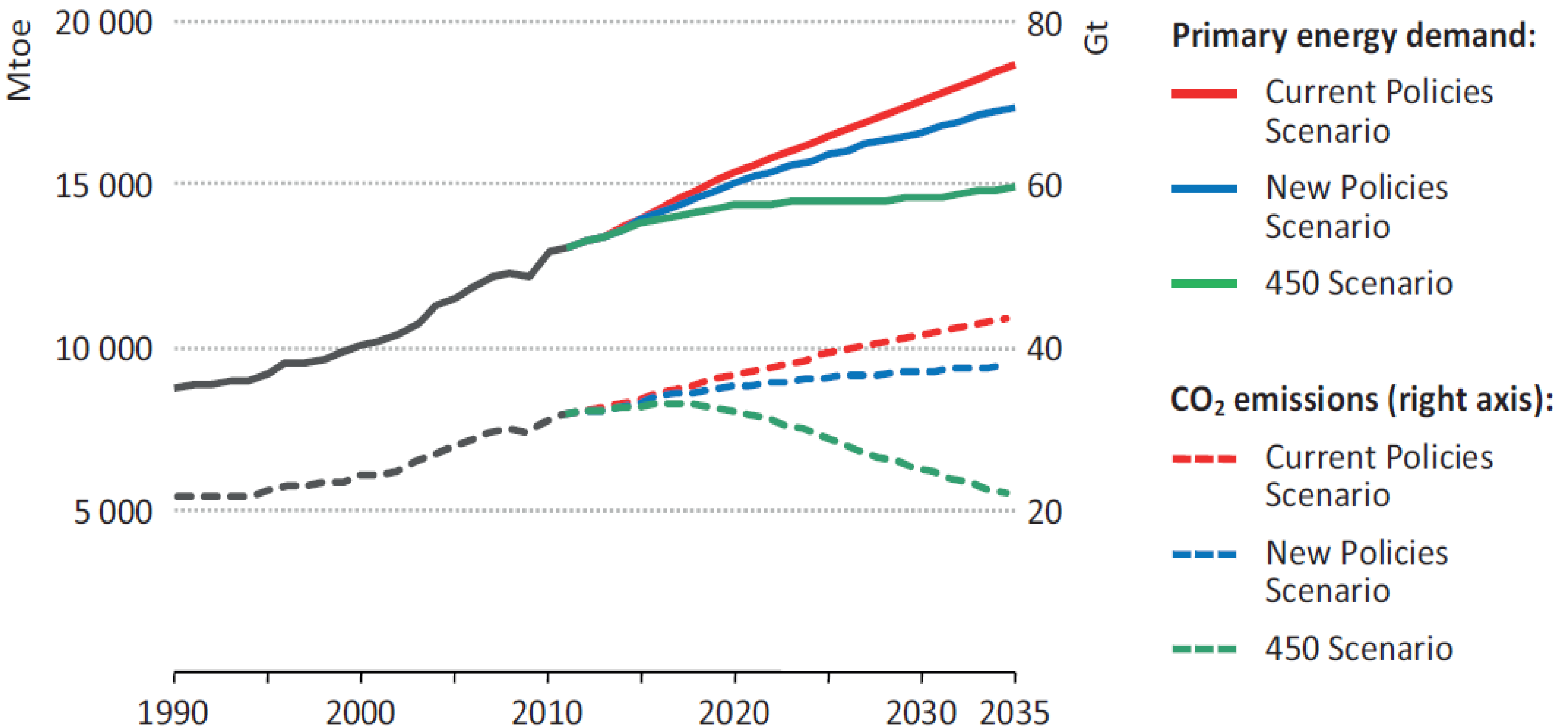
New Policies Scenario: cautious implementation of already announced policies (but not enacted yet).

450 Scenario: implementation of measures in order to have a 50% chance of keeping to 2°C the long-term increase in average global temperature.

Source: IEA 2014

Future trends

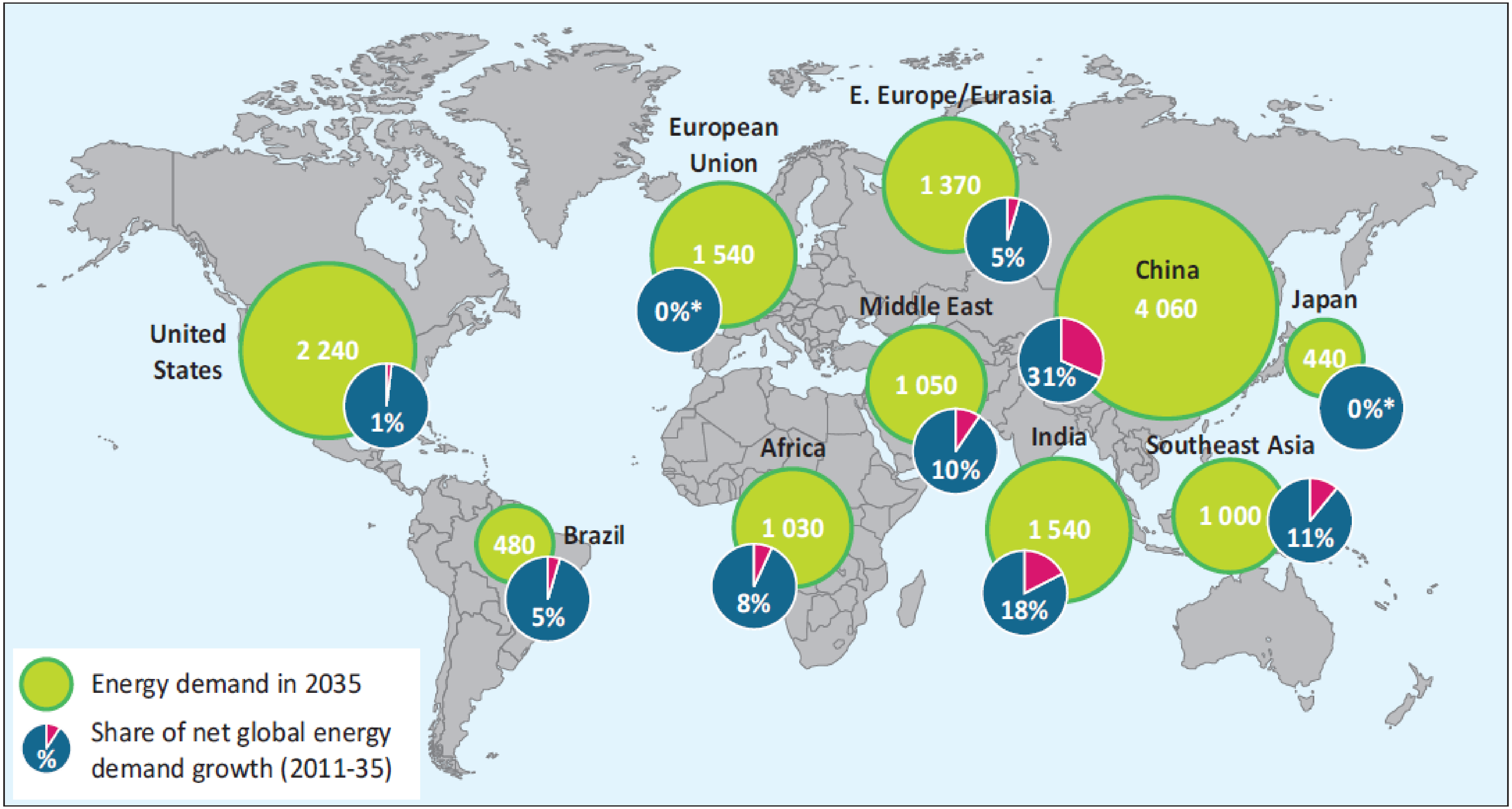
World primary energy demand and related CO2 emissions for different scenarios



Source: IEA 2014

Future trends

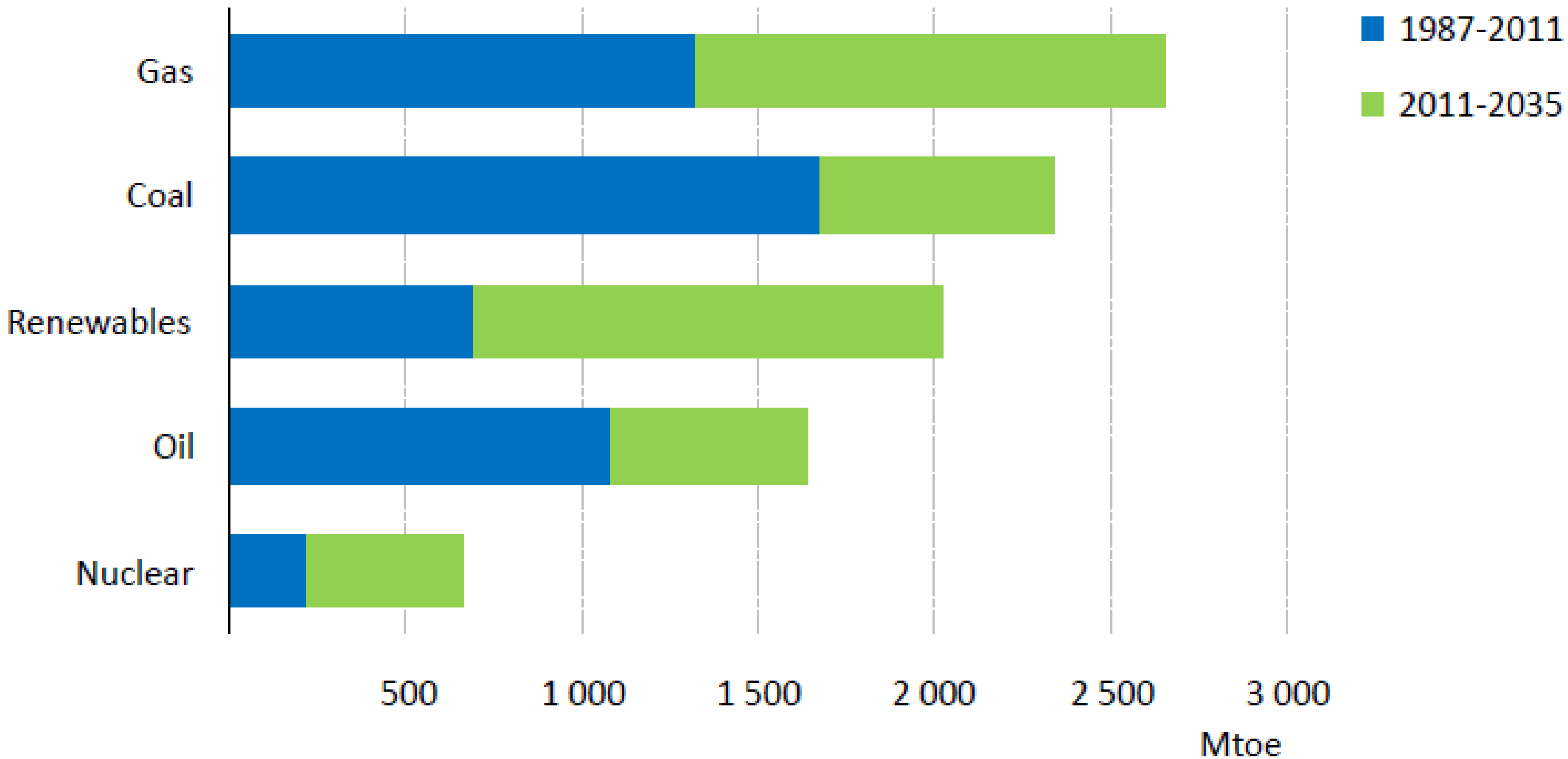
World primary energy demand for the new policy scenario



Source: IEA 2014

Future trends

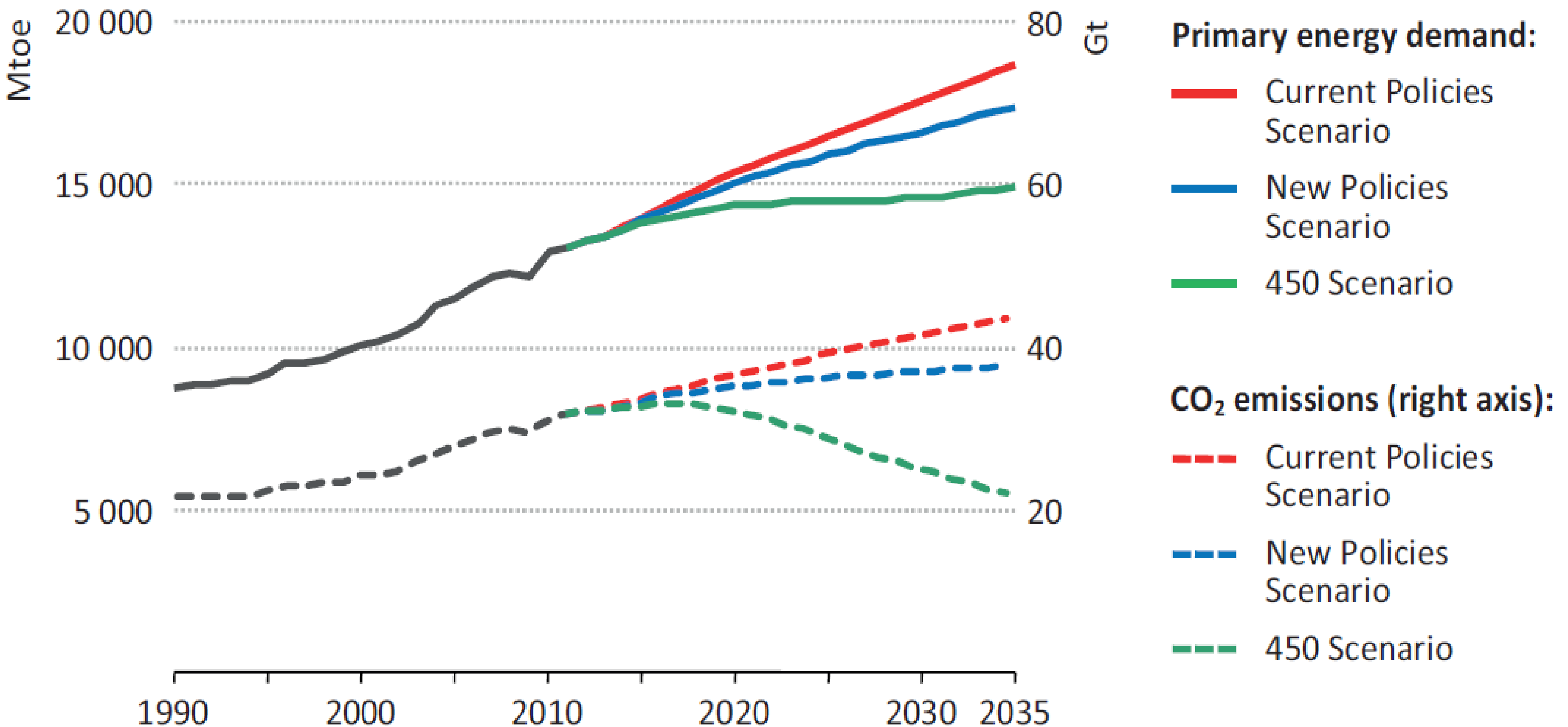
Today's share of fossil fuels in the global mix, at 82%, is the same as it was 25 years ago; the strong rise of renewables only reduces this to around 75% in 2035



Source: IEA 2014

Future trends

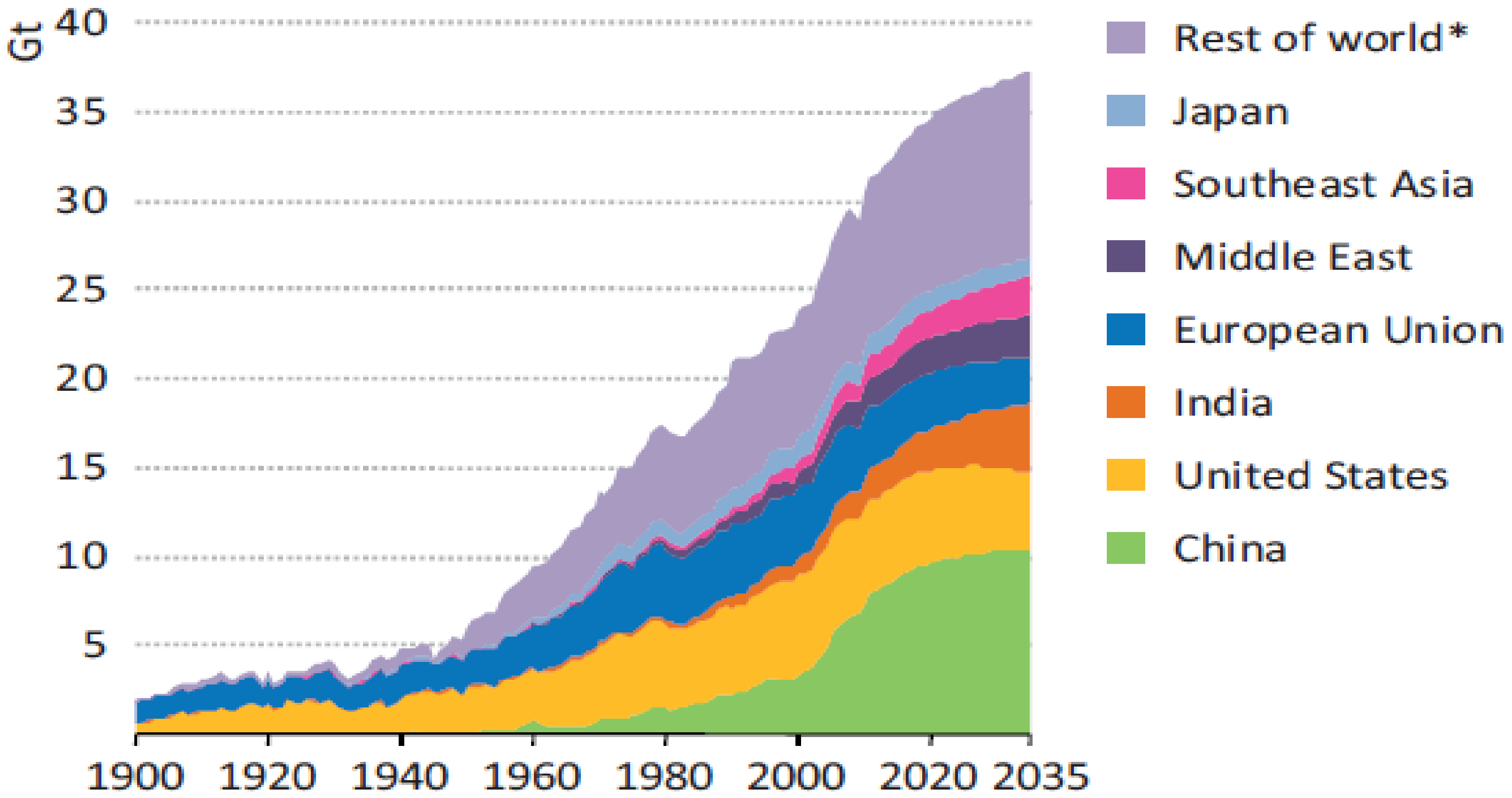
World primary energy demand and related CO2 emissions for different scenarios



Source: IEA 2014

Future trends

World primary energy demand and related CO2 emissions for different scenarios



Source: IEA 2014

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Fossil fuels

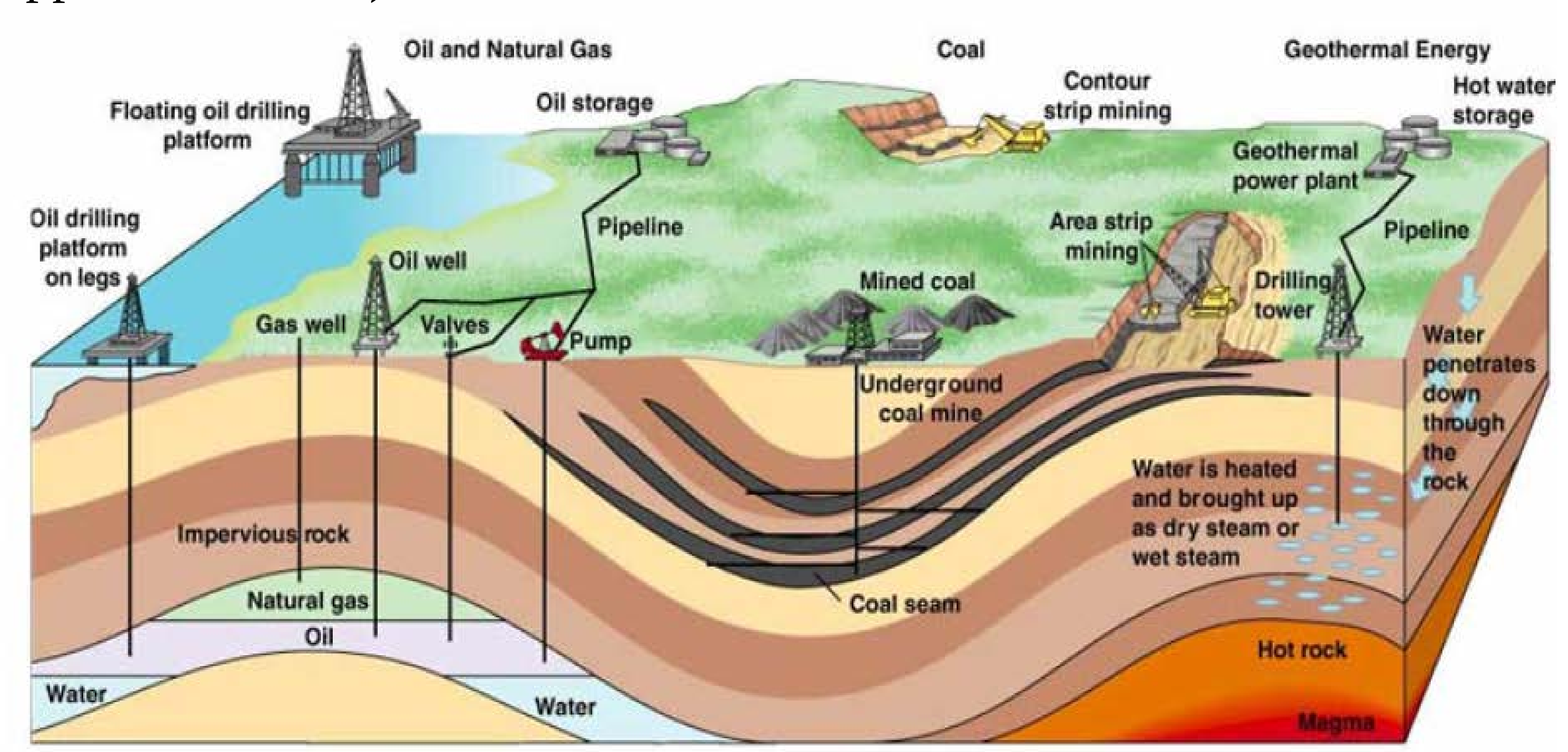
Tambov State Technical University (ТГТУ)
20th October 2014

Ing. Mattia De Rosa

Fossil fuels

Generally, fossil fuels consist of <u>hydrocarbon mixtures.</u>

It is possible to classify them depending on their: (i) physical state (liquid, solid or gases), (ii) lower heating value (LHV) and (iii) application fields).



Fossil fuels

The LHV value is an intrinsic characteristic of each fuel and it can be considered as a measure of their **energetic intensity**.

e.g. to produce 1 kWh (thermal) are necessary about:

- Wood: 0.5 kg
- Coal: 0.25 kg
- Oil: 0.18 kg
- Natural gas: 0.2 m^3

e.g. to supply a power plant of 1000MW kWh are necessary about:

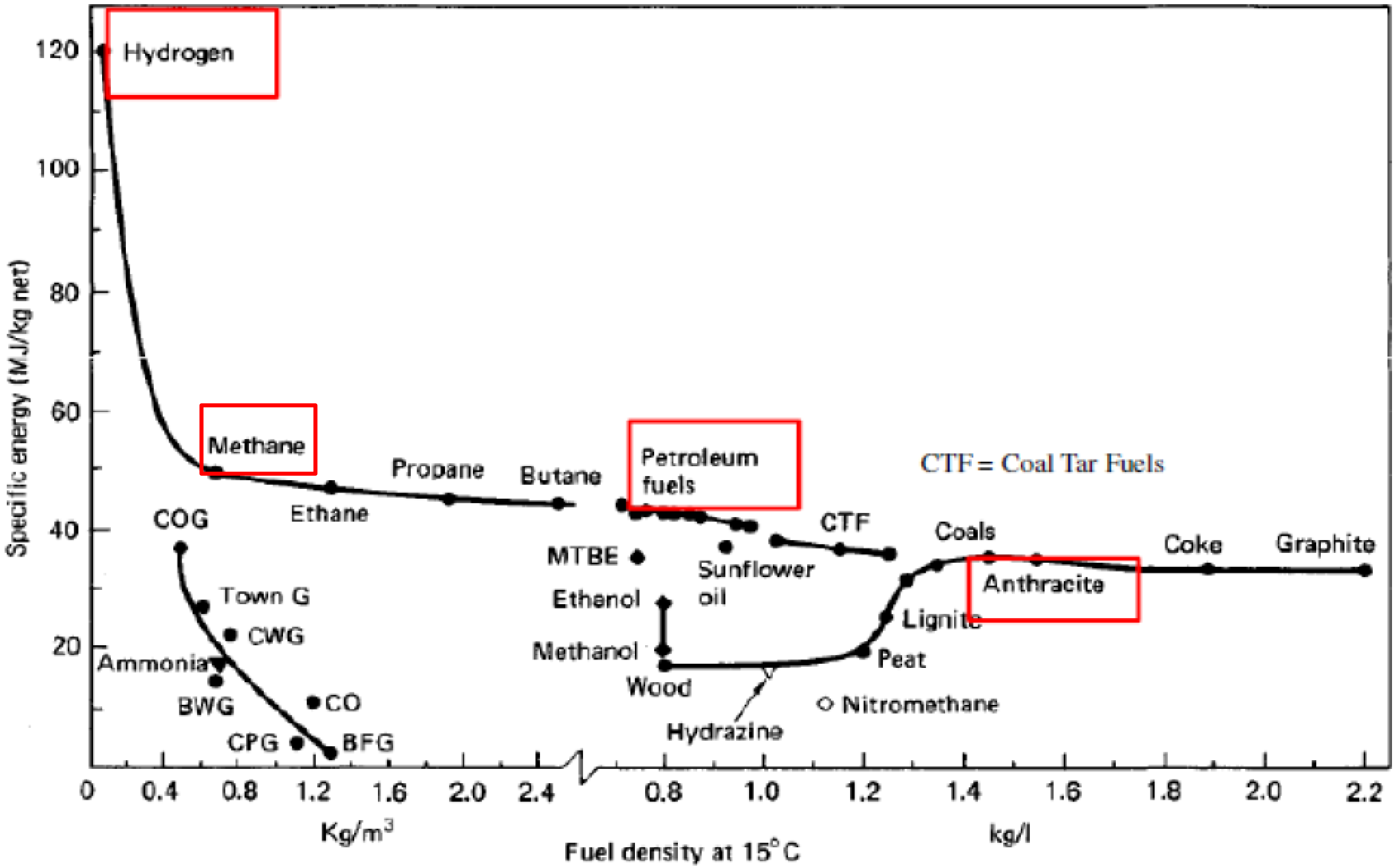
- PWR reactor: 20ton Uranium (1 truck)
- Breeder nuclear reactor: 2ton Uranium (about 1m^3)
- Fuel oil: $2 \cdot 10^6$ ton
- Coal: $2.5 \cdot 10^6$ ton (about 2-3 train/day)
- Combined gas cycle: 1 high pressure (~80bar) pipeline D=50cm

Energetic density: the surface necessary to produce an amount of electric energy or power.

e.g. to produce 1000MWel with a combined gas cycle or with a nuclear power plant, are necessary about 100-200 hectares of land. → **Power plant scale and costs**

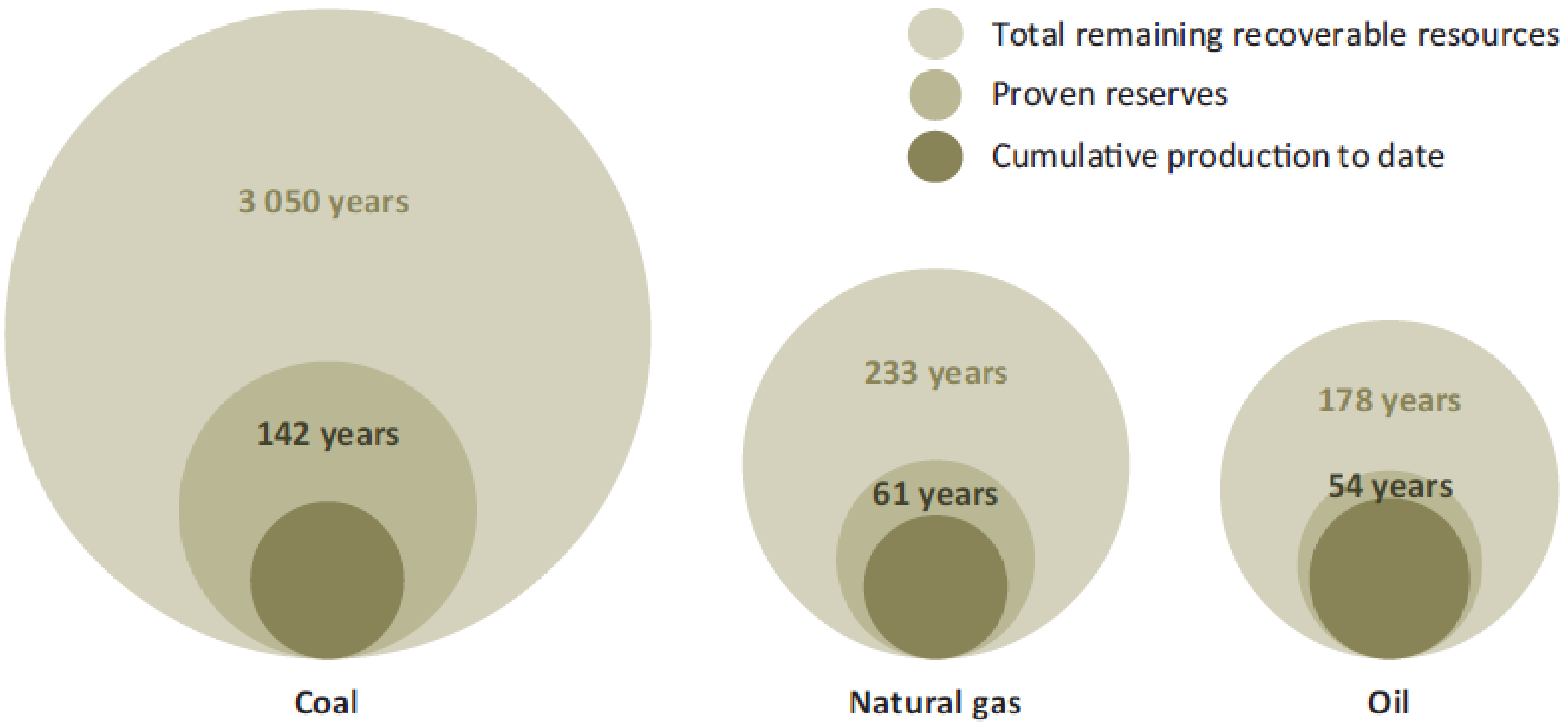
Fossil fuels

Density and heat for different fuels



Fossil fuels

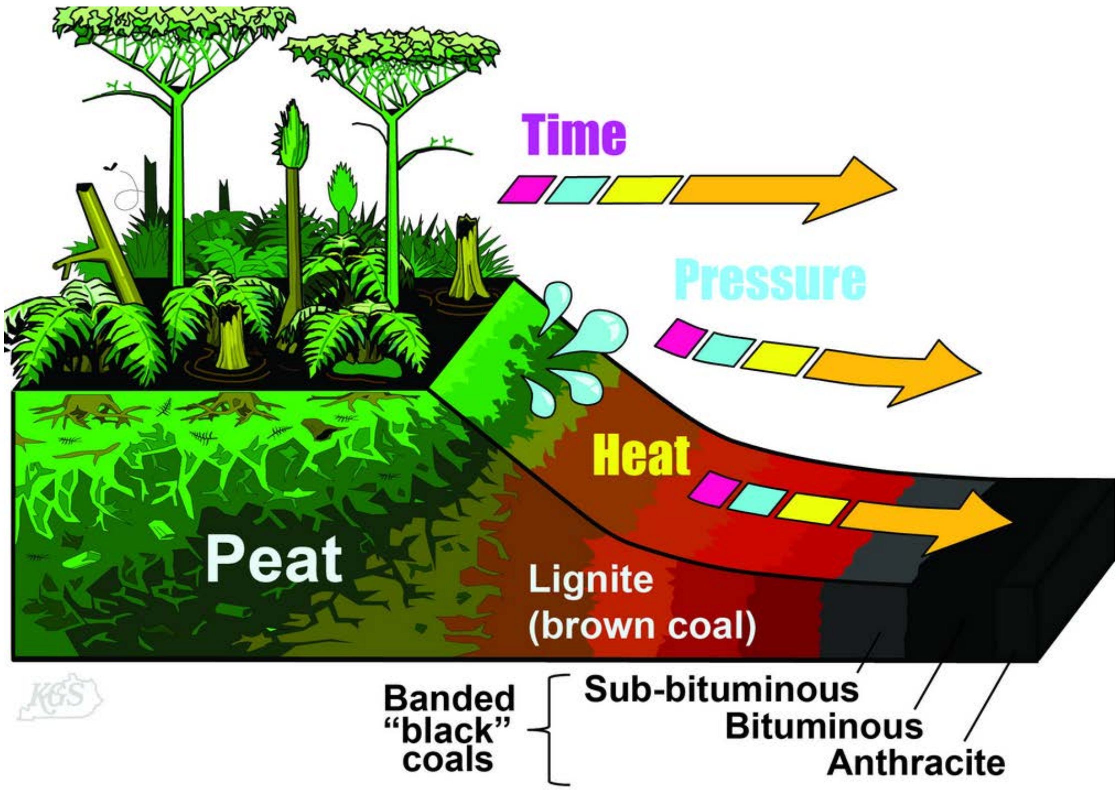
Expected total remaining recoverable resources



Source: IEA 2014

Coal

Sedimentary rock formed by accumulation of organic debris which are modified by pressure and temperature inside the Earth's crust.

