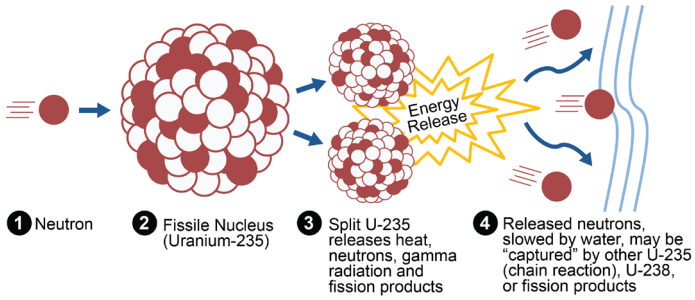
Nuclear Energy

Nuclear power plants generate electricity by using controlled nuclear fission chain reactions to heat water and produce steam to power turbines. Nuclear is often labeled a "clean" energy source because no greenhouse gases (GHGs) or other air emissions are released from the power plant. It has a higher capacity factor (93% in 2023) than any other type of power plant.[1,2] As the U.S. and other nations search for low-emission energy sources, the benefits of nuclear power must be weighed against the cost, operational risks, and challenges of storing spent nuclear fuel and managing radioactive waste.

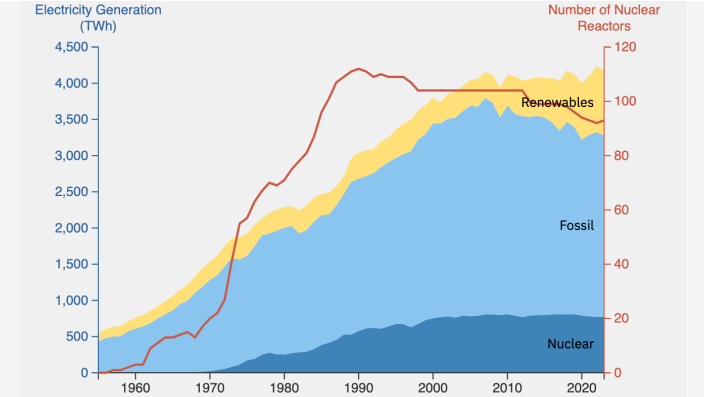
Fission of Uranium-235 in a Nuclear Reactor



Nuclear Resources and Energy Use

- Uranium is mostly extracted by in-situ leaching (ISL) (58%), open pit mining (19%), and underground mining (16%).[3]
- Most nuclear reactors use "enriched" uranium, meaning the fuel has a higher concentration of uranium-235 (U-235) isotopes, which are easier to split to produce energy. When it is mined, uranium ore averages less than 1% U-235. [4] The largest recoverable uranium deposits are in Australia (28% of global supply), Kazakhstan (13%), Canada (10%), Russia (8%), and Namibia (8%), with just 1% in the U.S.[3]
- U.S. nuclear plants purchased 23.4 kt of uranium in 2023, up 27% from 2022.[5] Fuel was imported from Canada (25%), Kazakhstan (21%), Australia (21%) and Russia (12%). [5] The U.S. banned the import of Russian uranium products in 2024.[6]
- The first U.S. nuclear power plant began commercial operations in 1958.[7] During the 1970s, more than 50 nuclear reactors went online.[8] As of August 2023, 28 states had 93 operating nuclear reactors at 54 plants.[7] Net summer capacity was 95 GW in 2022.[7]
- In 2022, the U.S. generated nearly a third of the world's nuclear electricity, followed by China, France, and Russia.[9] Nuclear energy provides about 19% of U.S. electricity, a share that has remained stable since 1990s.[8]
- Small modular reactors (SMRs) are defined as advanced reactors that produce up to 300 MW(e) per module. SMRs can fulfill the need for flexible power generation for a wide range of users and applications with savings in cost and

U.S. Electricity Generation by Source[8]



construction time.[10] 80+ commercial SMR designs are being developed globally, but only one has been commercially operational since 2020 (in Russia, with two 35 MW(e) SMRs). Other SMRs are under construction or in the licensing stage in Argentina, Canada, China, Russia, South Korea, and the U.S.[11]

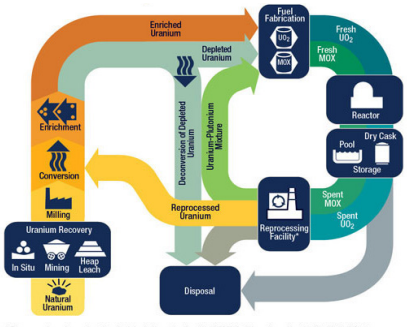
Economic Impacts

- Nuclear has several advantages relative to other forms of electricity generation: it requires relatively little land and fuel, and can operate continuously except for maintenance, refueling, and emergency shutdowns.
- Nuclear has a high levelized cost of energy (LCOE)- about twice that of combined cycle NG and three times that of utility solar or onshore wind in 2024.[12]
- Final construction costs for U.S. nuclear plants have typically been 2 to 3 times original estimates due to construction delays. A survey of plants begun after 1970 shows an average cost overrun of 241%.[13]
- There have only been two new U.S. nuclear power projects begun since 1990, both supported by federal government subsidies. The VC Summer dual reactor project in South Carolina was abandoned in 2017 with sunk costs of $9B.[13]
- The first of two Vogtle reactors in Georgia began operation in 2023, and the second reactor went online in 2024,[14] 7 years behind schedule.[13] The total cost of the two Vogtle reactors is now $35B, or 2.5 times the projected cost of $14B.[13]
- Recent projects in Great Britain, France, and Finland have suffered construction delays and cost overruns similar to the U.S., while China, Japan, and South Korea have been able to complete plants faster and closer to budget.[13, 15]

