The Role of Radioactive Waste Management and Nuclear Power Plants in the Energy Systems

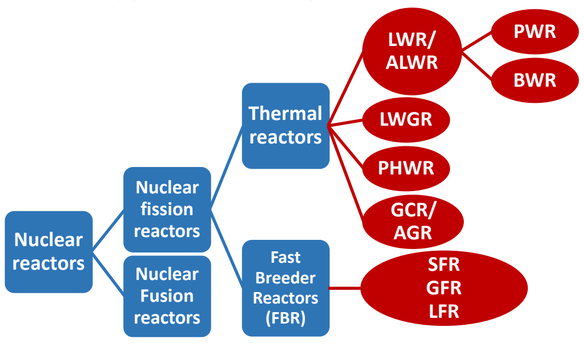
Mediya Etemadi, Nasser Kalantar-Nayestanaki, Machteld van den Broek
University of Groningen, Energy and Sustainability Research Institute Groningen

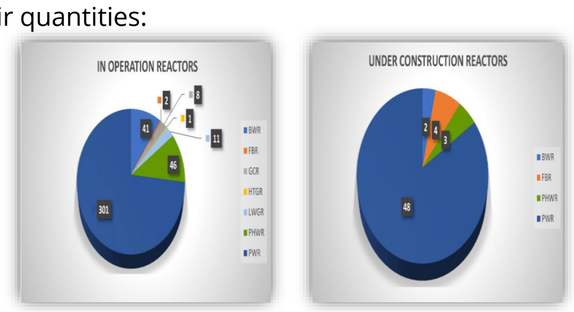
Introduction

- **Global population growth has increased energy consumption ➡ raising environmental concerns due to greenhouse gas emissions.**
- **The EU aims to cut GHG emissions 80-95% by 2050.**
- **Nuclear energy, with its absence of direct CO_2 emissions, play a significant role in the energy system.**
- **This research explores the potential of nuclear energy in achieving this goal, assessing various reactor types and waste management methods for their impact on the energy system.**

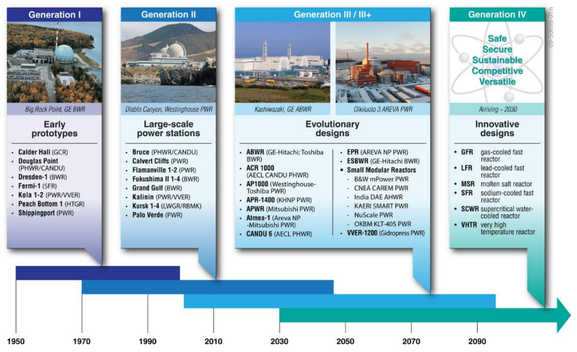
Nuclear Power Plants

Various types of nuclear power reactors and their quantities:

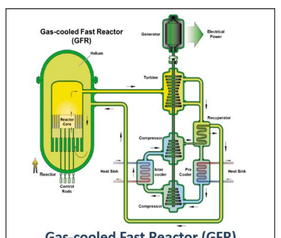




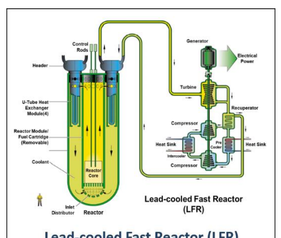
Source: The database on nuclear reactors, Power Reactor Information System (PRIS), International Atomic Energy Agency (IAEA), pris.iaea.org



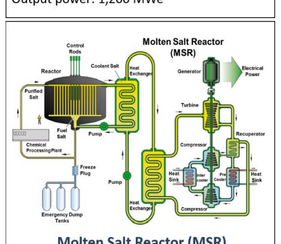
Six systems are chosen as Generation IV technologies:



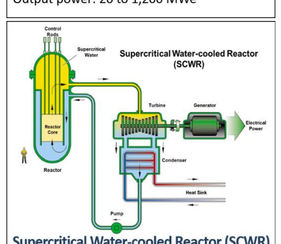
Gas-cooled Fast Reactor (GFR)
Neutron spectrum: High-speed neutron
Coolant: Helium
Outlet temperature: 850℃
Fuel cycle: Closed
Output power: 1,200 MWe



Lead-cooled Fast Reactor (LFR)
Neutron spectrum: High-speed neutron
Coolant: Lead
Outlet temperature: 80 to 570℃
Fuel cycle: Closed
Output power: 20 to 1,200 MWe



