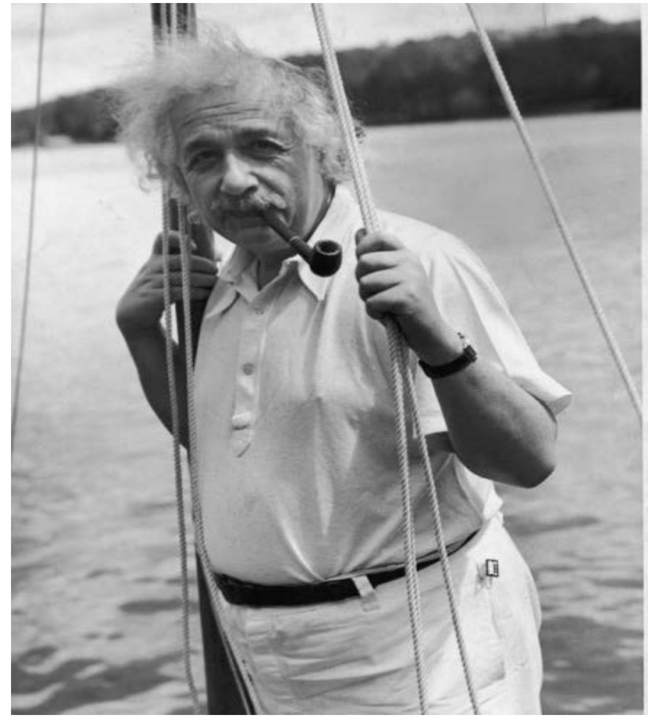
The Future of Nuclear in French and European Energy Policy and Strategy

Jean-Pierre Favennec
Tokyo May 24, 2017



Nuclear Energy

How powerful it is!

How many wind power installations to replace one Nuclear power plant?
Same thing in terms of surface for photovoltaic panels?

About 1,500 wind turbines of 1.5 MW each.
60 to 120 million m2, depending on the geographical location.

Uranium has a very high energy density compare to the other fuels.

under current techniques for producing energy:

One tone of Uranium = 10000 & 16000 tones of Oil

Unfortunately it was first introduced by military actions!

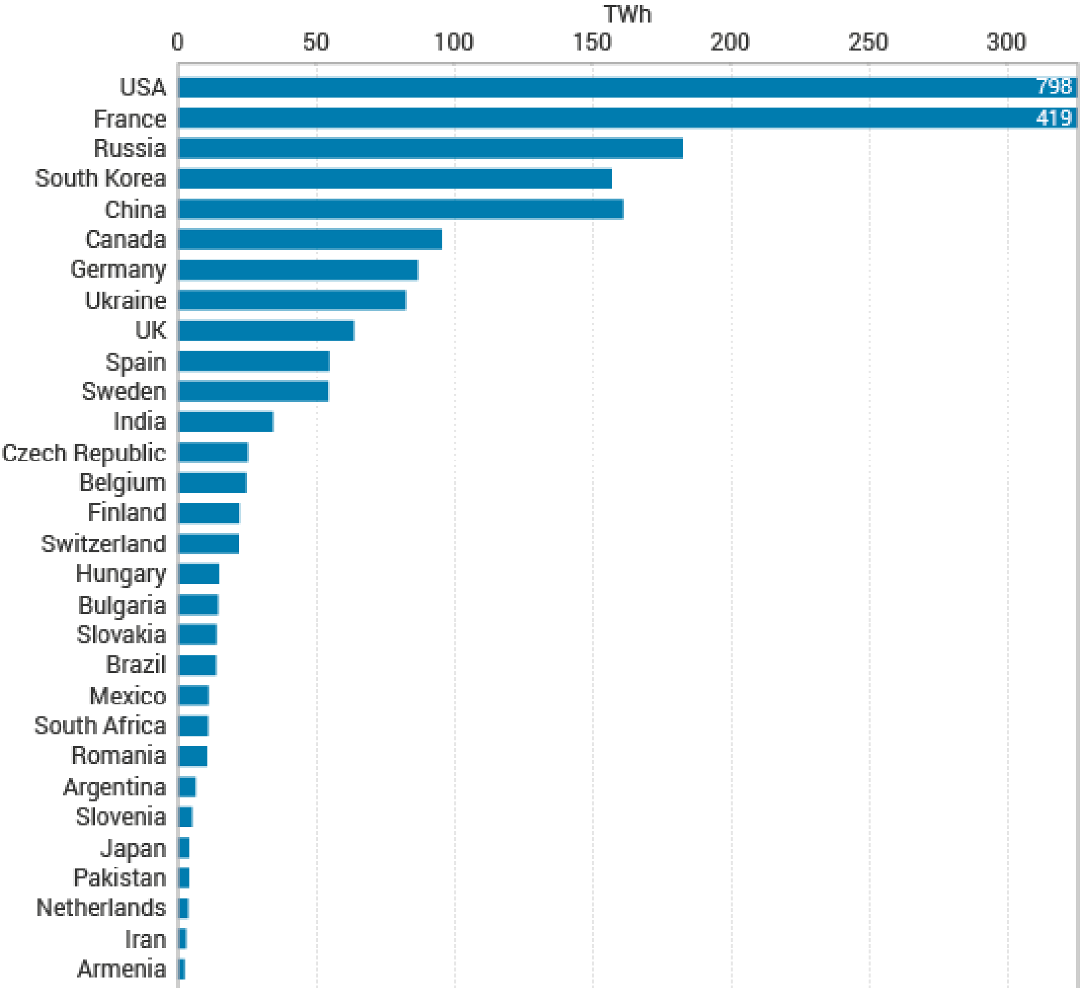
Little Boy & Fat MAN in 1945

Nuclear energy trend

- **An unfortunate birth (1945, Hiroshima)**
- **Very rapid development after the second war with commercial reactors in the early 1960s**
- **An almost halted in the 1980s after accidents TMI (1979) and Chernobyl (1986) but also for other reasons:**
  - Improved efficiency,
  - Reduced demand
  - Overcapacities
  - Collapse of fossil fuel prices
  - Liberalization of energy markets
  - High interest rates
- **A renewed motivation today (security of supply, fighting against greenhouse gases, still expensive renewable)**

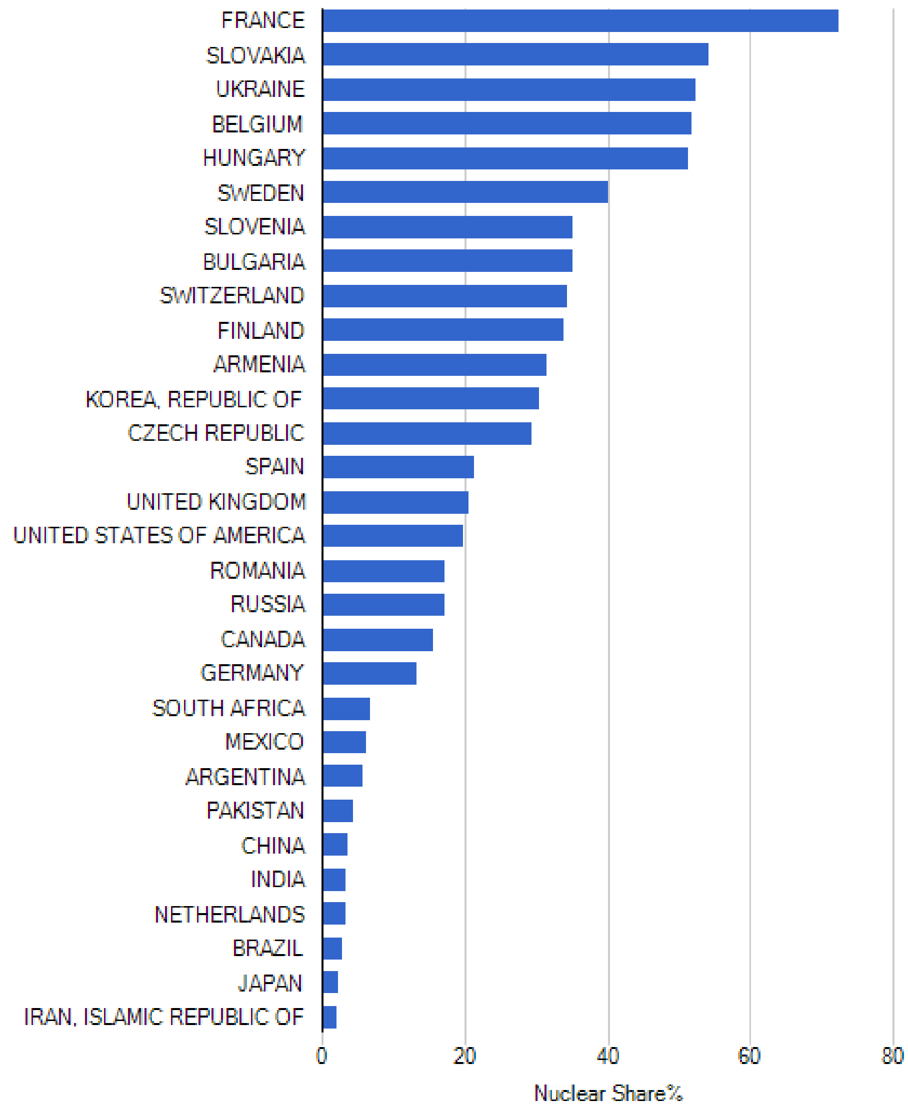
Nuclear by country (2015)

Generation by country



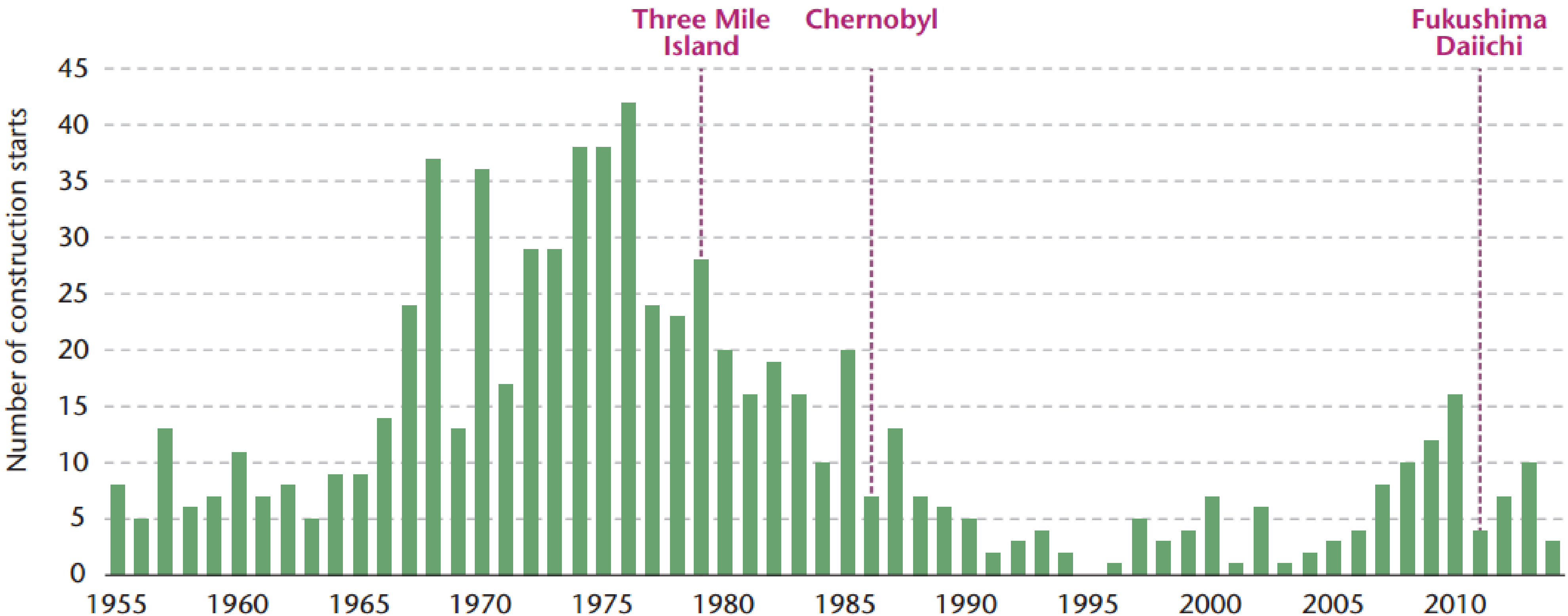
Source: IAEA PRIS Database

Share in the electricity mix



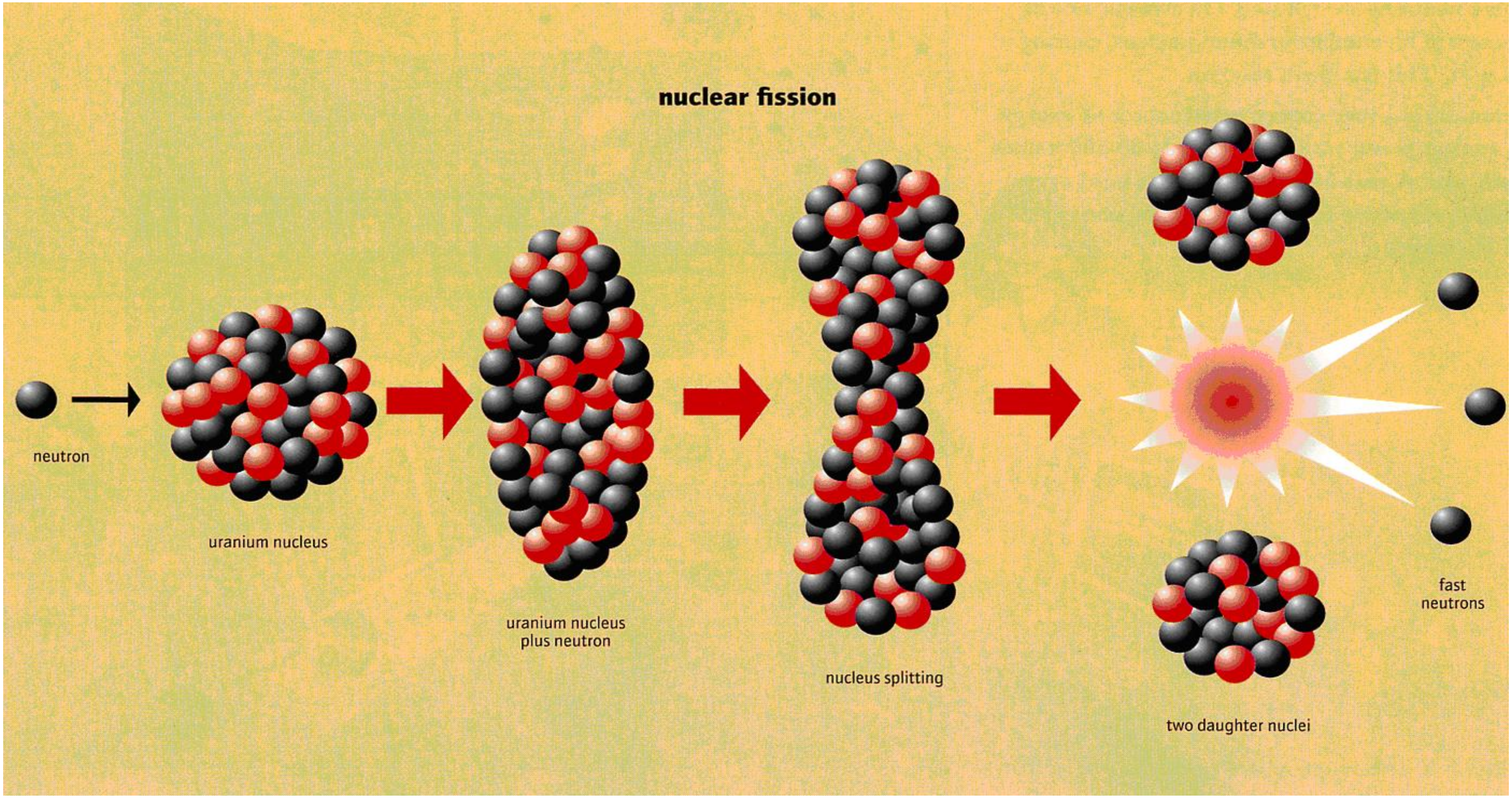
Nuclear power plants in the world (as of 2014)

Nuclear reactor construction starts (1955-2014)

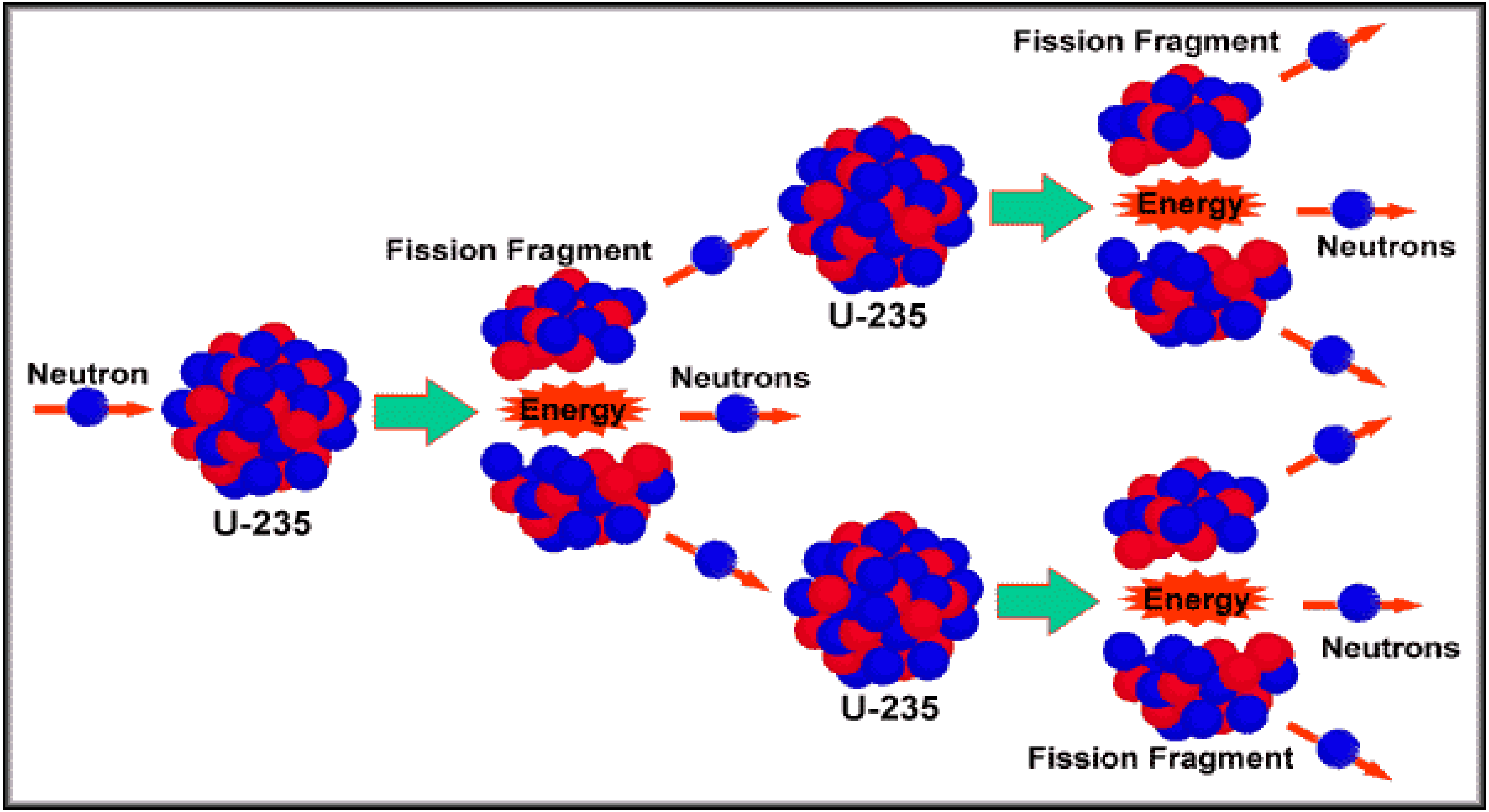


Source: IAEA Power Reactor Information System (PRIS).