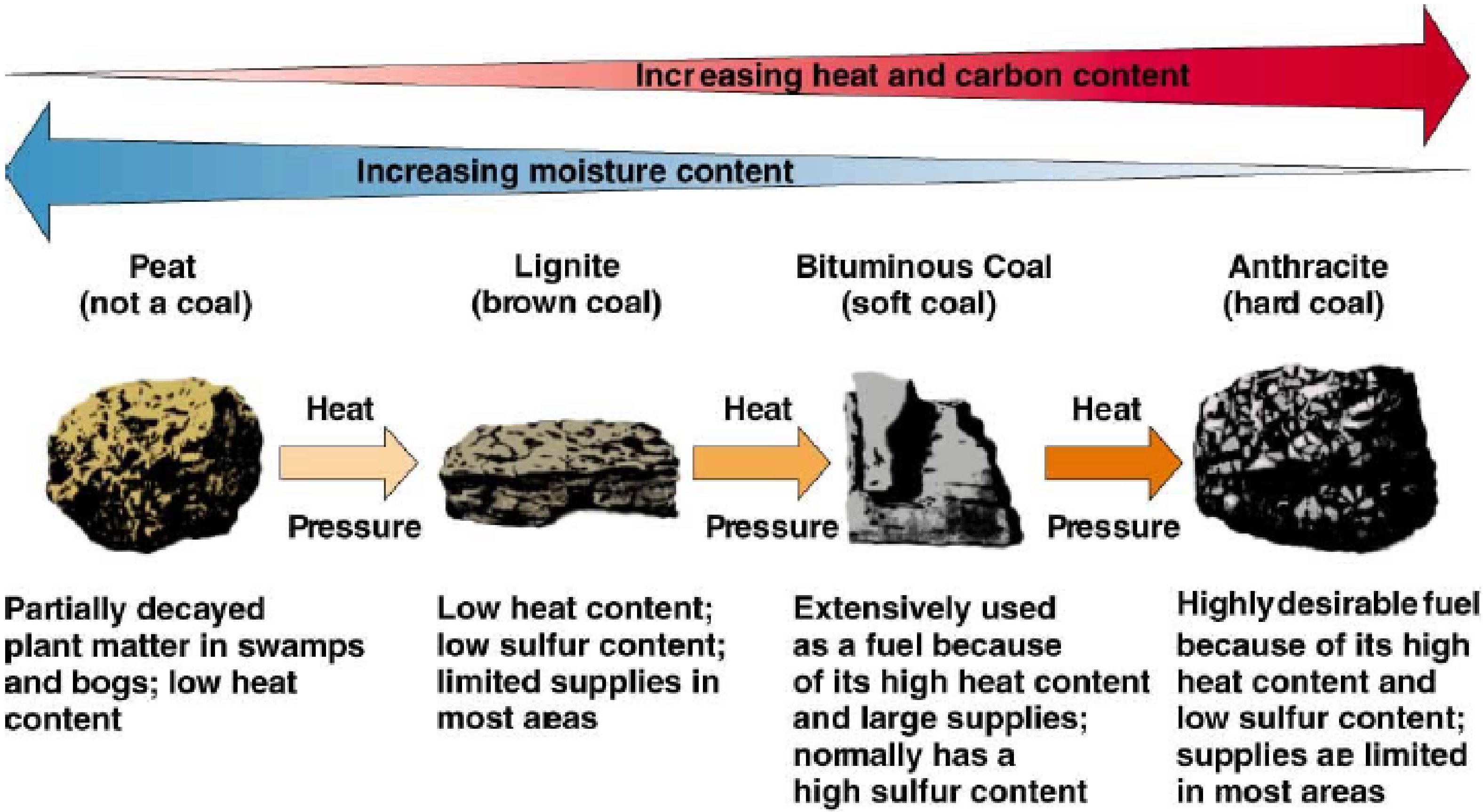


The transformation process is based on the gradual elimination of components, such as hydrogen and oxygen, with the consequent enrichment of carbon.

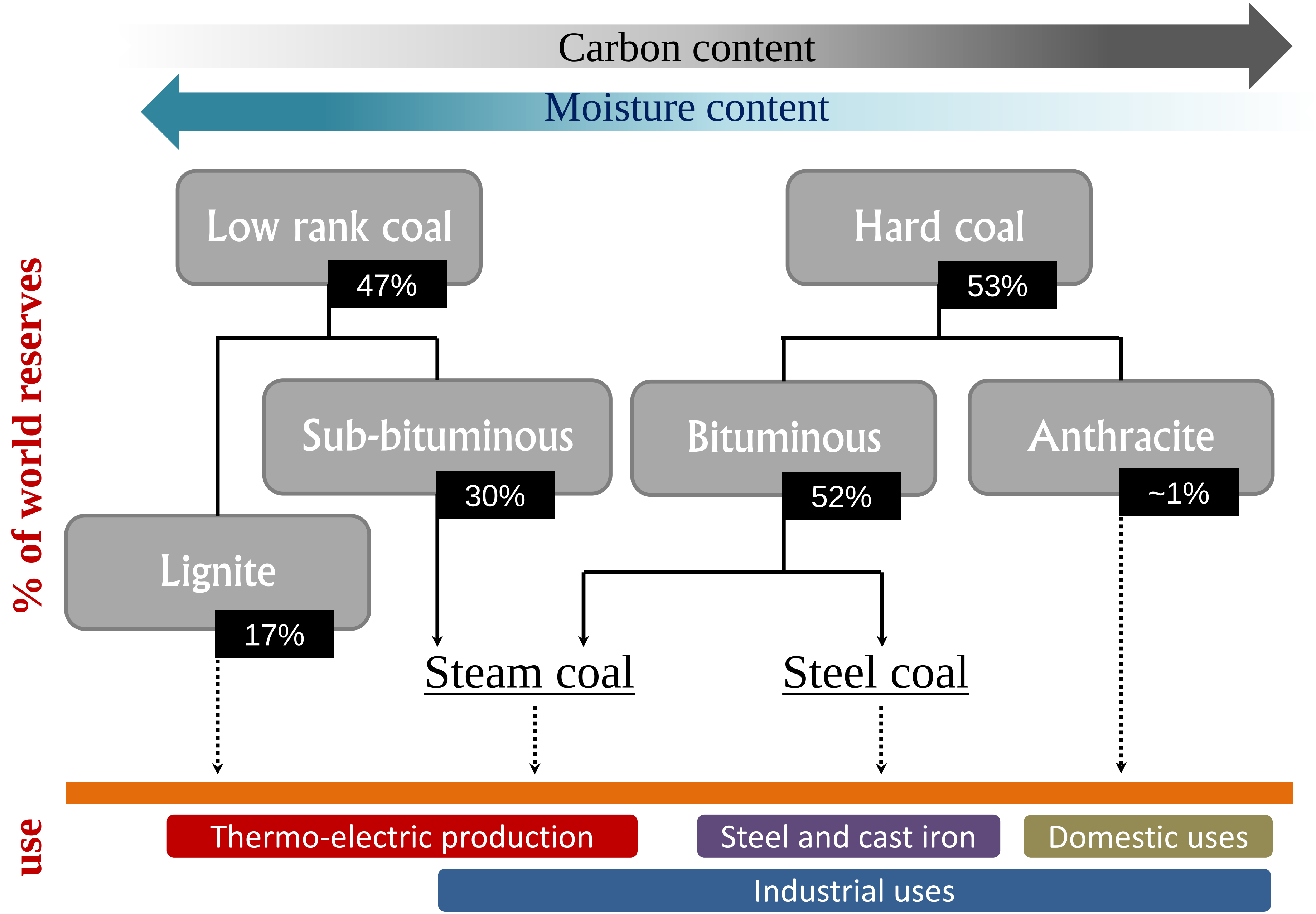
In practice, a continuous distribution of coals, from PEAT to ANTHRACITE, occur.

Coal

Sedimentary rock formed by accumulation of organic debris which are modified by pressure and temperature inside the Earth's crust.



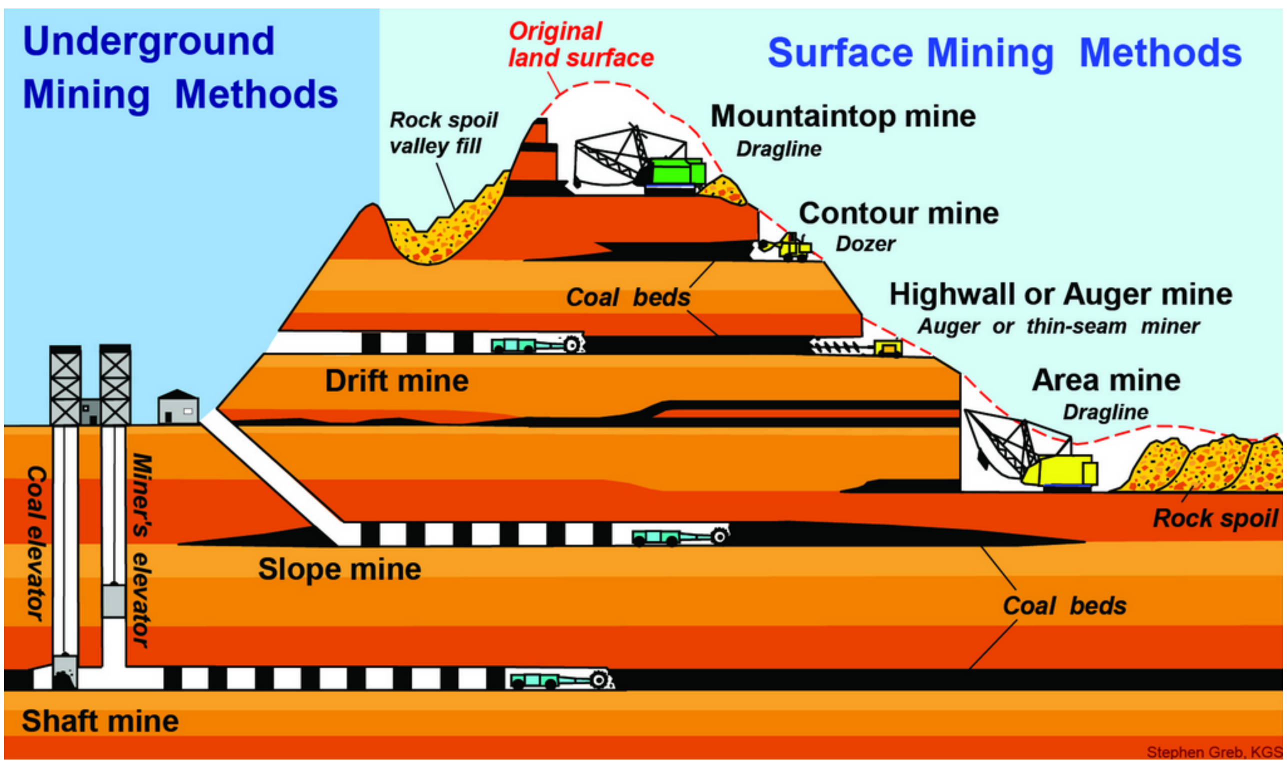
Coal


Carbon content
Moisture content
% of world reserves
Low rank coal
47%
Hard coal
53%
Sub-bituminous
30%
Bituminous
52%
Anthracite
~1%
Lignite
17%
Steam coal
Steel coal
use
Thermo-electric production
Steel and cast iron
Domestic uses
Industrial uses

Coal

Main coal types characteristics

Type of Coal	Composition	LHW [MJ/kg]
Peat	Humidity > 50%	10-15
Lignite (brown coal)	With sulfur and ashes	12-20
Sub-bituminous coal	60-70% C	20-25
Bituminous coal	70-80% C	25-30
Anthracite	>90% C	30-32



The main uses of coal are aimed to:

- Power generation (electrical power plant)
- Steel production
- Concrete production

Coal

The main problems related to the use of coal is the environmental impact of its **handling** (dusts) and **combustion** (dusts, ashes and smokes).

In particular, the combustion produces:

- CO_2 and CO related to a partial oxidation of carbon
- Particulate, dusts and ashes.
- SO_2 and SO_3 that, if in contact with water, can form sulfuric acid
- Nitrogen oxides (NO_x), especially for high temperature combustion

$\Rightarrow$ **Emissions treatment**

Petroleum

As a fossil fuel, petroleum is formed when large quantities of dead organisms, usually zooplankton and algae, are buried under sedimentary rock and subjected to intense heat and pressure.

The crude oil is a naturally occurring brown to black flammable liquid and it is mainly constituted of hydrocarbons mixed with variable amounts of sulfur, nitrogen, and oxygen compounds.

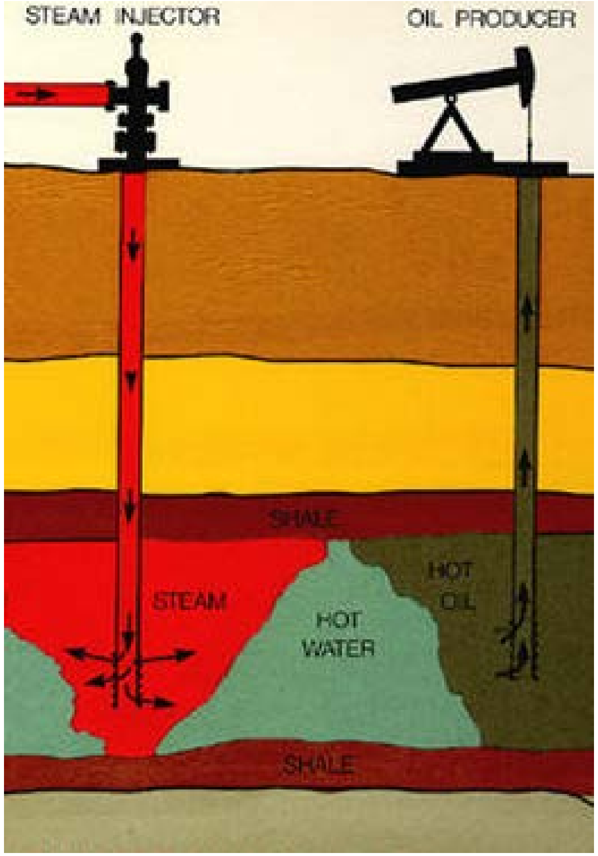
Composition by weight:

- Carbon: 82-87%
- Hydrogen: 10-14%
- Nitrogen: 0.1-2%
- Oxygen: 0.1-1.5%
- Sulfur: 0.1-6%
- Metals: < 1%

Petroleum

The methods and rates of **OIL EXTRACTION** in reservoirs are of three types:

- **Primary recovery**: the oil is extracted using the existing pressure in the reservoir (recovery rate: ~20%).
- **Secondary recovery**: the extraction is aided with artificial pressurization of the reservoir, made through the injection of inert gas (recovery rate: ~30-35%).

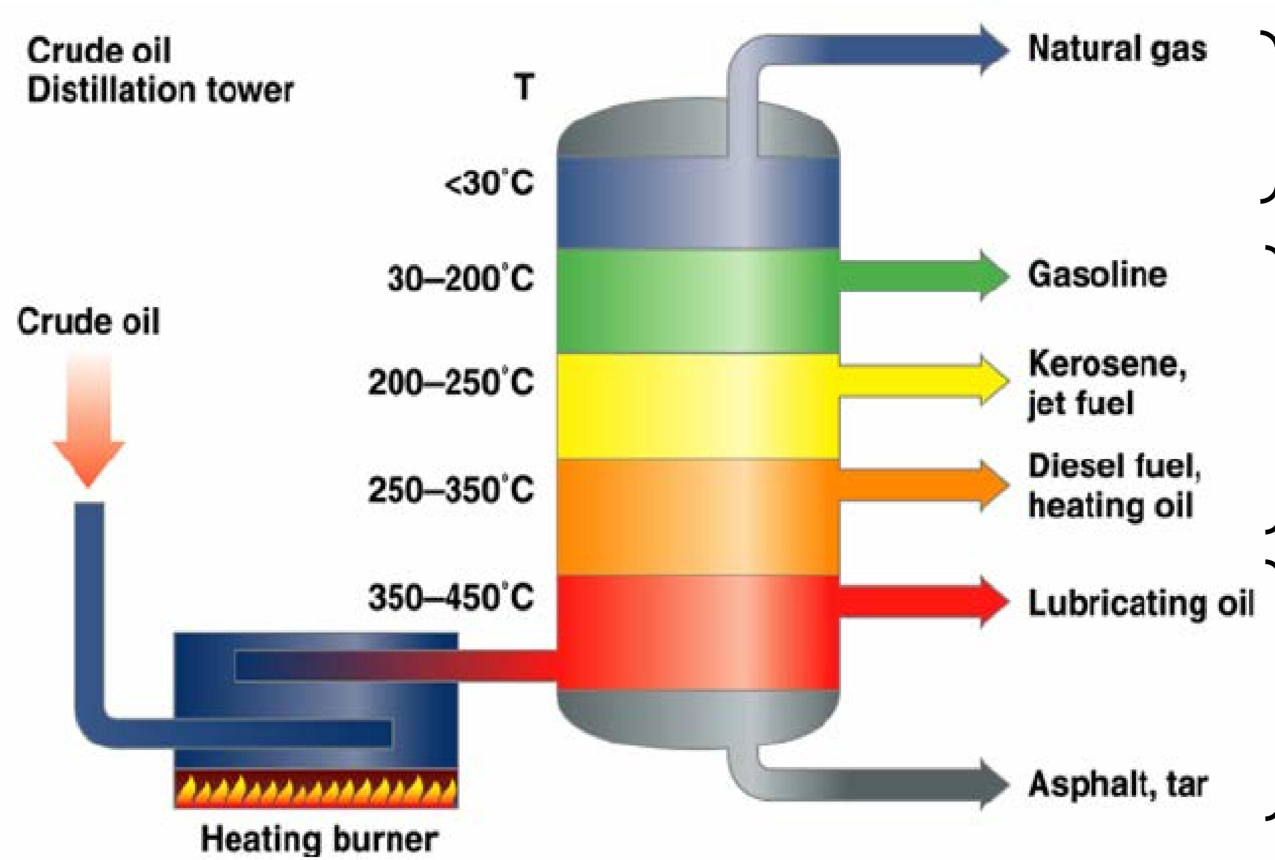


- **Tertiary recovery**: artificial pressurization and heating by injection of steam, or other chemical thinners fluids, in the reservoir (recovery rate: ~40-45%).

Petroleum

Generally, crude oils cannot be used directly as fuels, due to the complex nature of the crude oil mixture and the presence of some impurities that are corrosive or poisonous to processing catalysts.

REFINING



Light gas fractions

3 different liquid fractions

Heavy liquid and solid residuals

Petroleum

Crude oils differ appreciably in their properties according to origin and the ratio of the different components in the mixture.

The **American Petroleum Institute gravity scale (degrees API)** is the main scale of the relative density (or specific gravity) of crude oil.

$$\boxed{{}^{\circ}API = \frac{141.5}{\rho_{60^{\circ}F}} - 131.5}$$

Great API values (40-45°) indicate **light** (and more valuable) oil. **Heavy** oil normally assumes API values between 10-12°.

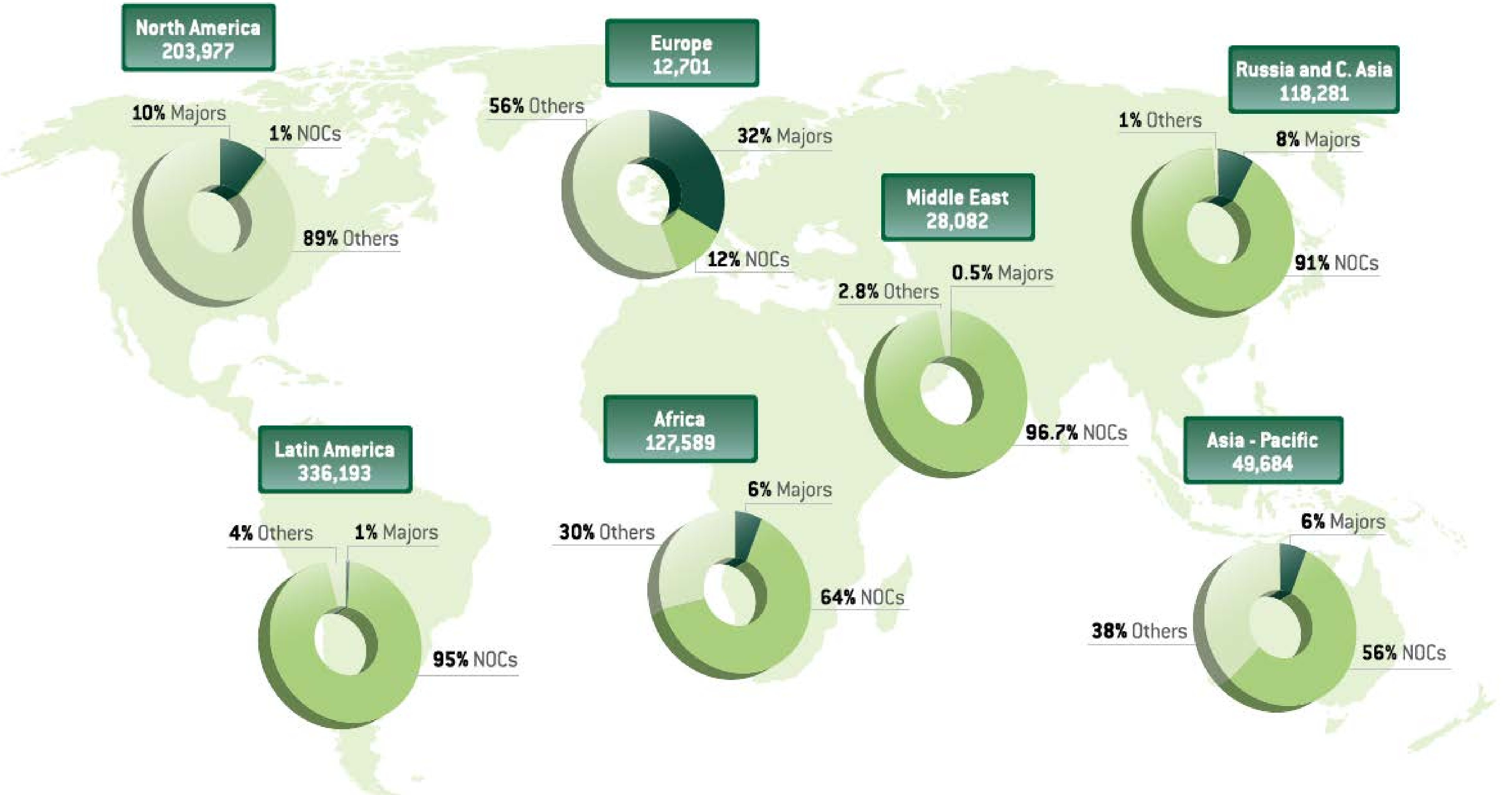
The sulfur content is another important parameter:

- **Low sulfur content** (< 0.42%) : sweet crude oil (more valuable)
- **High sulfur content** (> 0.50%): sour crude oil (less valuable)

The sulfur should be avoided because it is a source of pollution and corrosion in the power plants.

Petroleum

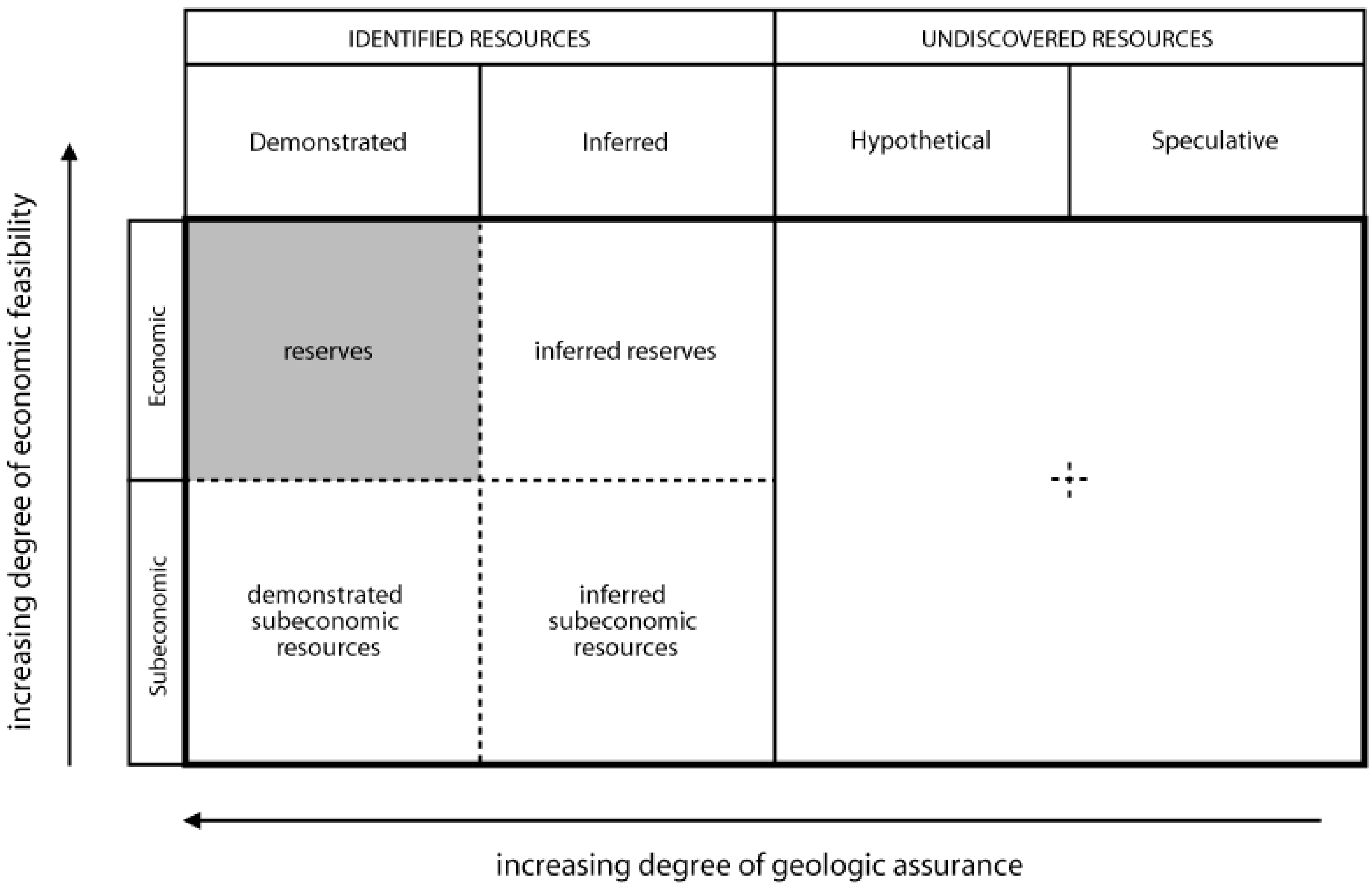
World Oil Reserves (2012)



Source: ENI Oil and Gas Review (2013)

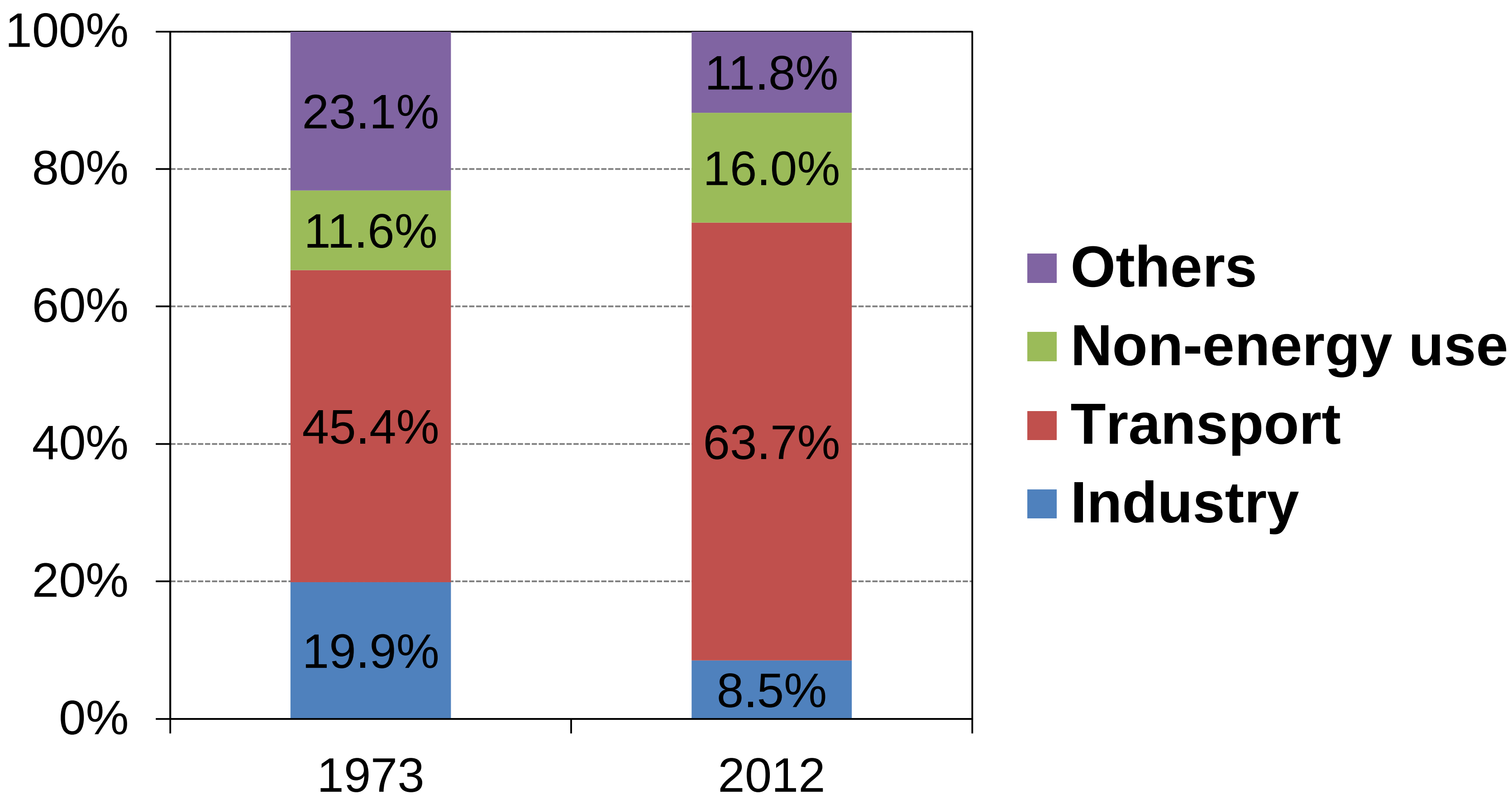
Petroleum

McKelvey diagram for coal (or gas) resources



Source: McKelvey, V.E. 1972. "Mineral Resource Estimates and Public Policy." American Scientist 60 (1): 32-40

The use of oil



Source: Elaboration from IEA data (2013)

Natural gas

Mixture of hydrocarbon, with a great prevalence of **METHANE** (CH4) and non-combustible in gaseous state.