Molten Salt Reactor (MSR)
Neutron spectrum: Thermal neutron or High-speed neutron
Coolant: Fluoride salt or Chloride salt
Outlet temperature: 700 to 800℃
Fuel cycle: Open or Closed
Output power: 1,000 MWe

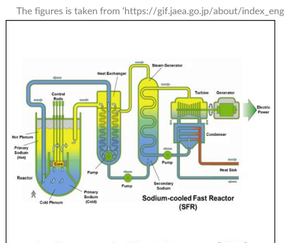


Supercritical Water-cooled Reactor (SCWR)
Neutron spectrum: Thermal neutron or High-speed neutron
Coolant: Water
Outlet temperature: 510 to 625℃
Fuel cycle: Open or Closed
Output power: 300 to 1,500 MWe

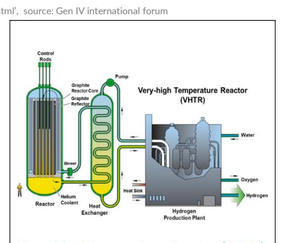
In recent decades, there have been significant development in the technology of nuclear power reactors. In general, the new generation of reactors have the following characteristics:

- Greater standardization of design for each type to expedite licensing, reduce capital cost and reduce construction time.
- A simpler and more rugged design, making them easier to operate and less vulnerable to operational issues.
- Higher availability and longer operating lifetimes.
- Reduced possibility of accidents in which the reactor's core melts, particularly through coping with decay heat following (the essential problem at Fukushima).
- Resistance of the structure to the serious damage that would allow radiological release from an aircraft impact.
- Higher burn-up of fuel, to use it more fully and efficiently and to reduce the amount of radioactive waste created.

The figures is taken from 'https://gif.jaea.go.jp/about/index_eng.html', source: Gen IV international forum

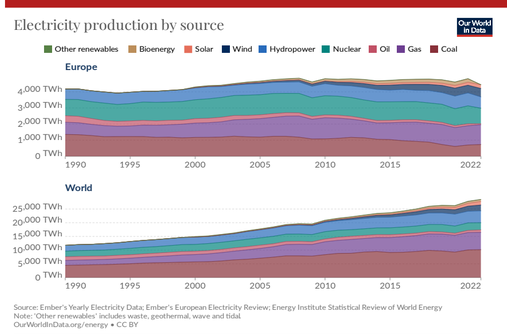


Sodium-cooled Fast Reactor (SFR)
Neutron spectrum: High-speed neutron
Coolant: Sodium
Outlet temperature: 500 to 550℃
Fuel cycle: Closed
Output power: 50 to 1,500 MWe

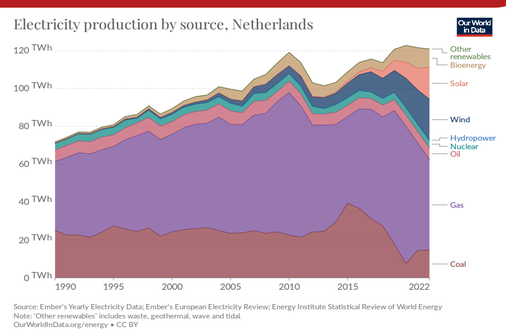


Very-high Temperature Reactor (VHTR)
Neutron spectrum: Thermal neutron
Coolant: Helium
Outlet temperature: 900 to 1,000℃
Fuel cycle: Open
Output power: 250 to 300 MWe

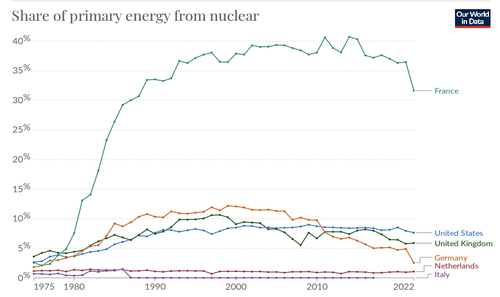
Nuclear Power in Energy Systems



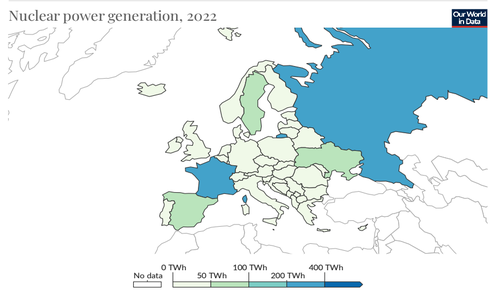
Source: Ember's Yearly Electricity Data; Ember's European Electricity Review; Energy Institute Statistical Review of World Energy
Note: 'Other renewables' includes waste, geothermal, wave and tidal
OurWorldInData.org/energy • CC BY