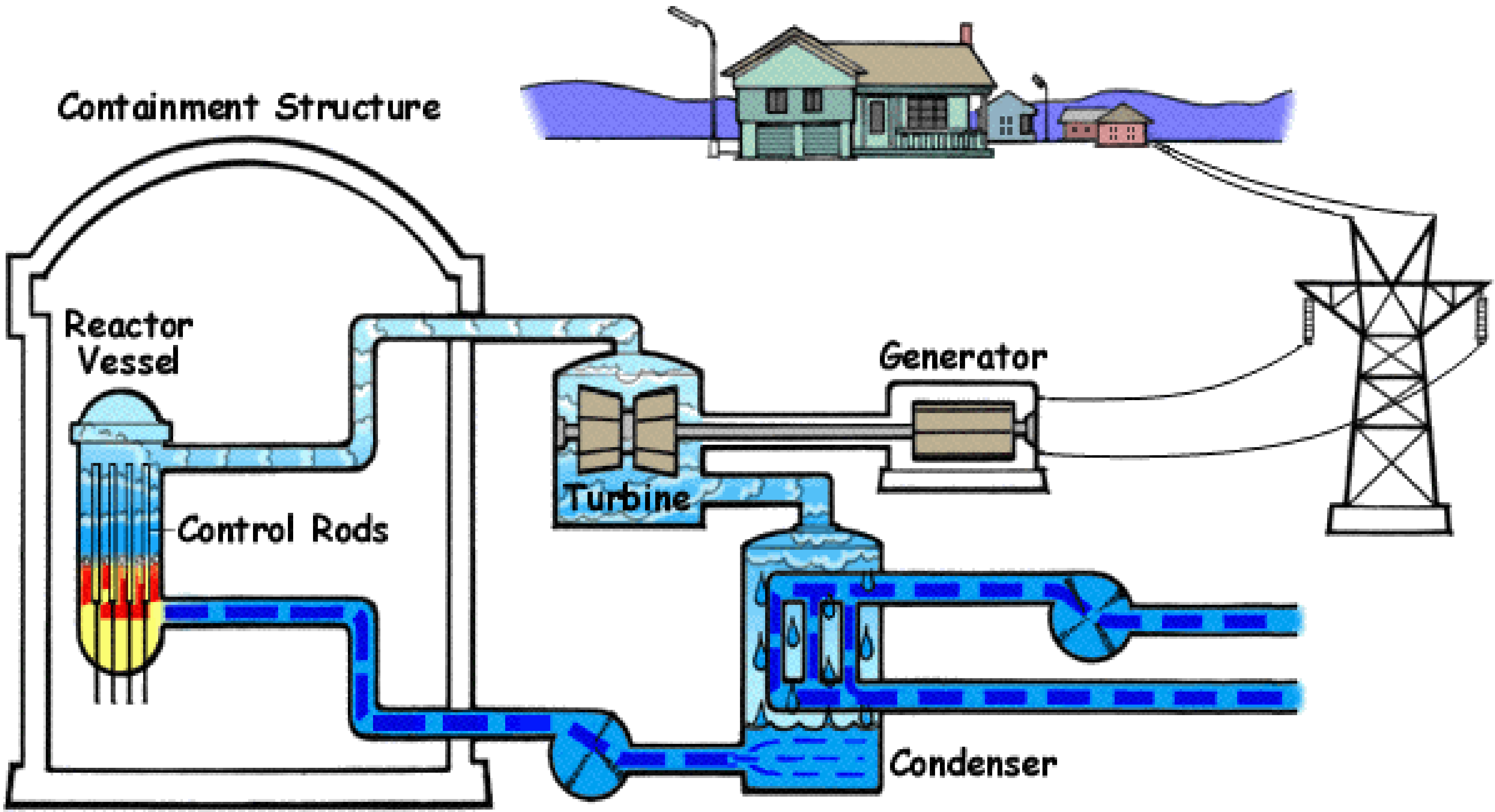
Fission


nuclear fission
neutron
uranium nucleus
uranium nucleus
plus neutron
nucleus splitting
two daughter nuclei
fast
neutrons

Chain reaction

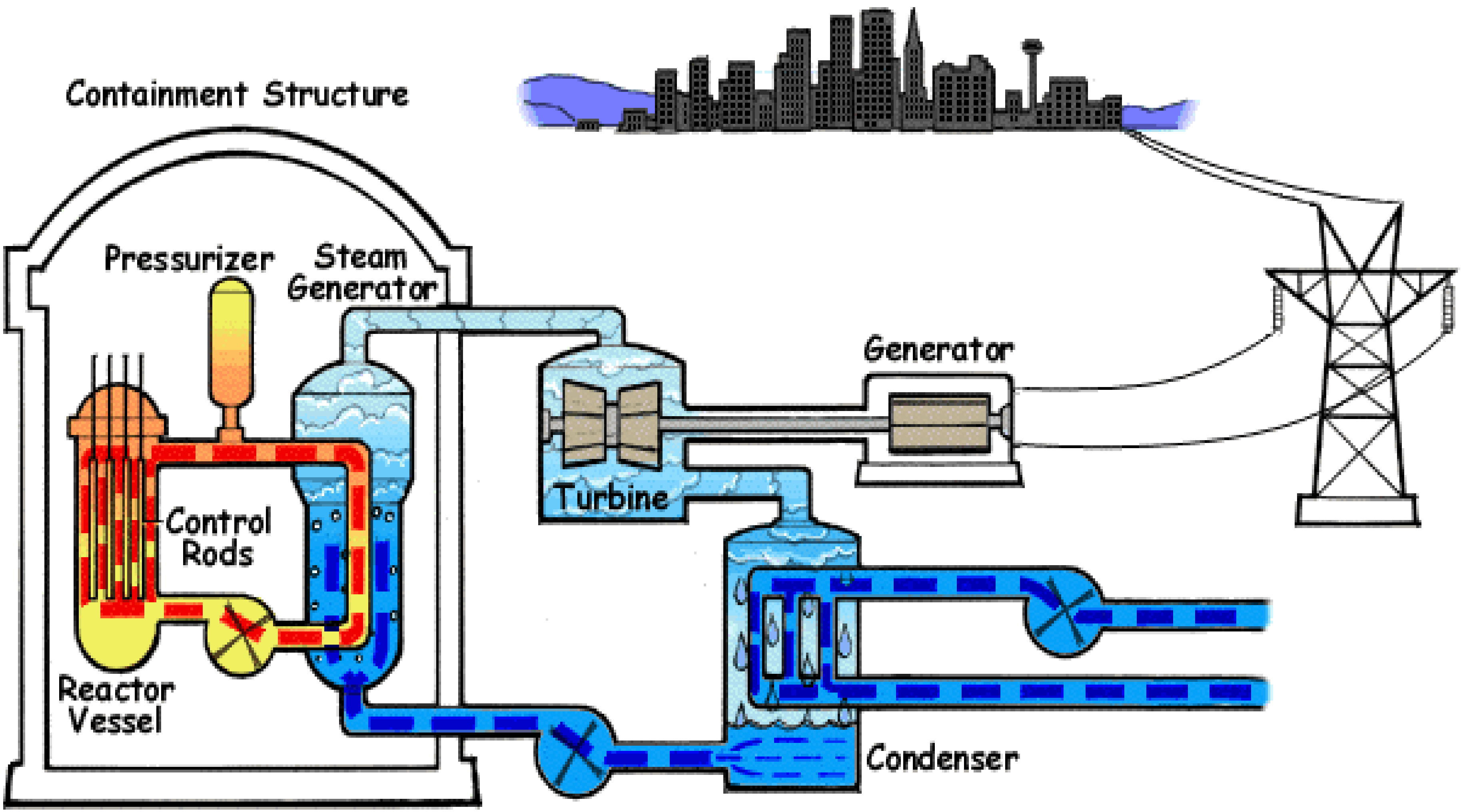


BWR reactor

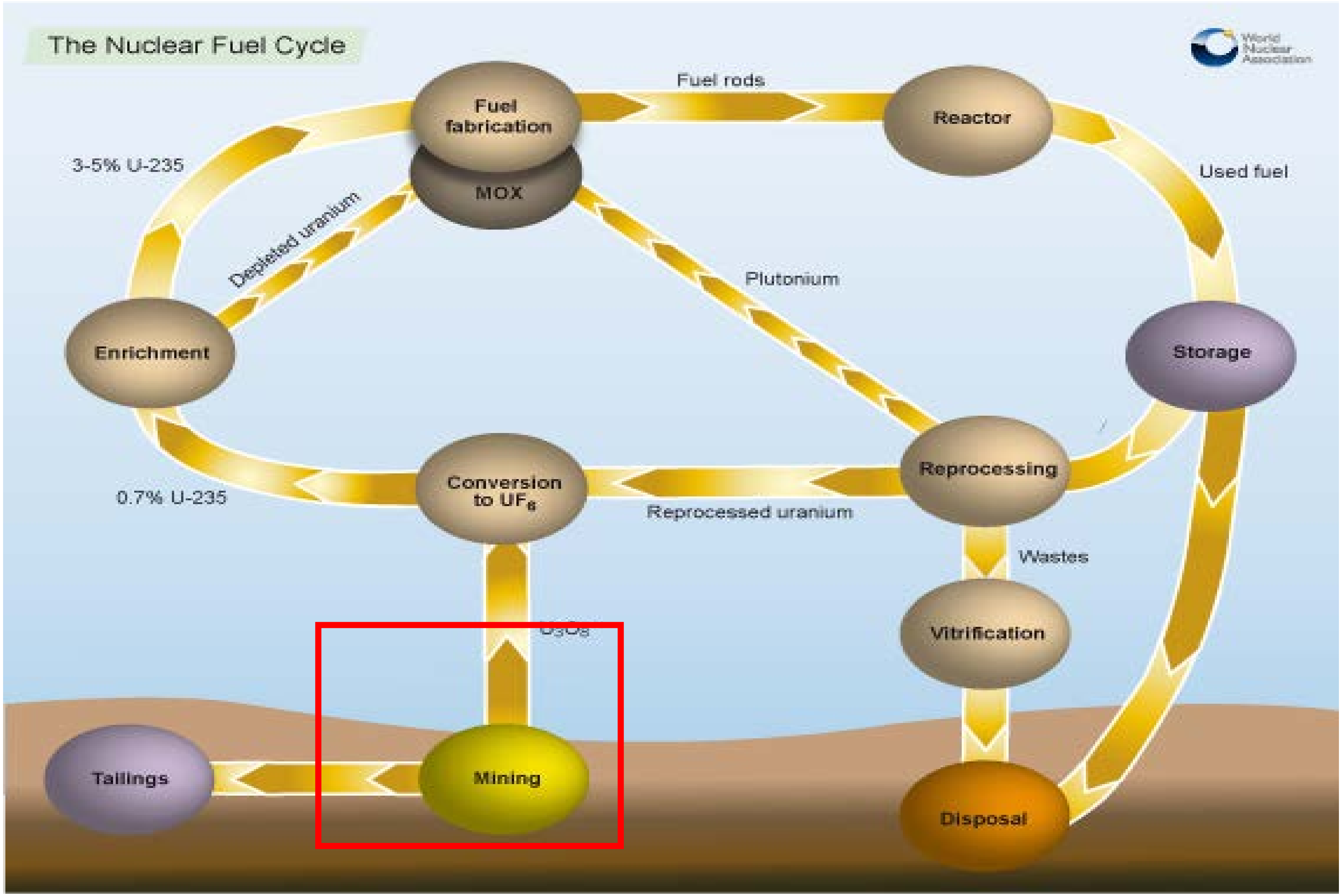


Containment Structure
Reactor Vessel
Control Rods
Generator
Turbine
Condenser

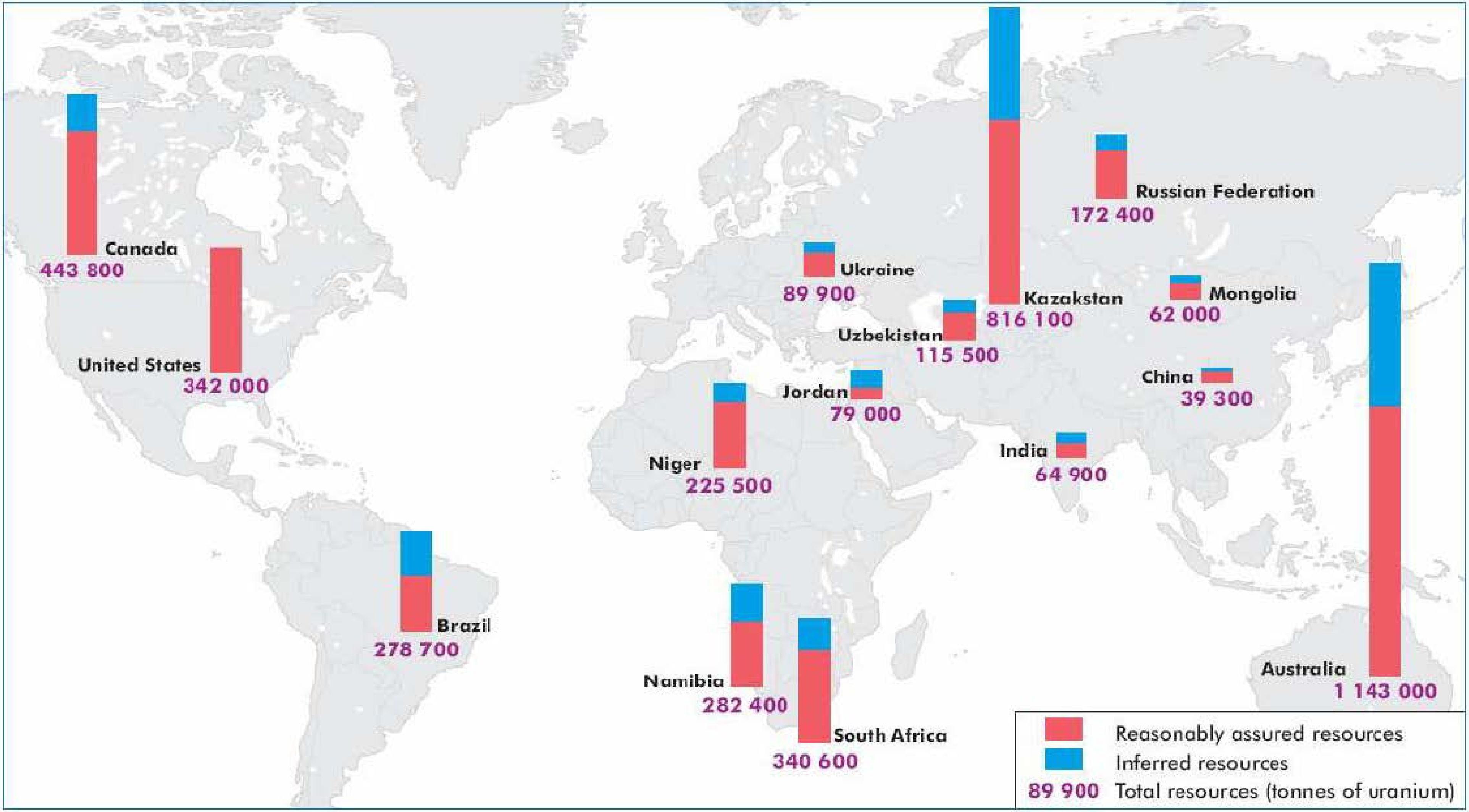
PWR reactor


Containment Structure
Pressurizer
Steam Generator
Generator
Control Rods
Turbine
Reactor Vessel
Condenser