Main characteristics:

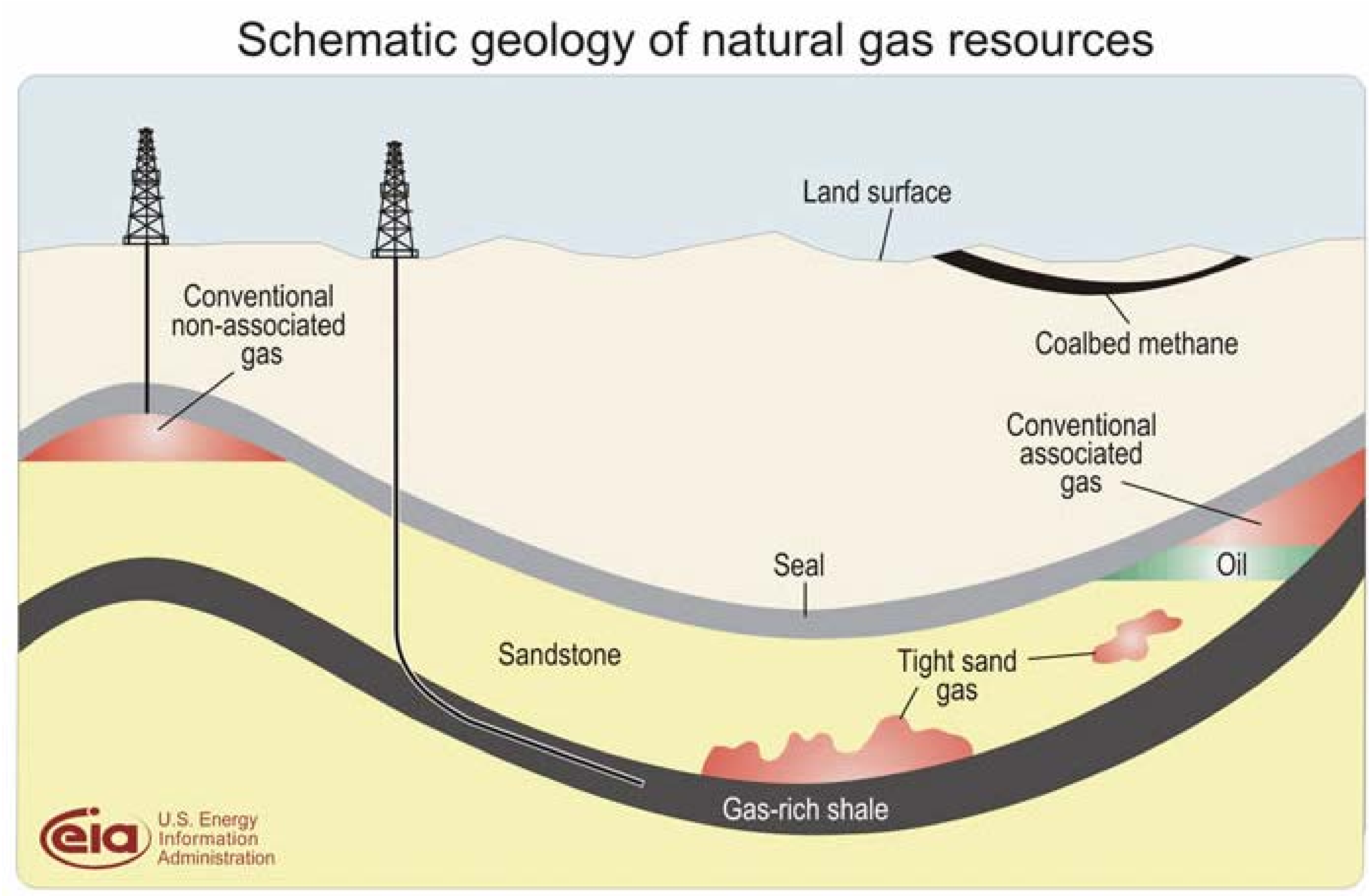
- Liquefaction temperature: -161 °C
- Specific weight (at SC) = 0.678 kg/m^3
- Odorless
- Colorless
- Non-toxic
- LHV = 50-55 MJ/kg

COMPOSITION

Gas	Algeria	Netherland	Russia	Italy
Methane	83.5	92.2	98.3	99.43
Ethane	7.7	3.4	0.6	0.06
Propane + Buthane	2.7	1.1	0.2	0.03
Others	0.3	1.2	0.03	0.02
CO_2	0.2	0.9	0.1	0.03
Nitrogen	5.6	2.2	0.8	0.43
Helium	0.15	0.03	0.01	0.00

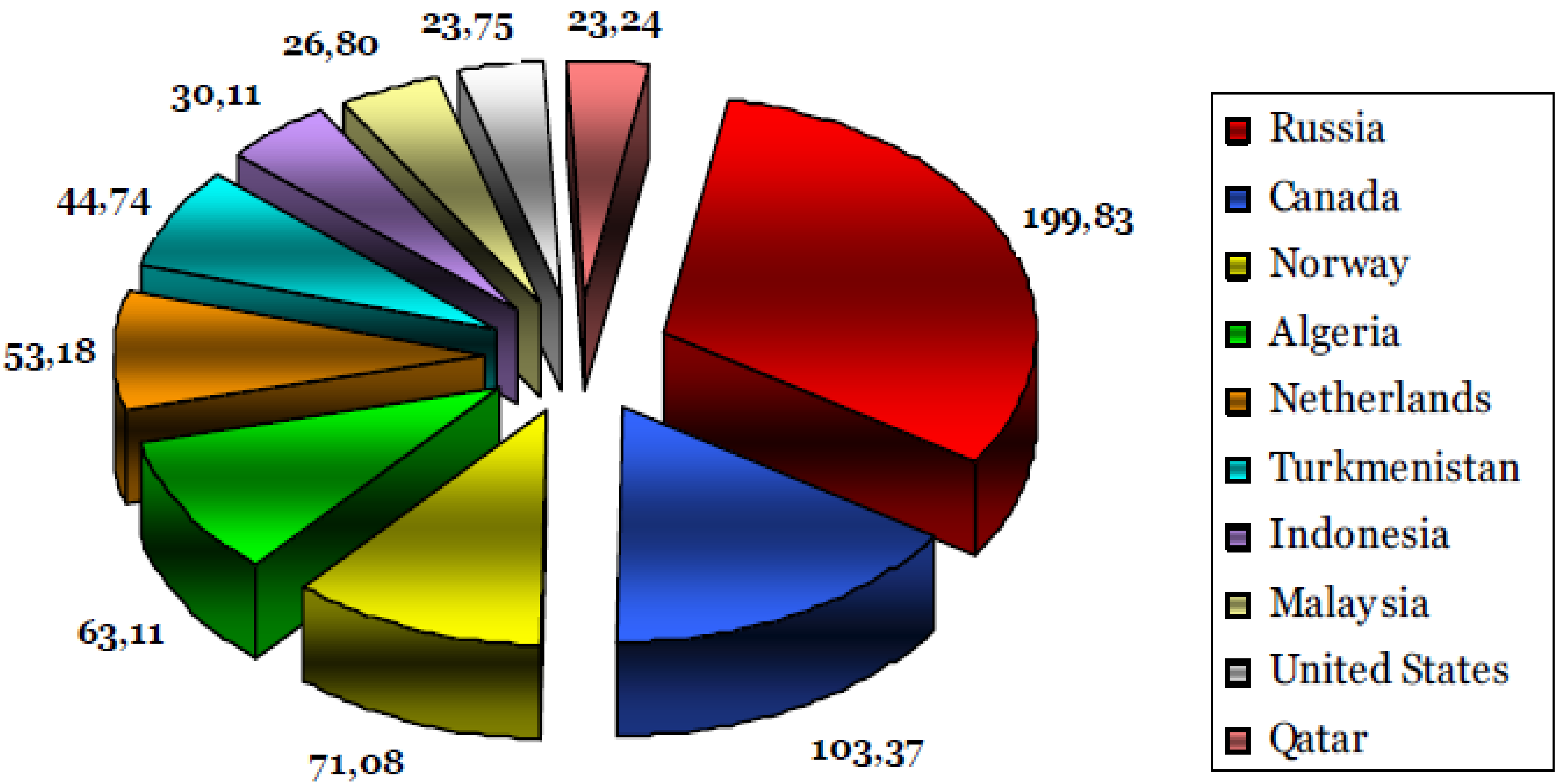
Generally, it is extracted from the underground in its natural state or togheter with liquid hydrocarbon from which it is subsequently separated.

Natural gas


Schematic geology of natural gas resources
Land surface
Conventional non-associated gas
Coalbed methane
Conventional associated gas
Oil
Seal
Sandstone
Tight sand gas
Gas-rich shale
eia
U.S. Energy Information Administration

Natural gas

Main exporting countries



Source: AIEE and ENI

Natural gas

Extraction → Transportation

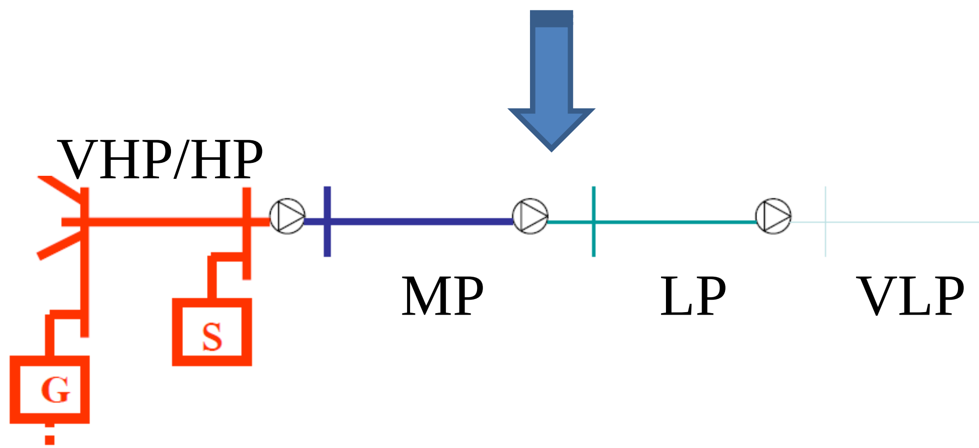
Treatment and transportation

TREATMENT

- Condensate removal
- CO_2 removal
- Dehydration
- H_2S and other gases removal

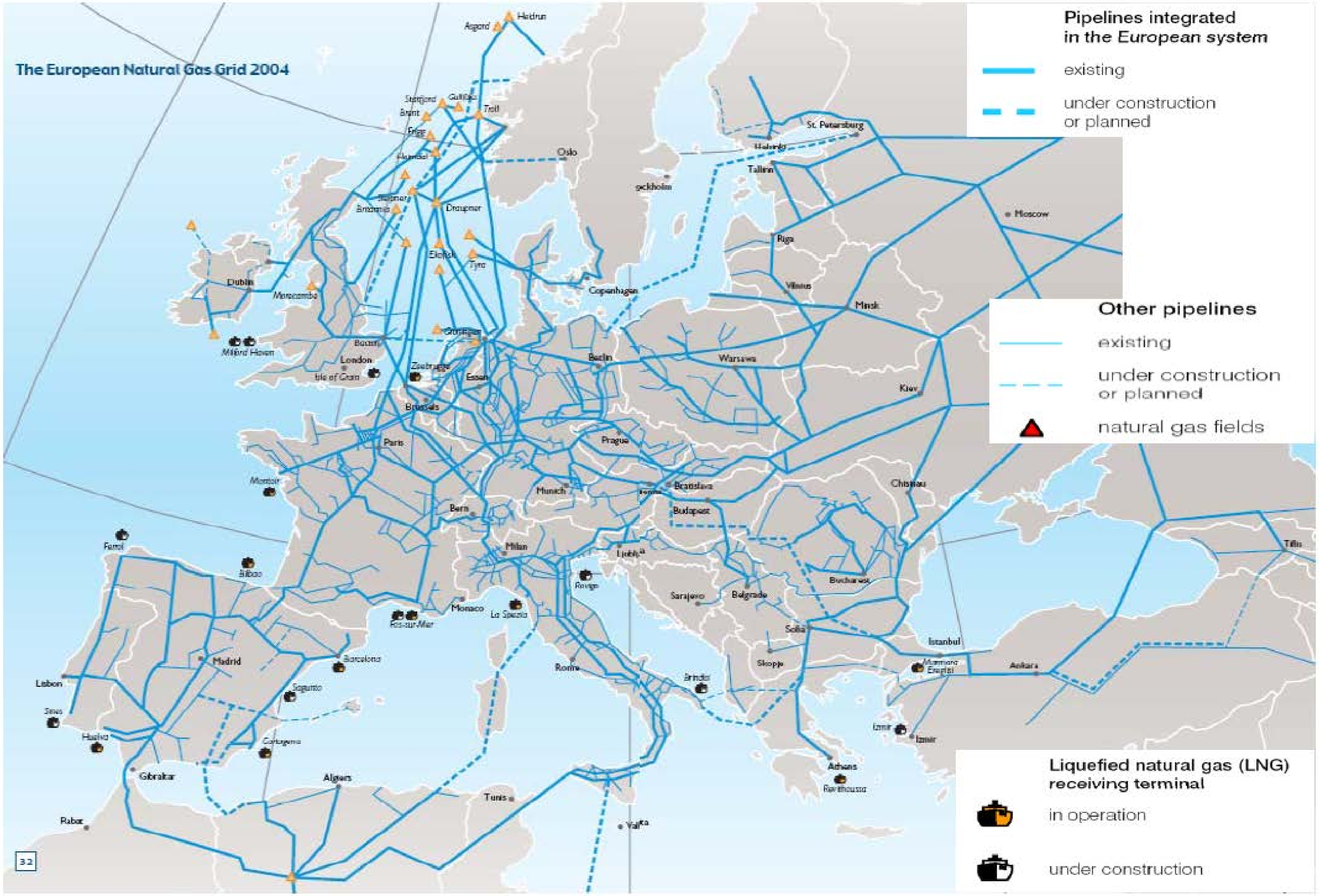
Refrigeration and Liquefaction → LNG carrier

Compression → Gas pipeline transport



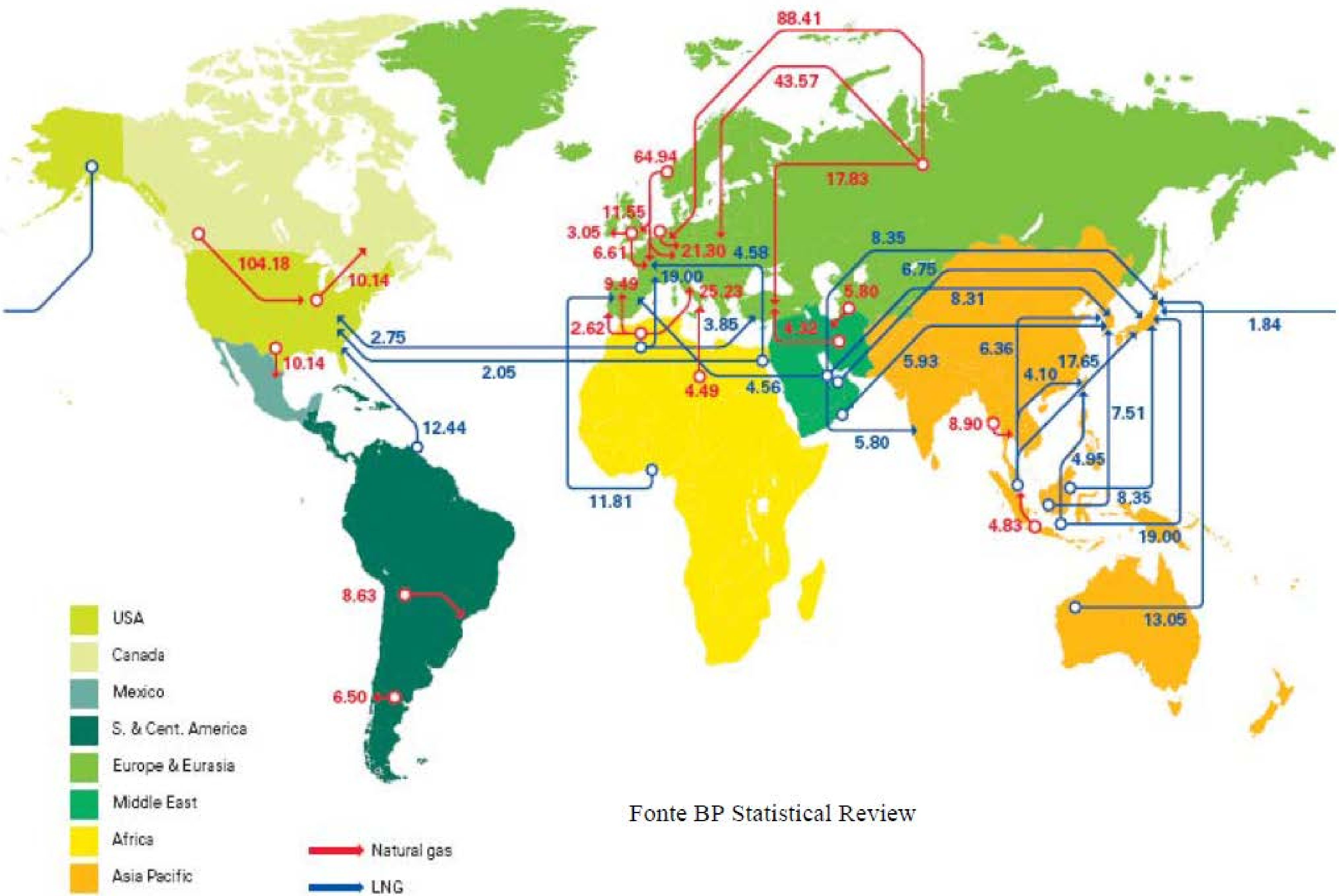
VHP: very high pressure (100 bar)
HP: high pressure (60-70 bar)
MP: medium pressure (12-24 bar)
LP: low pressure (3 bar)
VLP: very low pressure (0.1-0.4 bar)

Natural gas in Europe



Natural gas

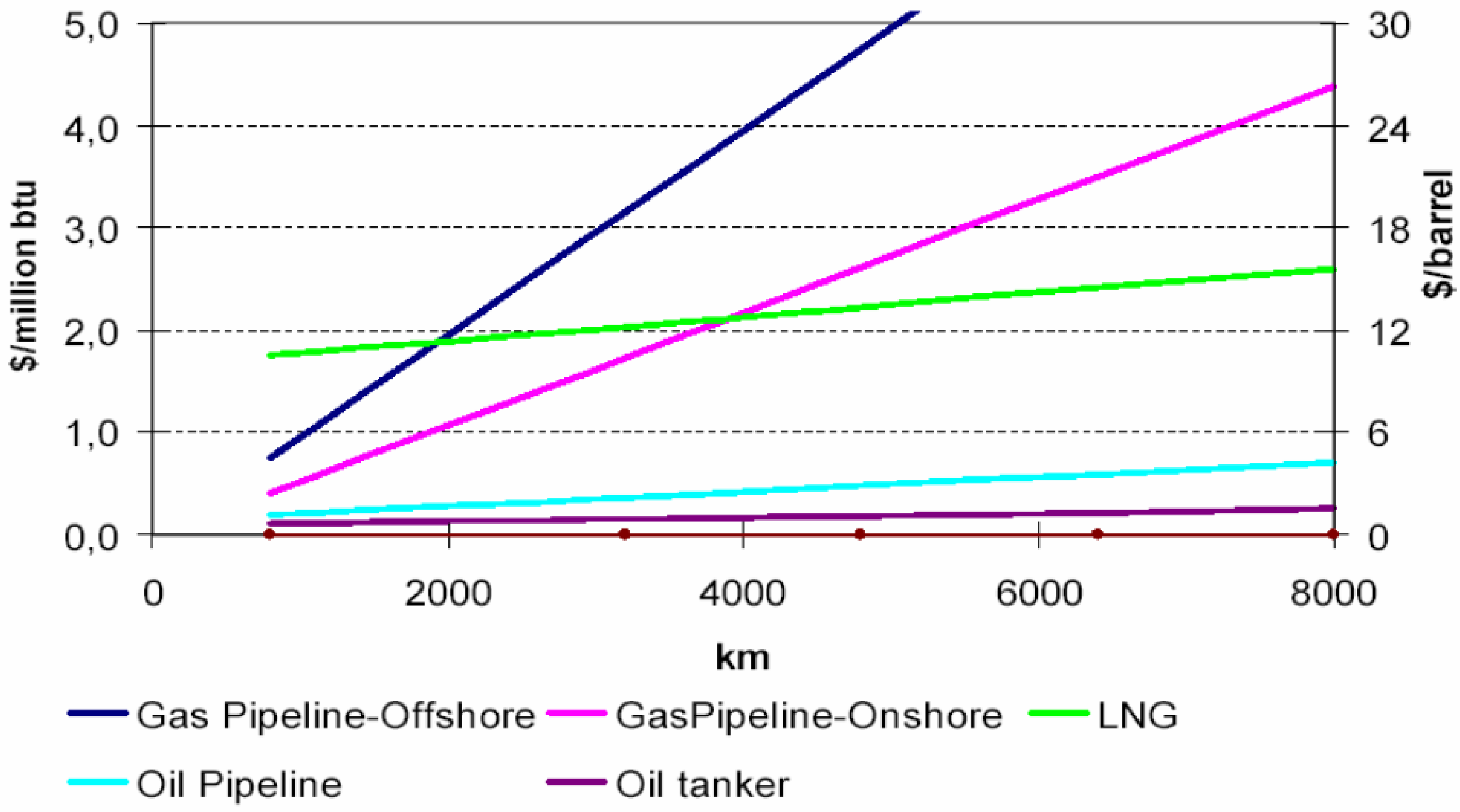
Main international trade (in 10^9 m^3)



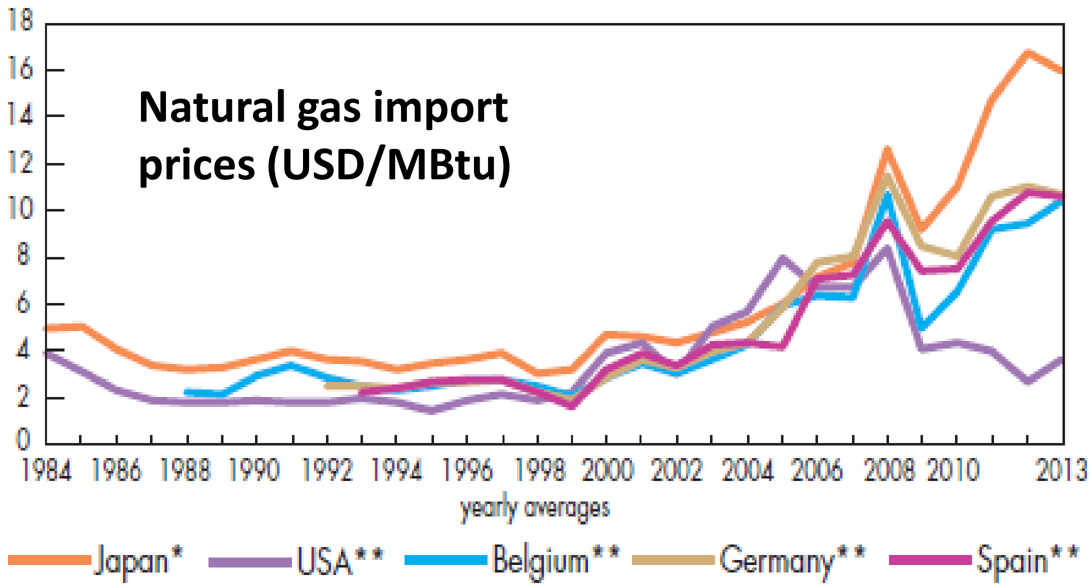
Fonte BP Statistical Review

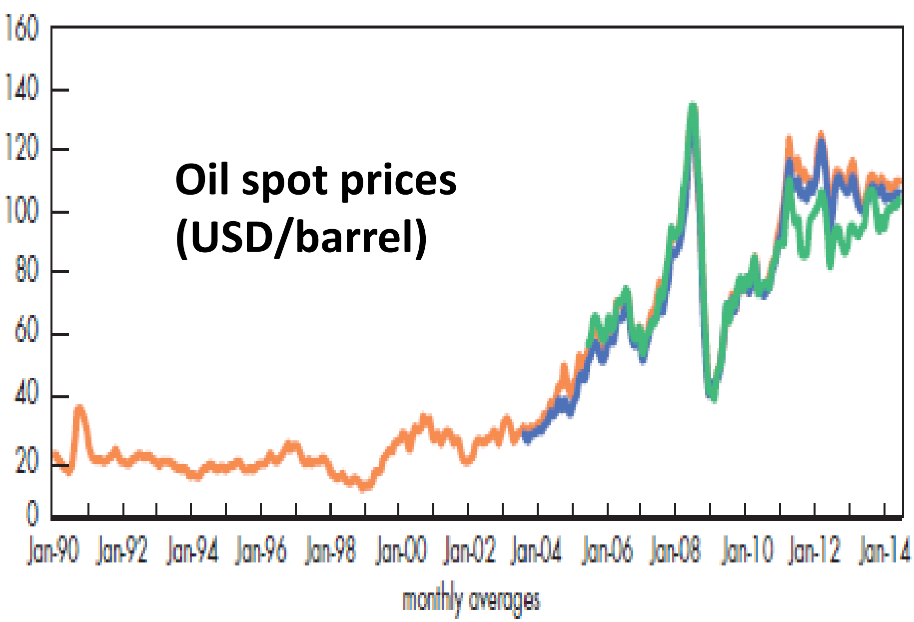
Natural gas

The impact of transportation costs on natural gas economics and on investment choices

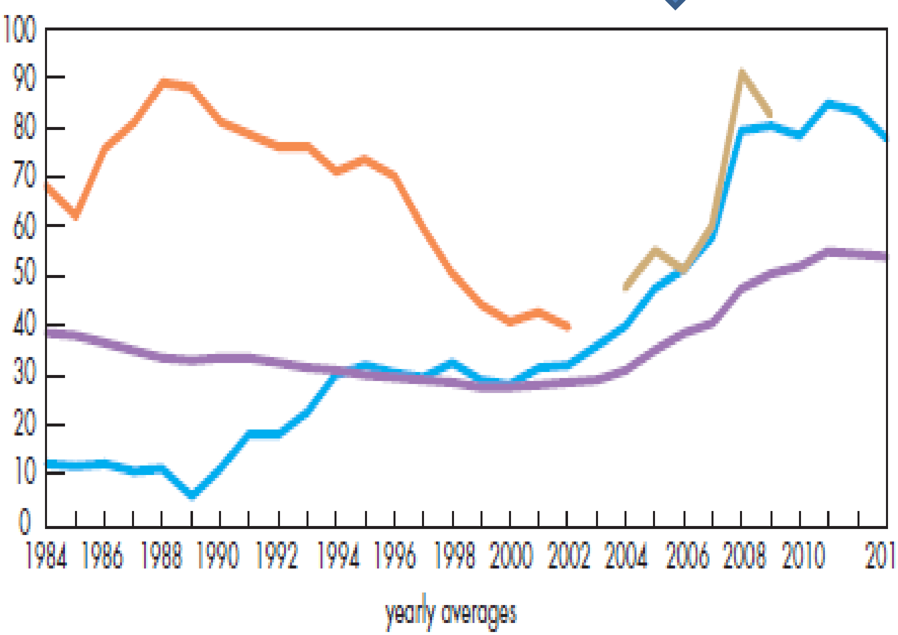


Prices





Steam coal for electric generation prices (USD/ton)



Renewable energies

Tambov State Technical University (ТГТУ)
20th October 2014

Ing. Mattia De Rosa

Renewable energies

The Earth can be seen as a closed system in which energy sources can be internal and external.

The majority of the energy sources in the Earth are strictly connected with the Sun.

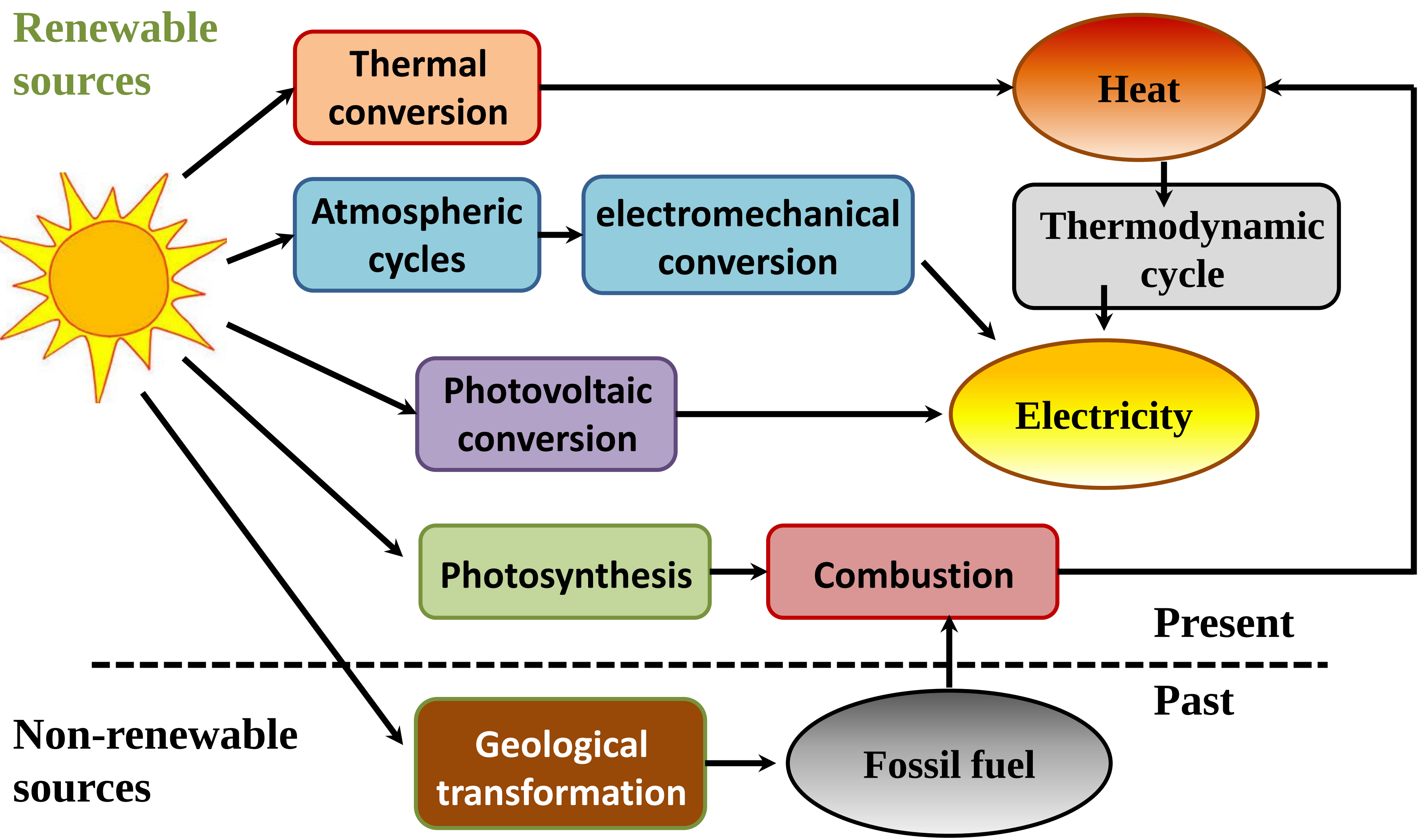
- Solar energy
- Wind energy
- Hydroelectric
- Biomass
- Wave motion

Takes their origin from the energetic cycles due to the Sun.

<u>Exceptions</u>: ➡

- Tides
- Geothermal energy

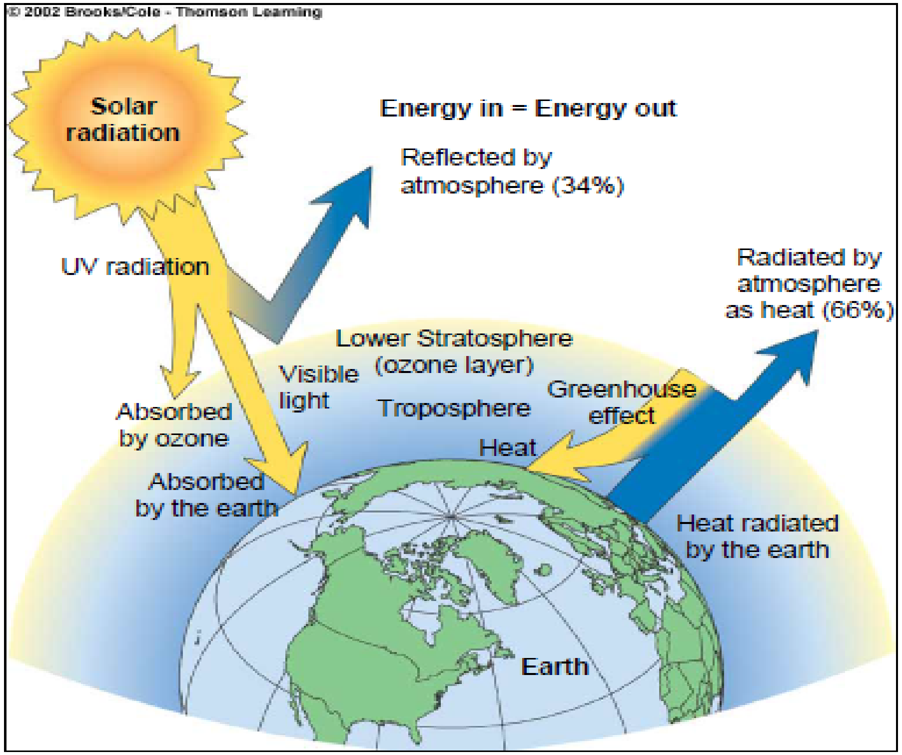
Sun energy cycles

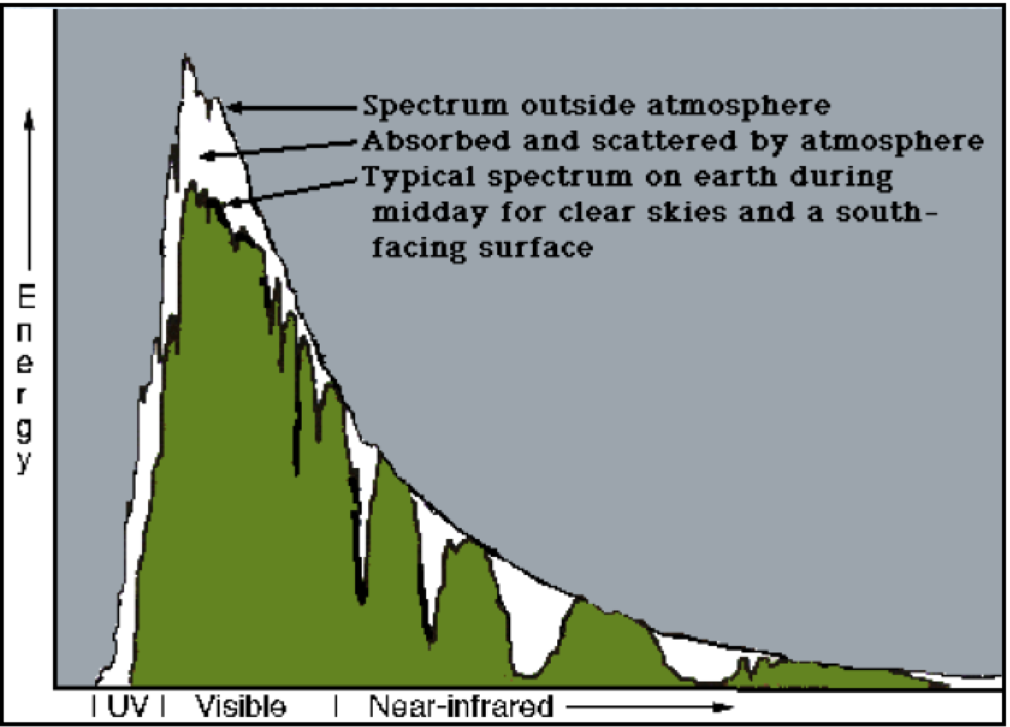


Solar energy

The solar energy reaches the Earth's ground in the form of electromagnetic waves after passing through the atmosphere that acts as a filter.

The **solar irradiance** on a normal surface outside the atmosphere is about **1637 W/m²**. This value fluctuates of about 3% with the variation of the distance Earth-Sun during the year.