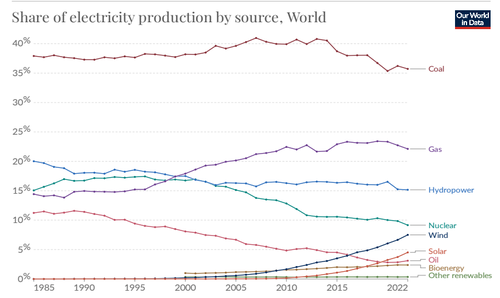
Source: Ember's Yearly Electricity Data; Ember's European Electricity Review; Energy Institute Statistical Review of World Energy
Note: 'Other renewables' includes waste, geothermal, wave and tidal
OurWorldInData.org/energy • CC BY



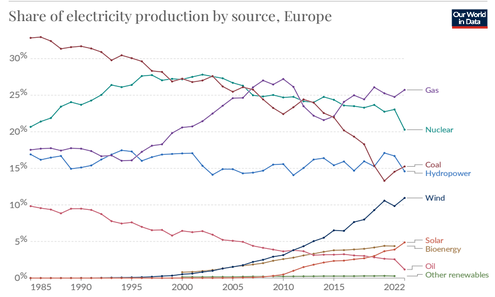
Source: Energy Institute Statistical Review of World Energy (2023)
Note: Primary energy is calculated using the 'substitution method', which accounts for the energy production inefficiencies of fossil fuels.
OurWorldInData.org/energy • CC BY



Source: Ember's Yearly Electricity Data; Ember's European Electricity Review; Energy Institute Statistical Review of World Energy
OurWorldInData.org/energy • CC BY

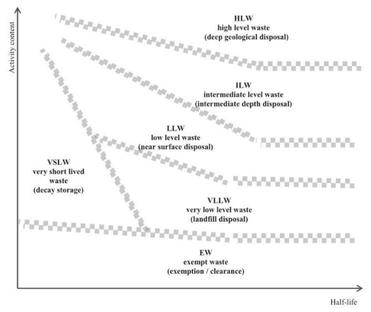


Source: Ember's Yearly Electricity Data; Ember's European Electricity Review; Energy Institute Statistical Review of World Energy
OurWorldInData.org/energy • CC BY

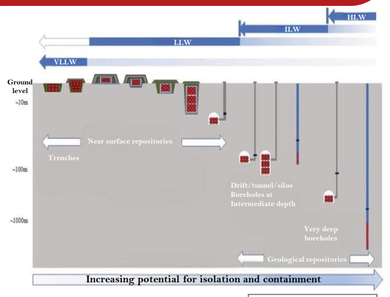


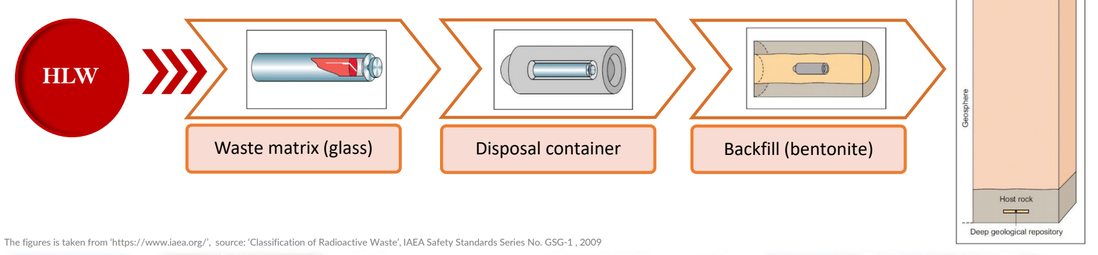
Source: Ember's Yearly Electricity Data; Ember's European Electricity Review; Energy Institute Statistical Review of World Energy
OurWorldInData.org/energy • CC BY