Fuel cycle

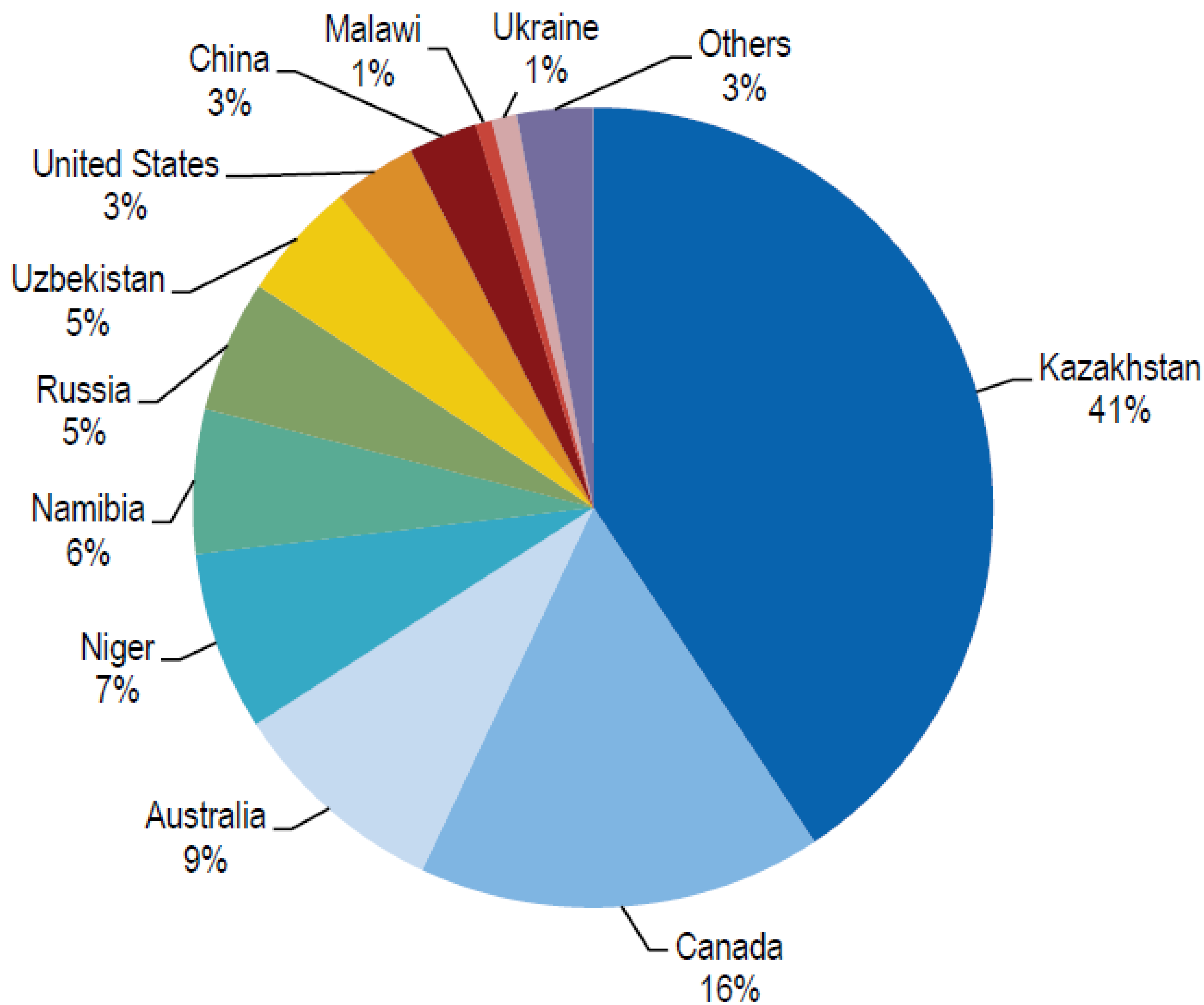

The Nuclear Fuel Cycle
World Nuclear Association
Fuel fabrication
MOX
Fuel rods
Reactor
Used fuel
3-5% U-235
Depleted uranium
Plutonium
Enrichment
Storage
Conversion to UF_6
Reprocessing
0.7% U-235
Reprocessed uranium
Wastes
U_3O_8
Vitrification
Tailings
Mining
Disposal

Uranium reserves (2015)



Source: IEA.

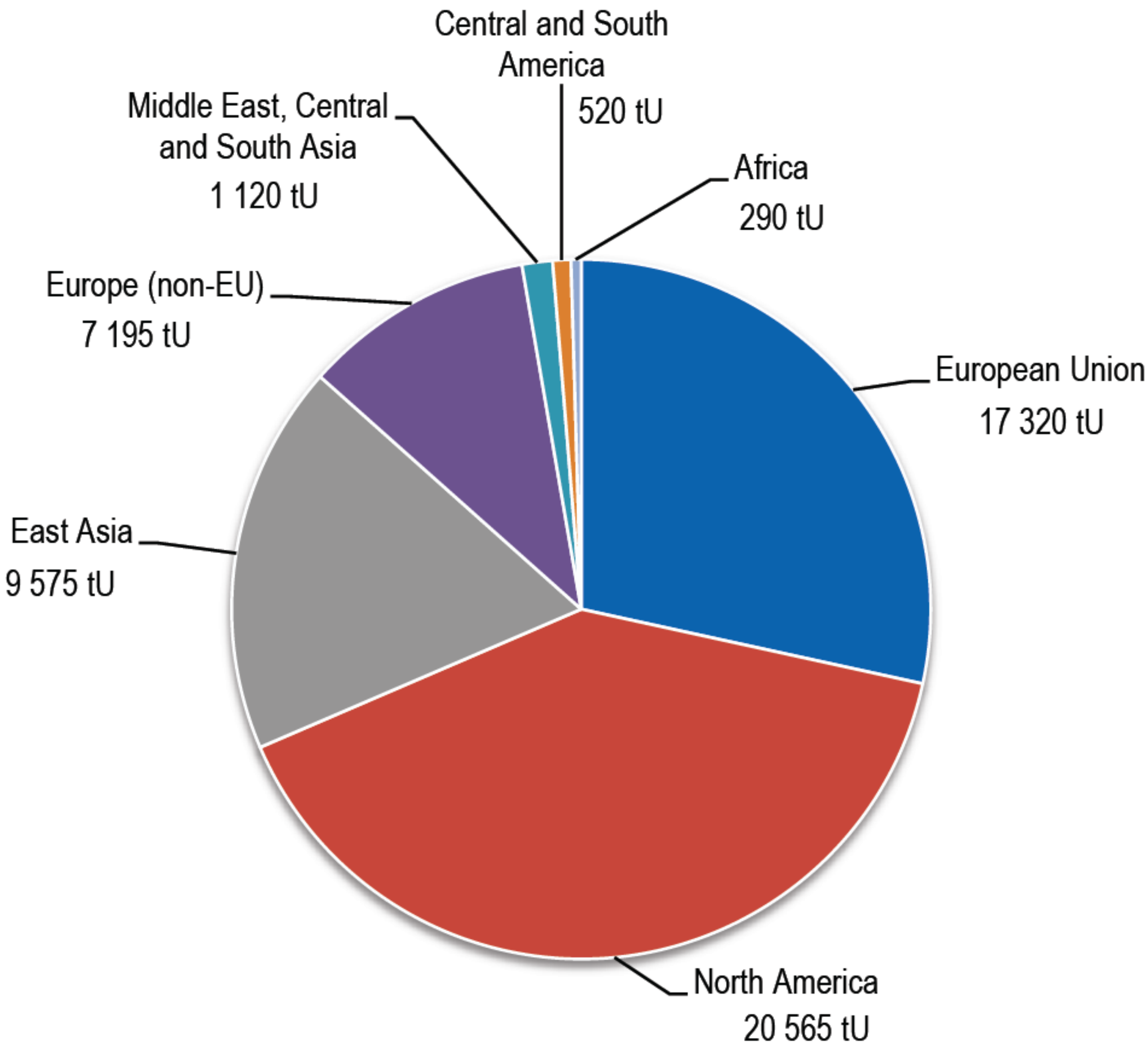
Uranium production (2015)



Total production = 56 000 tons

Source: Nuclear Energy Agency

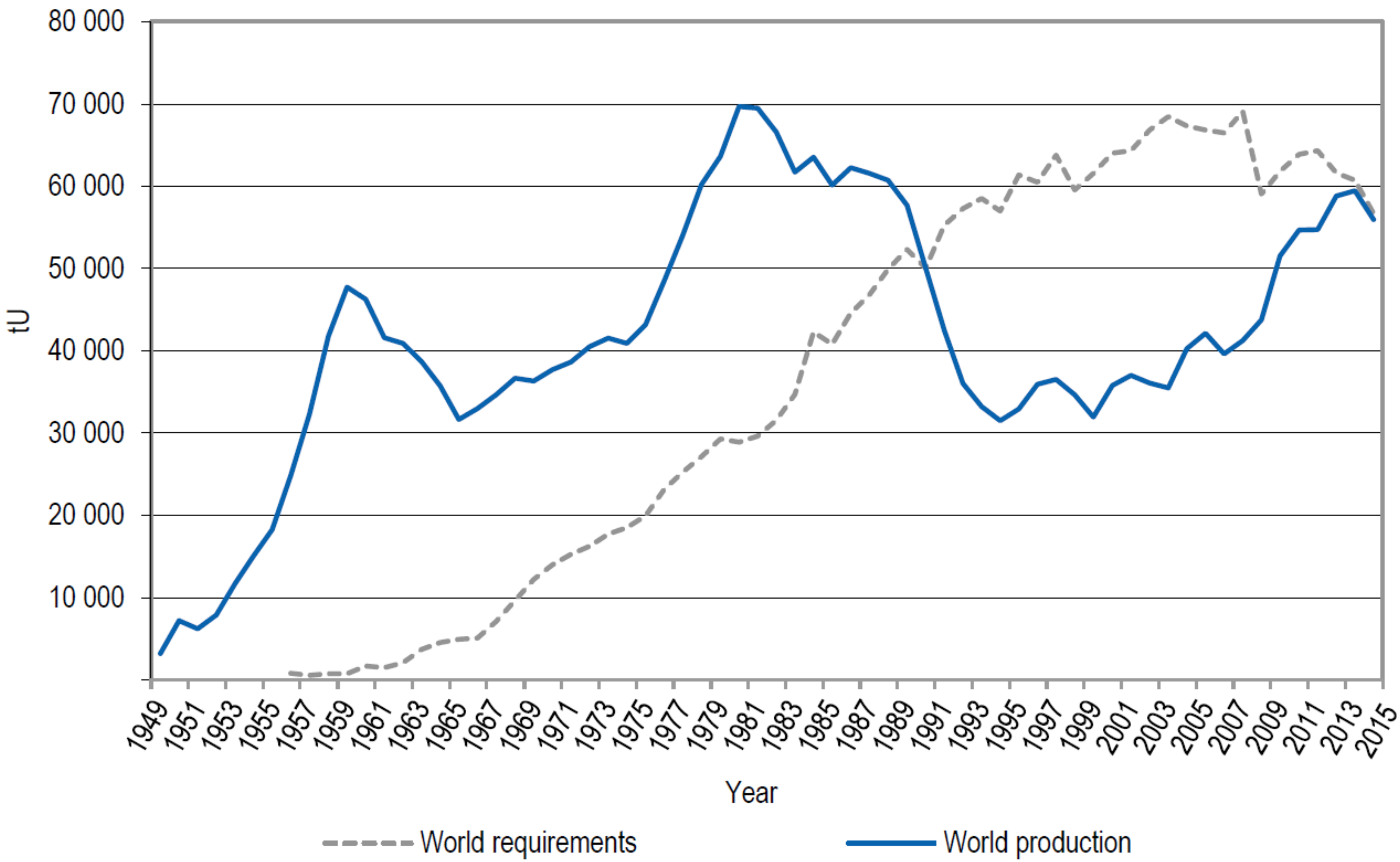
Uranium demand (2015)



Total demand = 56 600 tons

Source: Nuclear Energy Agency

Uranium production & requirements (1949-2015)



* Data as of 1 January 2015.

Source: Nuclear Energy Agency

Uranium conversion & enrichment

25% of the world enrichment

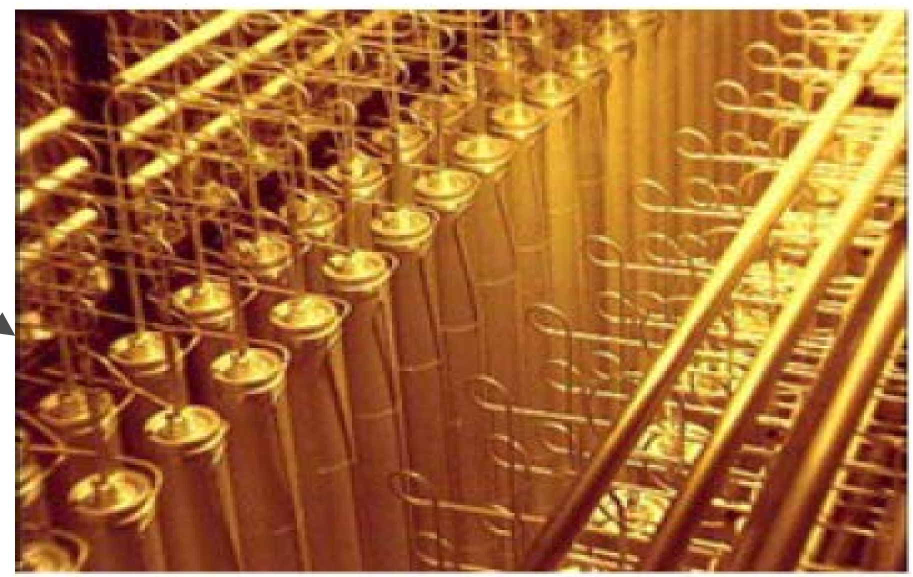
Gaseous diffusion enrichment

Conversion

Yellow cake to UF6 (gas state)

George Besse Plant
(Eurodif)

Centrifuge enrichment



URENCO Plant

Principle elements of a nuclear plant

- **Fuel** that undergoes fission.
- **Moderator** that slows down the speed of neutrons and maintain the chain reaction.
- **Coolant** which transmits the heat generated in the reactor and at the same time cooling of reactor.
- Fuel, moderator and coolant vary according to the reactors' types. It is the combination of these three elements which defines the **type of the nuclear power**.

Different types of reactor

	Fuel	Moderator	Coolant			Spent Fuel Reprocessing	Steam Cycle Efficiency	Main Economic and Safety Characteristics
			Heat extraction	Outlet temp.	Pressure			
Magnox	Natural uranium metal (0.7% U^{235}) Magnesium alloy cladding	Graphite	Carbon dioxide gas heated by fuel raises steam in steam generator	360°C	300 psia	Typically within one year, for operational reasons	31%	Safety benefit that coolant cannot undergo a change of phase. Also ability to refuel whilst running gives potential for high availability
AGR	Uranium dioxide enriched to 2.3% U^{235} Stainless steel cladding	Graphite	Carbon dioxide gas heated by fuel raises steam in steam generator	650°C	600 psia	Can be stored under water for tens of years, but storage could be longer in dry atmosphere	42%	Same operational and safety advantages as Magnox but with higher operating temperatures and pressures., leading to reduced capital costs and higher steam cycle efficiencies
PWR	Uranium dioxide enriched to 3.2% U^{235} Zirconium alloy cladding	Light Water	Pressurised light water pumped to steam generator which raises steam in a separate circuit	317°C	2235 psia	Can be stored for long periods under water giving flexibility in waste management	32%	Low construction costs resulting from design being amenable to fabrication in factory-built sub-assemblies. Wealth of operating experience now accumulated world wide. Off load refuelling necessary
BWR	Uranium dioxide enriched to 2.4% U^{235} Zirconium alloy cladding	Light Water	Pressurised light water boiling in the pressure vessel produces steam which directly drives a turbine	286°C	1050 psia	As for PWR	32%	Similar construction cost advantages to PWR enhanced by design not requiring a heat exchanger, but offset by need for some shielding of steam circuit and turbine. Off load refuelling necessary
CANDU	Unenriched uranium dioxide (0.7% U^{235}) Zirconium alloy cladding	Heavy water	Heavy water pumped at pressure over the fuel raises steam via a steam generator in a separate circuit.	305°C	1285 psia	As for PWR	30%	Good operational record but requires infrastructure to provide significant quantities of heavy water at reasonable costs.
RBMK	Uranium dioxide enriched to 1.8% U^{235}	Graphite	Light water boiled at pressure, steam used to drive a turbine directly	284°C	1000 psia	Information not available	31%	Information not available but operated in considerable numbers in the former USSR. Believed in the West to be inherently less safe

Nuclear power plants in commercial operation

Reactor type	Main Countries	Number	GWe	Fuel	Coolant	Moderator
Pressurised Water Reactor (PWR)	US, France, Japan, Russia, China	265	251.6	enriched UO_2	water	water
Boiling Water Reactor (BWR)	US, Japan, Sweden	94	86.4	enriched UO_2	water	water
Pressurised Heavy Water Reactor 'CANDU' (PHWR)	Canada	44	24.3	natural UO_2	heavy water	heavy water
Gas-cooled Reactor (AGR & Magnox)	UK	18	10.8	natural U (metal), enriched UO_2	CO_2	graphite
Light Water Graphite Reactor (RBMK)	Russia	12	12.3	enriched UO_2	water	graphite
Fast Neutron Reactor (FBR)	Japan, France, Russia	4	1.0	PuO_2 and UO_2	liquid sodium	none
Other	Russia	4	0.05	enriched UO_2	water	graphite
	TOTAL	441	386.5			