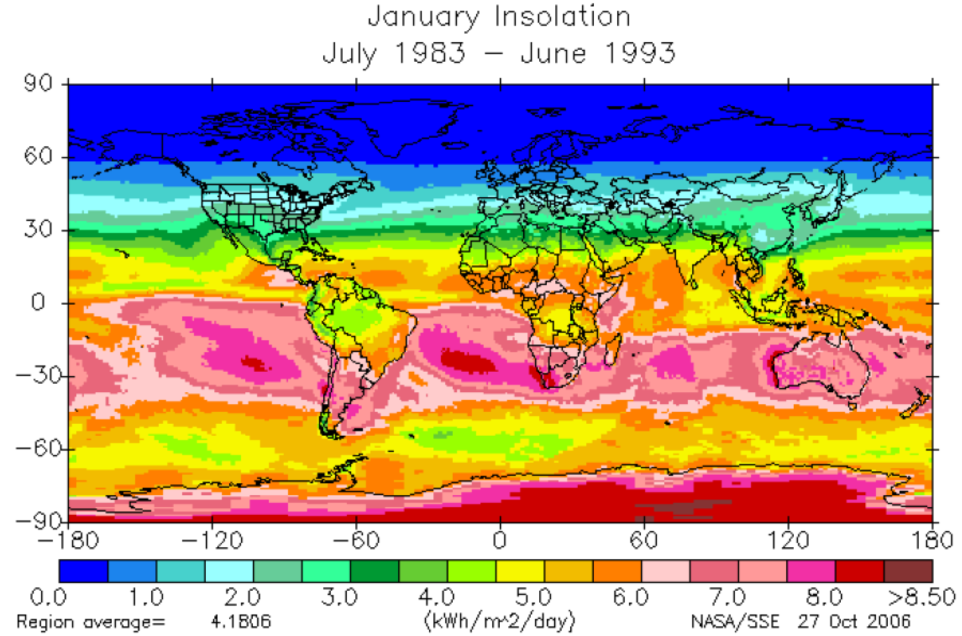


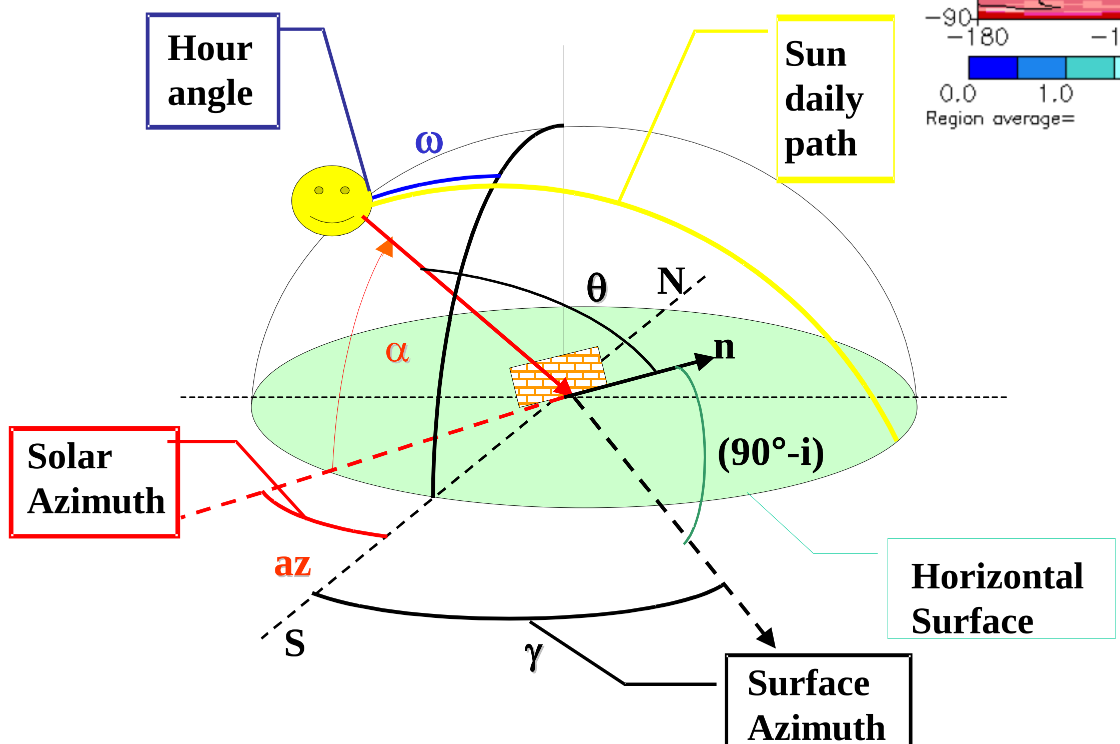
Effect of Earth's atmosphere on the solar spectrum

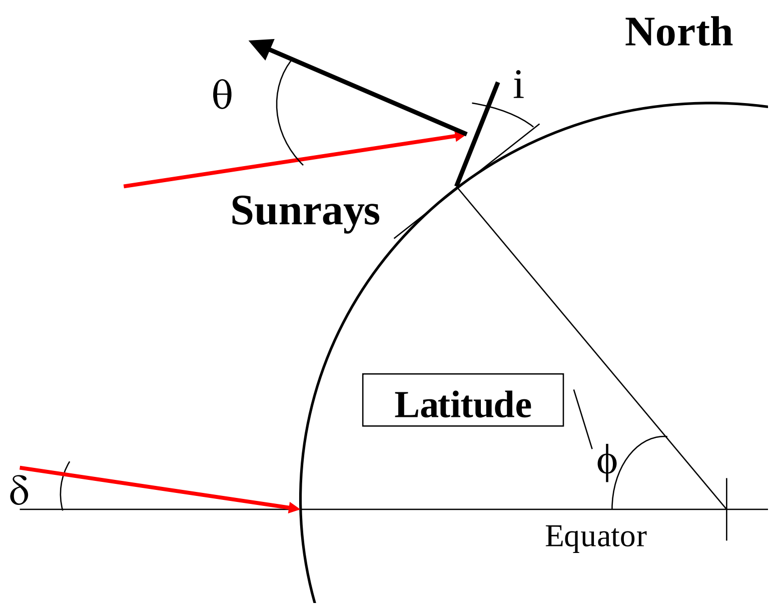
Solar energy

Solar angles:

$\alpha =$ solar height
$\delta =$ declination
$\gamma =$ azimut
$\omega =$ hour angle
$\phi =$ latitude
$\beta =$ tilt





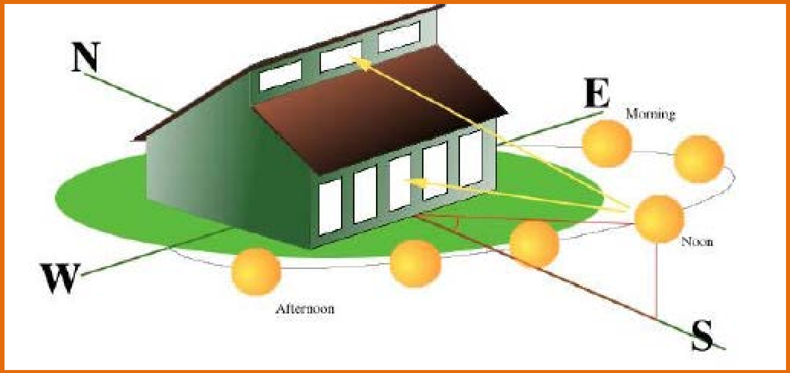


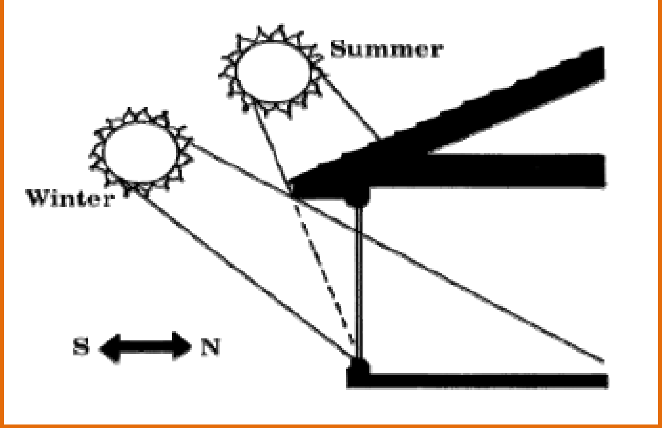
Solar energy

The use of solar energy

PASSIVE USE

Energy saving measures
Reduce the heating energy consumption in building by adopting several measures exploiting the solar radiation.





DIRECT USES

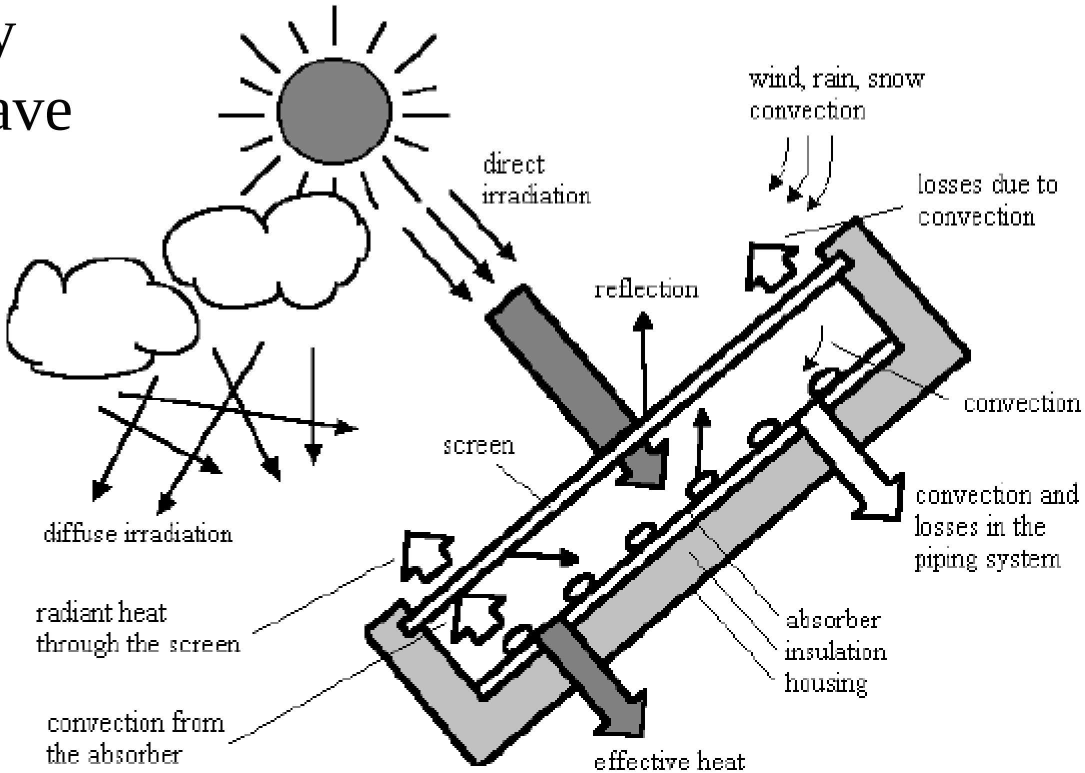
Thermal solar applications:
Heating of fluids for thermal uses, e.g. dhomestic solar collector, or electrical production, concentrating solar power (CSP).

Photovoltaic solar panels:
direct generation of electric energy

Solar thermal collector

The heat collected by the solar panels is used directly, e.g. DHW (Domestic Hot Water) → **LOW TEMP. APPLICATIONS**

In order to maximize the energy use, the solar collectors must have several characteristics, such as:



- Low temperature range of operation;
- High transmission coefficient of the glass;
- High absorptivity coefficient of the absorber at low wavelengths;
- Low emissivity coefficient of the absorber at higher wavelengths;
- Low heat transfer coefficient between the absorber and the external air.

Simplified solar collector energy balance

(steady state)

$$(\alpha\tau)AI_{p,n} - Q_{p,d} - Q_{p,w} = 0$$

- $Q_{p,w} = FrA\left[(\tau\alpha)_p I_{p,n} - U_c\left(T_{f,in,p} - T_e\right)\right]$
- $Q_{p,d} = AU_c\left(T_{pm} - T_e\right)$

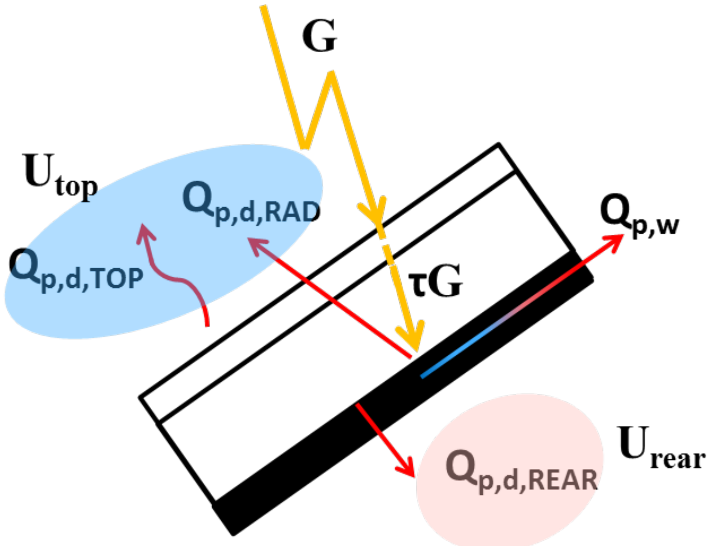
T_{pm} = mean temperature of the plate [°C]

$\dot{I}_{p,n}$ = incident solar radiation normal to the plate [W/m²]

α = plate absorbance

Fr = thermal heat removing factor

U_c = overall heat loss coefficient between plate and air [W/m²]



TOP REAR

$$U_c = U_t + U_r$$

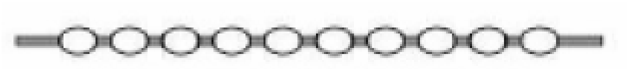
$$U_{rear} = \frac{k_i}{s_i}$$

$$U_t = \left\{\frac{N}{\frac{c}{T_{pm}}\left[\frac{T_{pm} - T_e}{N + f}\right]^e} + \frac{1}{h_e}\right\}^{-1} + \frac{\sigma\left(T_{pm} + T_e\right)\left(T_{pm}^2 + T_e^2\right)}{\left(\varepsilon_p + 0.00591Nh_e\right)^{-1} + \frac{2N + f - 1 + 0.133\varepsilon_p}{\varepsilon_g} - N}$$

Solar thermal collector

Types of collectors

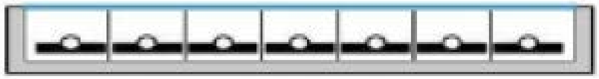
Collector without glass



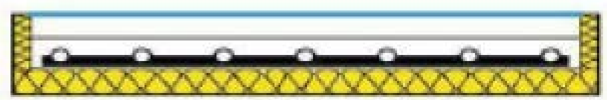
Selective surface collector

Single glazed collector

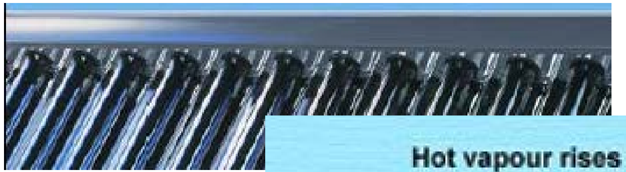
Flat plat vacuum collector

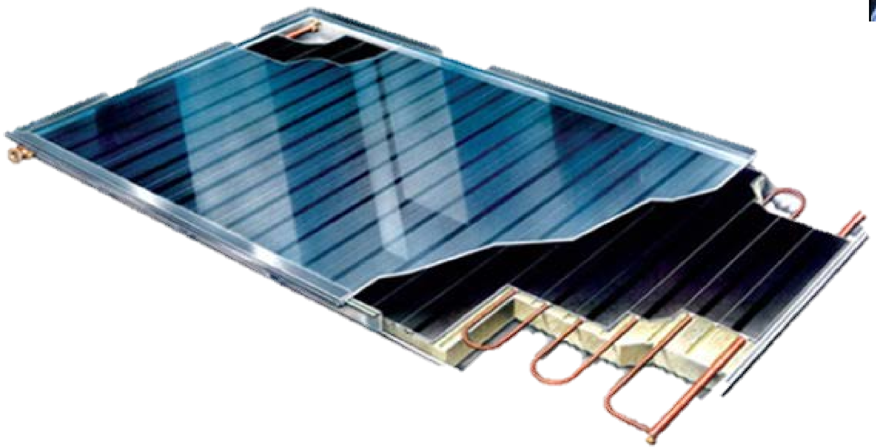


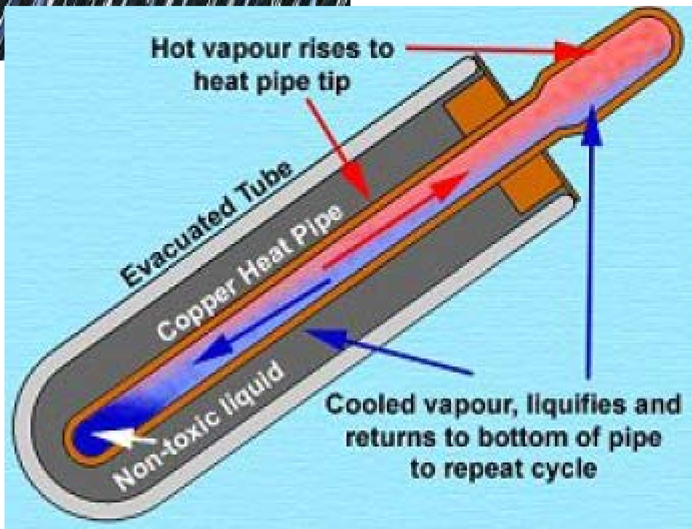
Double glazed collector



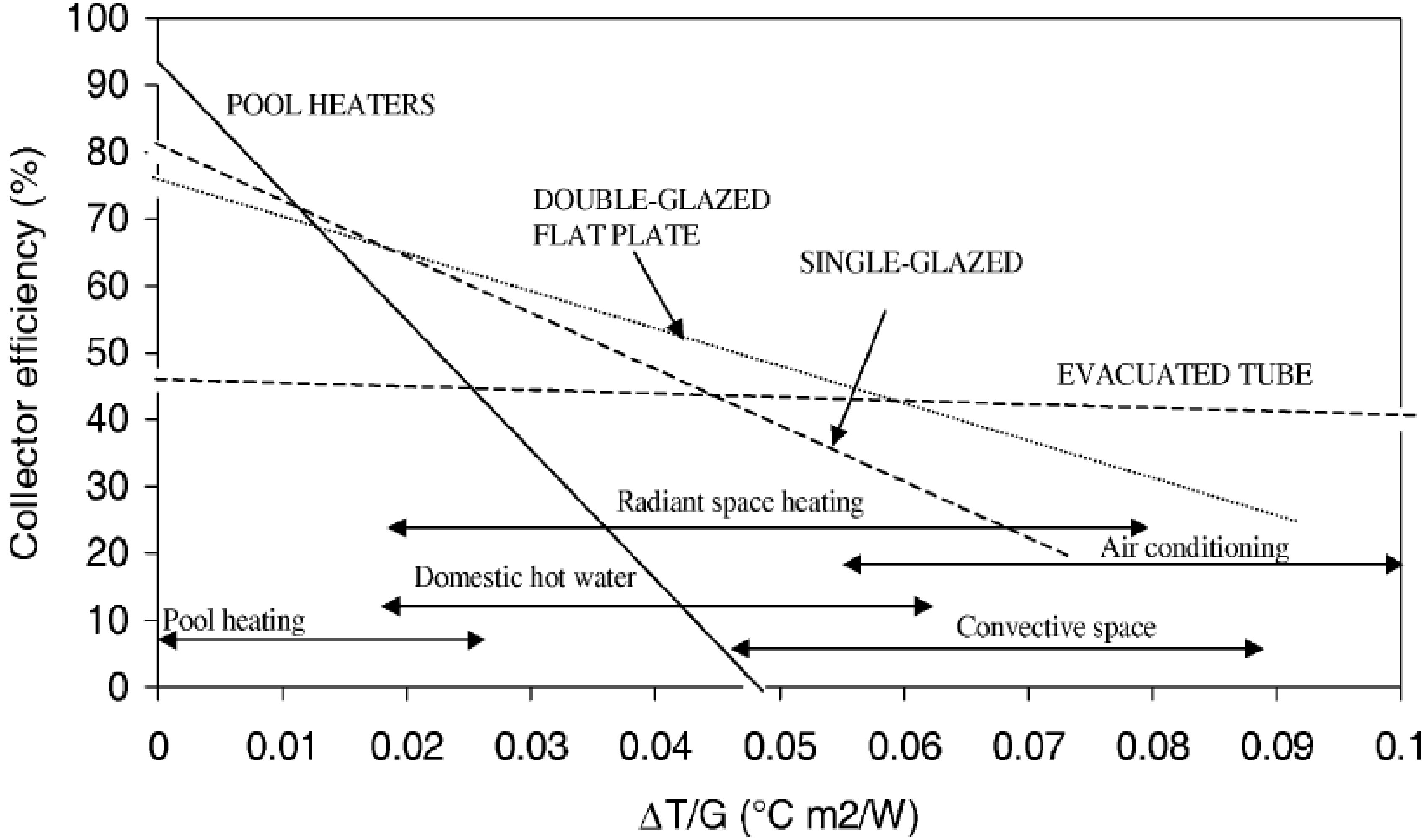
Evacuated solar collectors







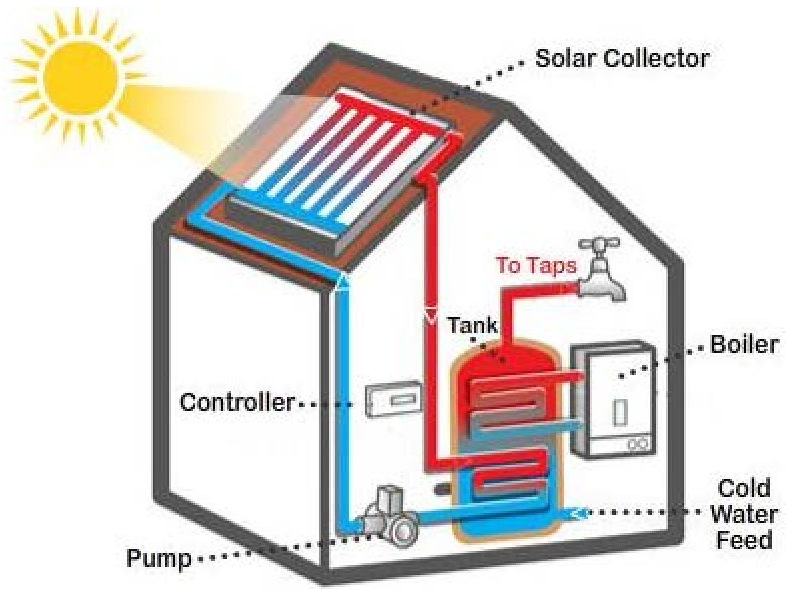
Collector efficiency of various liquid collectors



Source: S.A. Kalogirou. Progress in Energy and Combustion Science 30 (2004) 231–295

System configuration

Forced convection



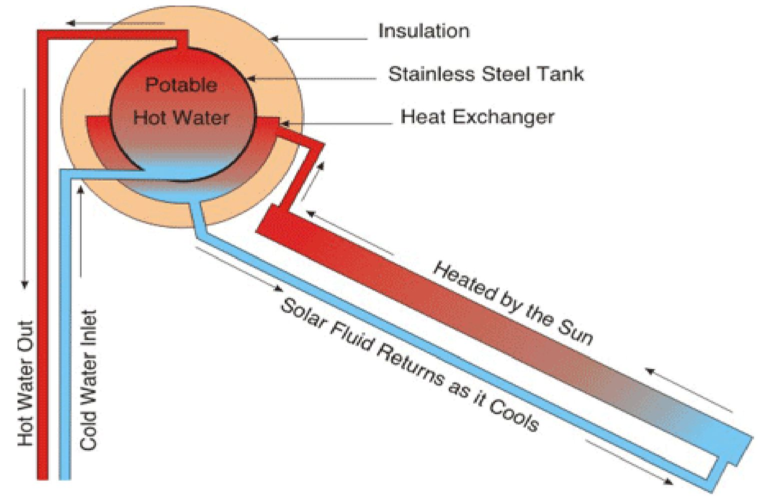
The fluid flows by using a circulating pump.

Higher cost and more complex installation.

Wide range of user demand.

Natural convection

Solar collector + Storage.



The fluid flows thanks to the natural convection (no pump).

Lower cost

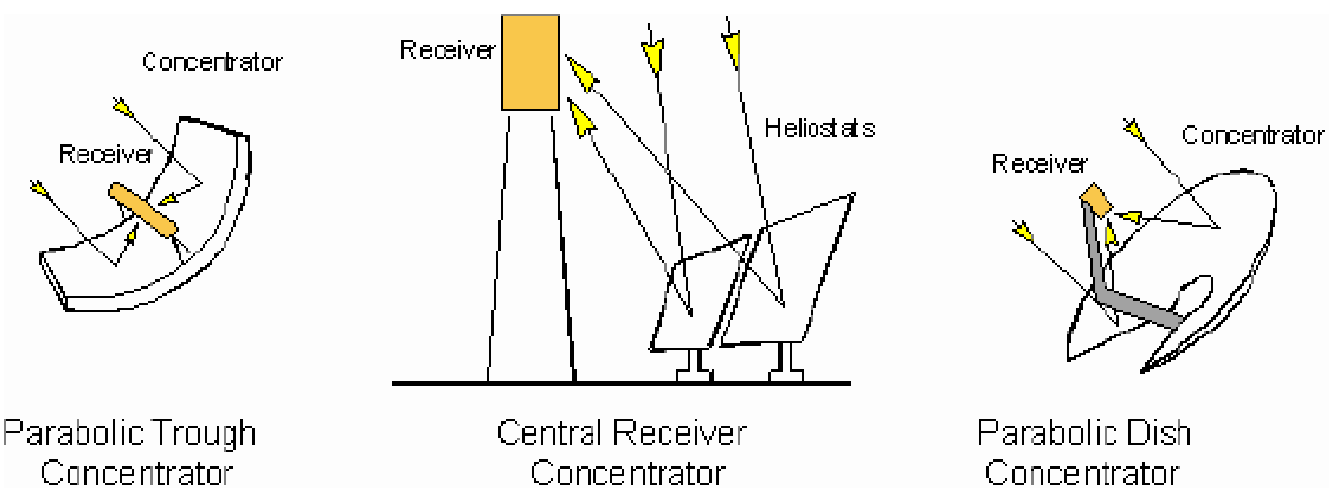
Simple installation.

Low user demand.

Concentrating Solar Power (CSP)

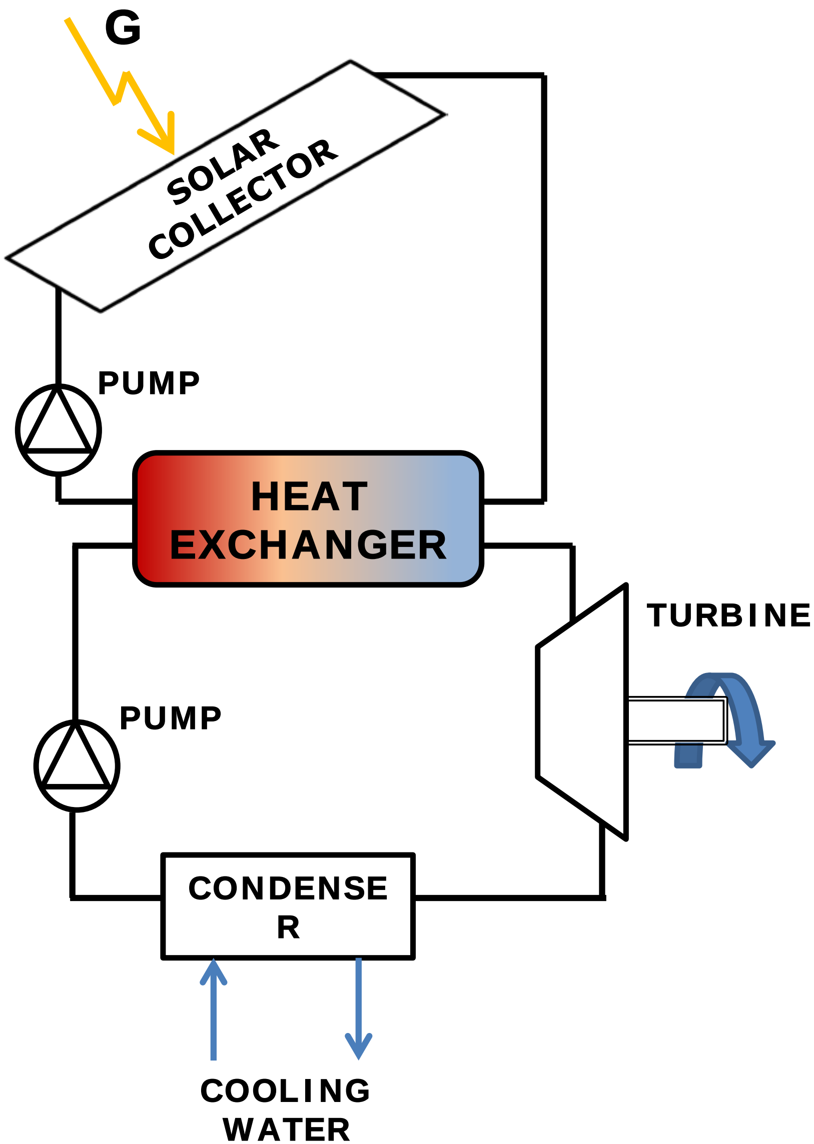
This technology is based on the fact that an absorber, subjected to a concentrated solar irradiation, can be heated up to hundreds Celsius degrees permitting a **thermodynamic cycle** to produce mechanical work convertible in electric energy.

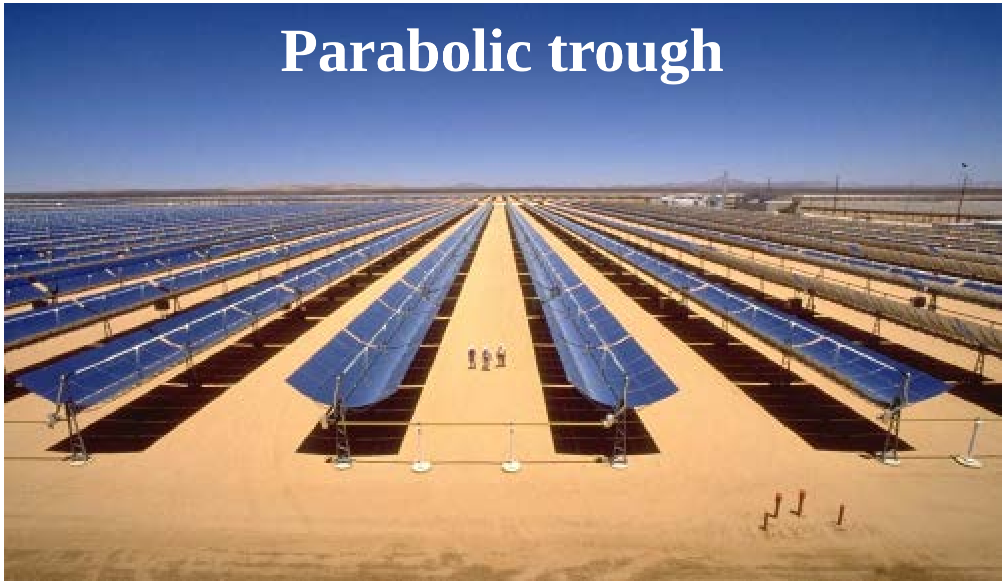
Type of Collector	Concentration Ratio	Typical Working Temperature Range (°C)
Flat plate collector	1	≤70
High-efficiency flat plate collector	1	60–120
Fixed concentrator	2–5	100–150
Parabolic trough collector	10–50	150–350
Parabolic dish collector	200–2000	250–700
Central receiver tower	200–2000	400–1000



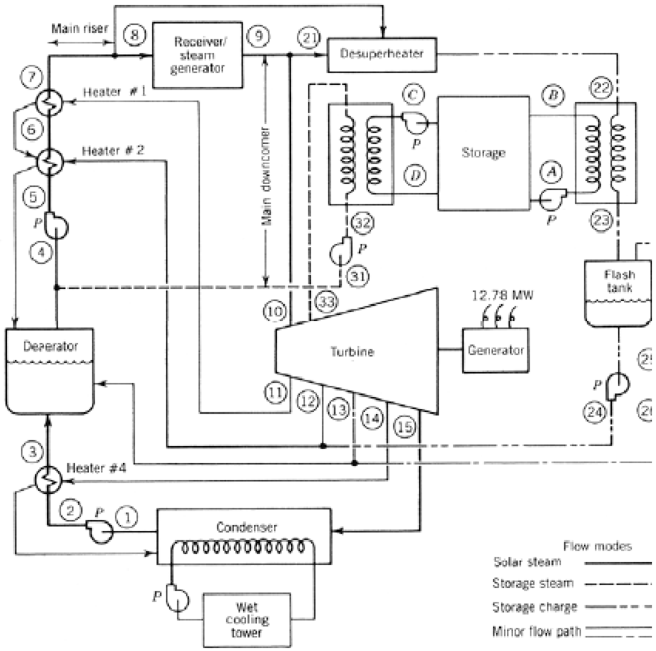
Concentrating Solar Power (CSP)

CSP simplified system





Solar Tower



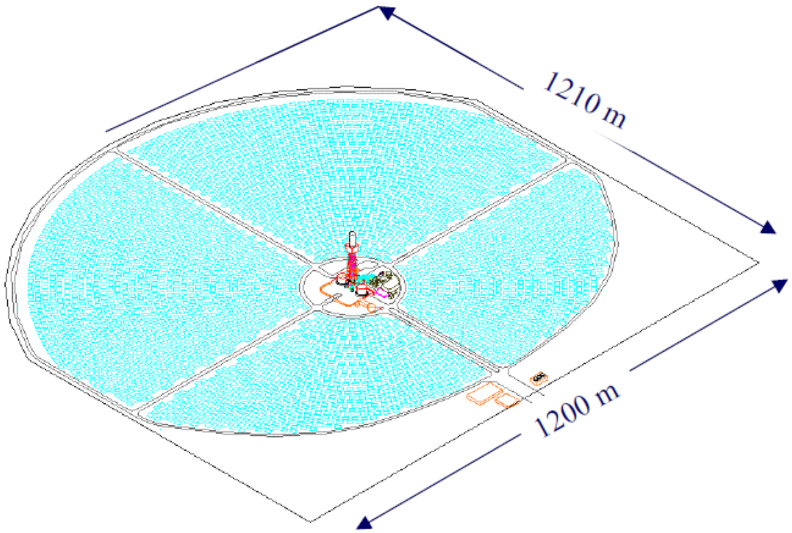
CSP “SOLAR ONE” (Barstow, California, USA)

- Solar field: 1818 heliostats with an active surface of 39.9 m^2
- Receiver: height 98.8 m. Active surface: 13.7 m (height) and 7 m (diameter)
- Inside the absorber: 1680 tubes with a diameter of 12.7mm
- Working fluid: water-steam
- Storage fluid: diathermic oil

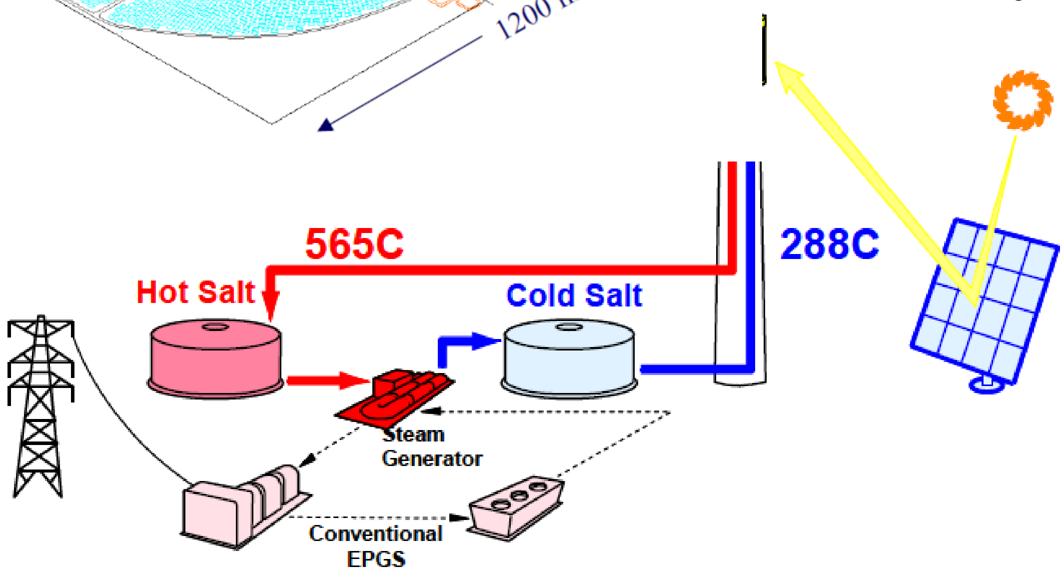
Solar Tower

Molten salt technology

Design, construction and commercial operation of a 15MWe "solar-only" power plant to be built in southern Spain.