Radioactive Waste Management

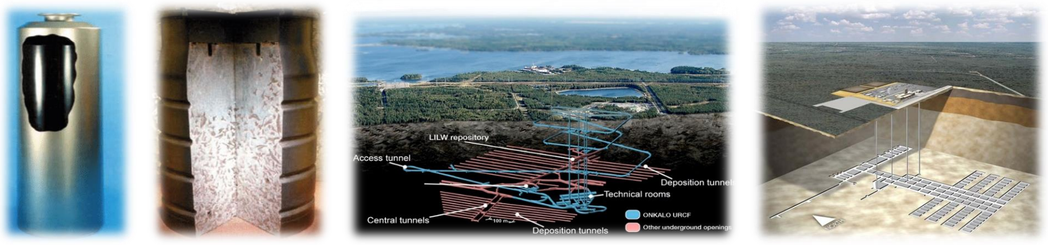


- Main focus in radioactive waste management: high-level waste, despite its smaller volume compared to other types.
- Growing interest in recycling used fuel to reduce waste volume and activity.





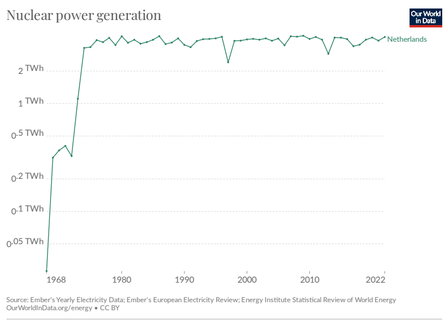
The figures is taken from 'https://www.iaea.org/', source: 'Classification of Radioactive Waste', IAEA Safety Standards Series No. GSG-1 , 2009



Nuclear Power Plant in the Netherlands

- The Netherlands has one nuclear reactor generating a small amount of its electricity.
- Its first commercial nuclear power reactor began operating in 1973.
- In 2021 the government announced plans to build two new nuclear units.
- Its main research reactor produces about half of Europe's medical radioisotopes.

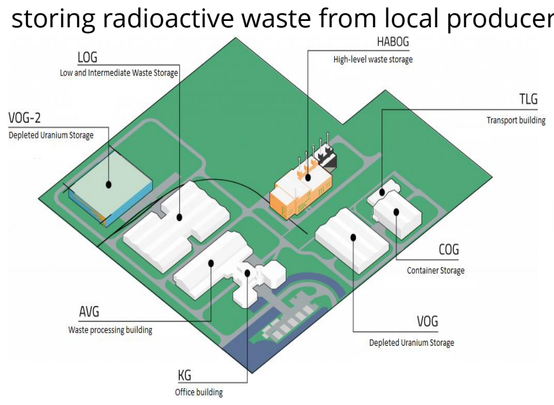
Reactor Name	Model	Reactor Type	Net Capacity (MWe)	Construction Start	First Grid Connection
Borssele	**2-loops KWU**	**PWR**	**482**	**1969-07**	**1973-07**

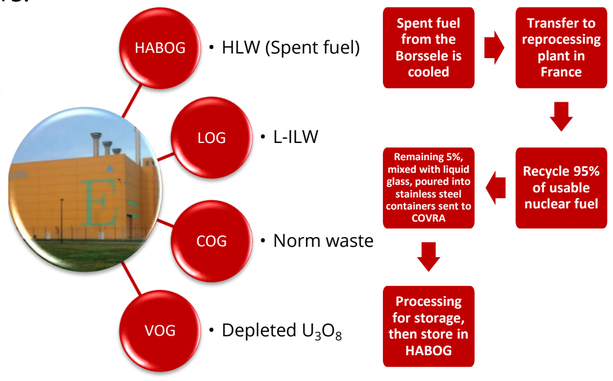


Source: Ember's Yearly Electricity Data; Ember's European Electricity Review; Energy Institute Statistical Review of World Energy
OurWorldInData.org/energy • CC BY

Radioactive Waste Management in the Netherlands

In the Netherlands, COVRA is the only organization responsible for collecting, processing, and storing radioactive waste from local producers.





Research Goal and Outlook

- Compile comprehensive data on the costs and quantities of radioactive waste management to aid decision-making in the energy sector.
- Optimize nuclear energy for diverse energy demands, identifying the right nuclear power plants to meet specific requirements in different regions and times.

Research stages

I. Compile existing data on radioactive waste management and various nuclear power plants, focusing on cost, output capacity, flexibility, and environmental effects.
II. Retrieve missing data through direct contact with relevant organizations or on-site visits.
III. Utilize the IESA-Opt model to analyze data and answer questions, comparing the impact of different radioactive waste management methods for various nuclear power plants in the energy system.