French nuclear power plants

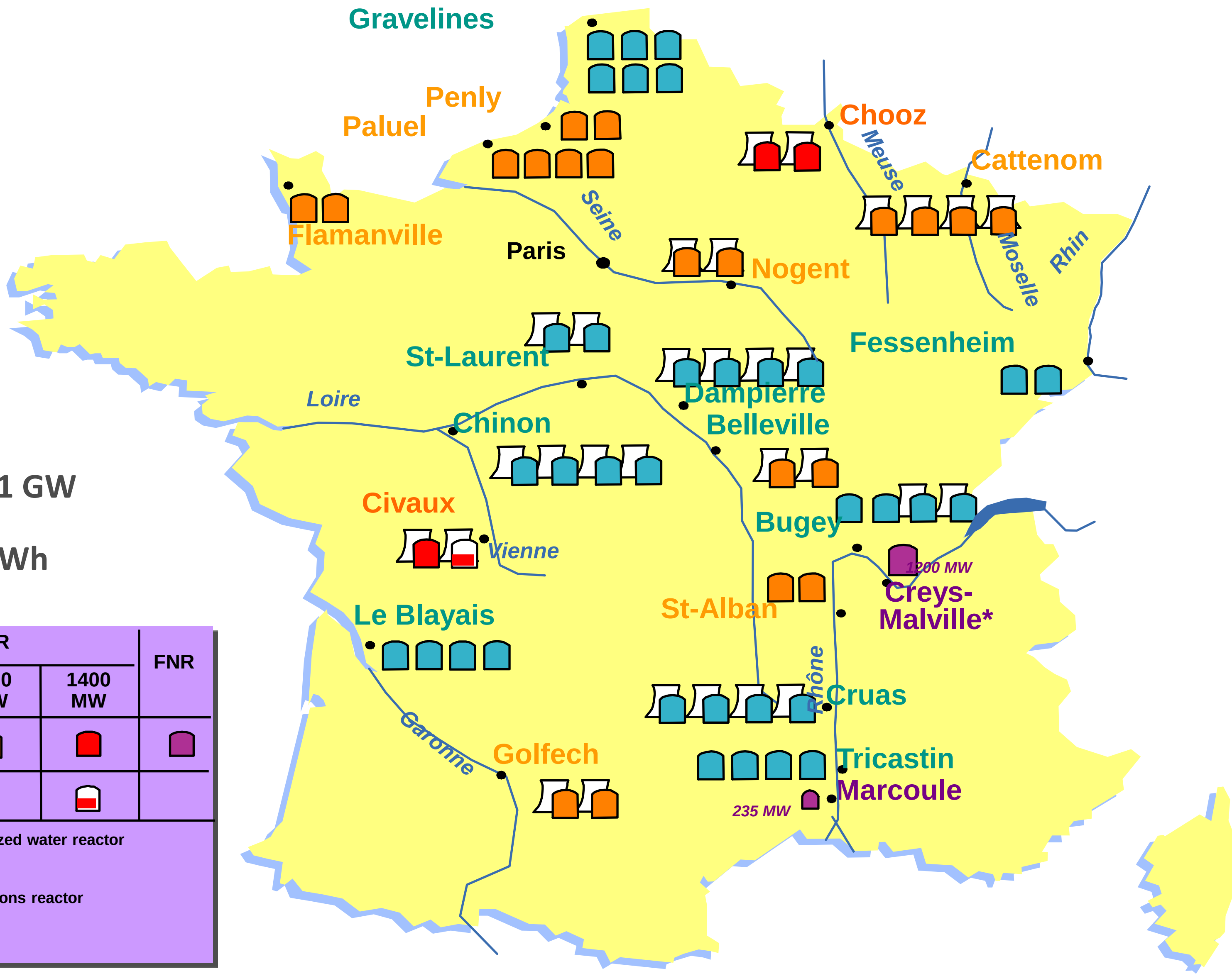
- Type : PWR
- Westinghouse Licence :
  - 34 of 900 MW
  - 20 of 1300 MW
- Framatome License :
  - 4 of 1450 MW
- Total installed power : 63.1 GW
- Production in 2016 : 427 TWh

PLANTS	PWR			FNR
	900 MW	1300 MW	1400 MW	
On operation				
Under construction				

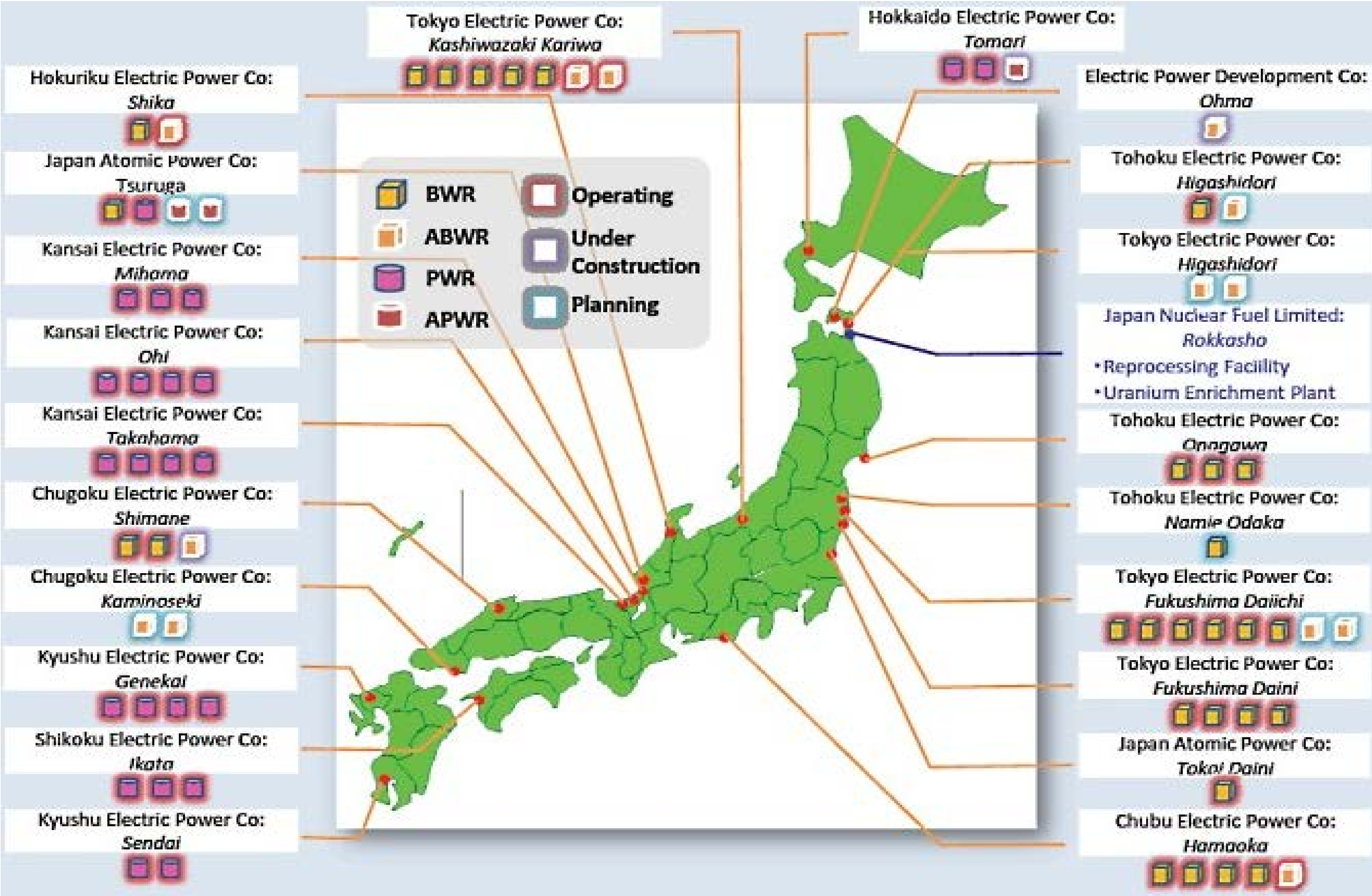
Cooling process
Open cycle
Closed cycle

RWP : Pressurized water reactor

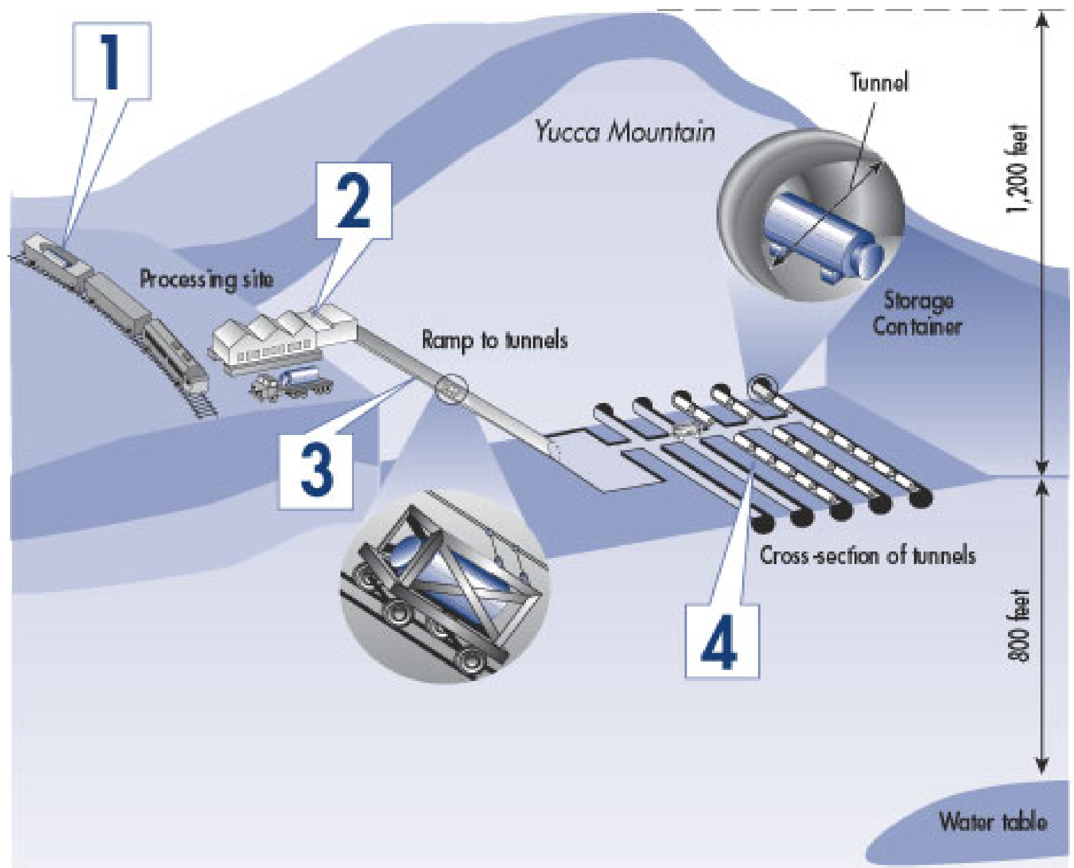
FNR : Fast neutrons reactor



Japan's reactors



The Yucca mountain disposal plant in Nevada



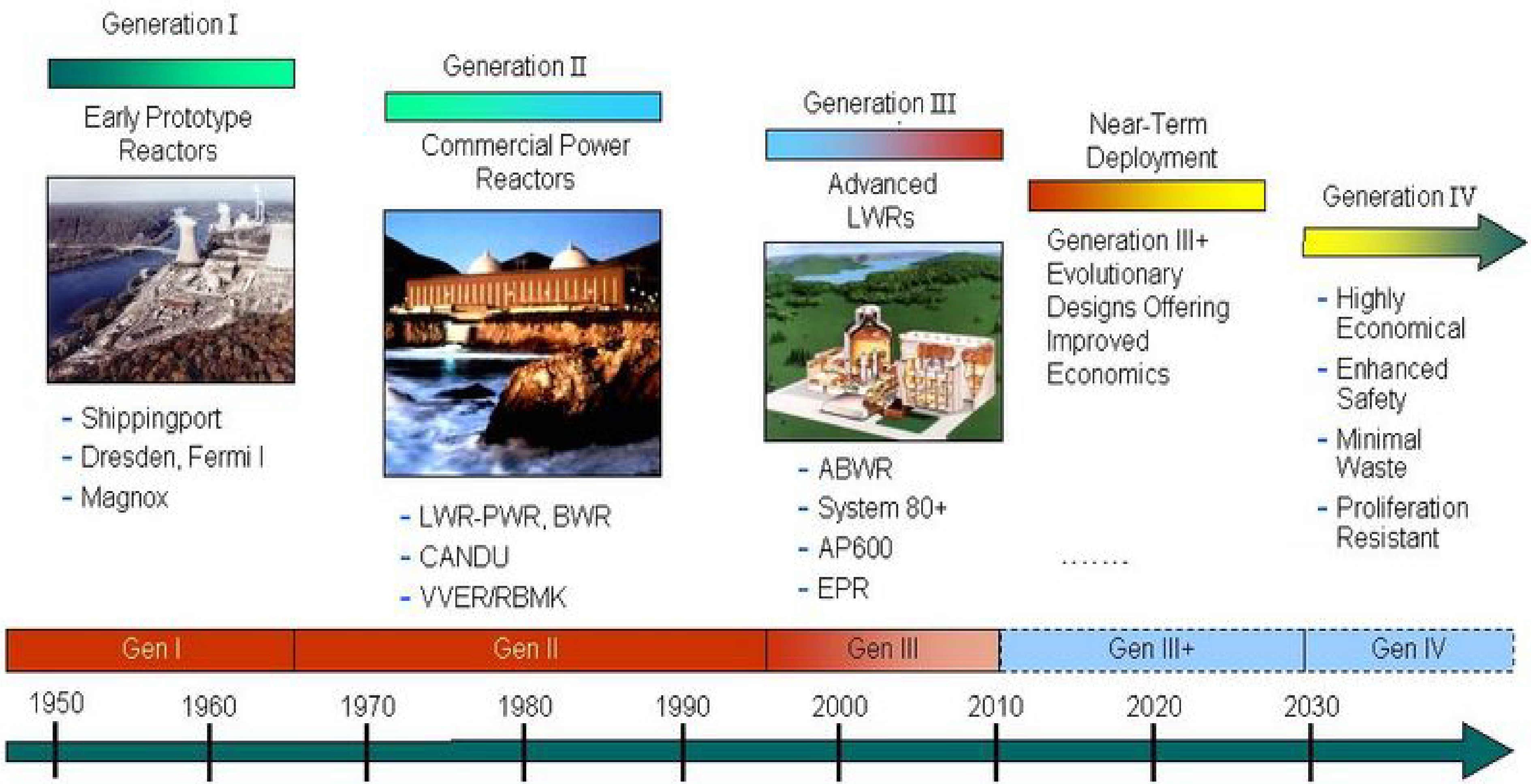
1 Shipping to the site by trucks or trains