- Power output (gross): 15 MW
- Annual production (gross): 84 GWh
- Steam generator: 40 MWt
- Receiver: cylindical 120 MWt

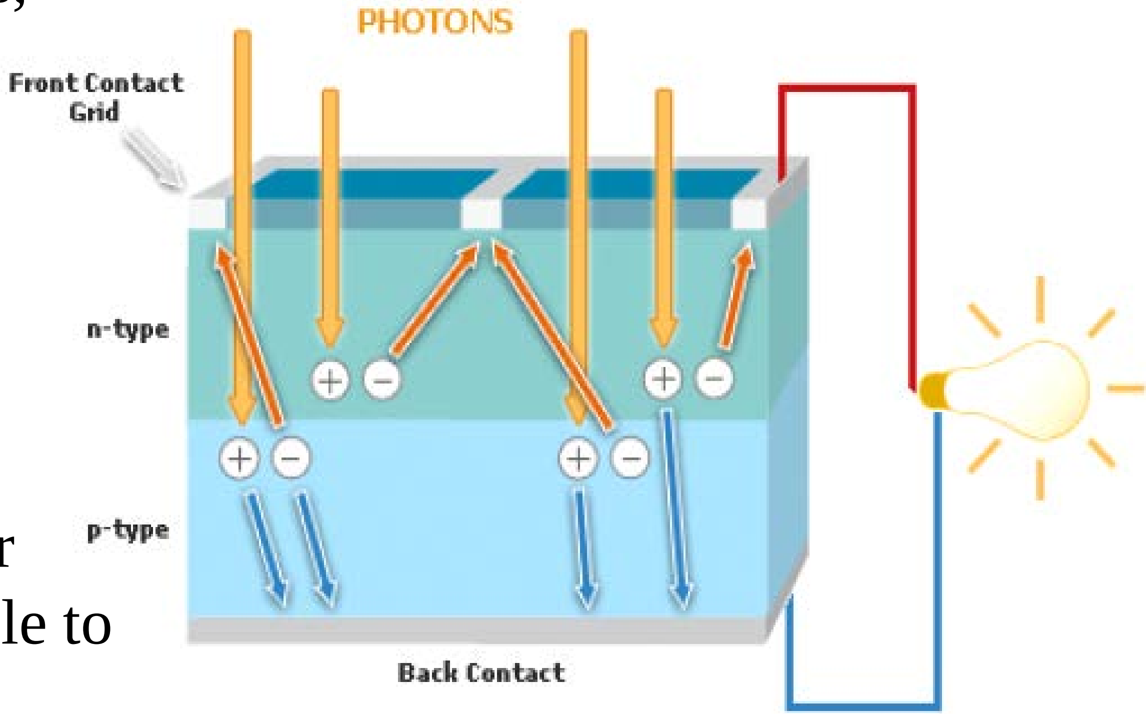


- Tower: 115 m
- Heliostat field: 263,600 m^2
- 3.8 solar multiple
- 63% annual capacity factor

Photovoltaic conversion

This technology allows to convert directly solar energy into electric energy, exploiting the property of several **semiconductors** (properly processed) to generate electricity when they are subject to the solar radiation.

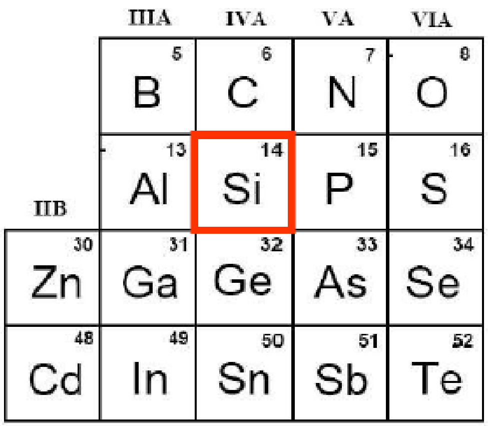
At high enough temperatures, or for **photon absorption**, some **electrons** in the valence band can move the conduction band, leaving holes (positive charges) in the valence band.



Both conduction electrons or valence holes are charges able to carry the electric current.

Photovoltaic conversion

Example: **silicon crystal (Si)**

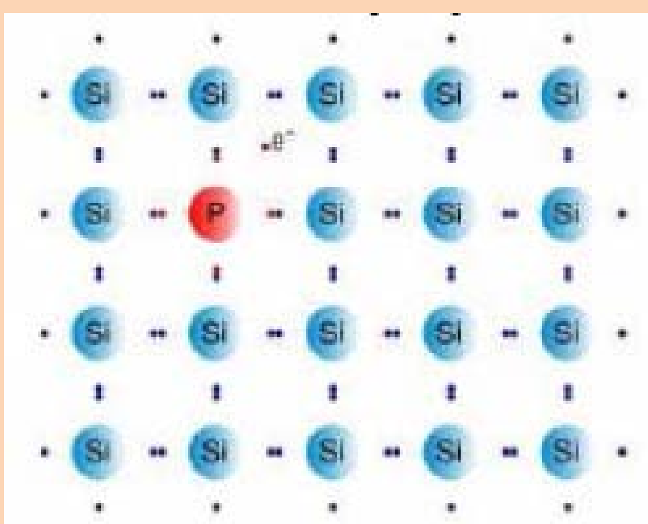


The Si is not a good conductor in its pure (or intrinsic) state due to the absence of free electrons

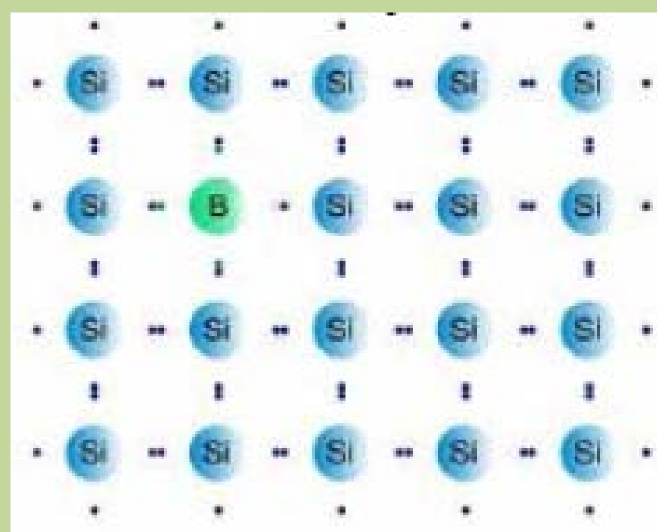
DOPING

Impurities insertion into an intrinsic semiconductor for the purpose of modulating its electrical properties.

p-Si



n-Si

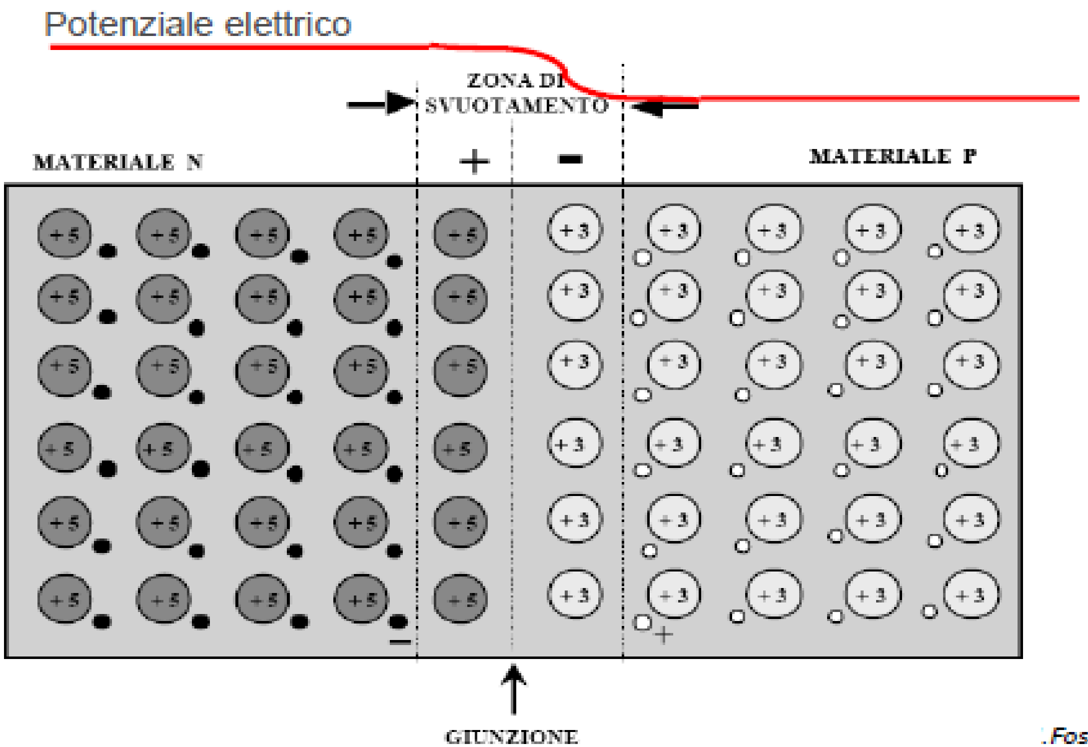


Photovoltaic conversion

The junction

Where an *n*-type semiconductor comes into contact with a *p*-type semiconductor, a *pn* junction is formed. In thermal equilibrium there is no net current flow

Since there is a concentration difference of holes and electrons between the two types of semiconductors, holes diffuse from the *p*type region into the *n*-type region and, similarly, electrons from the *n*-type material diffuse into the *p*-type region. As the carriers diffuse, an electric field (or electrostatic potential difference) is produced, which limits the diffusion of further holes and electrons.

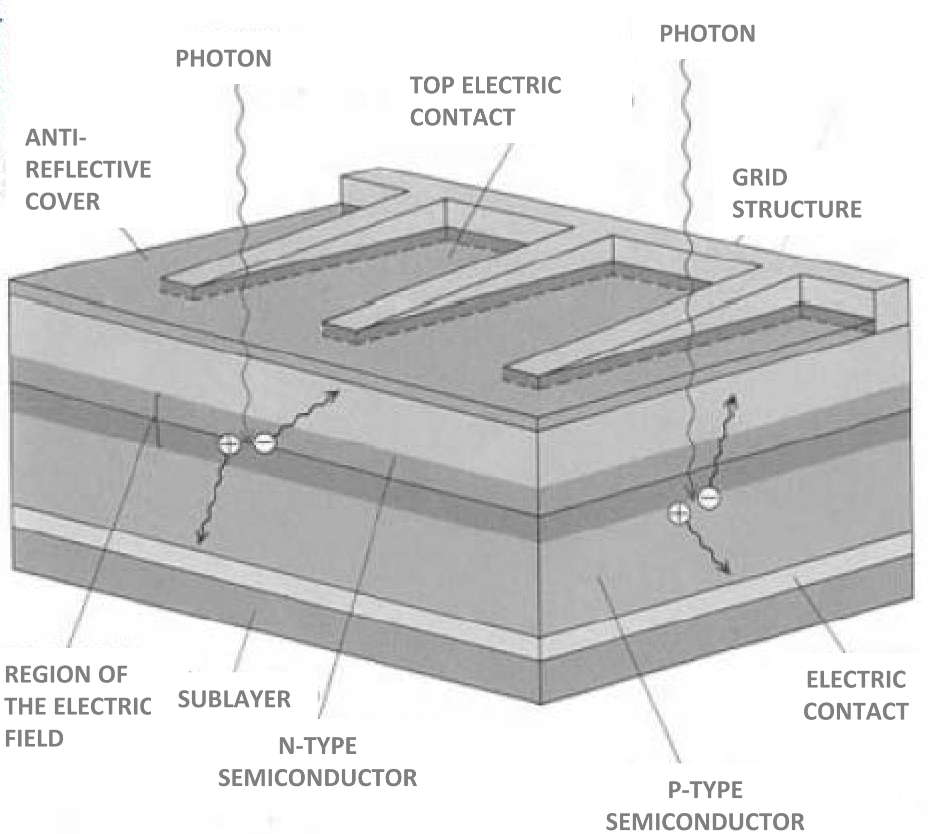


Depletion zone (zona di svuotamento)

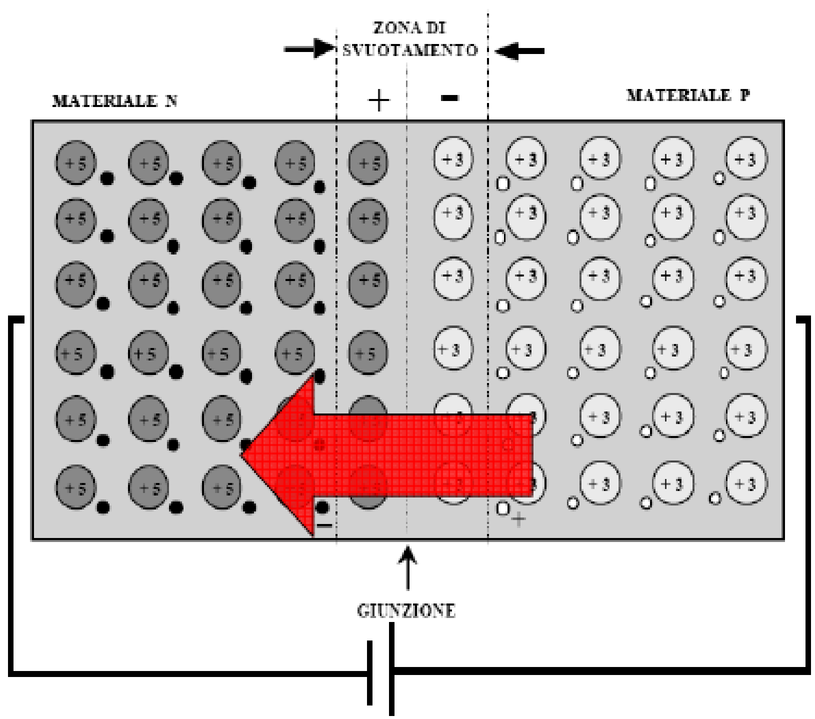
Photovoltaic conversion

The junction is a semiconductor diode and if a potential difference between P and N is applied, a migration of electric charges occur:

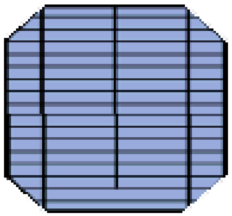
- with an open circuit, the migration of electric charges through the junction produces a charge accumulation until a voltage equilibrium is reached.
- if the circuit is close in a load, we obtain current.

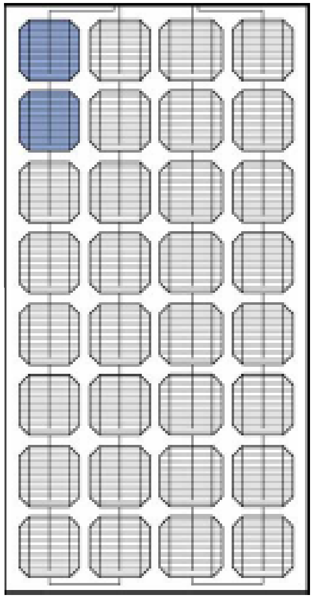


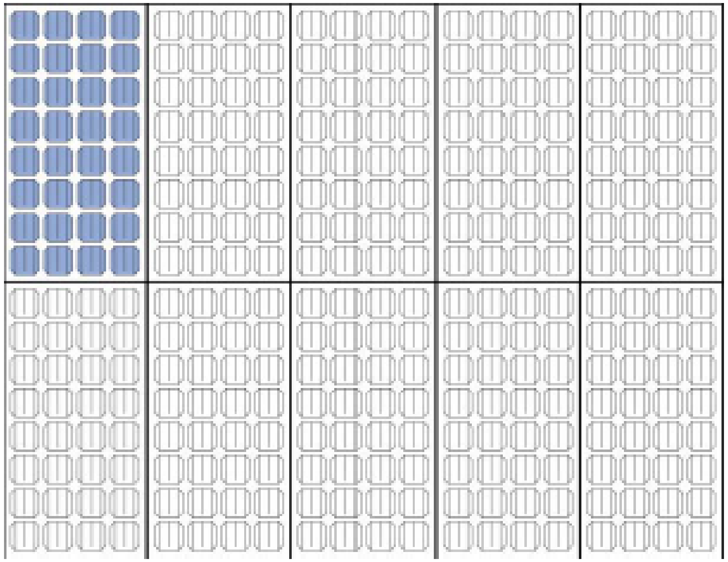
Fonte: Leee-Supsi



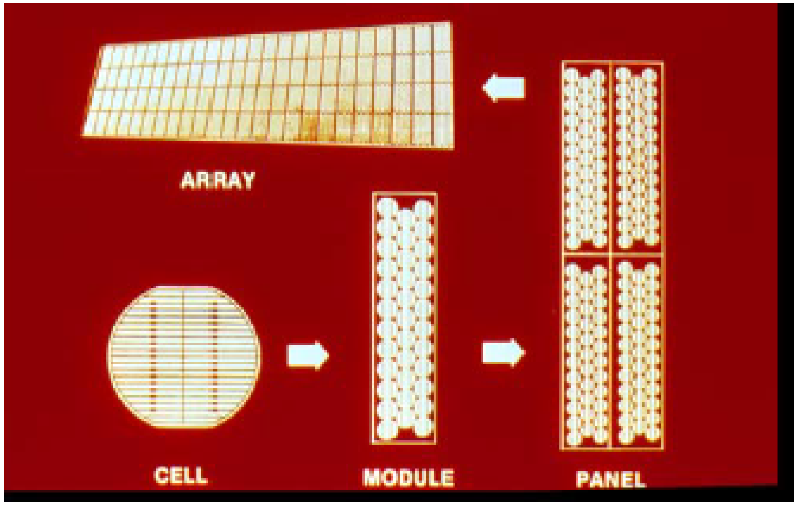
Photovoltaic conversion

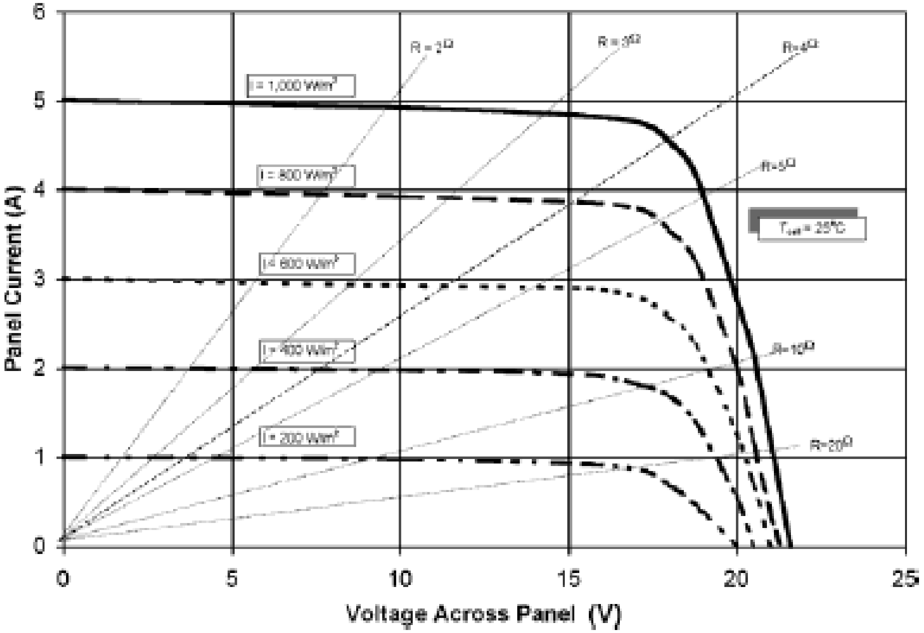






The cells are assemby in modules…. and the modules in arrays





Photovoltaic conversion

Commercial PV panel

Types of modules

Cell material	Required PV area for 1kW_p
Mono-crystalline	7m²–9m²
High performance cells	6m²–7m²
Polycrystalline	7.5m²–10m²
Copper indium diselenide (CIS)	9m²–11m²
Cadmium telluride (CdTe)	12m²–17m²
Amorphous silicon	14m²–20m²

Polycristalline module ***SHARP ND-(RxxxA5)***

ELECTRICAL DATA (AT STC)

		ND-R250A5	ND-R245A5	ND-R240A5	ND-R235A5	ND-R230A5	
Maximum power	P_{max}	250	245	240	235	230	W_p
Open-circuit voltage	V_{oc}	37.6	37.3	37.2	36.8	36.4	V
Short-circuit current	I_{sc}	8.68	8.62	8.57	8.49	8.41	A
Voltage at point of maximum power	V_{mpp}	30.9	30.7	30.4	30.3	30.3	V
Current at point of maximum power	I_{mpp}	8.10	7.99	7.90	7.76	7.61	A
Module efficiency	η_m	15.2	14.9	14.6	14.3	14.0	%

STC = Standard Test Conditions: irradiance 1,000 W/m², AM 1.5, cell temperature 25 °C.
Rated electrical characteristics are within ±10% of the indicated values of I_{sc}, V_{oc} and 0 to +5% of P_{max} (power measurement tolerance ±3%).

ELECTRICAL DATA (AT NOCT)

		ND-R250A5	ND-R245A5	ND-R240A5	ND-R235A5	ND-R230A5	
Maximum power	P_{max}	180.2	176.6	173.0	169.3	165.7	W_p
Open-circuit voltage	V_{oc}	36.7	36.4	36.4	36.0	35.6	V
Short-circuit current	I_{sc}	7.0	6.96	6.92	6.85	6.79	A
Voltage at point of maximum power	V_{mpp}	27.7	27.5	27.2	27.1	27.1	V
Nominal Operating Cell Temperature	NOCT	47.5	47.5	47.5	47.5	47.5	°C

NOCT: Module operating temperature at 800 W/m² irradiance, air temperature of 20 °C, wind speed of 1 m/s.

LIMIT VALUES

Maximum system voltage	1,000 V DC
Over-current protection	15 A
Temperature range	−40 bis +90 °C
Maximum mechanical load	2,400 N/m²

MECHANICAL DATA

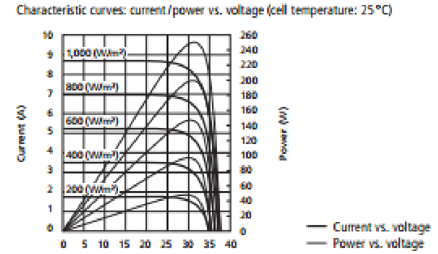
Length	1,652 mm (+/−3.0 mm)
Width	994 mm (+/−2.0 mm)
Depth	46 mm (+/−0.8 mm)
Weight	19 kg

TEMPERATURE COEFFICIENT

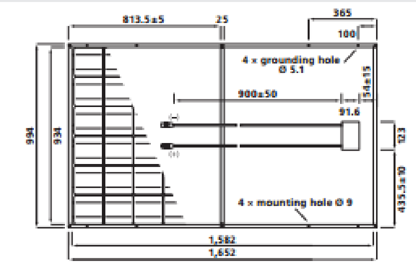
P_{max}	−0.440 % / °C
V_{oc}	−0.329 % / °C
I_{sc}	+0.038 % / °C

CHARACTERISTIC CURVES ND-R250A5

Characteristic curves: current/power vs. voltage (cell temperature: 25 °C)



REAR VIEW



GENERAL DATA

Cells	polycrystalline, 156.5 mm × 156.5 mm, 60 cells in series
Front glass	low iron tempered glass, 3 mm
Frame	anodized aluminium alloy, silver
Connection box	PPE/PPO resin, IP65 rating, 58 × 125 × 15 mm, 3 bypass diodes
Cable	4 mm², length 900 mm
Connector	SMK (MC4 compatible), Type CCT9901-2361F/2451F (Catalogue no. P51-7H/R51-7), IP67 rating To extend the module connection leads, only use SMK connector from the same series or MultiContactAG MC4 connector (PV-KST04/PV-KBT04)

REGISTRATION

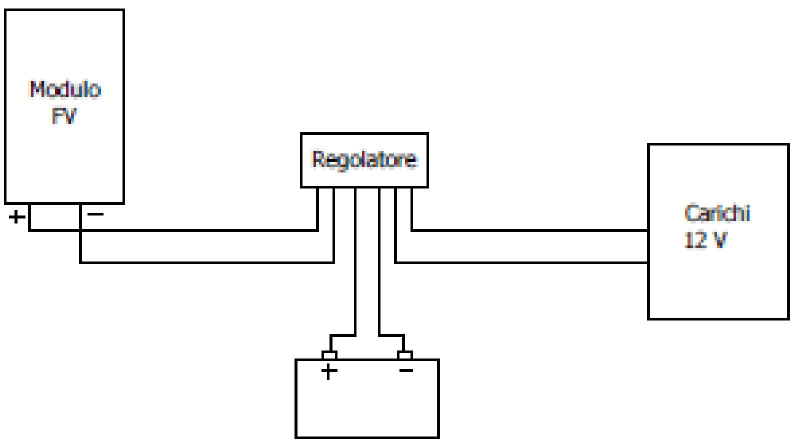
Sharp Solar guarantees the safety, quality and value of your product over many years – the only thing we ask you to do is to register your modules with the serial number, so that we can send you the guarantee certificate. Register your modules quickly and easily at www.brandaddedvalue.net.

Sharp Energy Solution Europe · a division of Sharp Electronics (Europe) GmbH · Sonninstrasse 3, 20097 Hamburg, Germany · Tel: +49(0)40/2376-0 · Fax: +49(0)40/2376-2193

System configuration

Stand-alone configuration

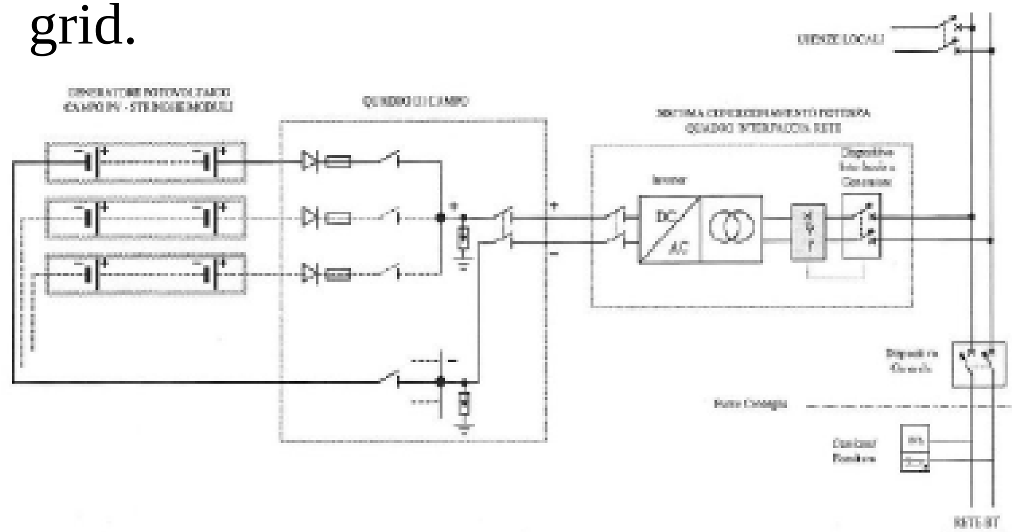
Several batteries are installed as storage for the energy produced in surplus.



- High cost of the batteries.
- Low consumption users.
- Energy supply is not guaranteed.

Grid-connected configuration

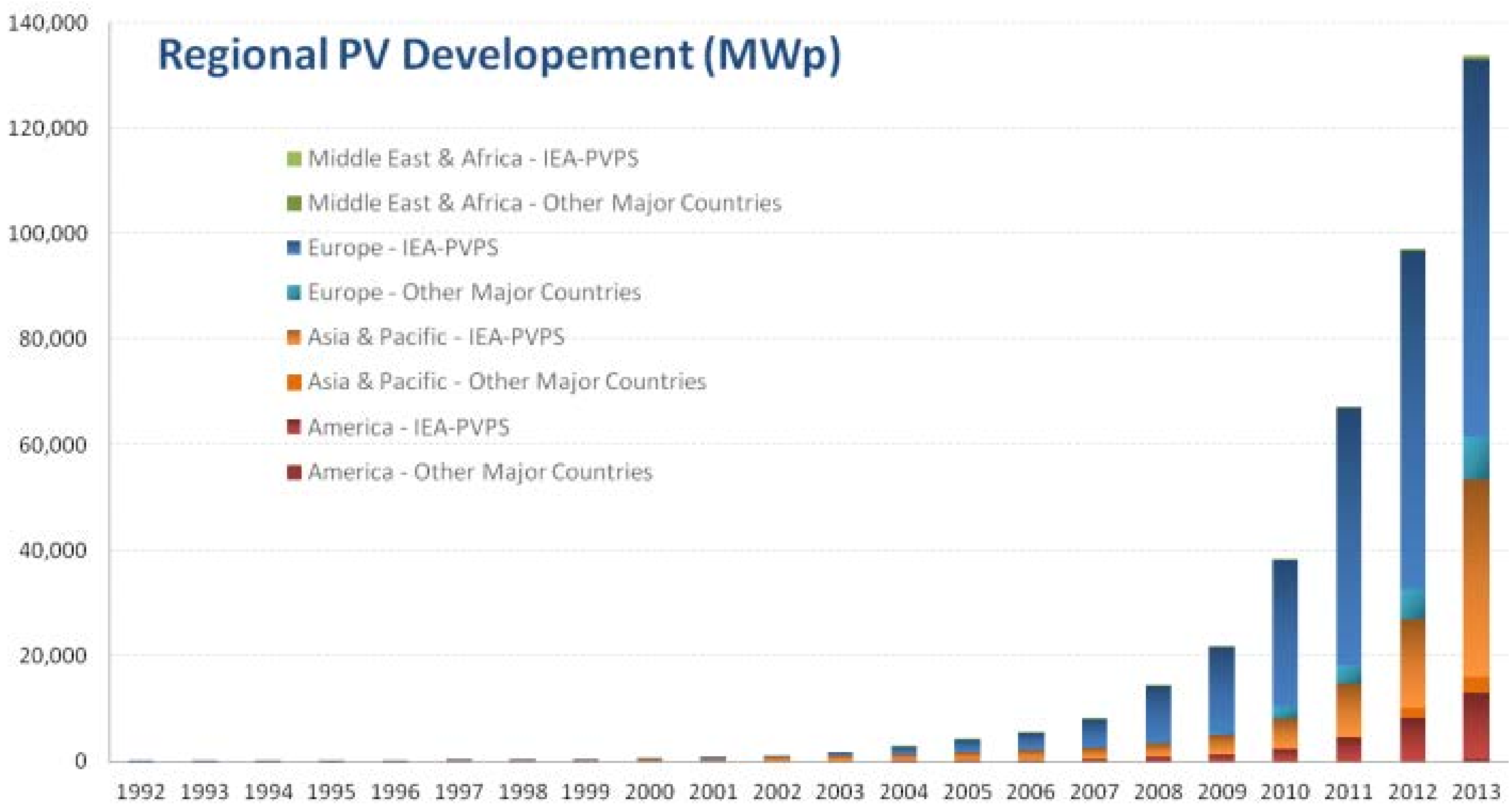
The direct current produced by the PV panels is converted in alternative current (inverter) and, then, led into the grid.



- Production system is decoupled from the user.

VERSATILITY

Evolution of total installed PV capacity in the world



Source: IEA PVPS Report IEA-PVPS T1-24:2014

Photovoltaic conversion

Not integrated PV configuration

Building-integrated PV configuration

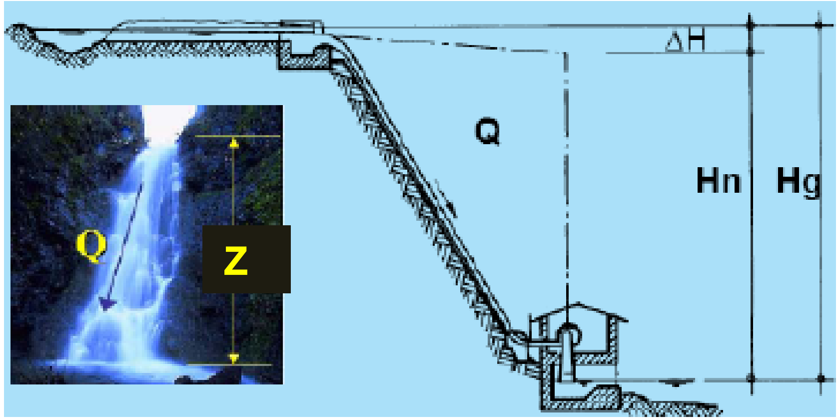
Partially building-integrated PV configuration

Hydropower

Hydroelectric power plants use the kinetic and potential energies owned by water masses located at different altitude above the ground level.