2 Preparation for storage (removing shipping casks and putting inner tubes in a steel container)

3 An automated system for sending containers to the tunnels

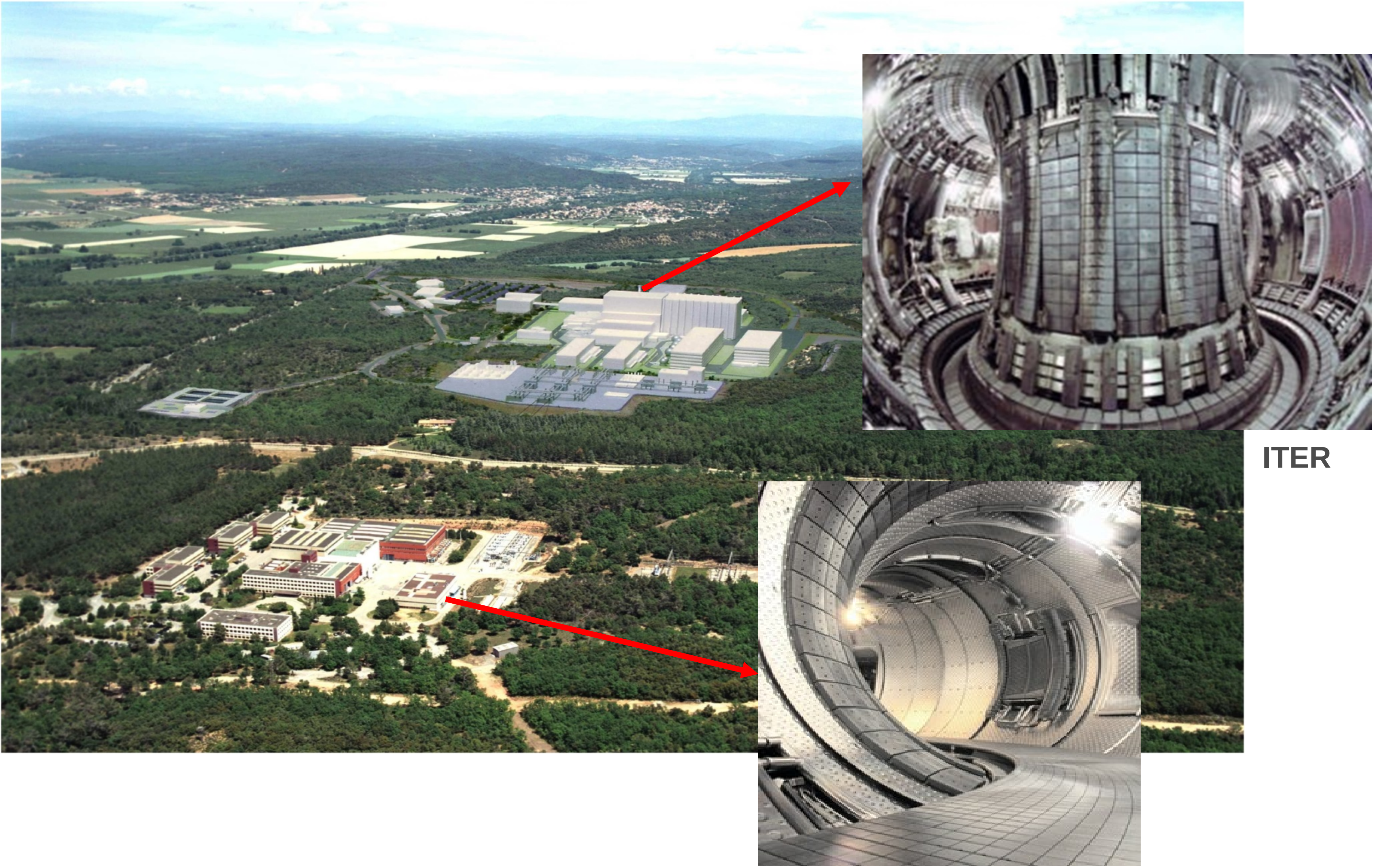
4 Storing containers along the tunnels

Different reactor's generations



Fast neutron reactors

CEA site in CADARACHE

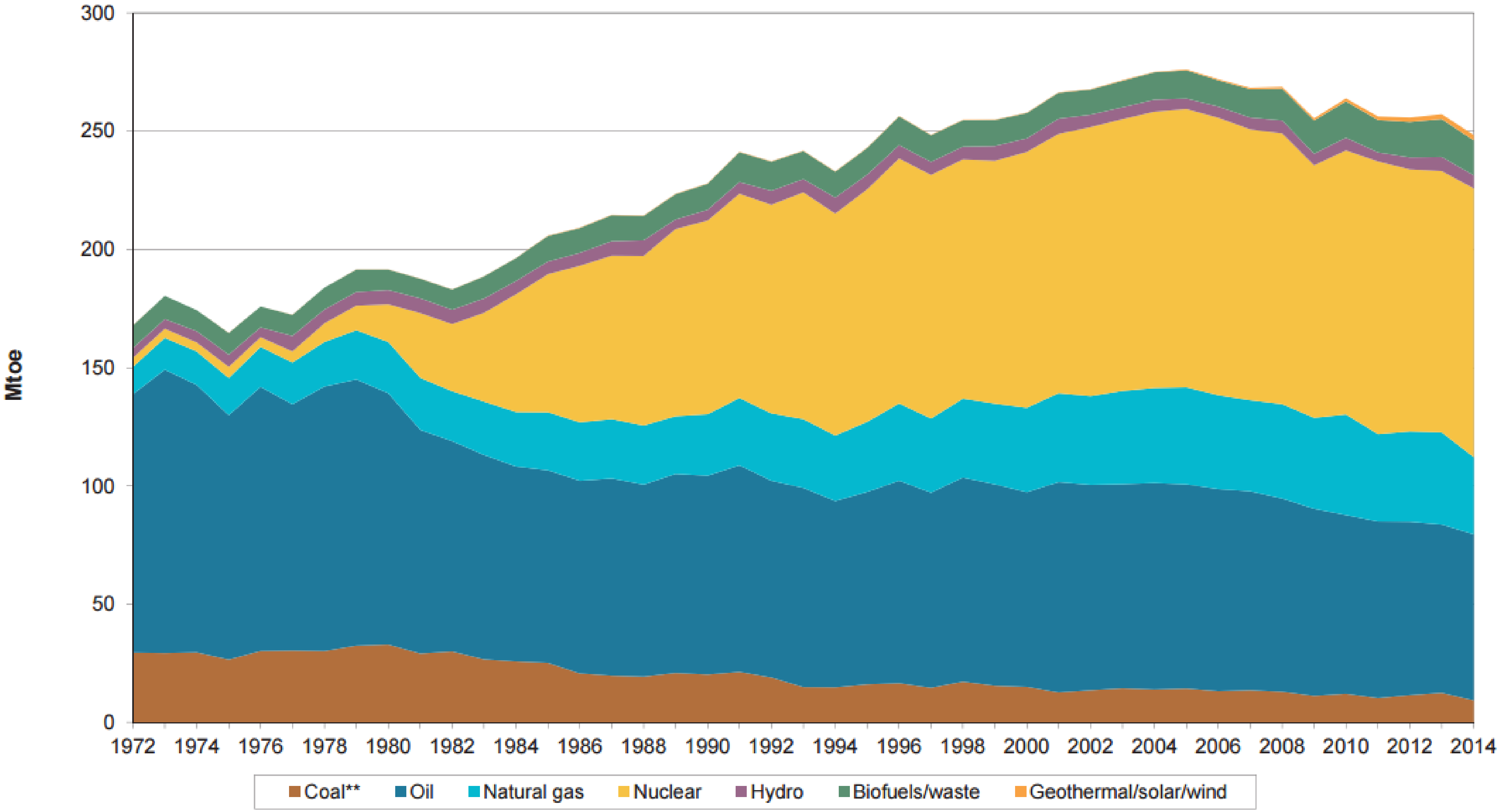


ITER

TORE SUPRA

Energy in France

Total primary energy supply in France (1972-2014)

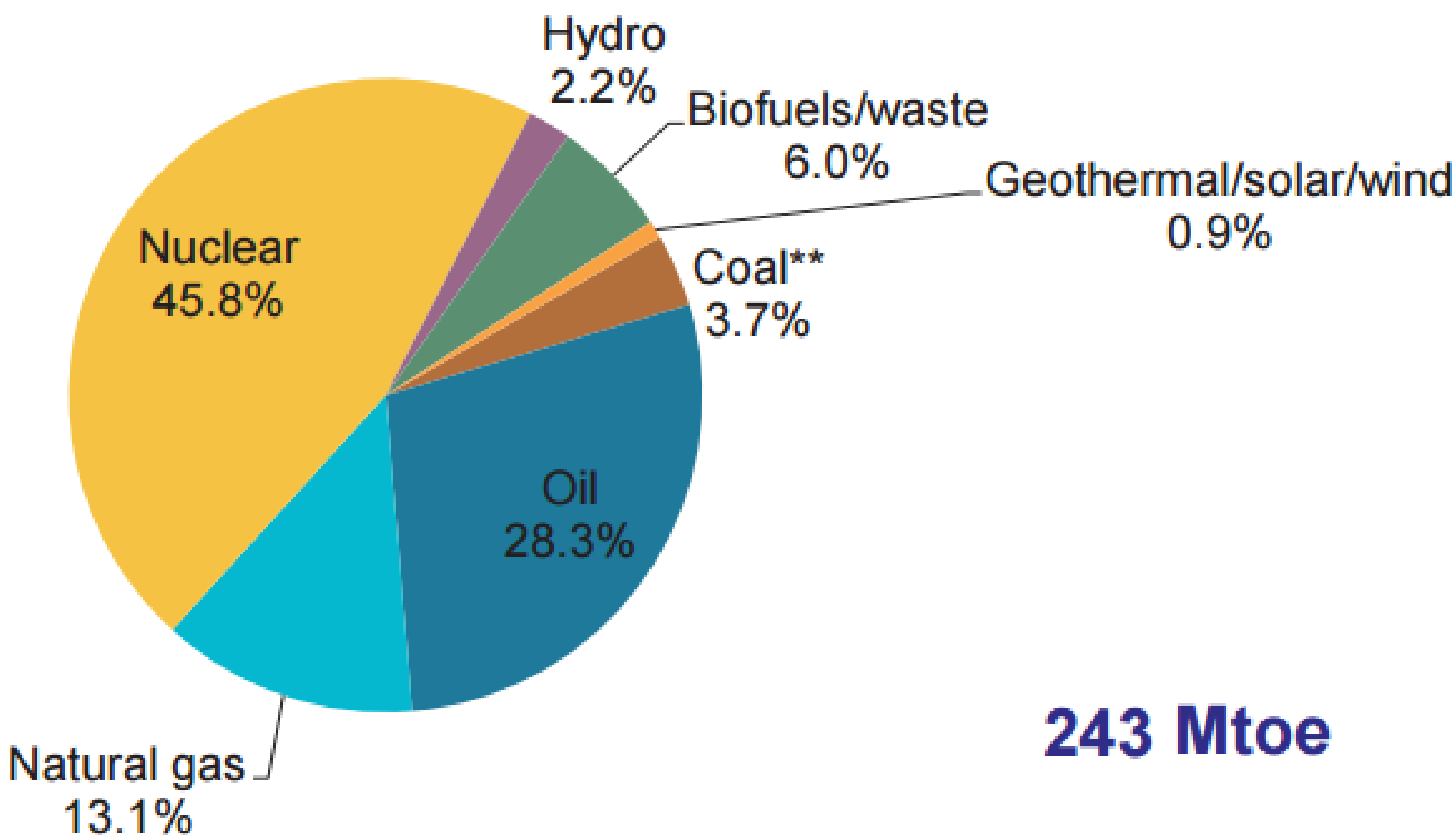


* Excluding electricity trade.

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

Source: IEA.

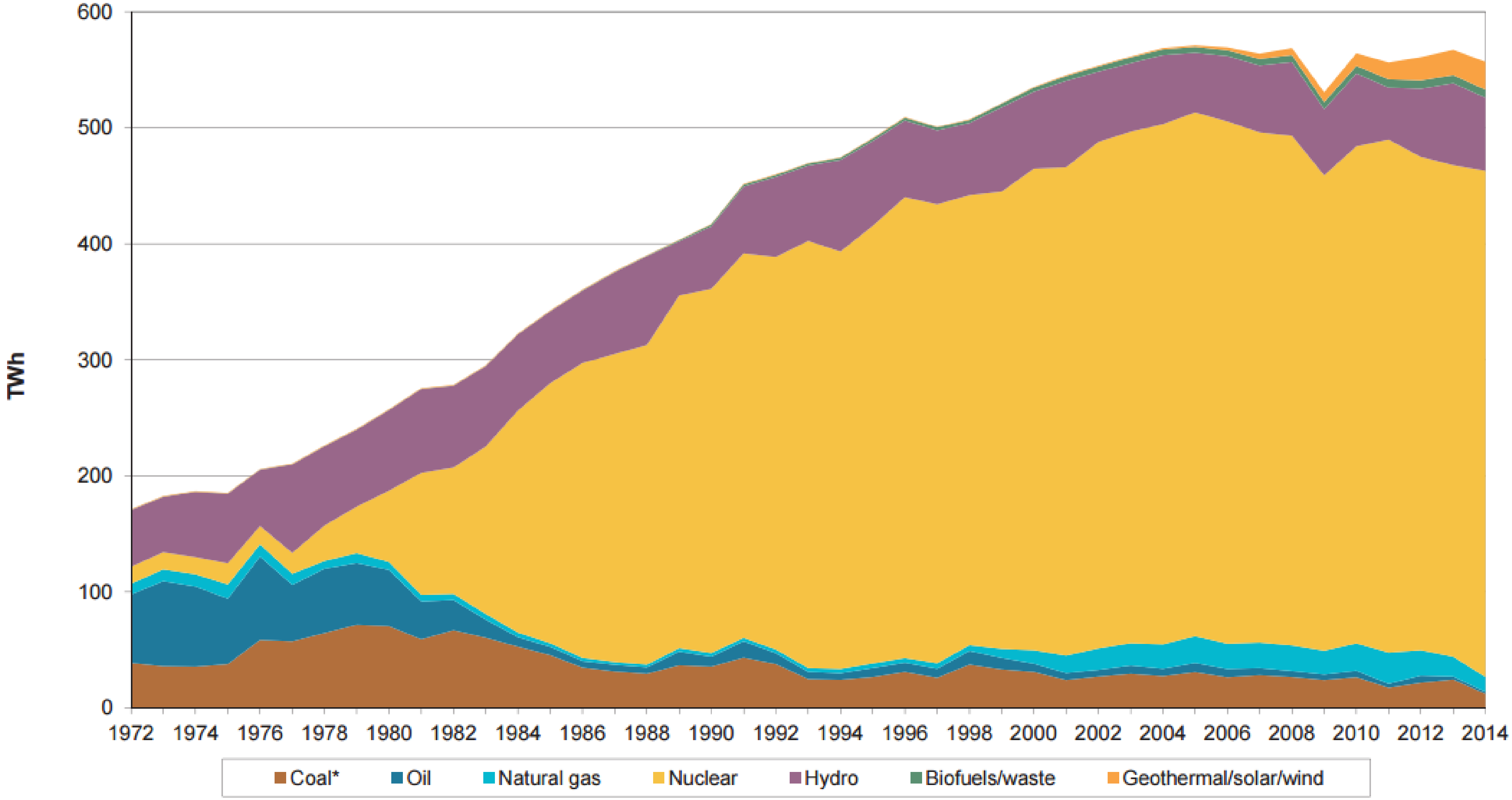
Share of total primary energy supply in France (2014)



243 Mtoe

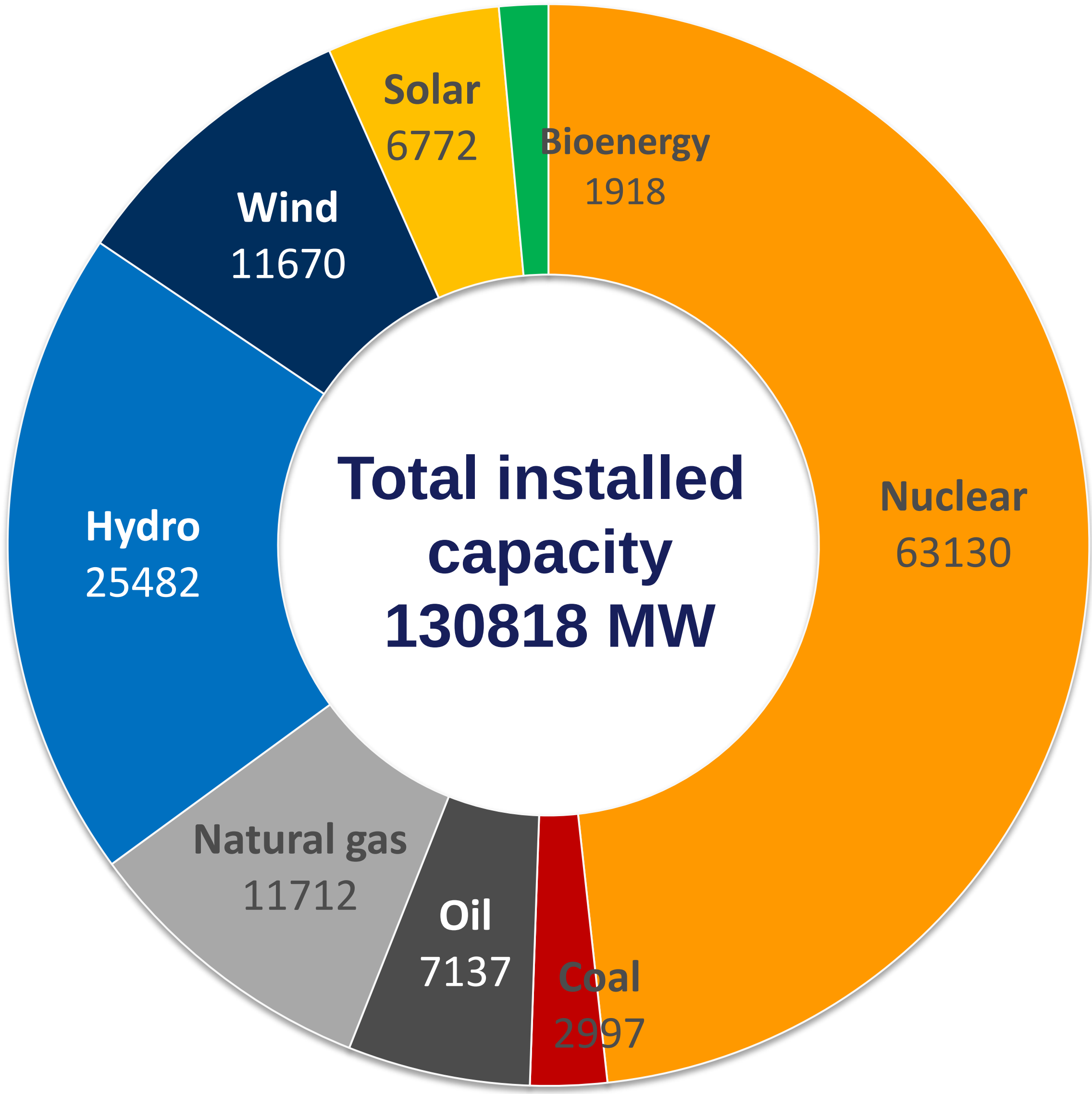
Source: IEA.

Electricity generation by fuel in France (1972-2014)



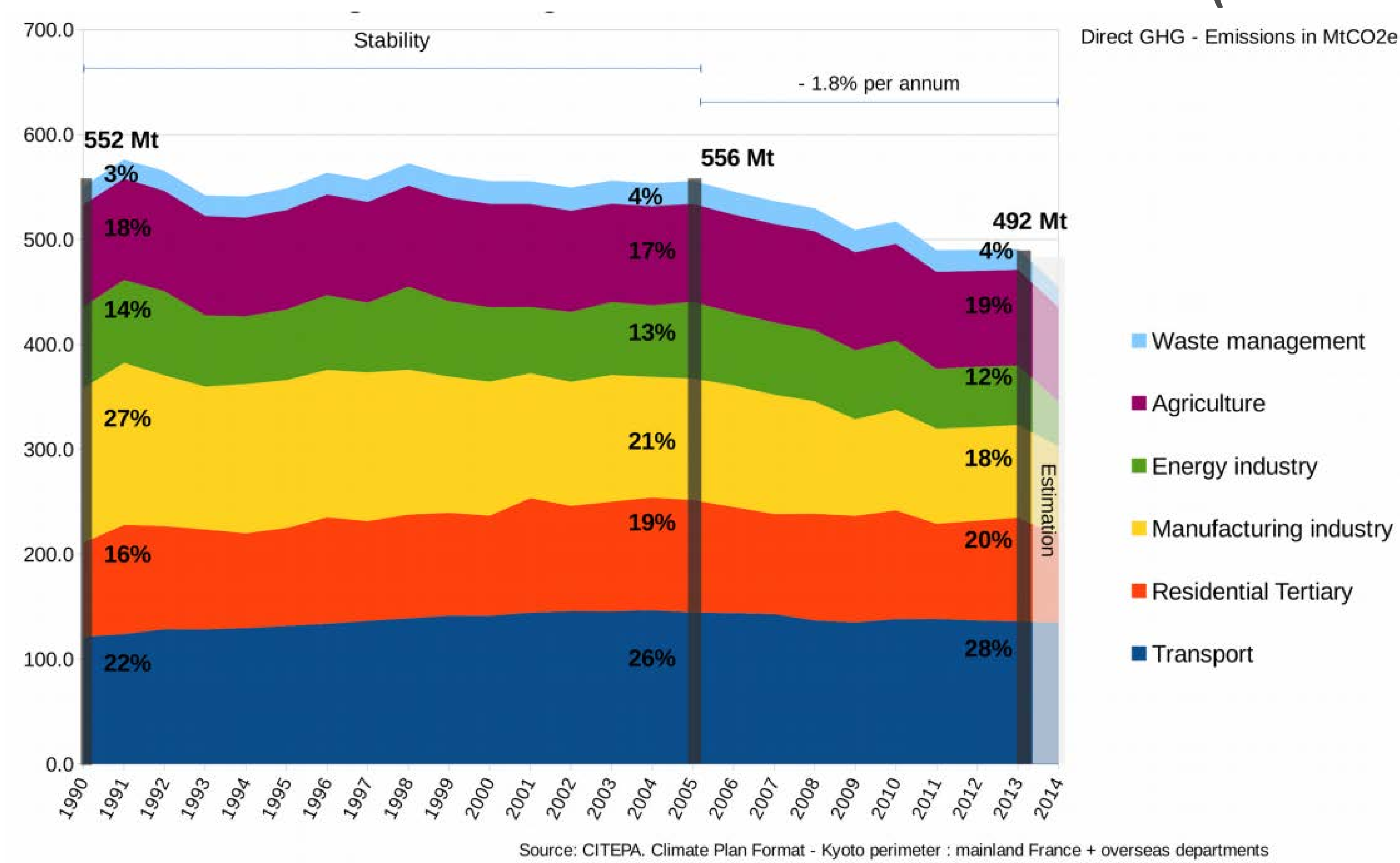
Source: IEA.

Installed power capacity in France (end 2016)



Source: RTE, Bilan électrique 2016.

France greenhouse gas emissions (1990-2013)



Source: French Ministry of Energy

France GHG objectives & trajectory towards 2050

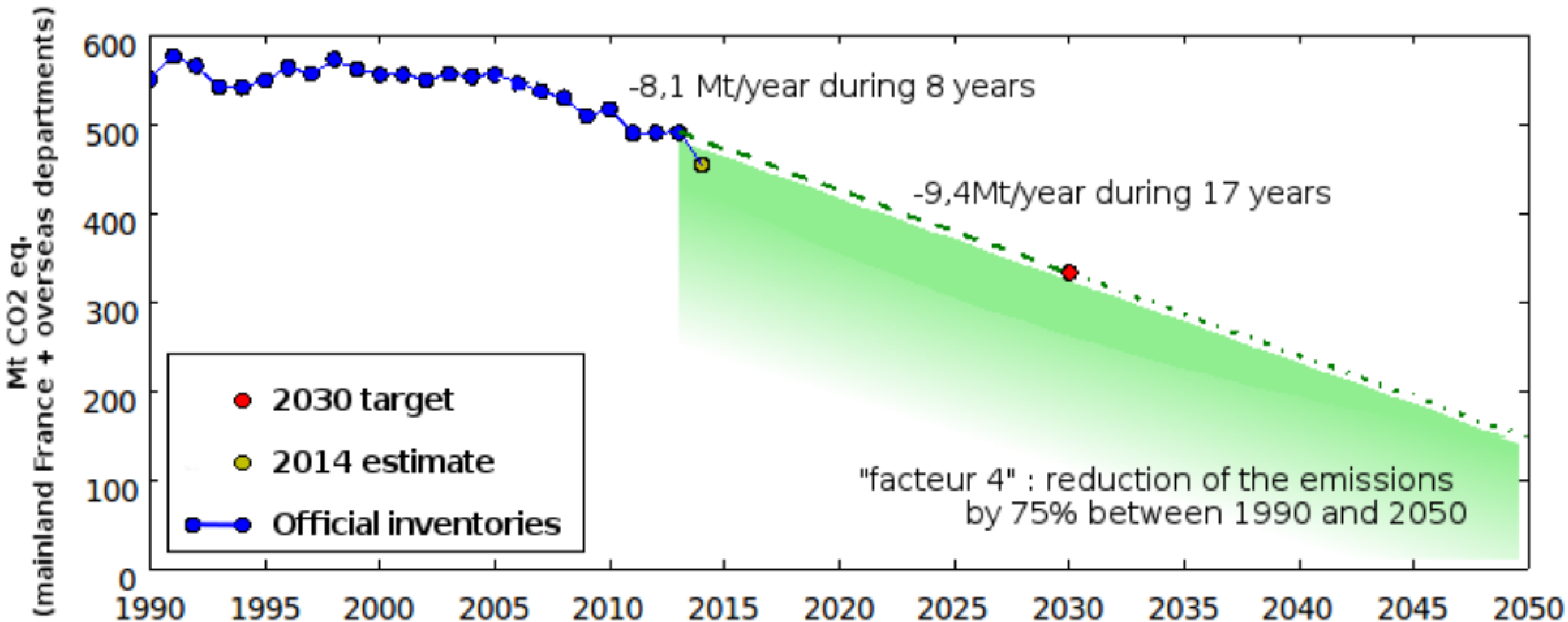


Figure 2.1 : inventories of greenhouse gases emissions (1990-2013), preliminary estimate of 2014 emissions in mainland France and the overseas departments and France emissions reduction targets for the 2030 and 2050 time horizons. Source : CITEPA and MEDDE/DGEC

Source: French Ministry of Energy

France's "Energy Transition Law"

The objectives:

Reduce greenhouse gas emissions by **40%** in 2030 compared with 1990

Reduce the use of fossil fuels by **30%** in 2030 compared with 2012

Increase the share of renewable energy sources to **32%** of total energy consumption by 2030 and to **40%** of electricity generation

Reduce total energy consumption by **50% in 2050** compared with 2012

Reduce the amount of landfill waste by **50%** by 2025

Diversify electricity generation and reduce the share of nuclear to **50%** by 2025

Source: RTE, Bilan électrique 2016.

Nuclear energy in France

- **Creation of Commissariat à l'Energie Atomique after the war both for military and civil purposes**

- **First reactors : Graphite Gas in the 60'S**

- **1973 : first oil shock**
  - A large fraction of electricity is coming from heavy fuel oil (15 MT per year)
  - 5 relatively small nuclear plants
  - March 1974 : meeting of the council of ministers – decision to speed up the nuclear programme

- **59 reactors built between 1976 and 1990 (4 to 5 reactors per year)**

- PWR plants (Westinghouse technology adapted to french technology)
- Capacity : from 900 MW at the beginning to 1400 MW at the end

Nuclear energy in France : public perception

- By 1975, some opposition from part of the scientific community. Argument : nuclear energy consumes more electricity than it produces (first construction period)
- Later limited opposition
- Up to recently political parties from the left (communist party, some socialists) and from the right (« Gaullist and followers ») support the nuclear programme
- During the last campaign, the new President (Emmanuel Macron) supports nuclear. But the lftt wing (remaining of the socialist party, new left wing party) are against nuclear
- However more than 50 % of the population supports nuclear, even if this percentage is slightly declining

Nuclear energy in France : public perception

- So only a limited fraction of the population is strongly against nuclear
- The percentage of people against nuclear is still lower if you explain that thanks to nuclear the electricity price is low

Nuclear energy in France : energy transition law

- For years, as in many countries, environmental protection has become a major issue (Rio Summit – 1992; Jacques Chirac, french president, in 2002 in South Africa :our house is burning and we do not look at it.)

- In 2007 « Grenelle de l’ environnement » - large conference on environmental issues. Good decisions but unfortunately, few endorsed because of the 2008 crisis (subprimes)

- More recently : only 50 % of electricity should come from nuclear by 2025 (against 75 %) now

- Keep in mind that electricity consumtion is slightly declining now

- The total capacity of nuclear plants will be limited to 63 GW

Nuclear energy in France : life duration of the reactors

- As in many countries, life expectency of a reactor is expected to be 40 years when it is built
- However, in the US for example, the operation of most reactors has been extended to 60 years
- Since most reactors have been built between 1975 and 1990, without extension we should start closing reators now
- Life duration will very probably extended to 50 years, probably to 60
- This will make necessary (according to Agence de Sécurité Nuvléaire – Agency for Nuclear Security) un « grand carénage » - large maintenance programme.
- Cost of this programme : about 50 billions Euros

Nuclear energy in France : decommissionning

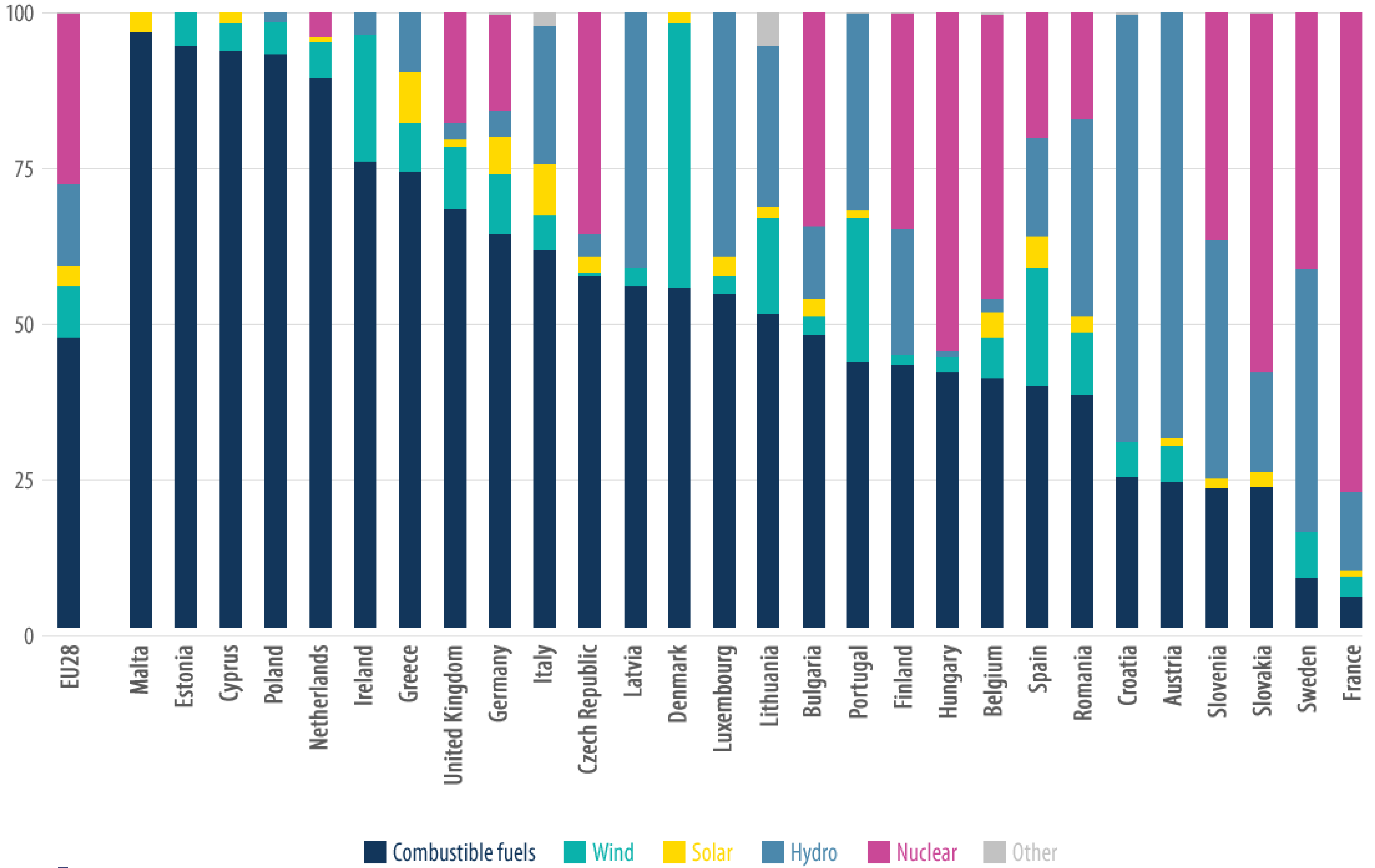
- A few reactors built in the 50's and 60's have been closed and decommissionning started
- Cost of decommissionning of a plant buil between 1975 and 1990 is estimated around 800 million Euros (15 % of construction plant, which was close yo 5 billion euros (5000 Euro per KW installed))
- Cost of decommissioning is included in the electricity bill of the french consumers
- EDF set up a fund which has now collected 10 Billion Euros and will continue to feed the fund
- A subsidiary has been created to deal with decomissionning

Nuclear energy in France : waste disposal

- Some countries (US) do not process wastes in order to avoid the production of plutonium which could be used to make atomic weapons
- France has set up the La Hague plant where french wastes (and wastes fromseveral other countries) are processed
- Ultimate wastes should be stored in underground storage. La Bure site should be 500 meters deep in very old clay layers

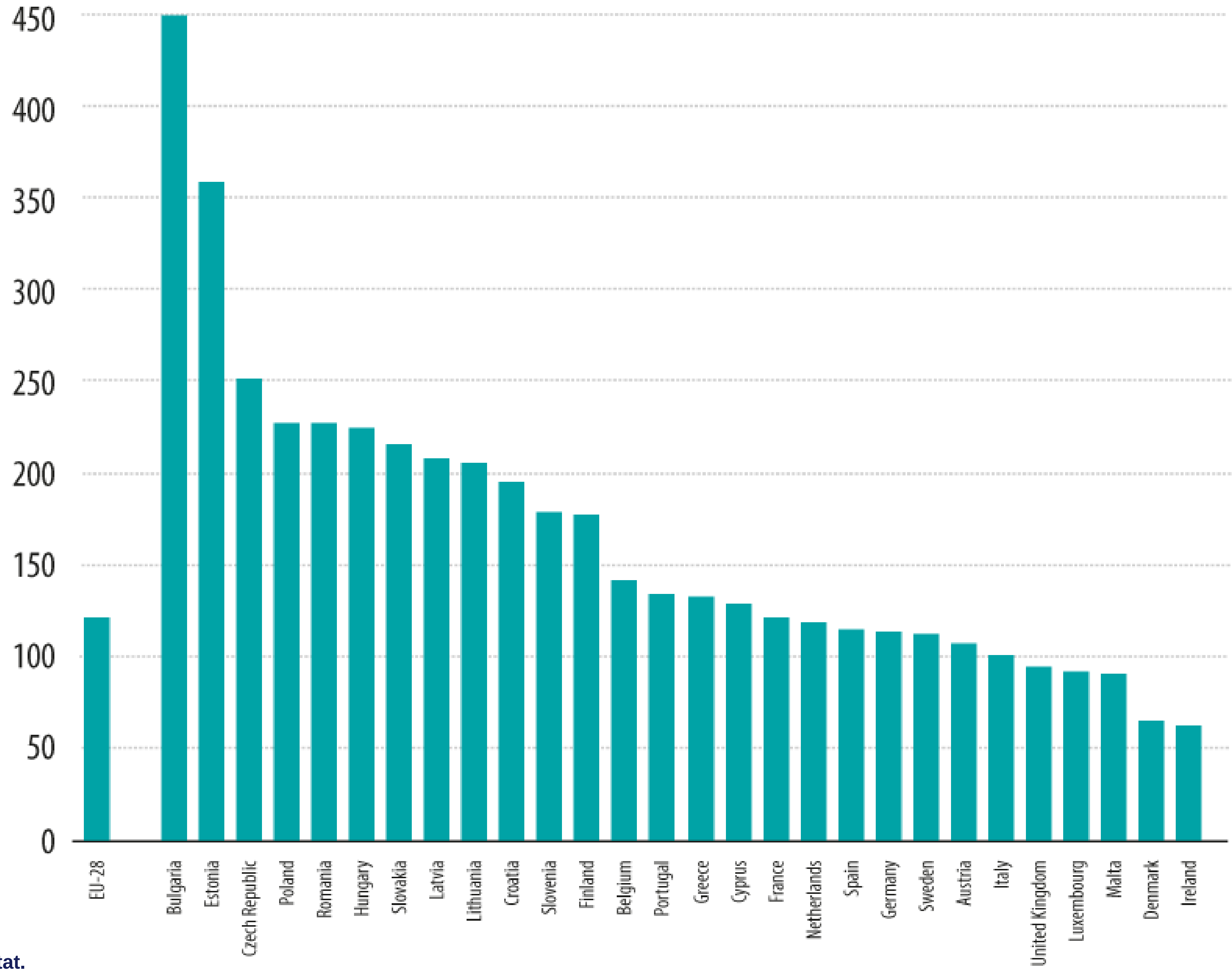
Energy in Europe

Electricity production share by sources in Europe (2014)



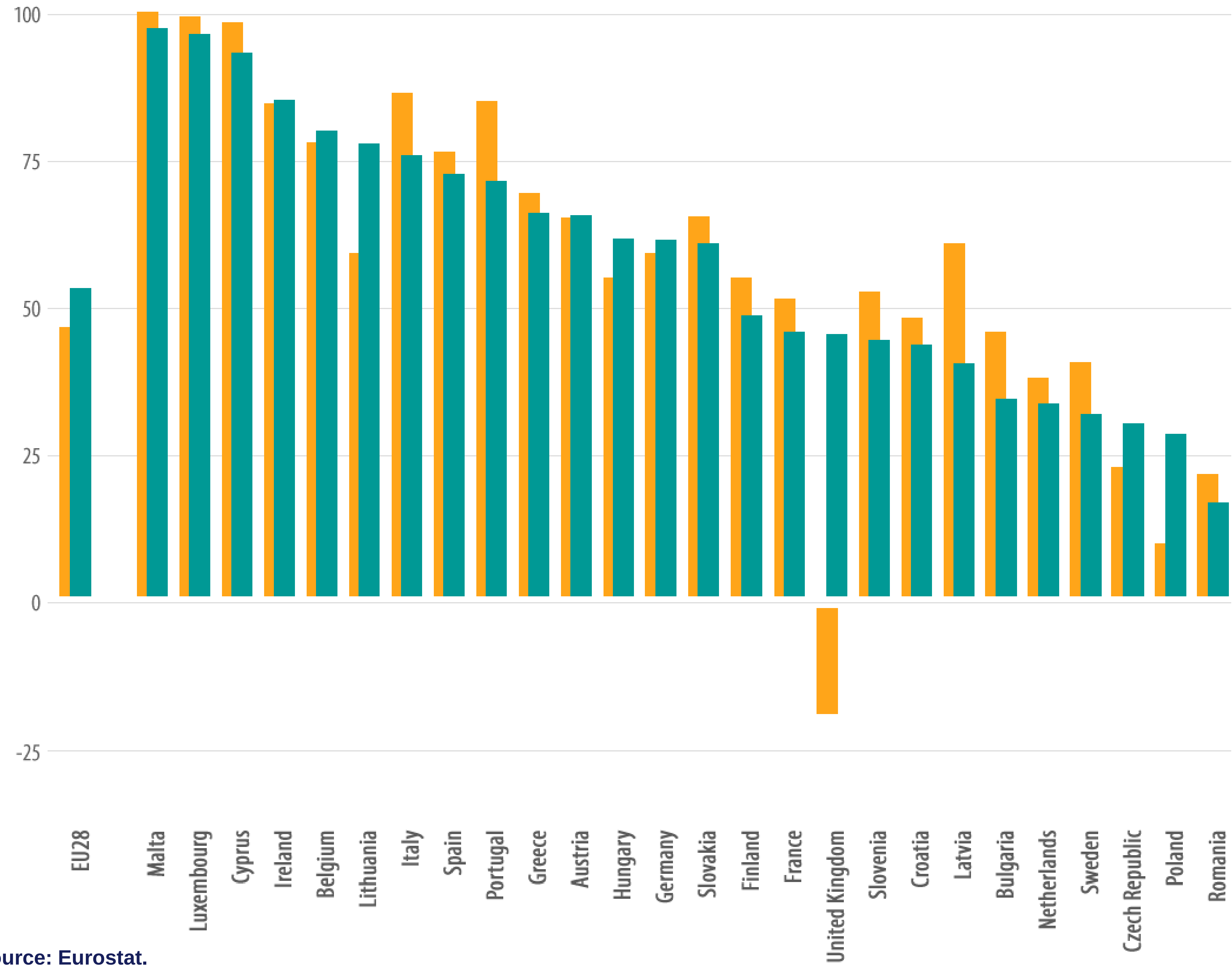
Source: Eurostat.