Considering a water mass located at a height **Z** and with the following characteristics:

- γ (= $\rho \cdot g$) = specific weight [$kg/(m^2 s^2)$]
- $\mathbf{Q_v}$ = volumetric flow rate [m^3/s]
- **p** = pressure [MPa]
- **v** = water velocity [m/s]



POWER

$$\mathbf{P} = \gamma Q_v \mathbf{H}$$

$$H = Z + \frac{p}{\gamma} + \frac{v^2}{2g} - Y$$

Pressure drops

Piezometric head

Kinetic term

Hydropower

Classification:

On the base of the **water head**:
- Lower (Z < 20 m)
- Medium (Z < 250 m)
- High (Z > 250 m)

On the base of volumetric **flow rate**:
- Small ($Q_v < 10\ m^3/h$)
- Medium ($Q_v < 100\ m^3/h$)
- Great ($Q_v > 100\ m^3/h$)

The **Reservoir duration** is the time required for filling the useful hydroelectric reservoir with the mean yearly volumetric flow rate. Therefore:
- Seasonal storage system: reservoir duration greater than 400 hours;
- Modulating storage system: reservoir duration between 2 and 400 hours.
- Run-of-the-river: no or limited reservoir (duration less than 2 hours).

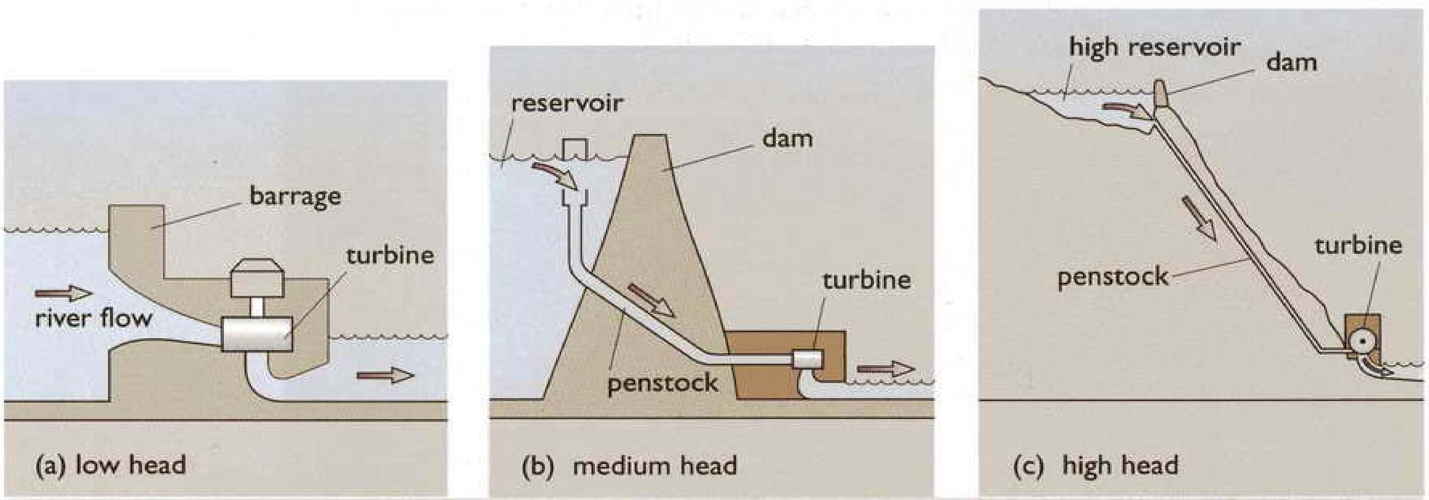
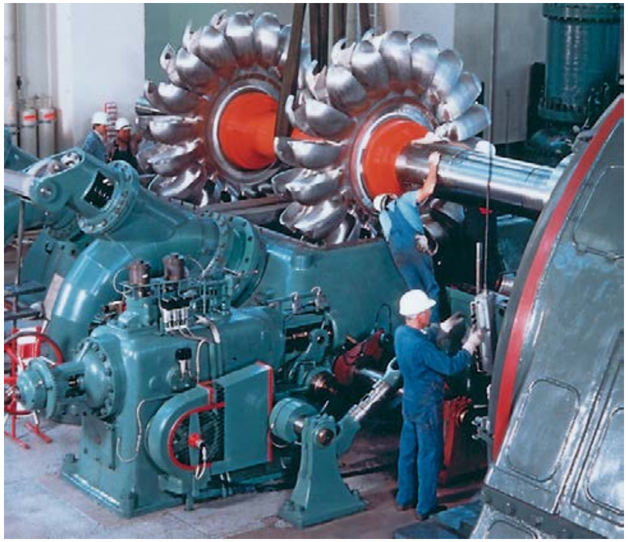
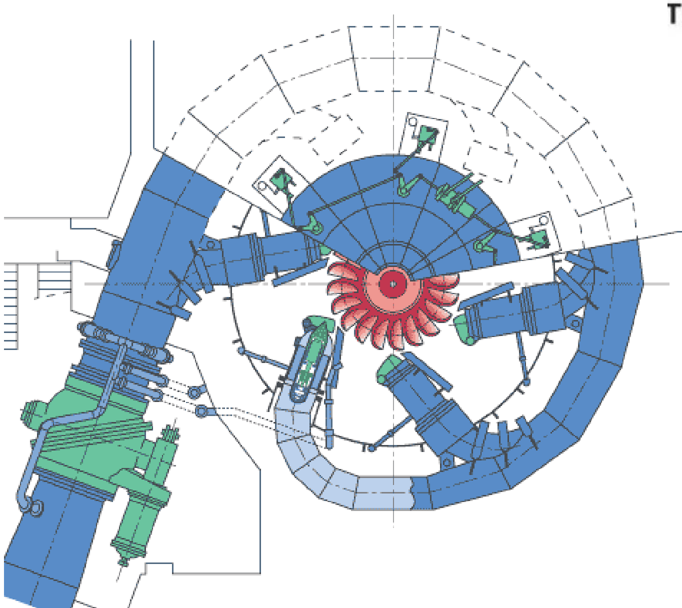


Figure 5.13 Types of hydroelectric installation

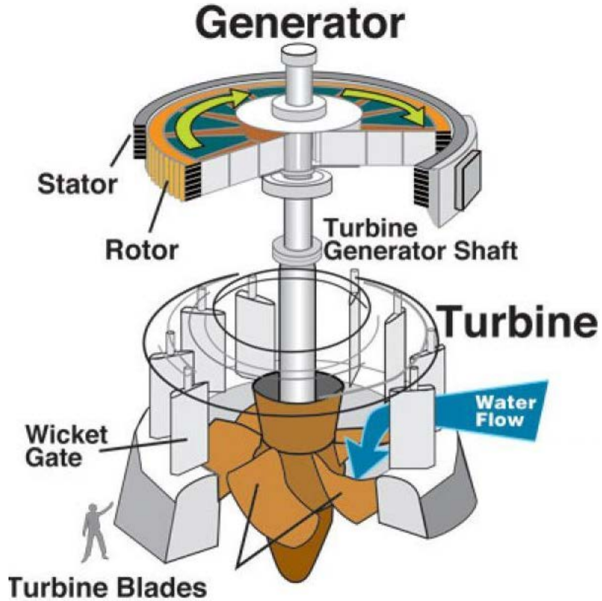
Hydropower

Pelton turbine

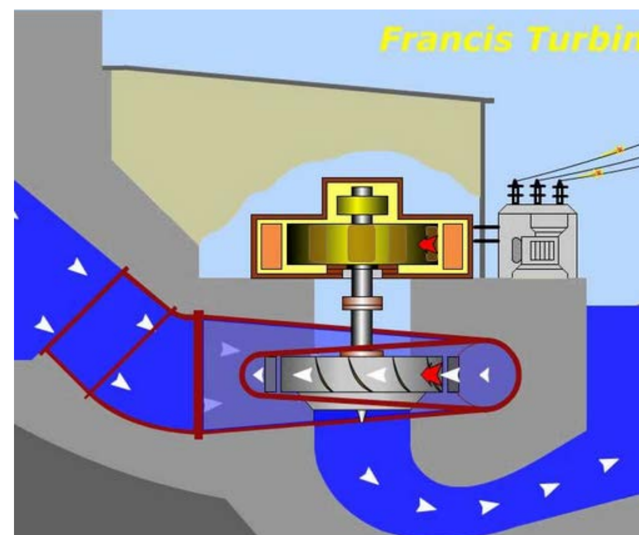




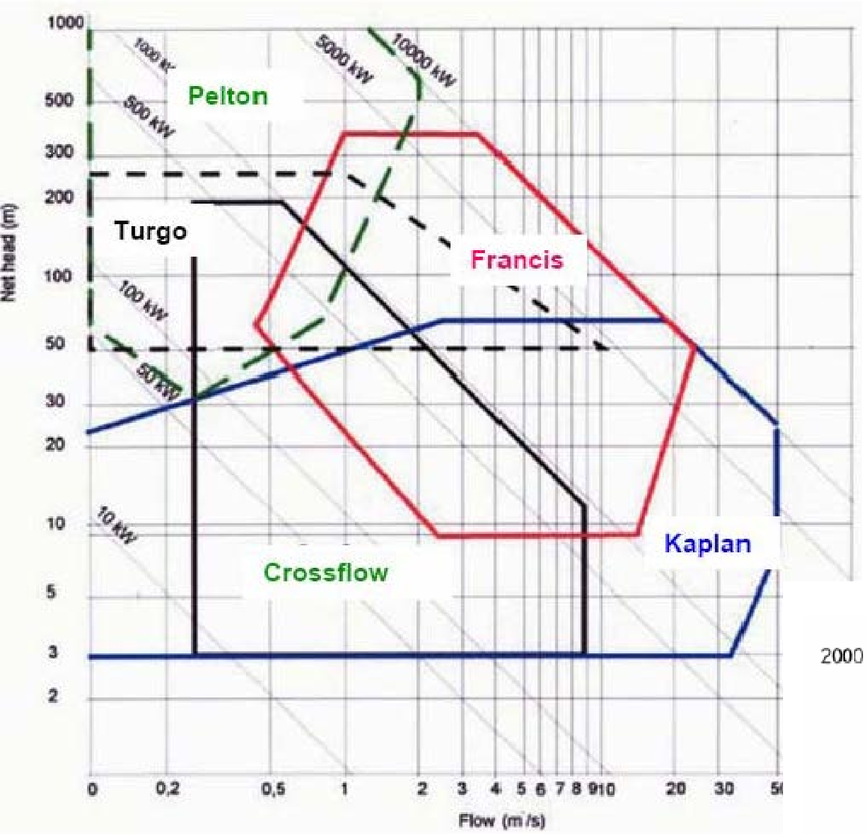
Kaplan turbine



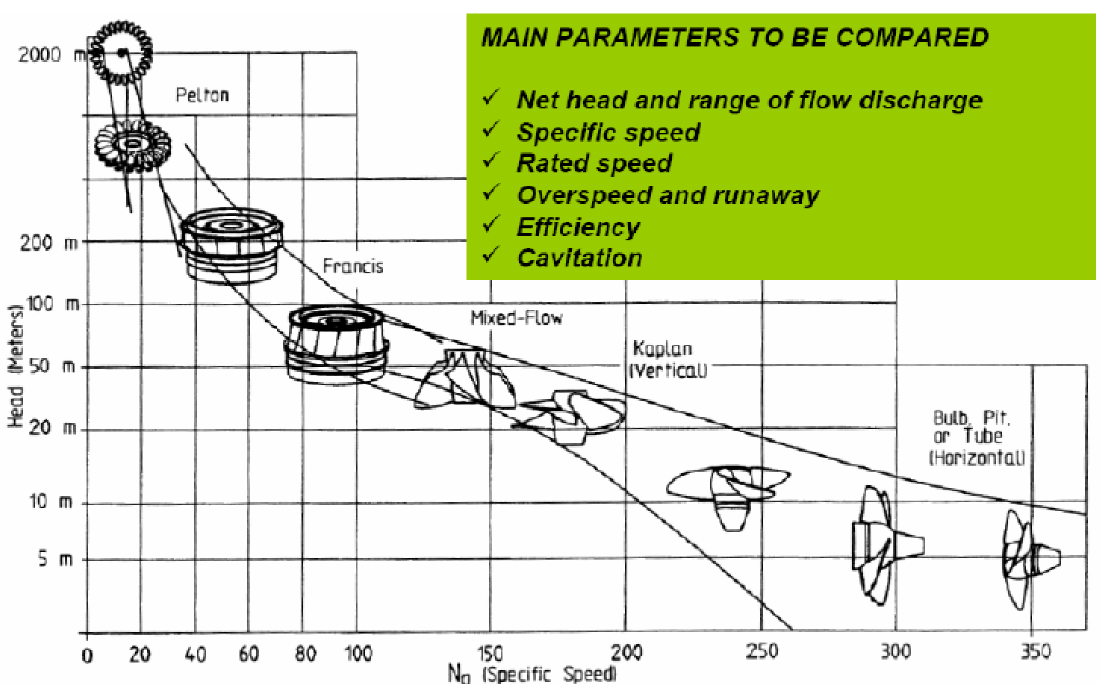
Francis turbine



Hydropower



Turbine characteristics



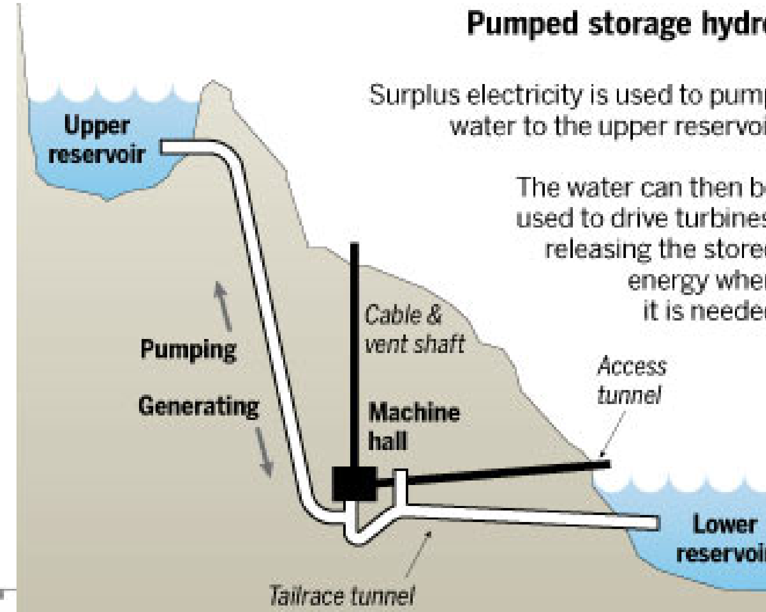
MAIN PARAMETERS TO BE COMPARED

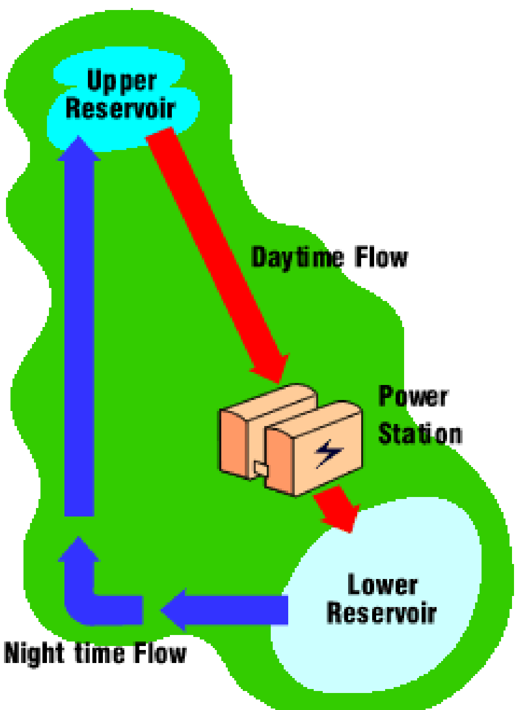
- ✓ ***Net head and range of flow discharge***
- ✓ ***Specific speed***
- ✓ ***Rated speed***
- ✓ ***Overspeed and runaway***
- ✓ ***Efficiency***
- ✓ ***Cavitation***

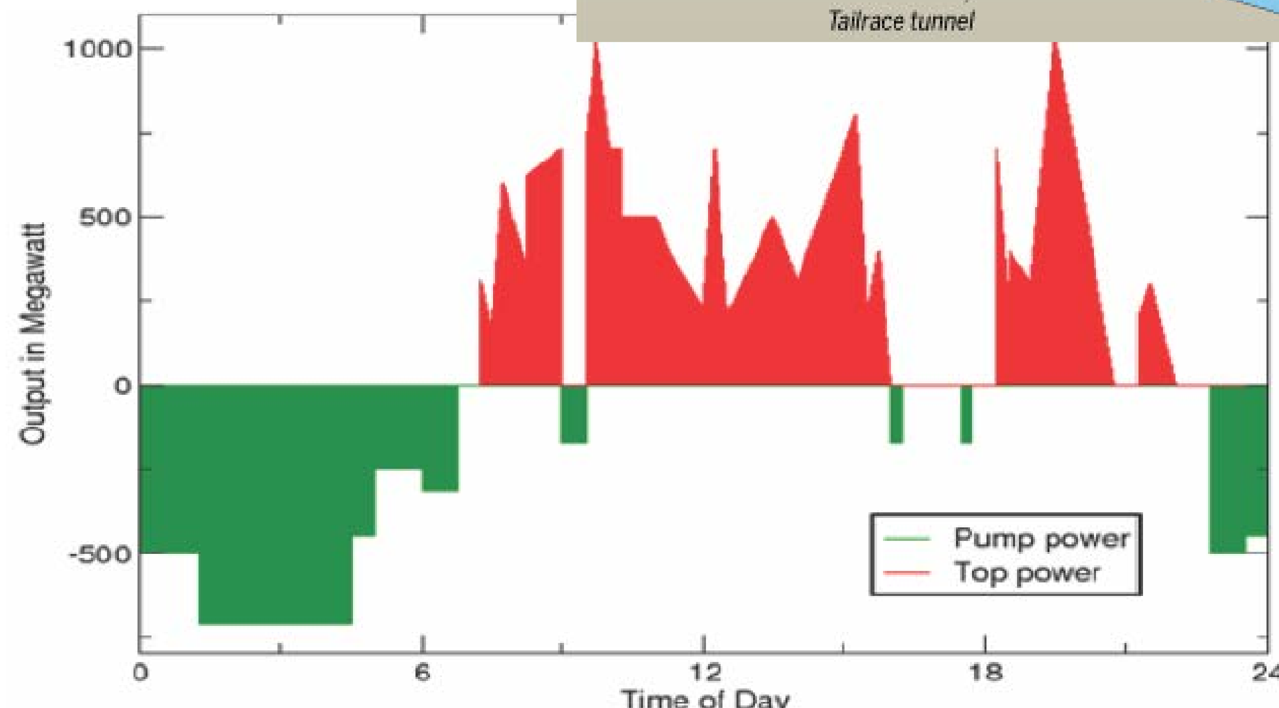
Hydropower

Pumped-storage system

- During periods of high electrical demand, the water stored is released through turbine to produce electricity.
- During the low-cost off-peak electric power is used to pump the water in the upper reservoir.



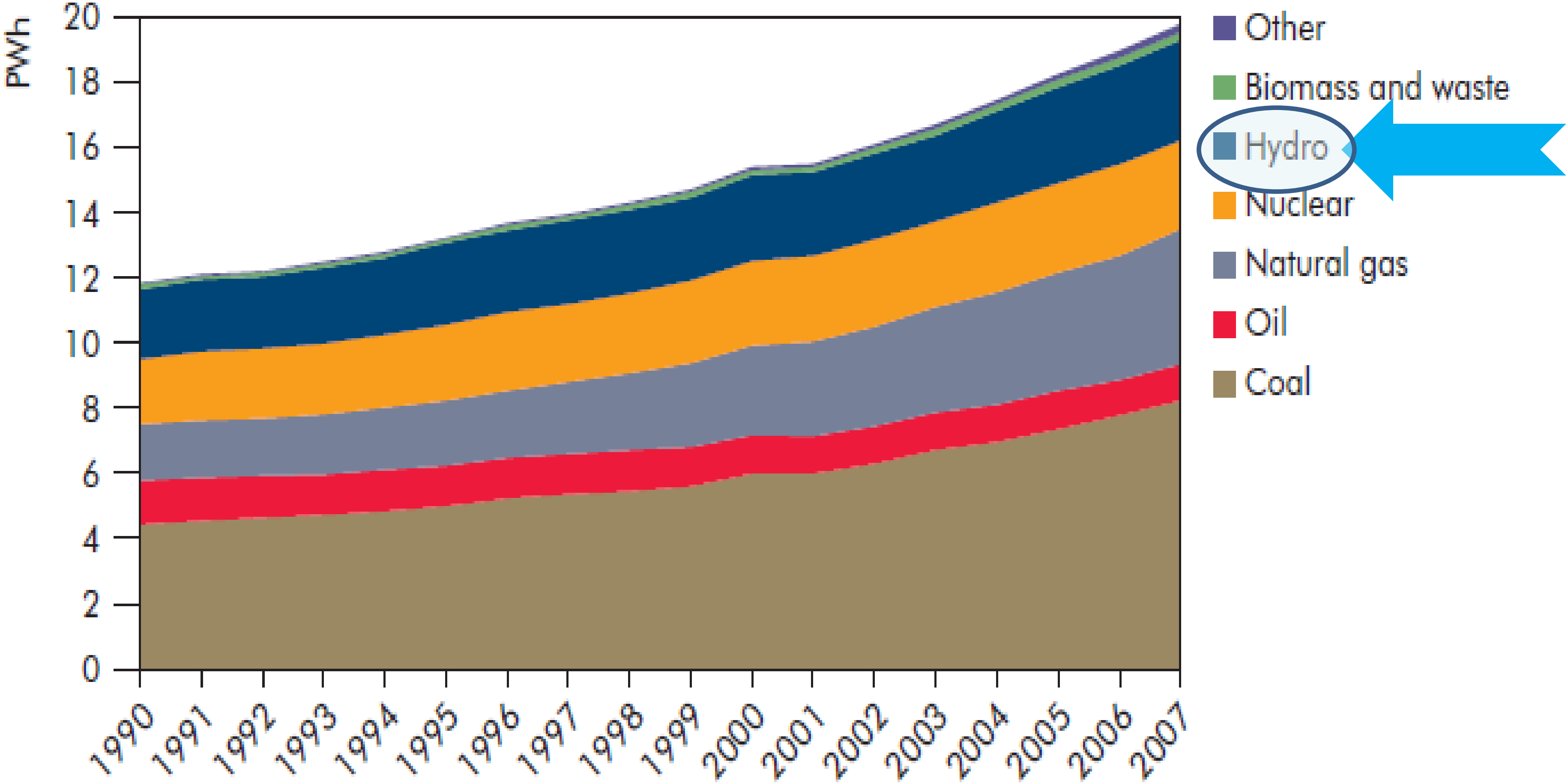




Hydropower

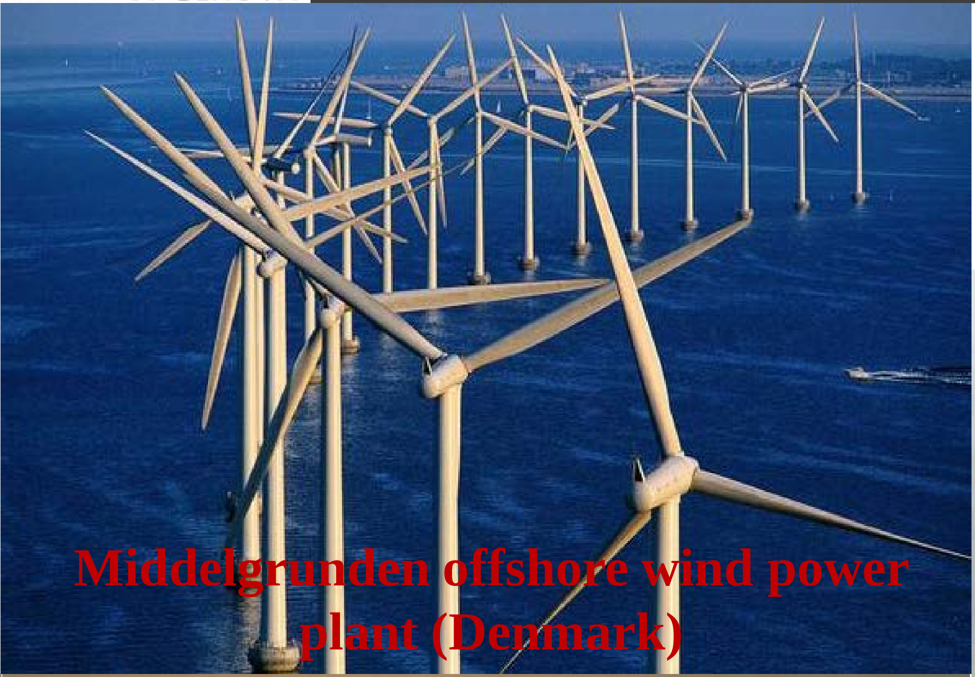
Historical trends in world electricity production

The role of Hydropower



Wind power

Wind power is the conversion of wind energy into mechanical energy by using wind turbines.



Middelgrunden offshore wind power plant (Denmark)

Wind power plants in Xinjiang, China

1888, Cleveland, Ohio (USA)

Charles F. Brush

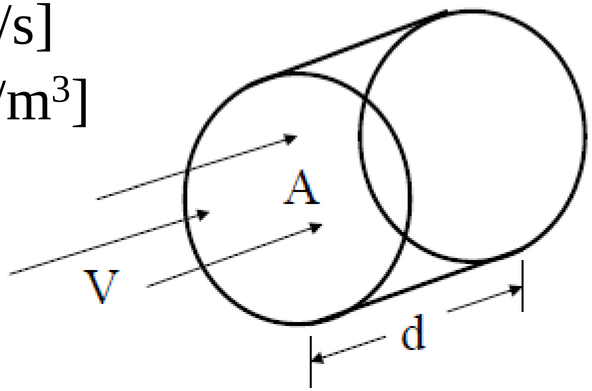
Wind power

The wind source

The power extracted from an air stream that moves through a surface A can be calculated as follows:

$$P = \frac{1}{2}\dot{m}V^2 = \frac{1}{2}\rho A V^3$$

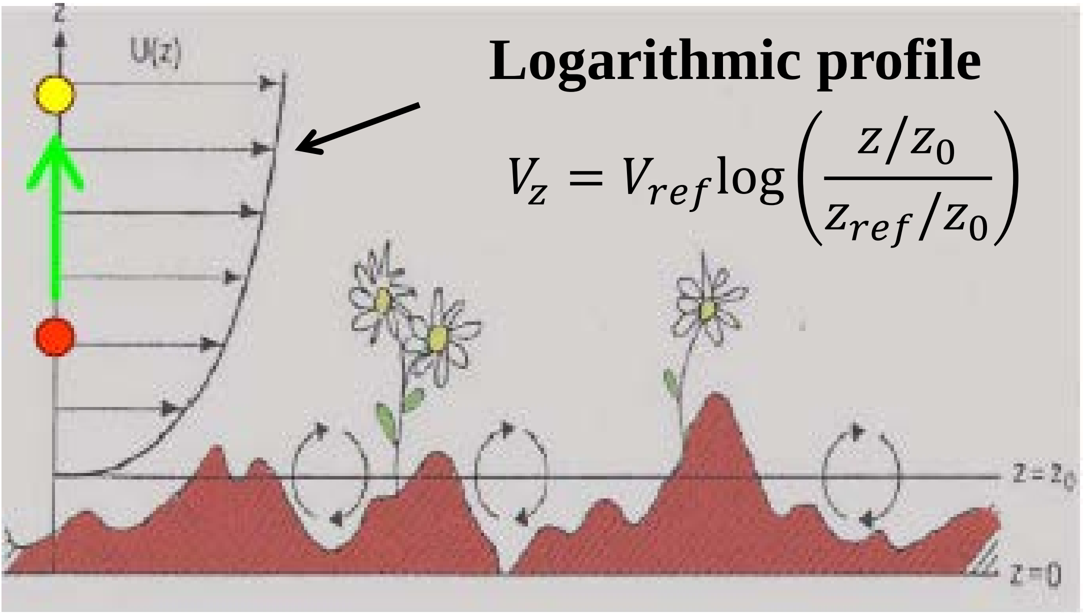
where:
- $\dot{m}$ air mass flow rate [kg/s]
- V air velocity [m/s]
- ρ air density [kg/m^3]



V_{ref} Wind velocity at the reference altitude z_0

V_z Wind velocity at the altitude z

z_0 Roughness length



Logarithmic profile

$$V_z = V_{ref}\log\left(\frac{z/z_0}{z_{ref}/z_0}\right)$$

Term	Beaufort Scale	Wind Speed, u Knots	Wind Speed, u ms^{-1}
Calm	0	<1	<0.515
Light	1–2	1–7	0.515–3.605
Gentle	3	7–11	3.605–5.665
Moderate	4	11–17	5.665–8.755
Fresh	5	17–22	8.755–11.330
Strong	6–7	22–34	11.330–17.510
Gale	8–9	34–48	17.510–24.720
Storm	10–11	48–65	24.720–32.960
Hurricane	12	>65	>32.960

Wind power

Roughness

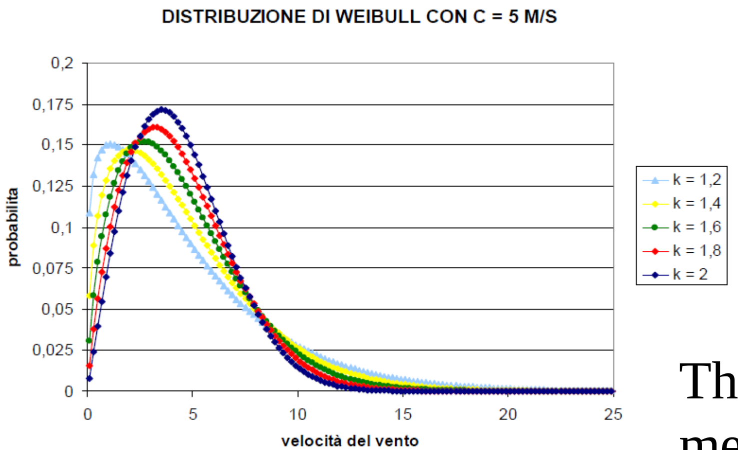
Class	Roughness Length m	Landscape Type
0	0.0002	Water surface
0.5	0.0024	Completely open terrain with a smooth surface, e.g.concrete runways in airports, mowed grass, etc.
1	0.03	Open agricultural area without fences and hedgerows and very scattered buildings. Only softly rounded hills
1.5	0.055	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 1250 metres
2	0.1	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 500 metres
2.5	0.2	Agricultural land with many houses, shrubs and plants, or 8 metre tall sheltering hedgerows with a distance of approx. 250 metres
3	0.4	Villages, small towns, agricultural land with many or tall sheltering hedgerows, forests and very rough and uneven terrain
3.5	0.8	Larger cities with tall buildings
4	1.6	Very large cities with tall buildings and skycrapers

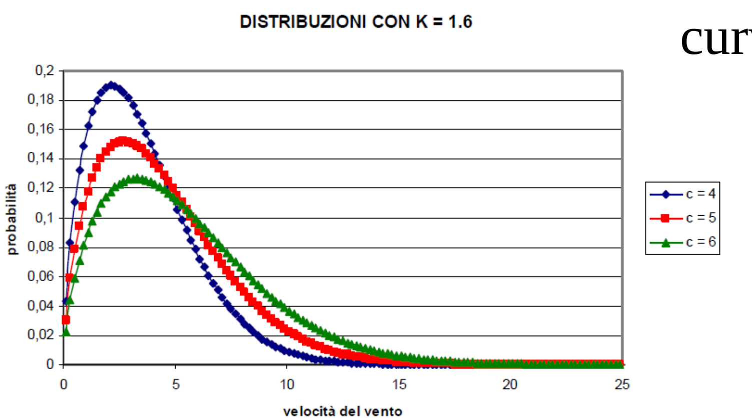
Wind power

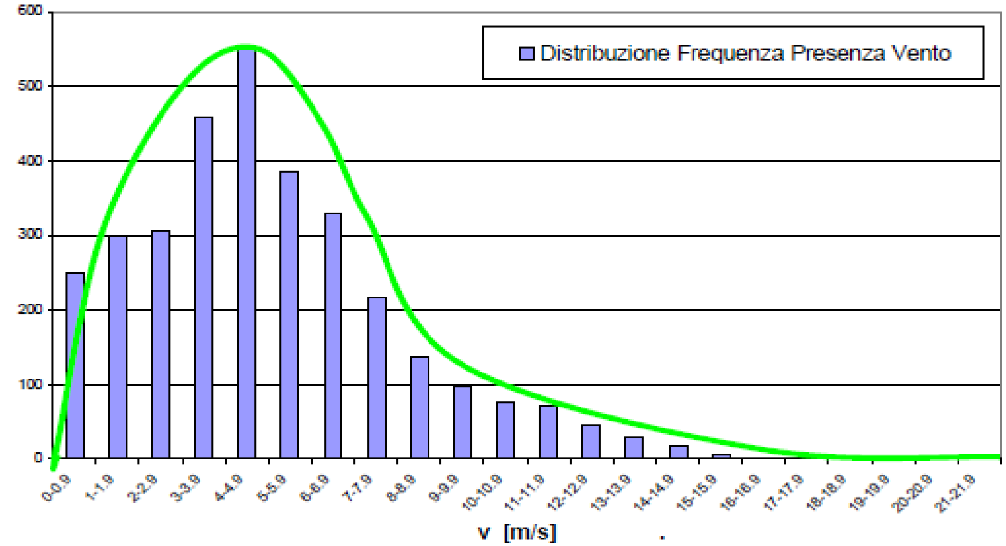
Wind availability

WEIBULL DISTRIBUTION

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} \exp\left[-\left(\frac{V}{c}\right)^{k}\right]$$







c = scaling parameter

k = peaked distribution

These parameters have to be determined by on-site measurements. Starting from the probabilistic Weibull curve several characteristic values can be defined, e.g.:

speed which corresponds to the maximum energy

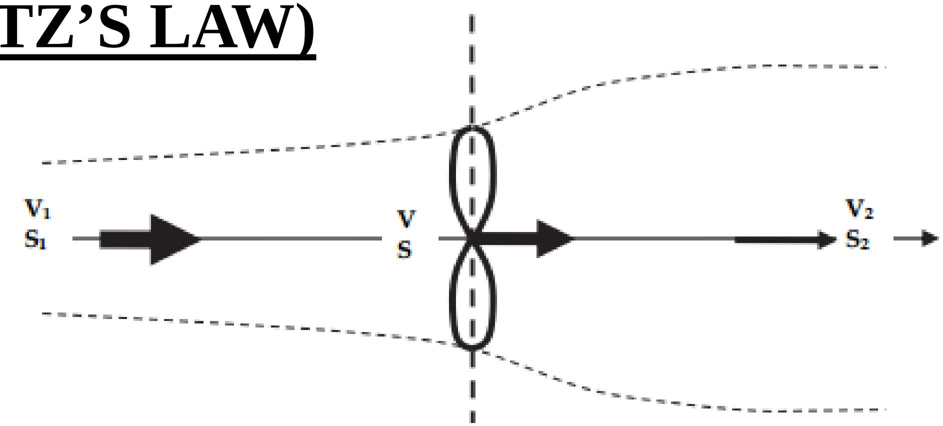
$$V_{MaxE} = c\left(\frac{k+2}{k}\right)^{1/k}$$

speed with maximum probability

$$V_{MP} = c\left(\frac{k-1}{k}\right)^{1/k}$$

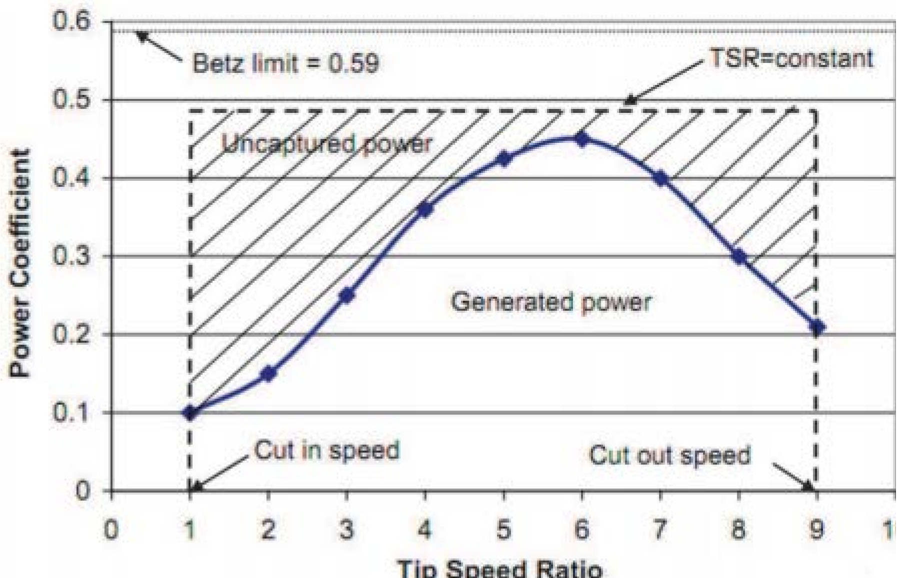
Power curve of a wind turbine (BETZ'S LAW)