Energy intensity in kgoe per 1000 EUR (2015)



Source: Eurostat.

Energy dependency rate in % (2000 & 2014)



The energy dependency rate shows the proportion of energy that an economy must import. It is defined as net energy imports (imports minus exports) divided by gross inland energy consumption plus fuel supplied to international maritime bunkers, expressed as a percentage. A negative dependency rate indicates a net exporter of energy.

Source: Eurostat.

EU imports of crude oil by partners in % (2015)

Source: Eurostat.

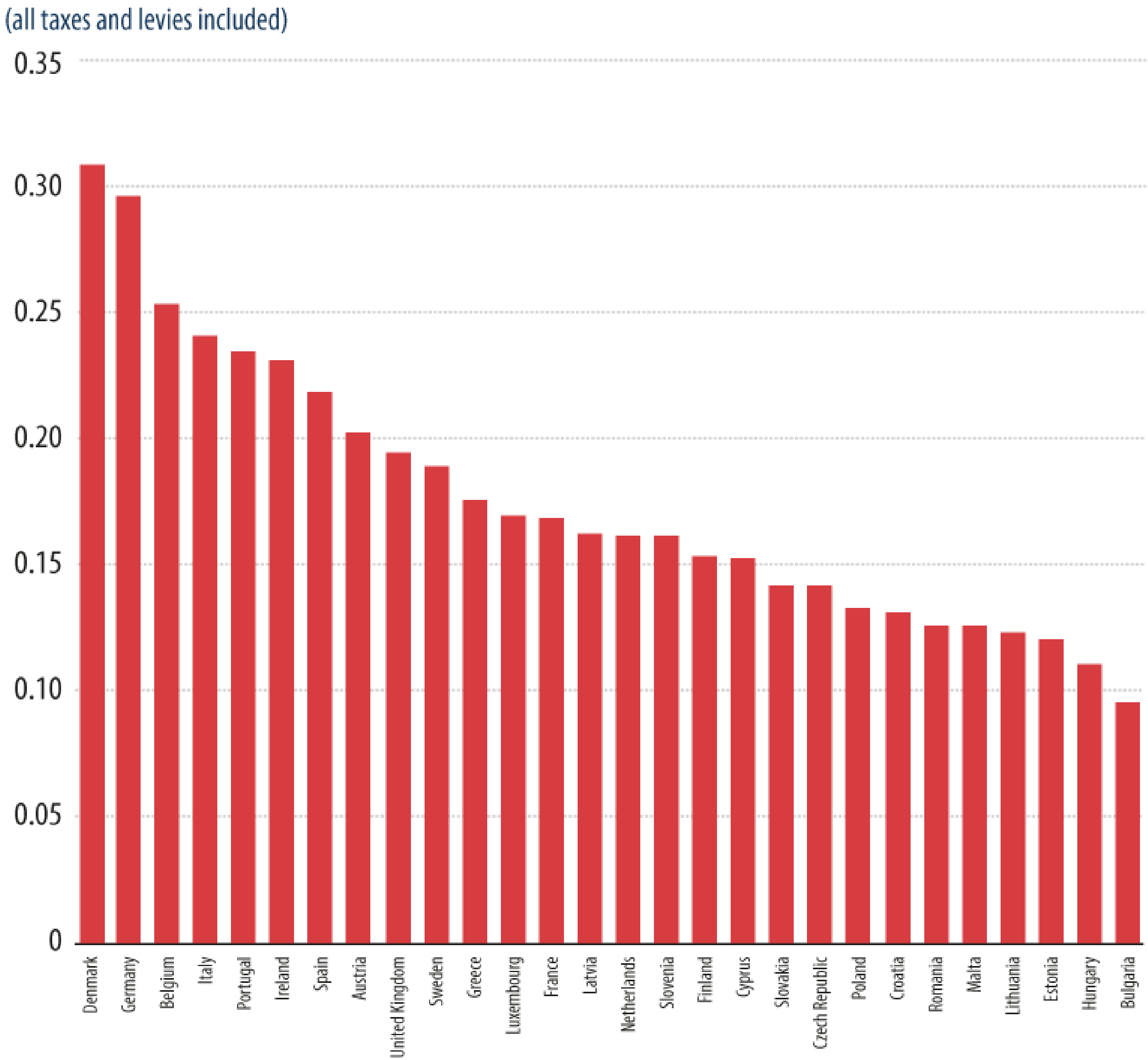
EU imports of coal by partners in % (2015)

Source: Eurostat.

EU imports of natural gas by partners in % (2015)

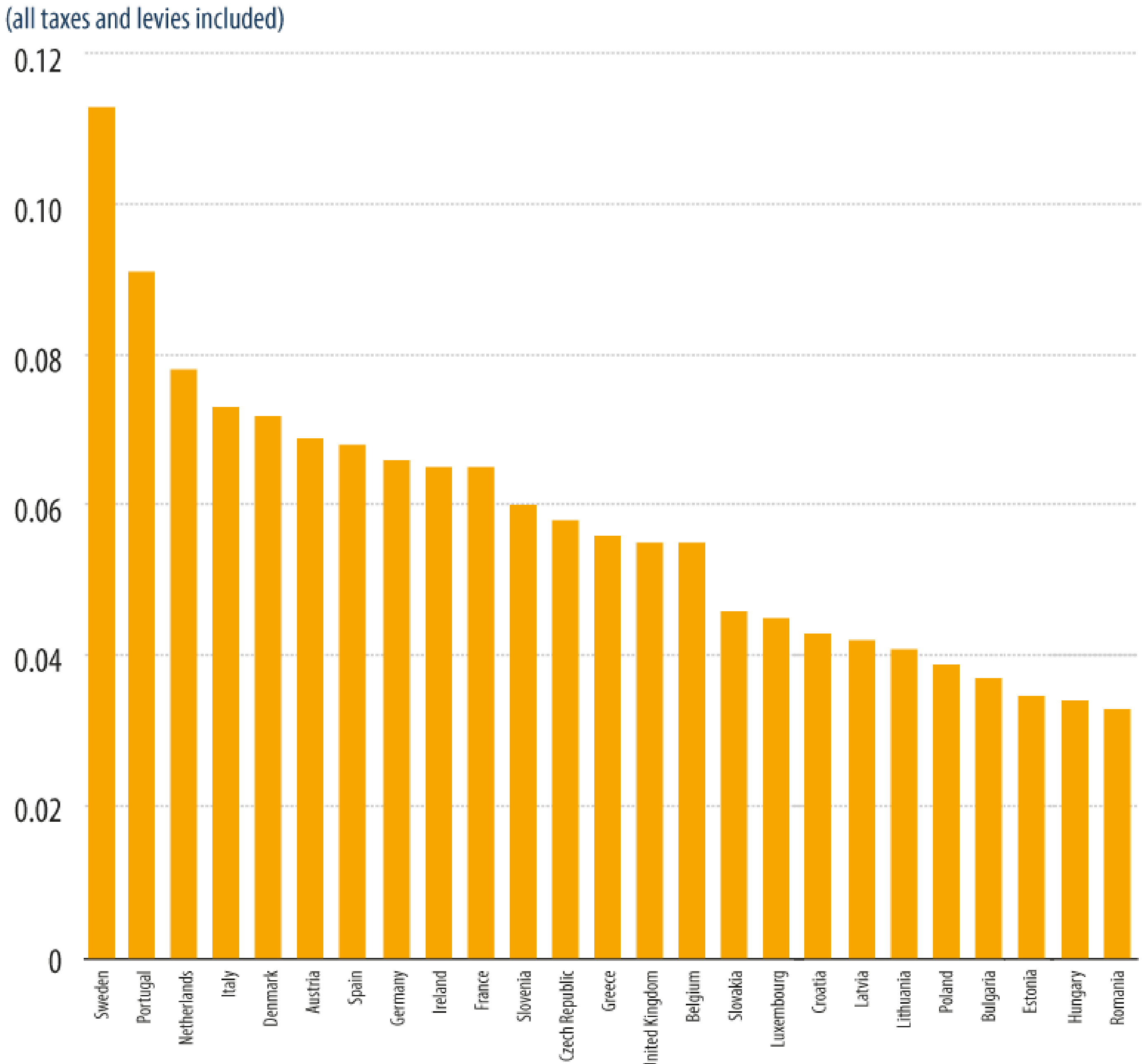
Source: Eurostat.

Electricity prices for households in €/kWh (H1 2016)



Source: Eurostat.

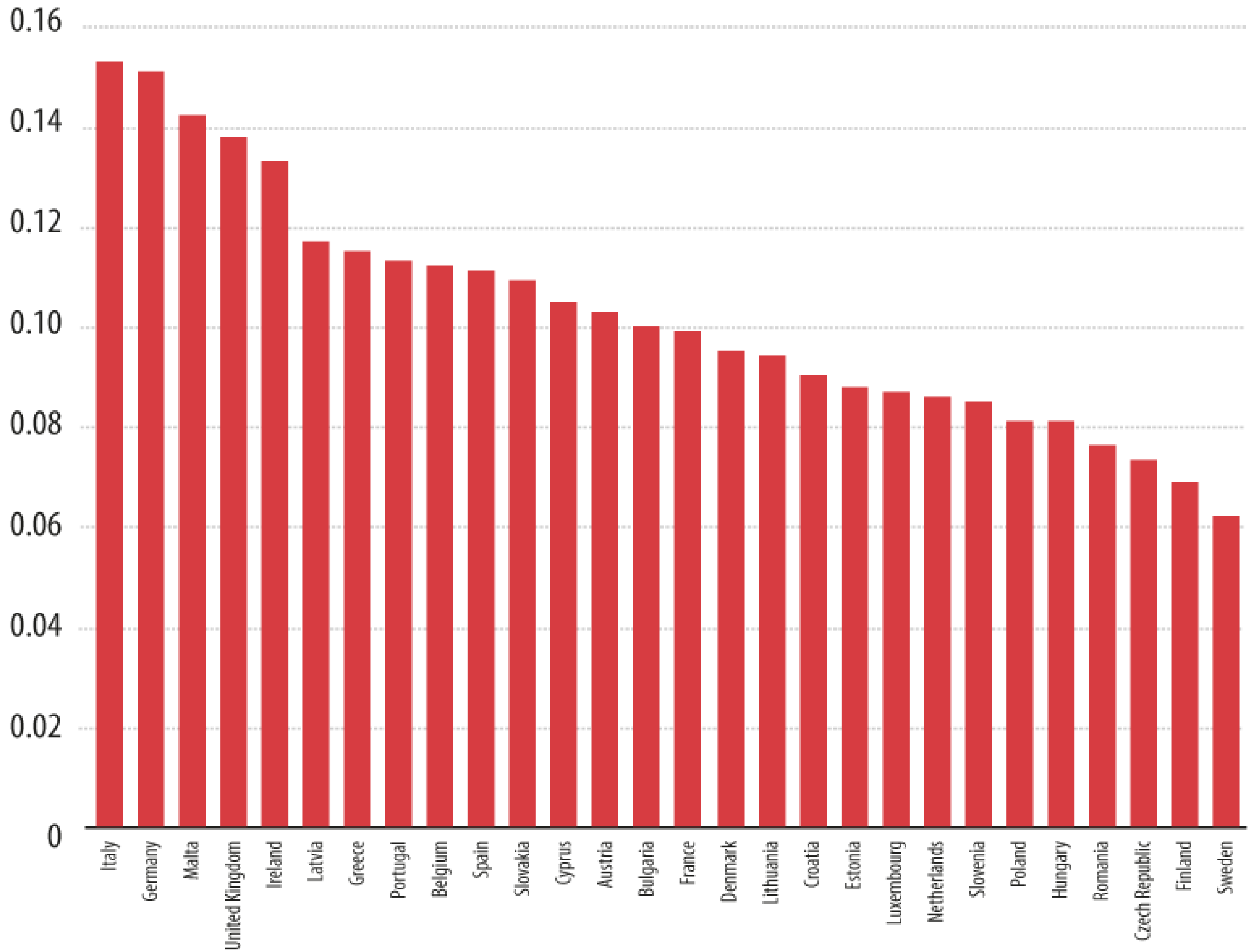
Gas prices for households in €/kWh (H1 2016)



Source: Eurostat.

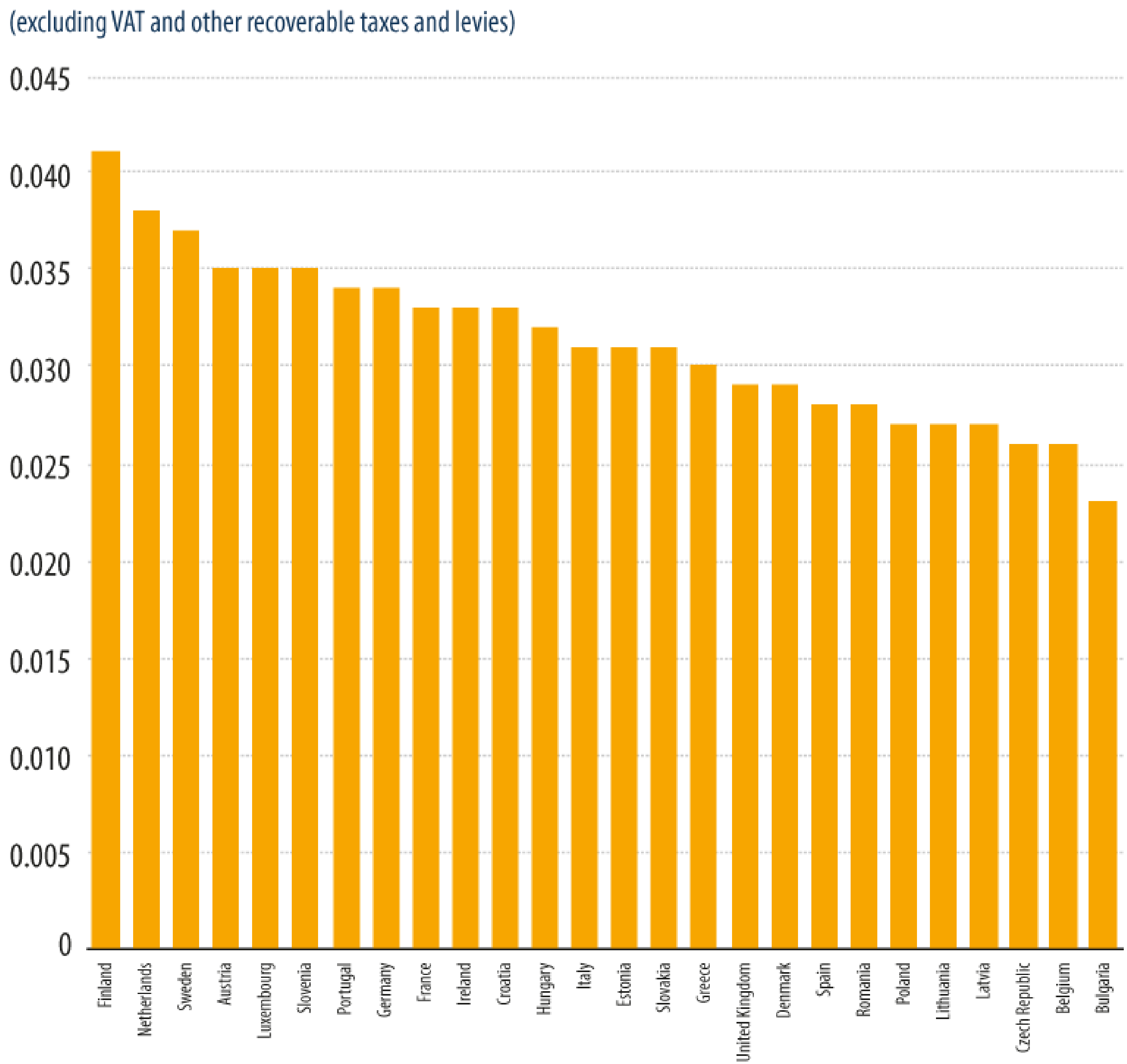
Electricity prices for industries in €/kWh (H1 2016)

(excluding VAT and other recoverable taxes and levies)