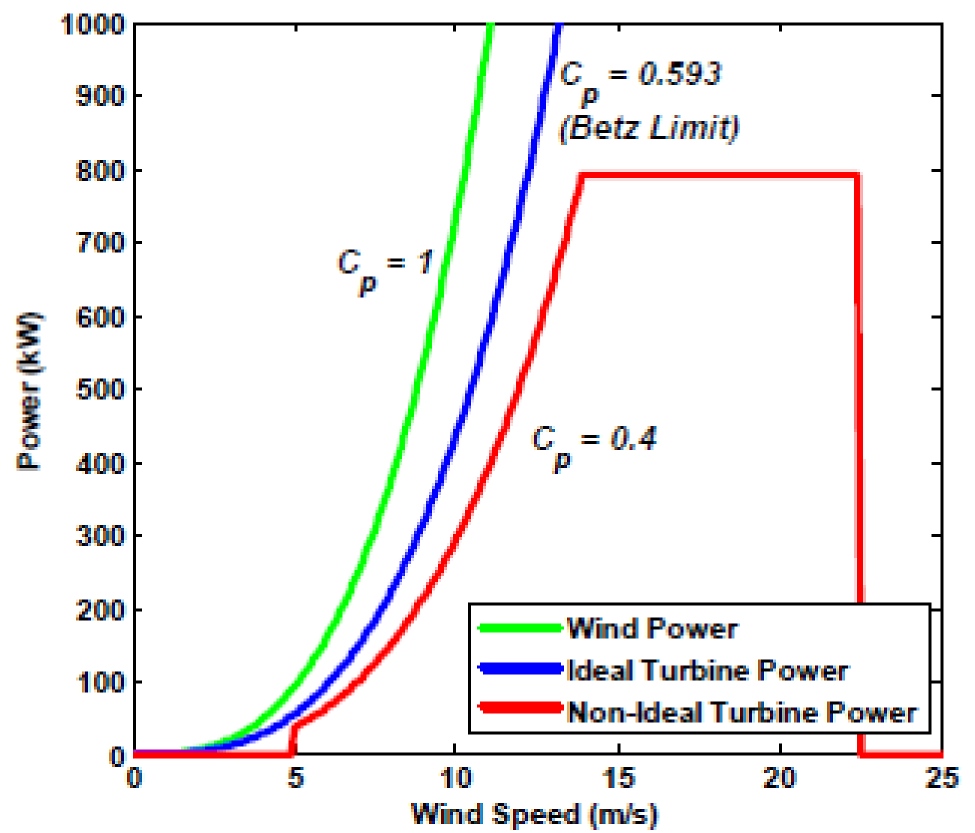
Considering the wind rotor an ideal energy converter (no friction factor and no rotational velocity component), it is not possible to capture more than 59.3% of the kinetic energy owned by the wind.



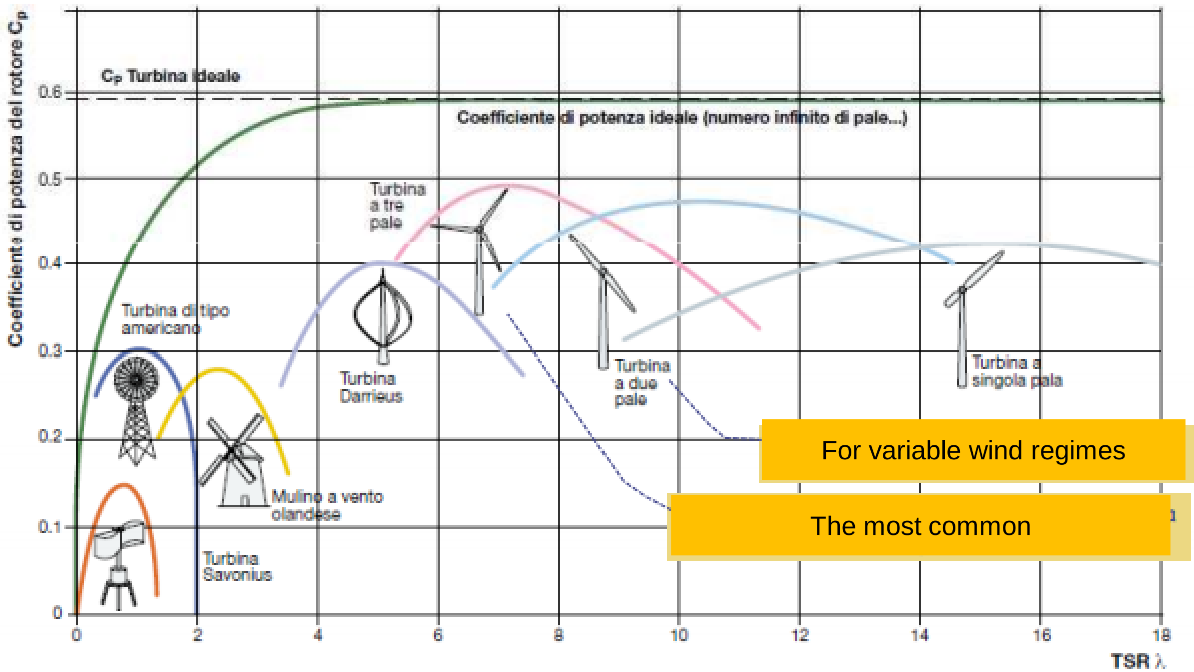
BETZ'S LIMIT

$$C_{p,max} = \frac{P_{max}}{P_0} = 0.593$$

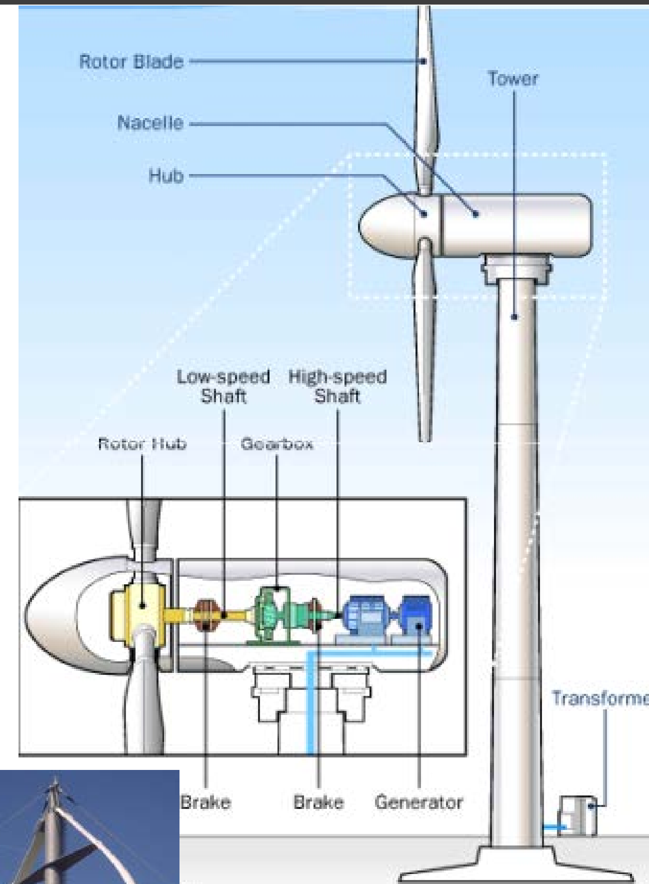


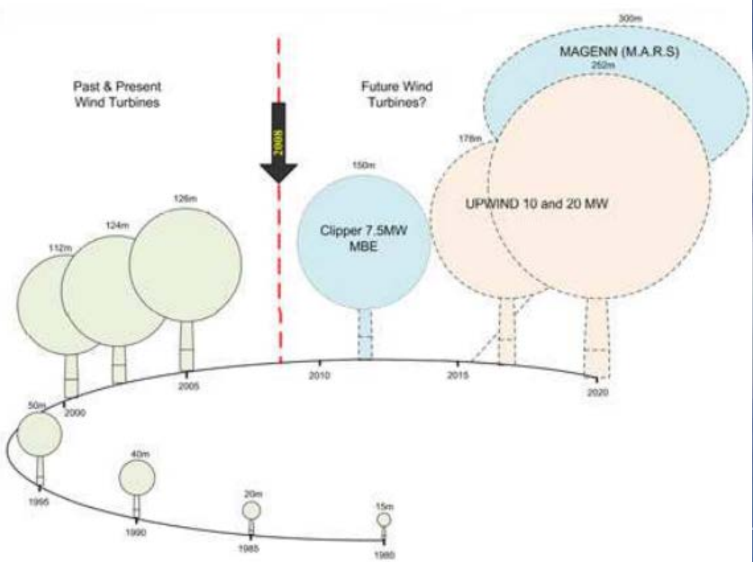


Wind power



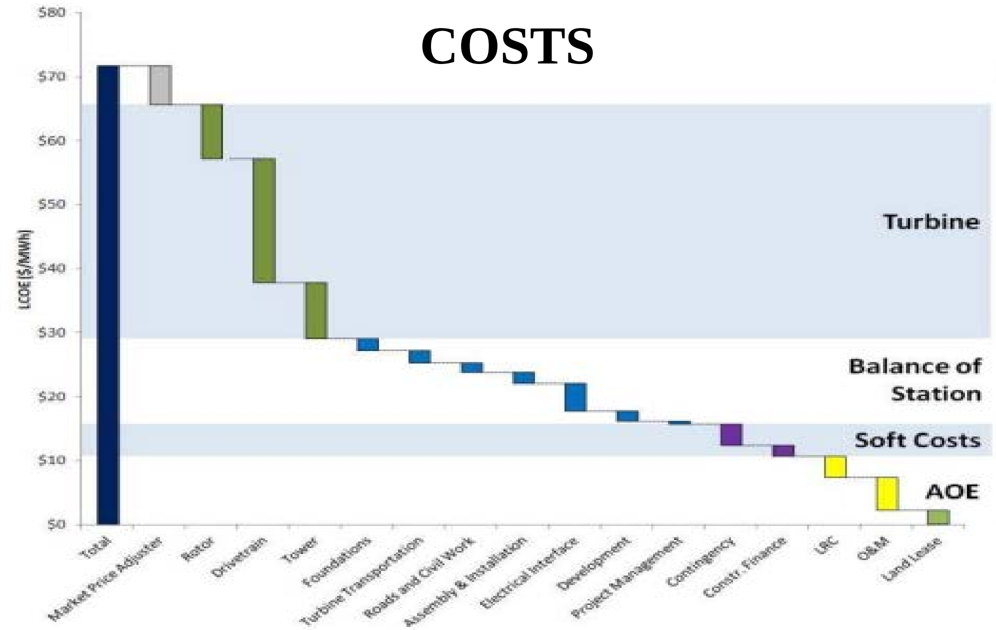
$\lambda = u/v_0$

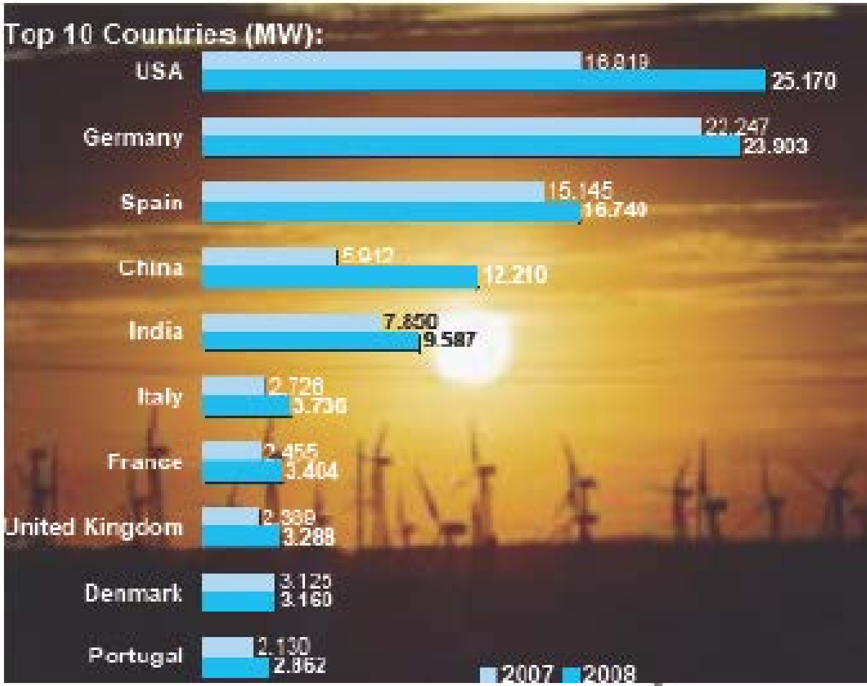




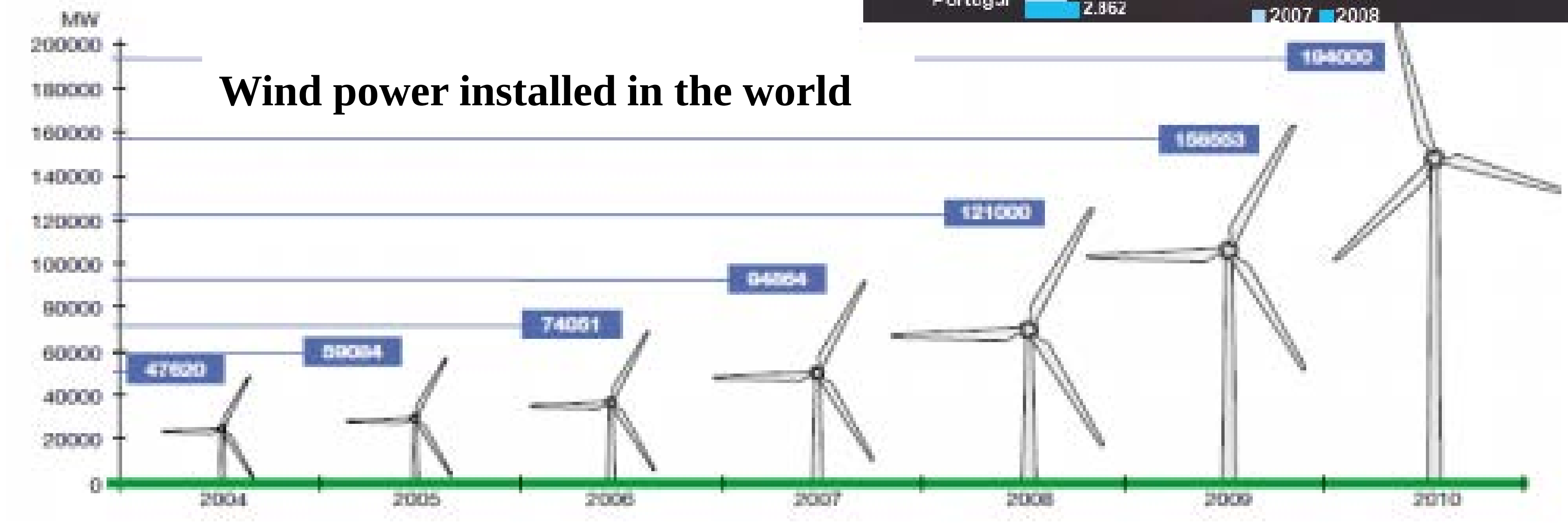
Wind power

COSTS





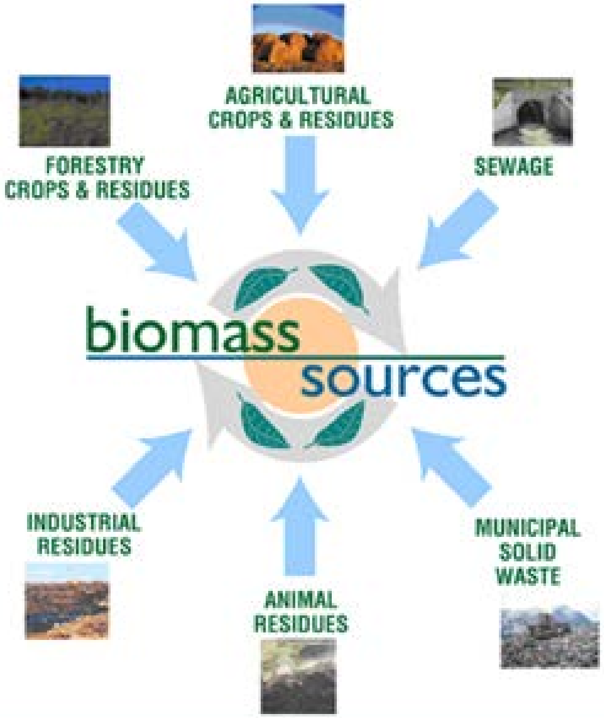
Wind power installed in the world



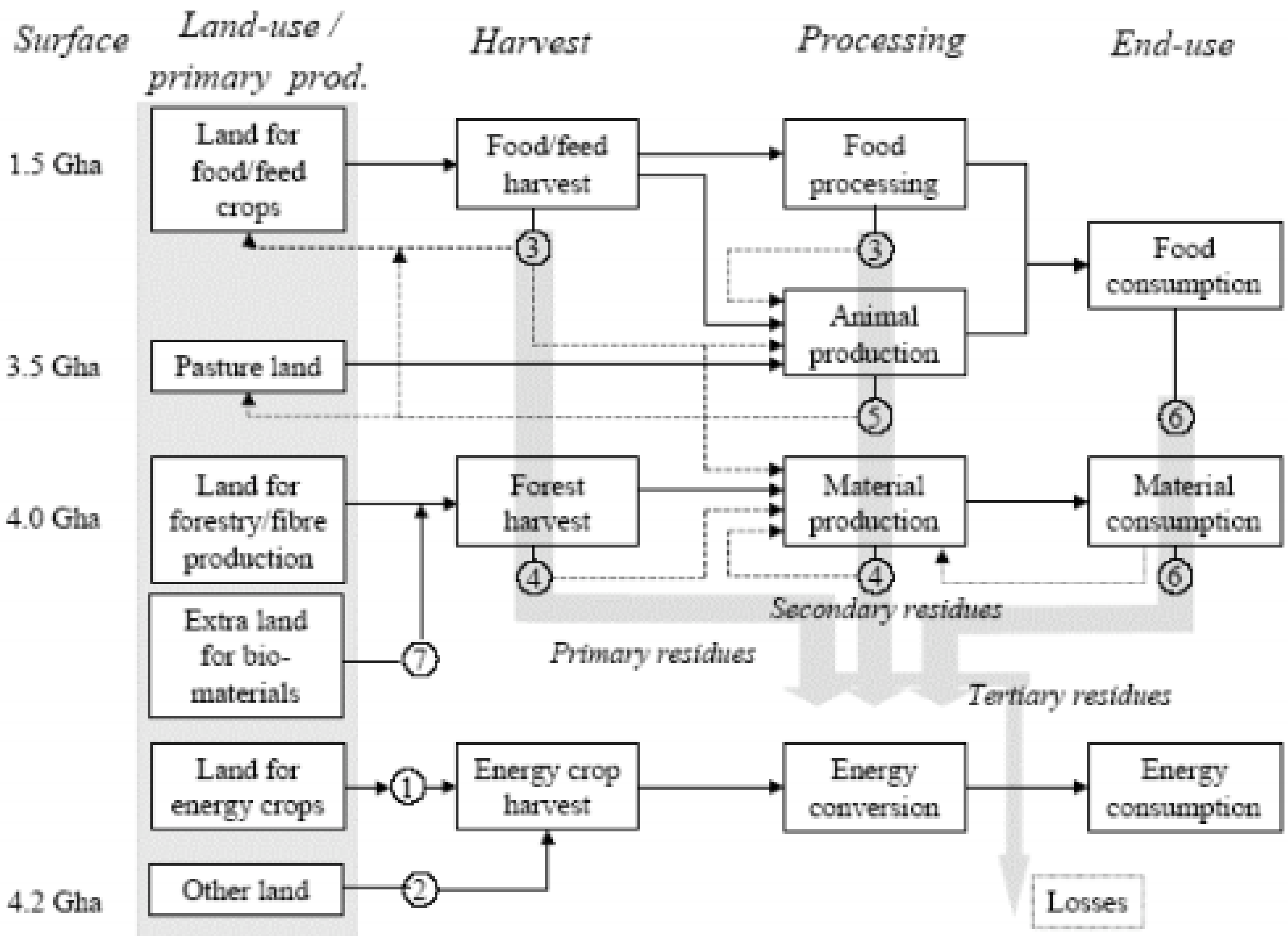
Biomass

The term BIOMASS indicates a broad range of heterogeneous biological materials. This definition covers:

- Wastes from wood industry
- Wastes from paper mills
- Animal residuals
- Municipal solid waste
- Agricultural and forestry products and waste;
- Short rotation forestry dedicated to energy use;



Biomass production

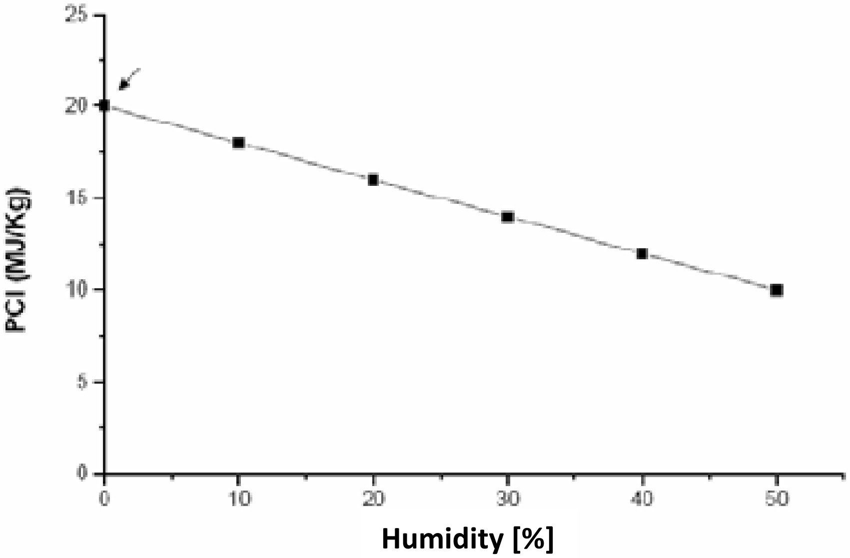


Biomass

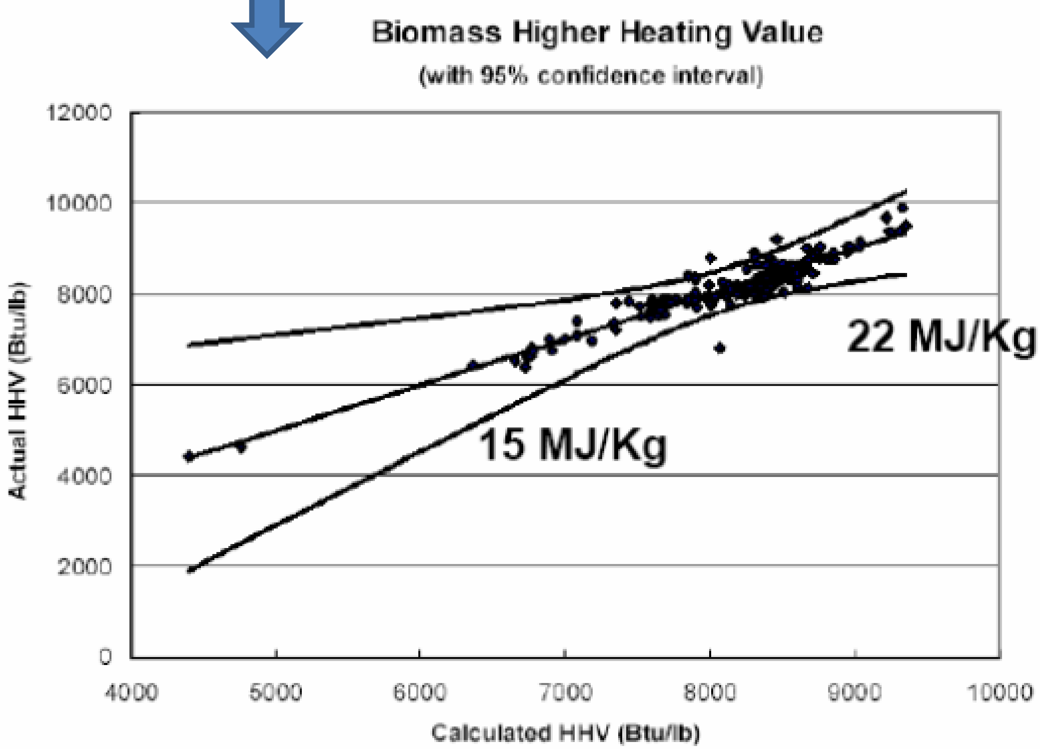
Thermal characteristics

The main thermal characteristics are:

Humidity



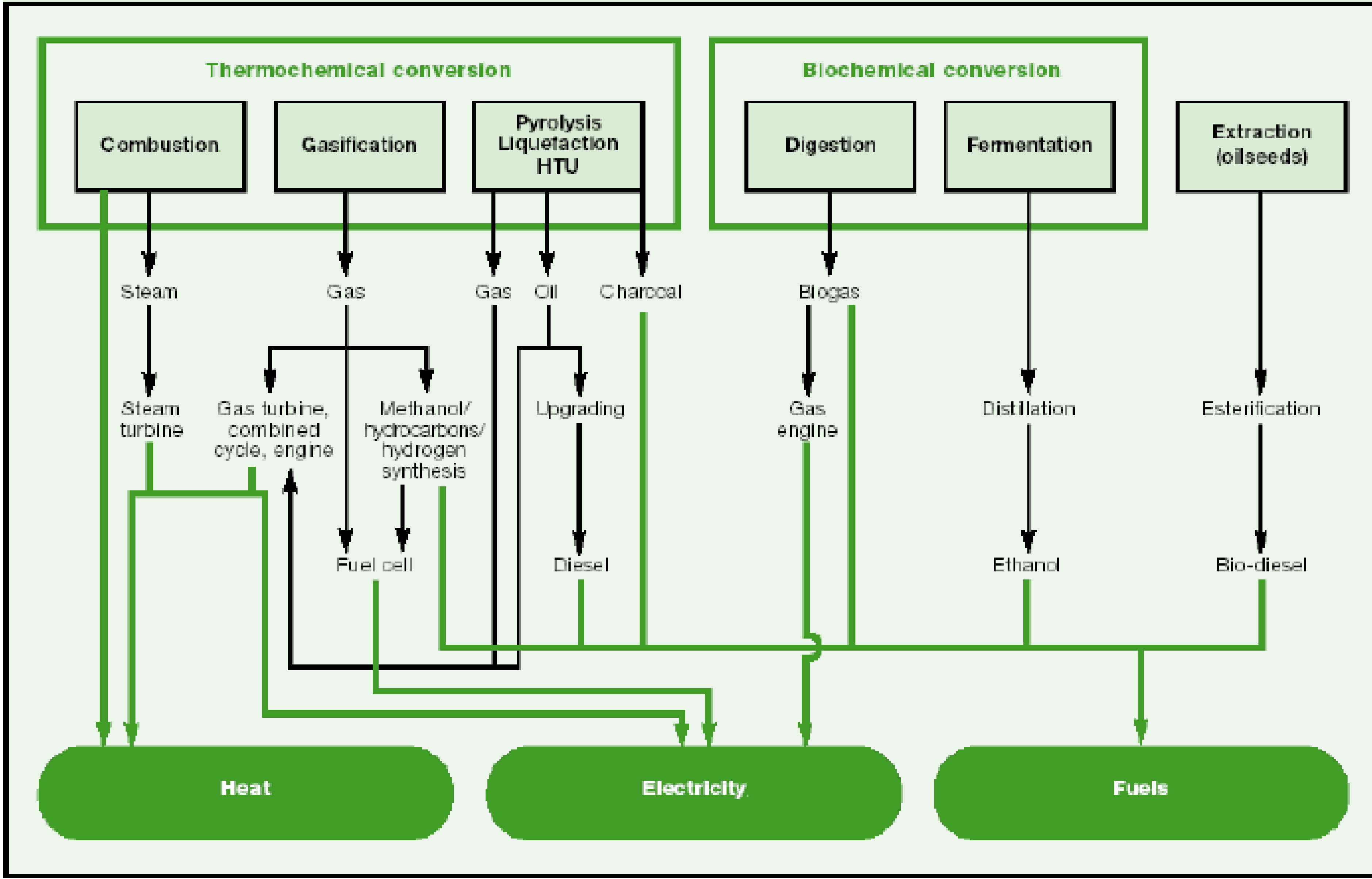
Lower heating value (LHV)



Pellets

Biomass

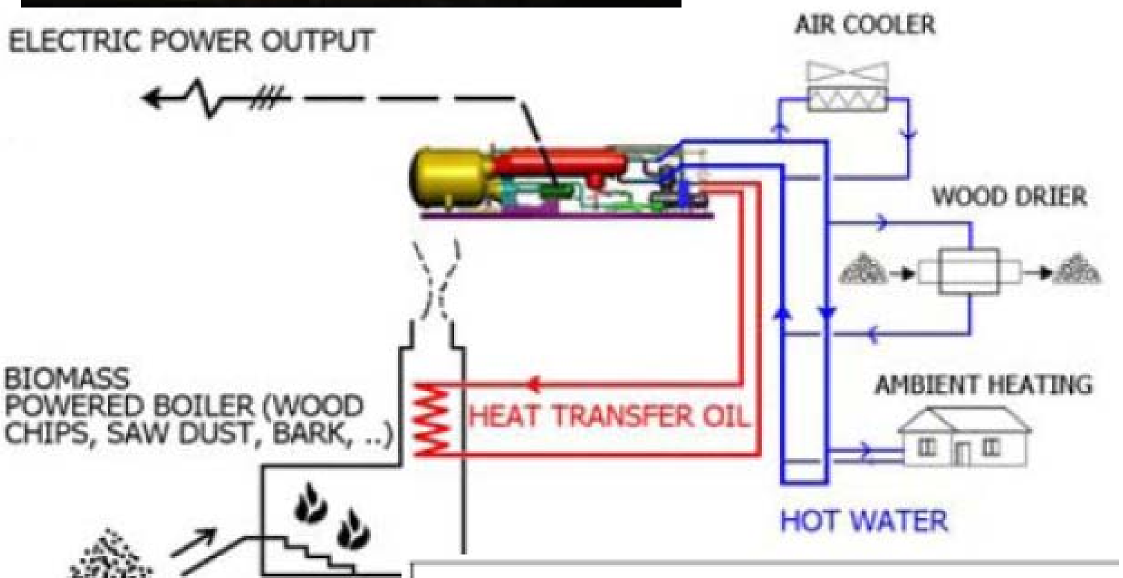
Conversion technologies



Biomass power plant

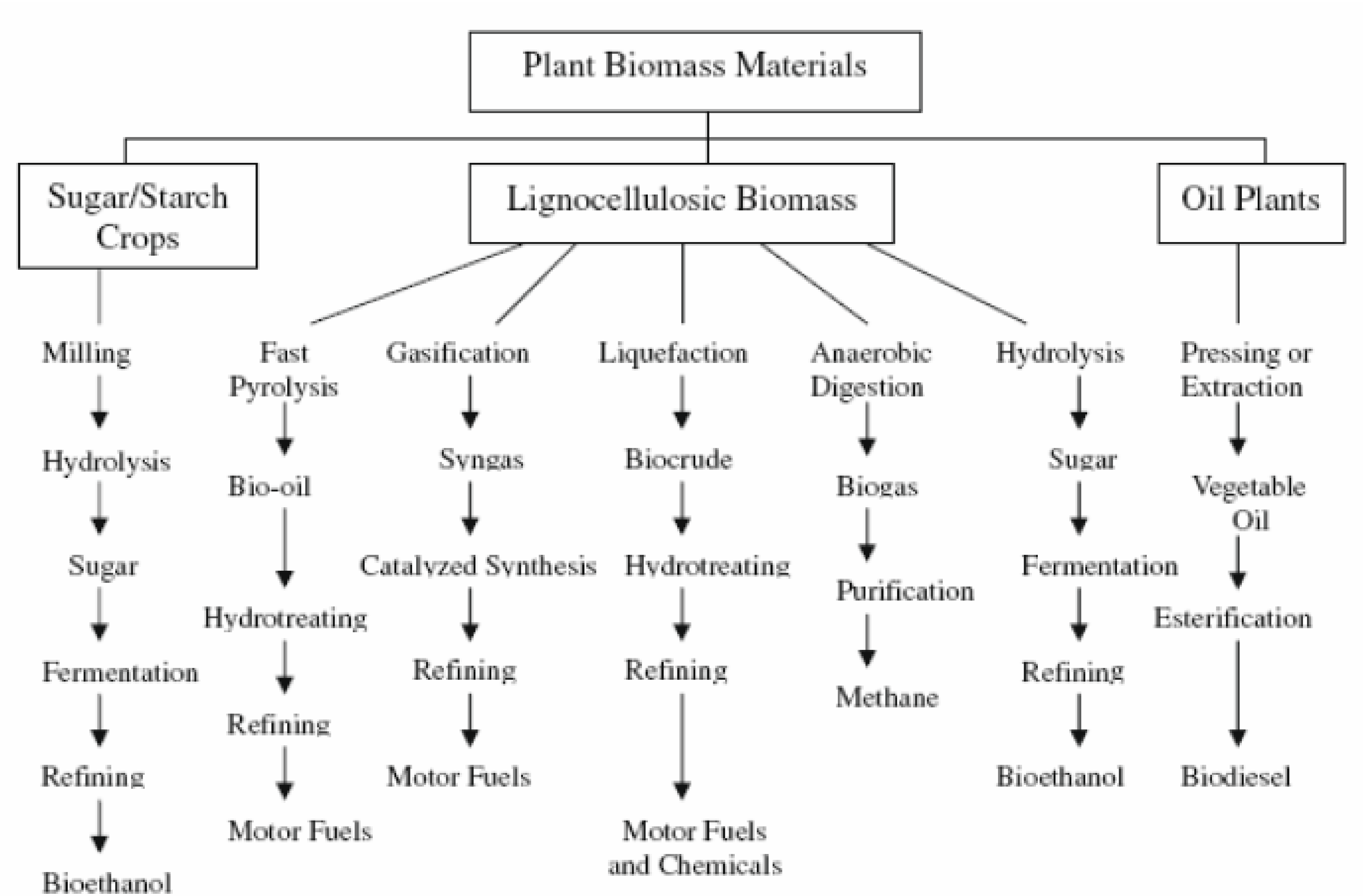
Biomass power plant

Biomass cogeneration plant Tirano	
Nominal power of biomass fired hot water boilers	2 x 6 MW
Nominal power of biomass fired thermal oil boiler	8 MW
Nominal thermal oil power to ORC	6,2 MW
Nominal electric power ORC	1,1 MW_{el}
Nominal power of oil fired stand-by boiler	6 MW
Length of district heating net	about 21 km
Connected thermal load	about 39 MW
Nominal capacity of air coolers	5 MW



Small systems

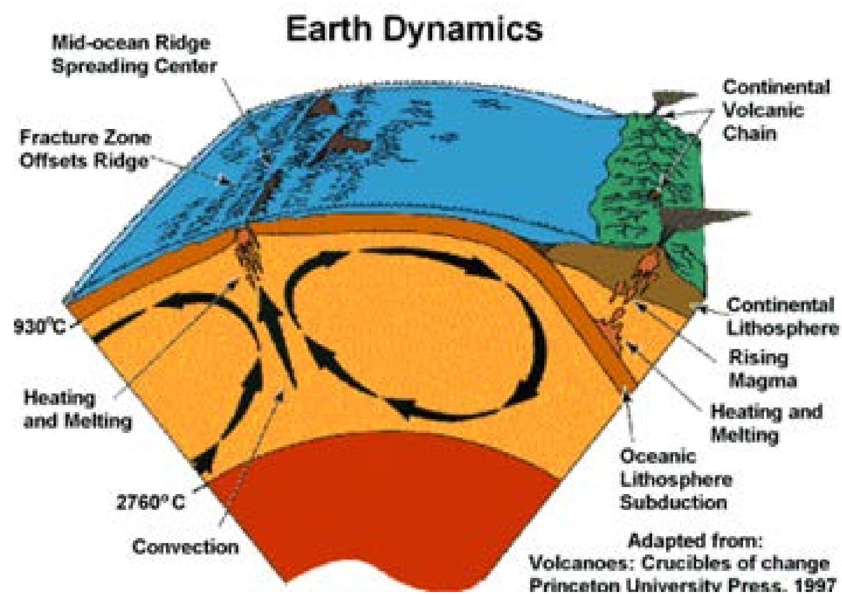
Biofuels

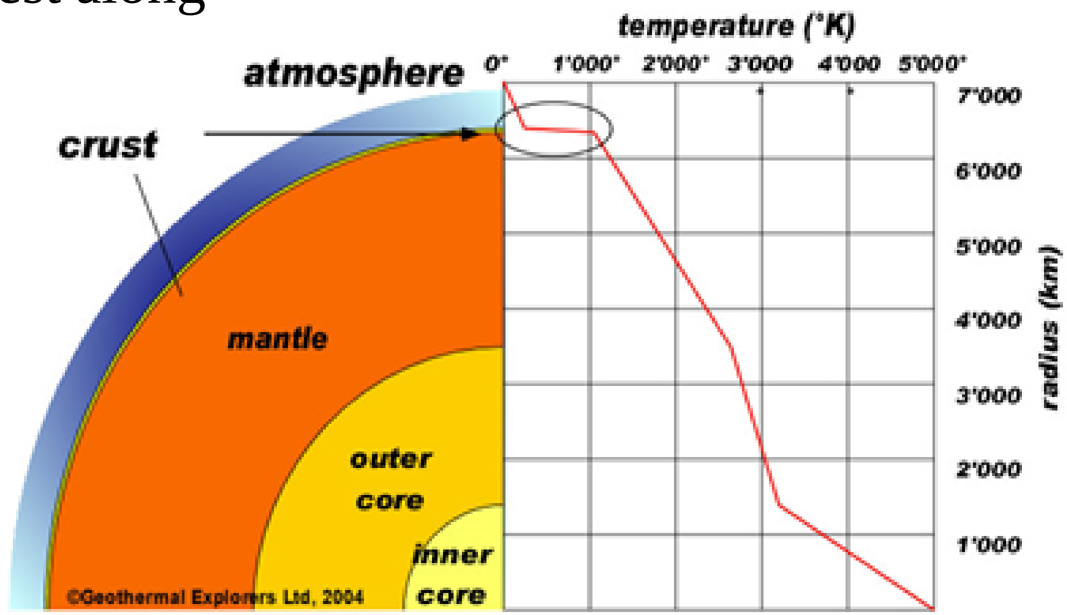


Plant Biomass Materials
Sugar/Starch Crops
Lignocellulosic Biomass
Oil Plants
Milling
Hydrolysis
Sugar
Fermentation
Refining
Bioethanol
Fast Pyrolysis
Bio-oil
Hydrotreating
Refining
Motor Fuels
Gasification
Syngas
Catalyzed Synthesis
Refining
Motor Fuels
Liquefaction
Biocrude
Hydrotreating
Refining
Motor Fuels and Chemicals
Anaerobic Digestion
Biogas
Purification
Methane
Hydrolysis
Sugar
Fermentation
Refining
Bioethanol
Pressing or Extraction
Vegetable Oil
Esterification
Biodiesel

Geothermal energy

- More than 99% of Earth mass has a temperature greater than 1000 °C.
- Earth’s core maintains temperatures in excess of 5000 °C
- Heat energy continuously flows from hot core by convection and conduction processes.
- The heat flux at Earth’s surface (about 16 kW/km2) tends to be strongest along tectonic boundaries.
- Volcanic activity transports hot materials near the surface (5-20 km beneath the surface).
- Hydrological convection forms high temperature geothermal systems (depth 500-3000m).



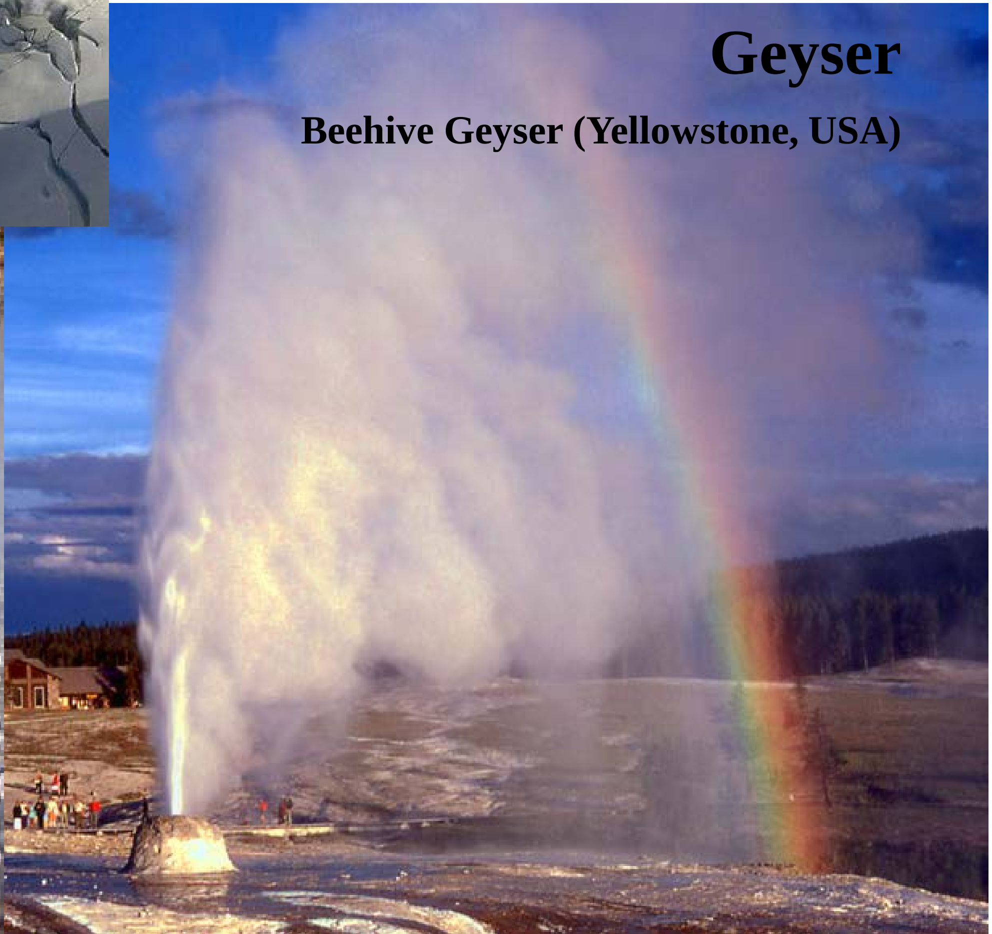


Geothermal energy

Geothermal phenomena

Fumaroles

Fourpeaked volcano, Alaska



Geyser

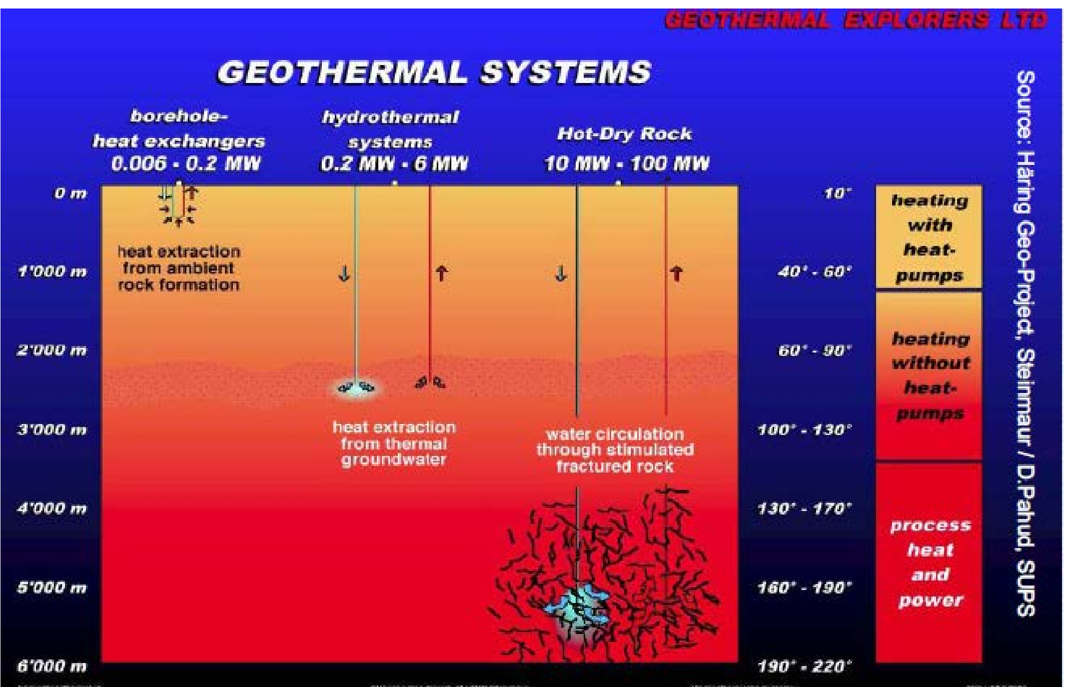
Beehive Geyser (Yellowstone, USA)

Hot spring

Geothermal energy

Generally, a geothermal source is constituted by a natural underground heat storage whose exploitation is technically and economically feasible.

The type of geothermal application depends on the temperature level of the geothermal reservoir. Considering a standard geothermal temperature gradient (~3°C per 100m), the type of application is related to the depth:



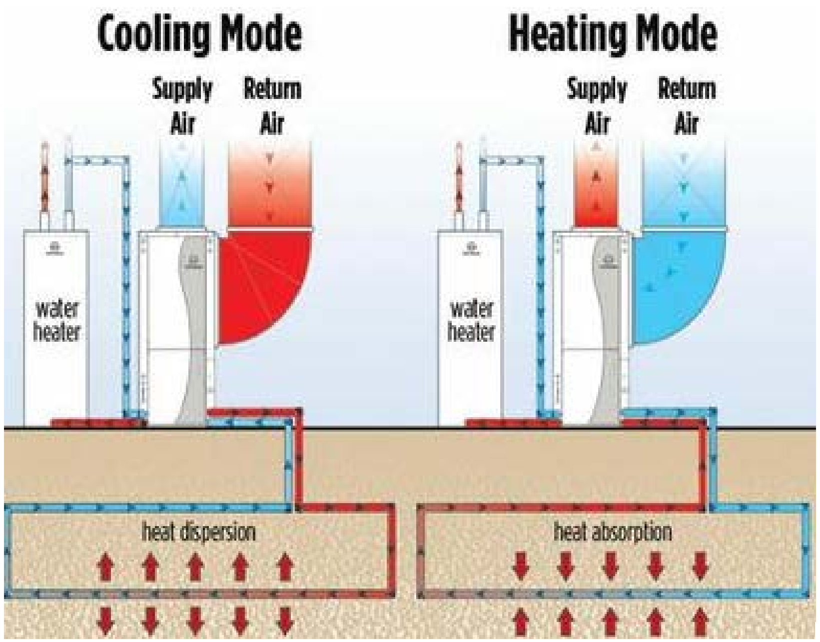
- 0-1000 m: heating with heat pumps
- 1000-3500 m: heating using the aquifers
- 3500-6000 m: hot dry rock systems for heat and power generation.

Geothermal energy

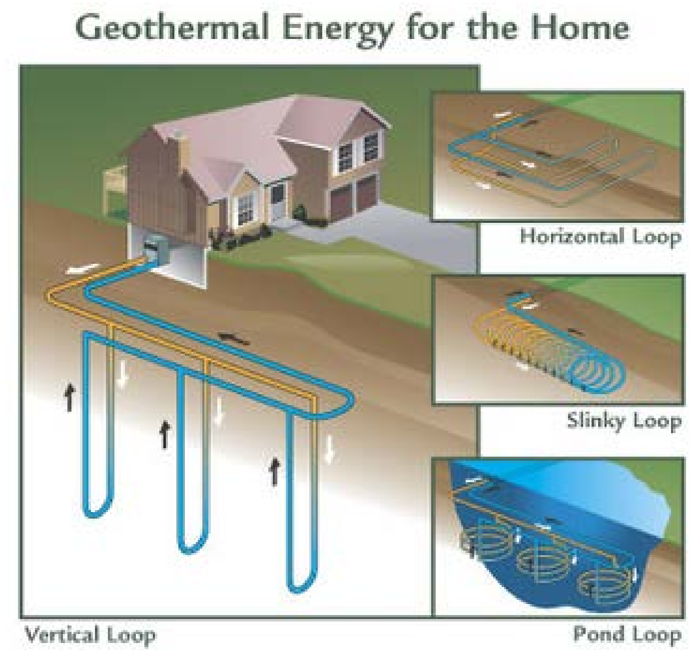
Geothermal reservoir temperature	Fluid	Common use	Type of installation
≥ 220 °C	Water Steam	Power Direct fluid uses	• Flash steam • Combined cycles • Direct fluid use • Heat Exchangers • Heat pumps
100-220 °C	Water	Power Direct fluid uses	• Binary cycle • Direct fluid use • Heat Exchangers • Heat pumps
50-150 °C	Water	Direct fluid uses	• Direct fluid use • Heat Exchangers • Heat pumps

Geothermal energy

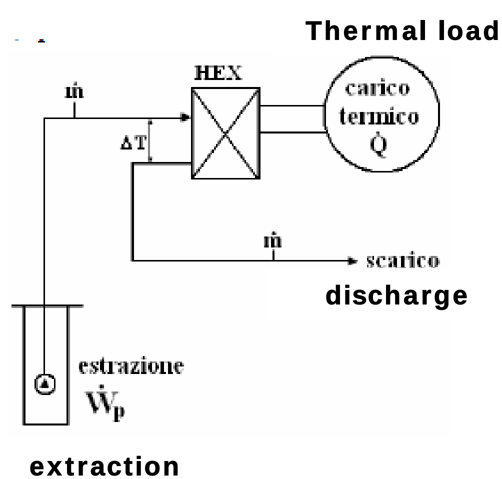
GEOTHERMAL HEAT PUMP SYSTEM

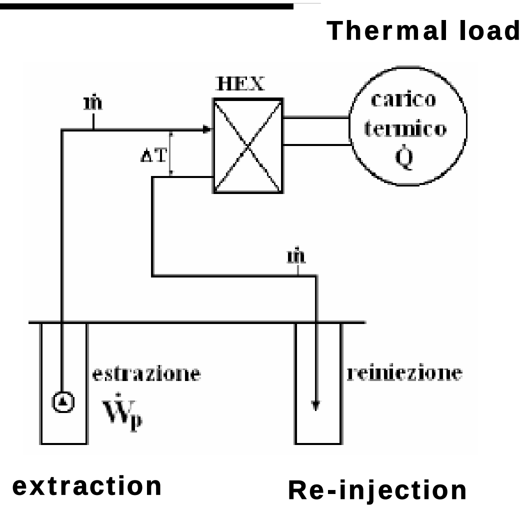


Geothermal heat can be used directly or for power generation. Here, two typical applications.



HEAT EXCHANGERS



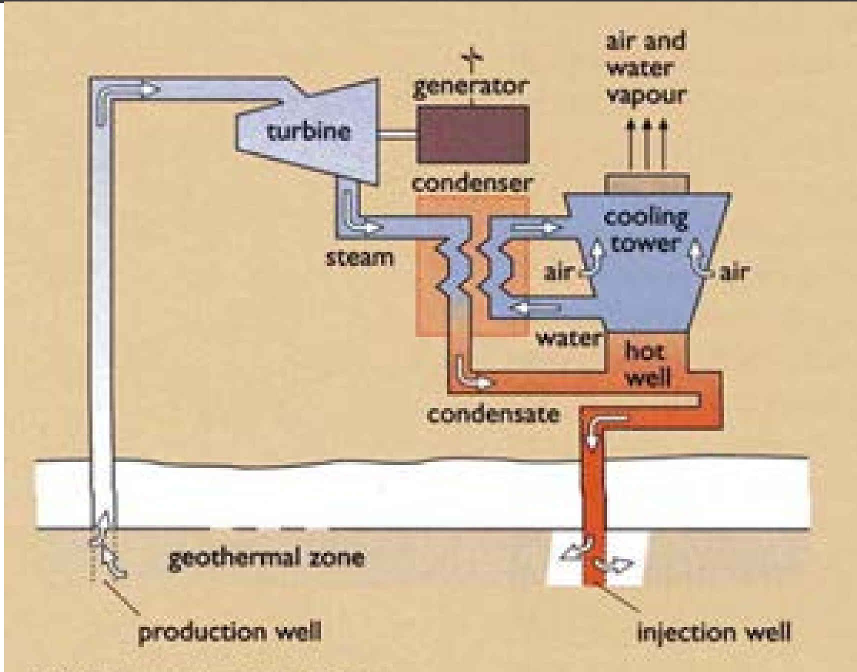


Geothermal energy

Dry system power plant

“Dry” steam is extracted from the geothermal reservoir and used directly to drive a turbo-generator. Then, the steam is condensed and pumped back into the ground.

- 180-225 °C
- 4-8 Mpa
- 200+ km/h



(a) dry steam power plant

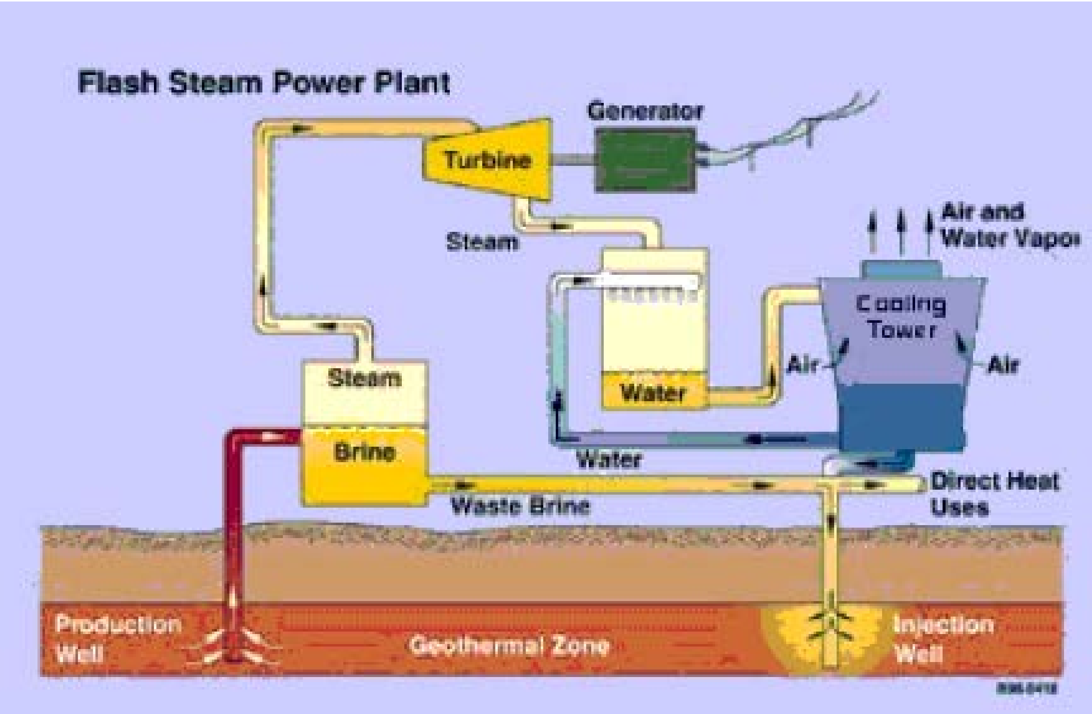

First Geothermal Power Plant, 1904, Larderello, Italy

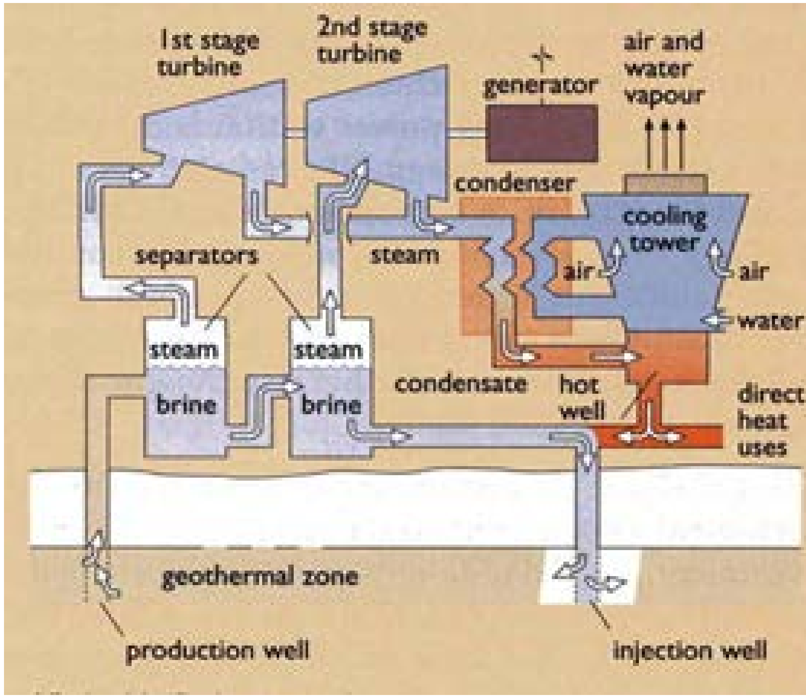
This is the oldest type of geothermal power plant. It was first used at Lardarello (Pisa) in Italy in 1904.

Single/Double Flash Steam Power Plants

The mixture water/steam is extracted from the ground. Thanks to the rapidly decrease of the pressure, the steam is separated from water.

Then, the steam drives a turbine and, later the condenser, is mixed with the separated water and re-injected in the ground.

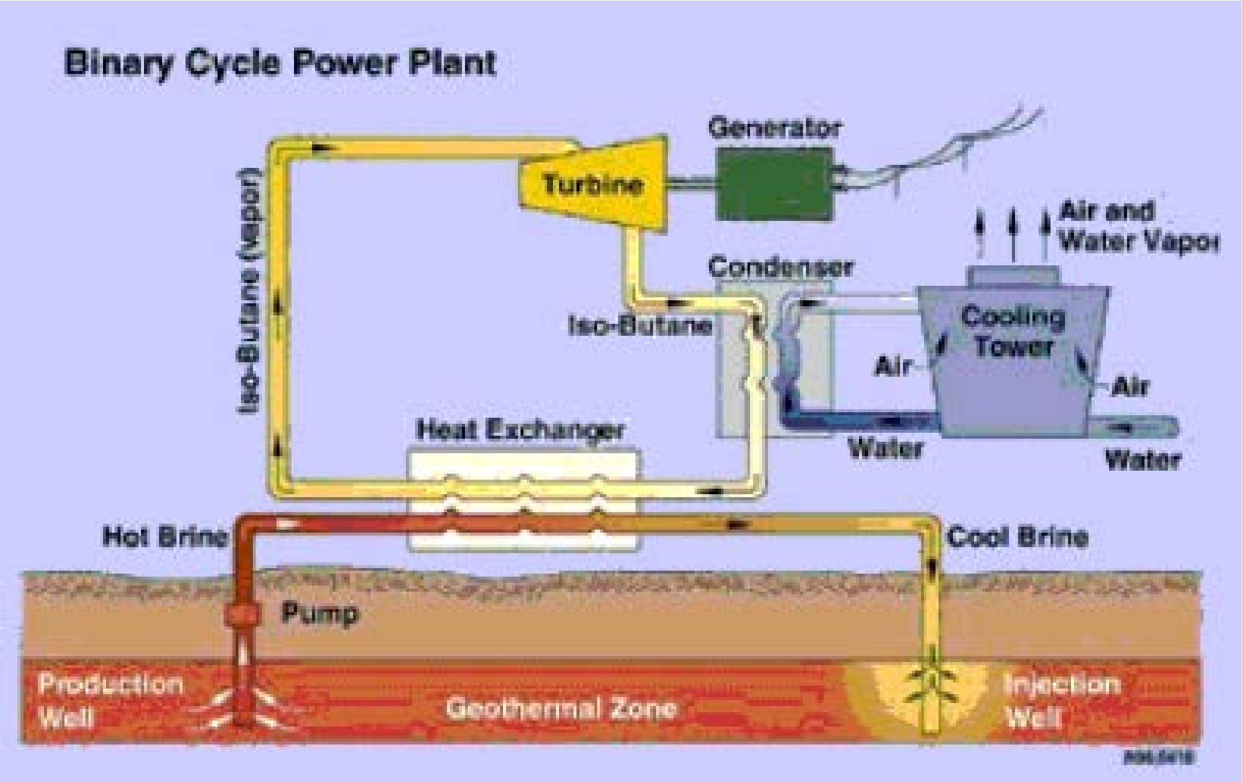




Binary Cycle Power Plants

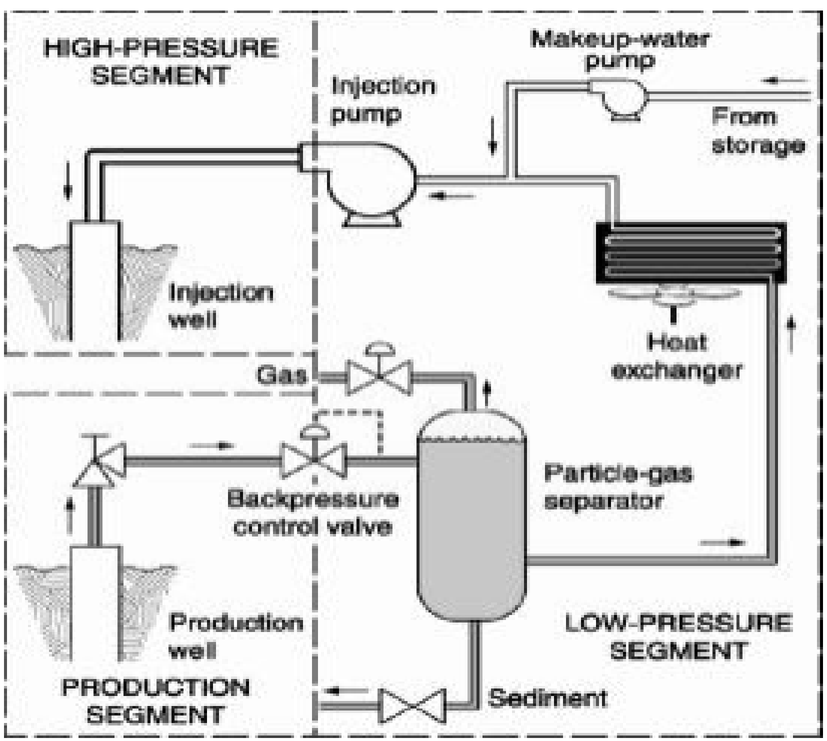
Commonly used for water ground reservoir at low temperatures (120-180 °C), the Binary cycle uses the geothermal fluid to evaporate a secondary fluid through an heat exchanger.

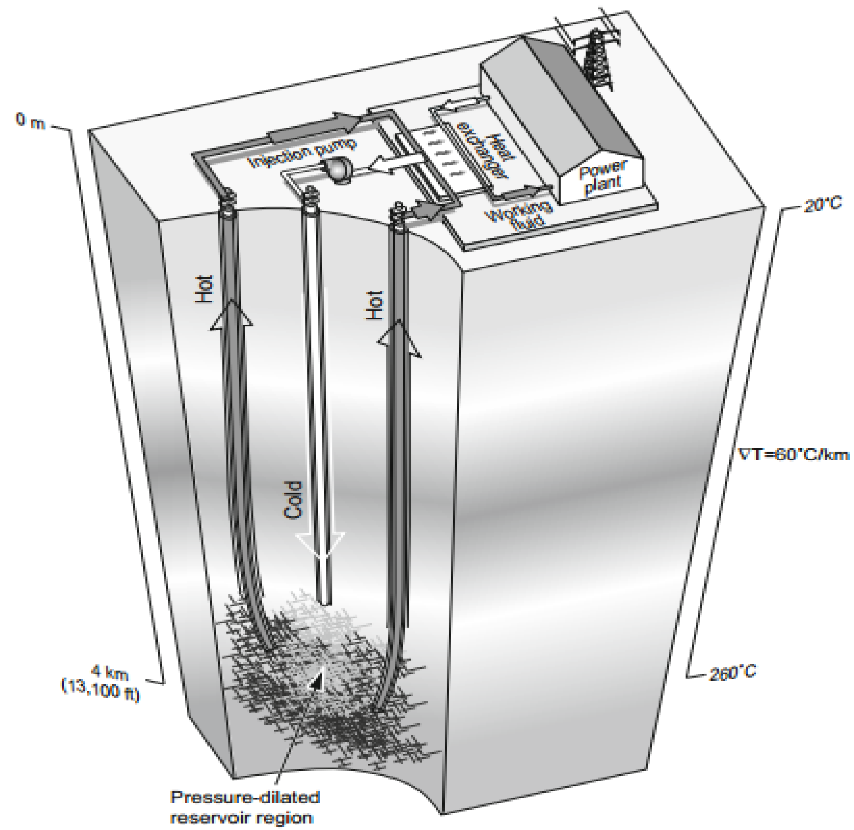
The secondary fluid performs the thermodynamic cycle (as, e.g. Organic Rankine Cycle), while the geothermal one is re-injected in the ground.



Hot dry rock systems (HDR)

The Hot Dry Rock (HDR) concept uses heat recovered from subsurface rocks to generate electricity. High pressure cold water is pumped down several kilometers (usually between 3 and 7 kilometers) into hot, porous rocks in order to extract heat. Then, hot steam returns to surface and it is used to generate power.





Thanks for your attention

Спасибо за внимание

Ing. Mattia De Rosa
mattia.derosa@unige.it
m.derosa@hotmail.it