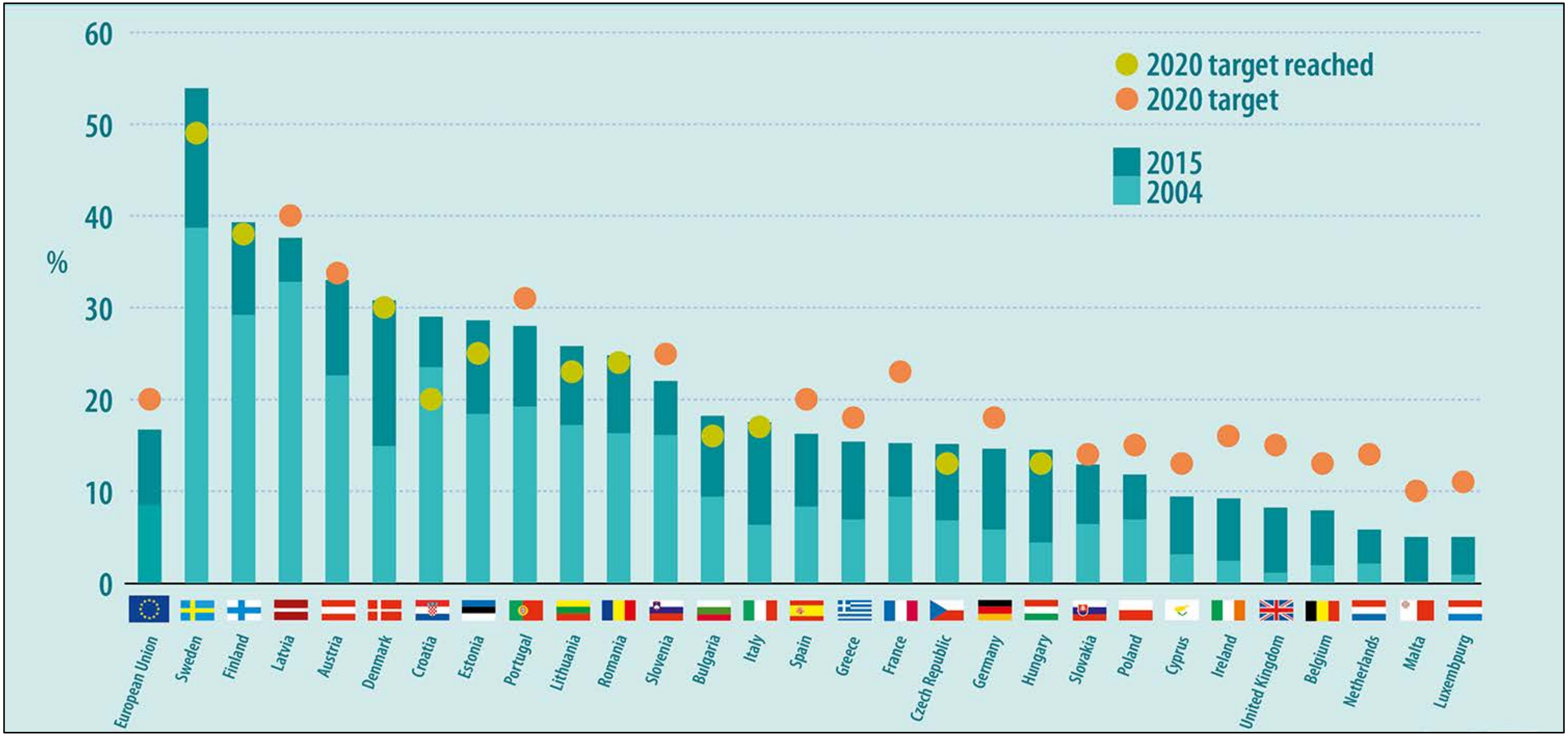
Source: Eurostat.

Gas prices for industries in €/kWh (H1 2016)



Source: Eurostat.

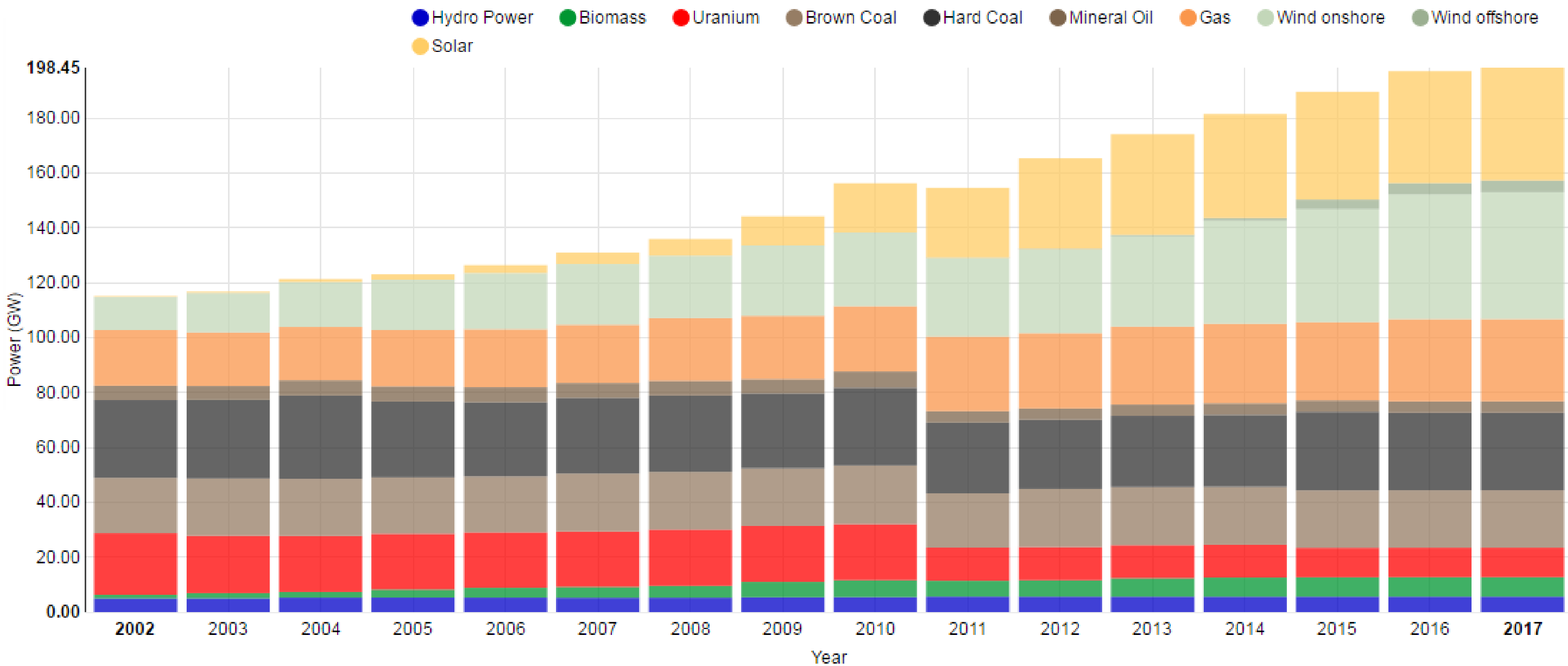
Share of renewables in final energy consumption in % (2015)



Source: Eurostat.

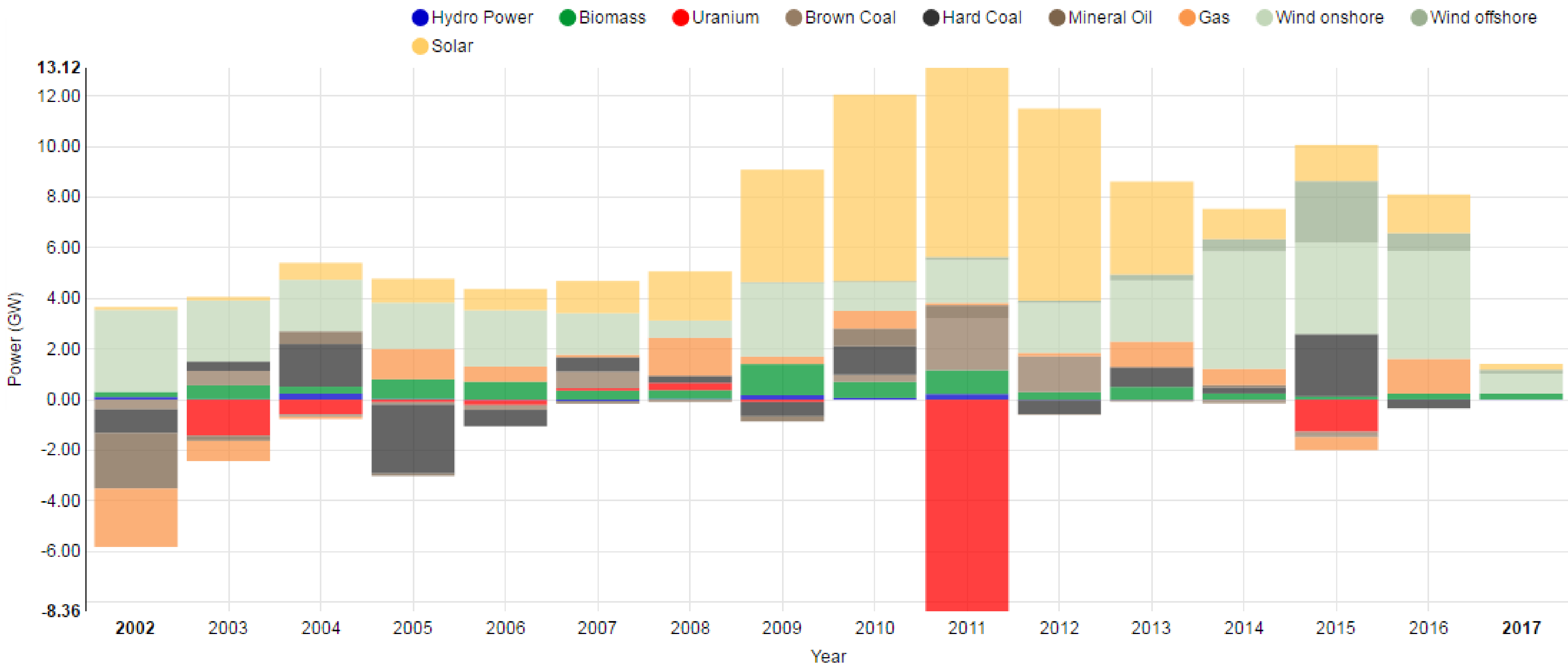
Energy in Germany

Electricity generation capacity in Germany (2002-2017)



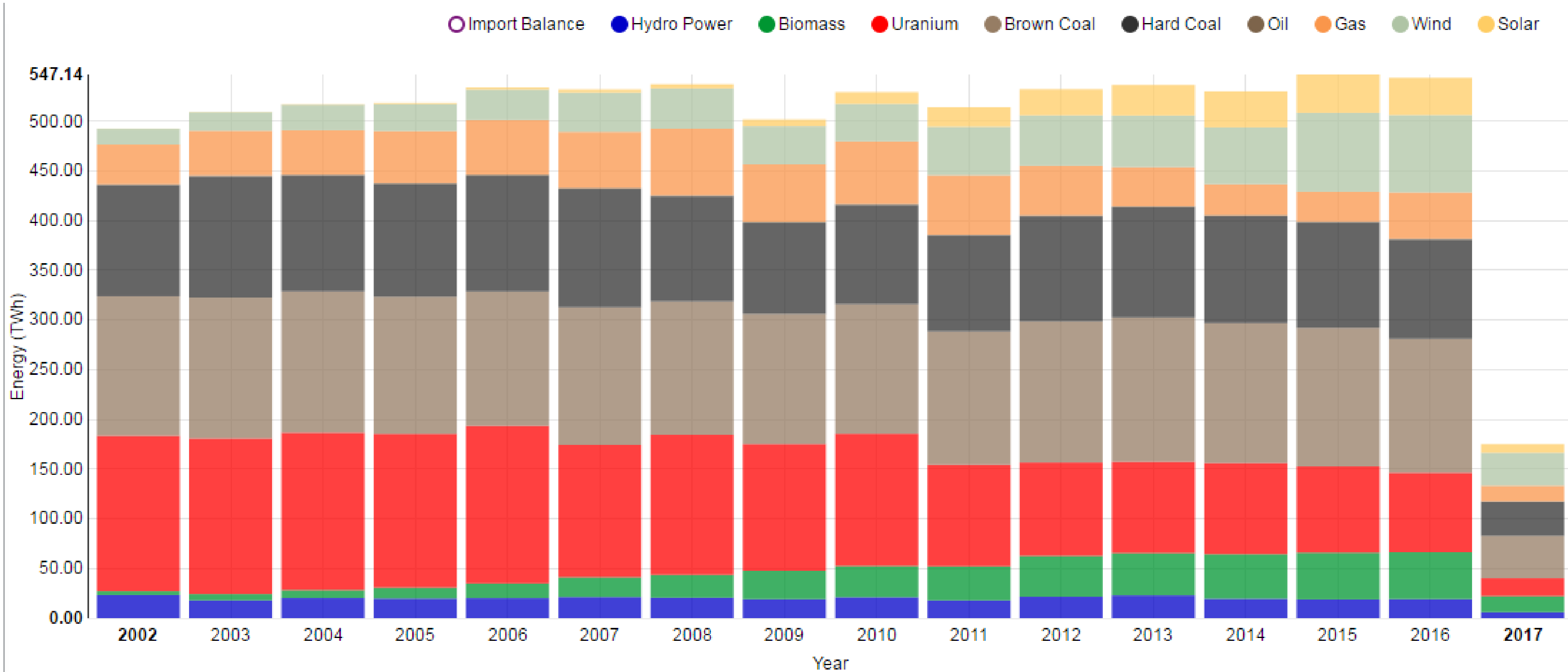
Datasource: AGEE, BMWi, Bundesnetzagentur
Last update: 19 Apr 2017 23:18

Annual variation of net installed generation capacity in Germany (2002-2017)



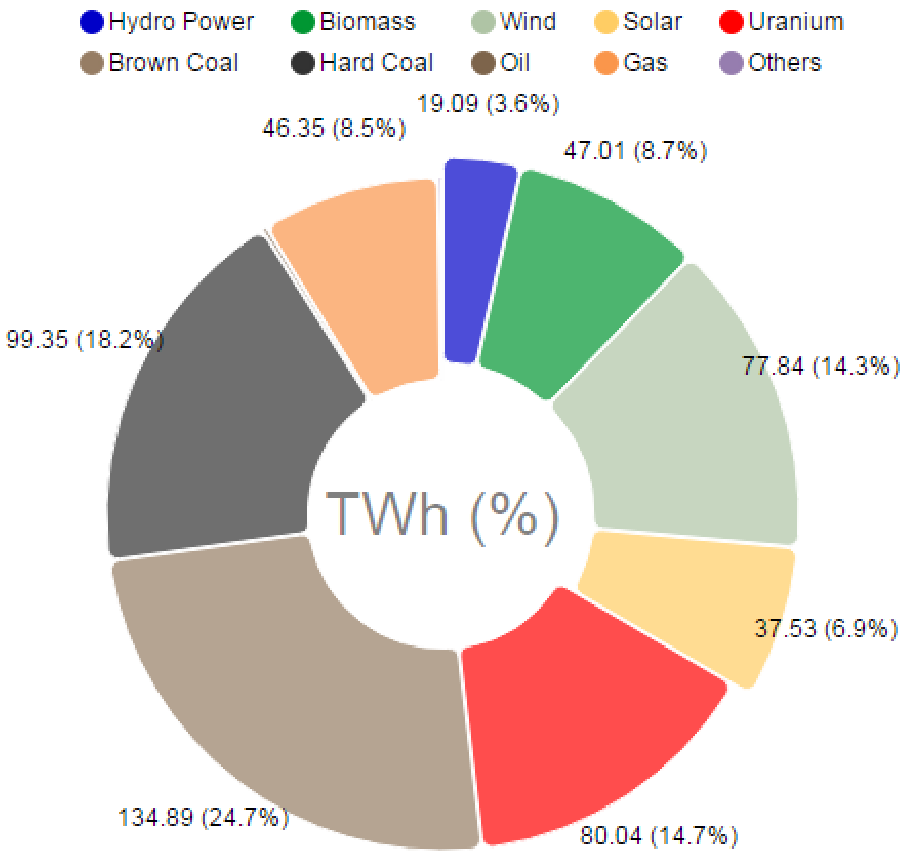
Datasource: AGEE, BMWi, Bundesnetzagentur

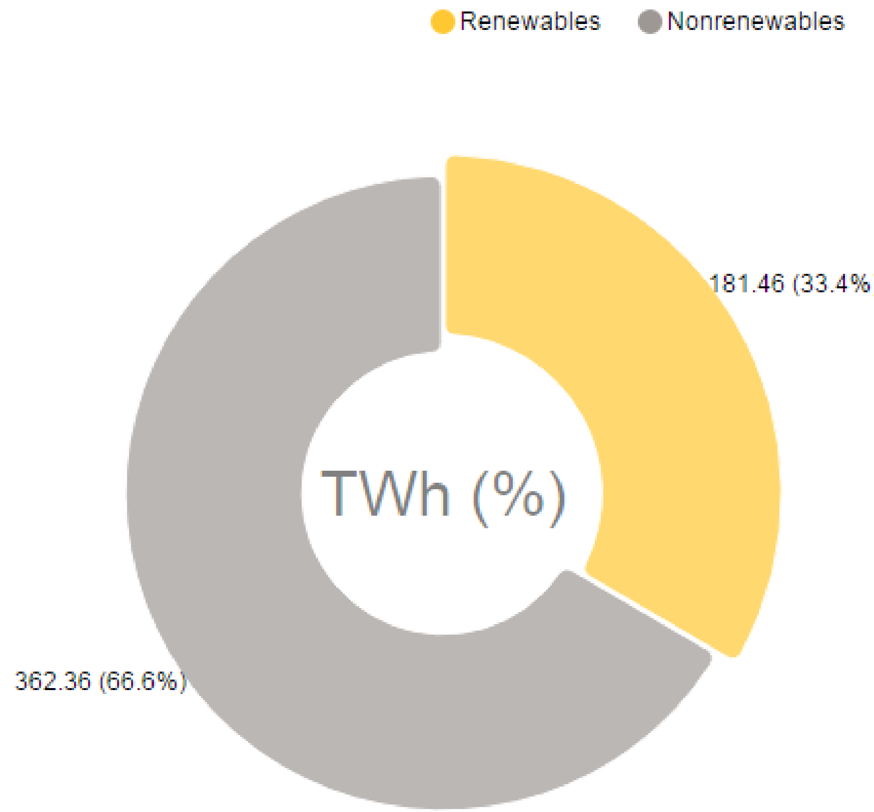
Annual electricity generation in Germany (2002-2017)



Net generation of power plants for public power supply.
Datasource: 50 Hertz, Amprion, Tennet, TransnetBW, Destatis, EEX

Electricity generation in Germany (2016)





Net generation of power plants for public power supply.
Datasource: 50 Hertz, Amprion, Tennet, TransnetBW, Destatis, EEX

Contact :report@tky.ieej.or.jp