Energy and Environmental Impacts

- A uranium fuel pellet (~1/2" in height and diameter) contains the energy equivalent of one ton of coal or 149 gal of oil.[17] A typical reactor (1 GW) holds 18M pellets.[18]
- The nuclear fuel cycle is the entire process of producing, using, and disposing of uranium fuel. Powering a 1 GW plant for a year requires mining 20-40 kt of ore, processing it into 27.6 t of uranium fuel[19], and disposing of 27.6 t of spent fuel,

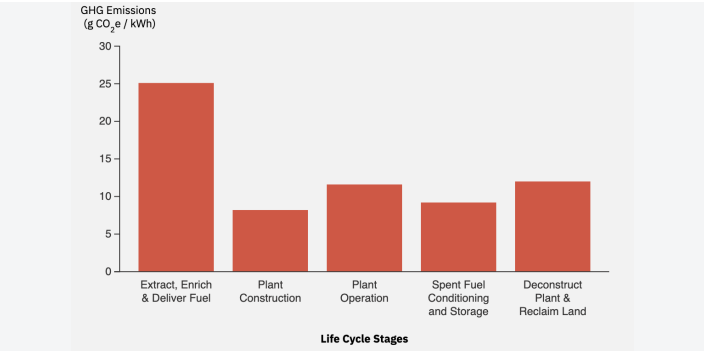
Nuclear Fuel Cycle[16]



of which 3% (0.8 t) is high-level waste that requires cooling and shielding[20]. Each kWh of nuclear electricity requires 0.1-0.3 kWh of life cycle energy inputs.[21]

- Although nuclear electricity generation itself produces no GHG emissions, other fuel cycle activities do release emissions.[22] The life cycle GHG intensity of nuclear power is estimated to be 34-66 g CO_2e/kWh[22, 23], far below other baseload sources such as coal (1,001 g CO_2e/kWh).[24]
- Nuclear power plants use 270-670 gal/MWh of water, depending on operating efficiency and site conditions.[25] For pressurized water reactors and boiling water reactors, most environmental impacts are caused by the extraction and production of fuel elements.[26]

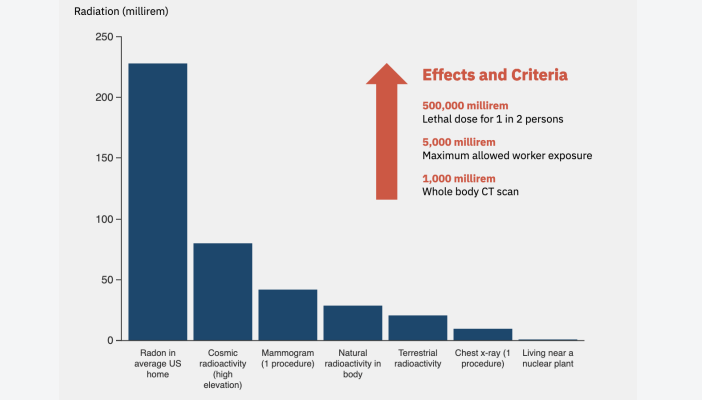
Life Cycle GHG Emissions of Nuclear (g CO_2e/kWh)[23]



Nuclear Waste

- The U.S. generated 89,178 t of commercial spent fuel and reprocessing waste, stored at more than 100 sites across 39 states as of 2021.[27] Reprocessing used nuclear fuel can reduce waste and extract 25-30% more energy.[28]
- Spent fuel is stored either in wet pools or dry casks in the U.S. Wet pools were more common but many sites are reaching capacity.[29] Dry casks are increasingly used in most nuclear reactor sites, storing 50% of spent fuel in 2021, up from 27% in 2011.[27 29]
- Ten years after use, the surface of a spent fuel assembly releases 10,000 rem/hr of radiation, far greater than the fatal whole-body dose for humans of 500 rem received all at once.[30] Managing nuclear waste requires very long-term planning. The U.S. EPA was required to set radiation exposure limits in permanent waste storage facilities over an unprecedented timeframe—one million years.[31]
- The U.S. has no permanent storage site. Nevada's Yucca Mountain was proposed as a site to hold 70 kt of waste,[32] but is no longer under consideration mostly due to political pressure and local opposition.[33]

Dose from Common Radiation Sources (mrem)[36]



- The Nuclear Waste Policy Act required the U.S. federal government to begin taking control of spent nuclear fuel in 1998. When this did not occur, the government became liable for the costs associated with storage at reactor sites.[34]

Safety and Public Policy

- In 1986, a series of explosions occurred at the Chernobyl nucler plant in Ukraine. 134 workers and emergency responders were diagnosed with acute radiation syndrome and 28 died within weeks. About 350k people were evacuated and/or permanently resettled, and a 1,000 mi^2 Chernobyl Exclusion Zone was established to restrict public access.[37]
- On March 11, 2011, an M9.0 earthquake occurred near Fukushima, Japan. The resulting tsunami damaged the reactor cooling system, leading to meltdowns. Radiation releases were lower than from Chernobyl, and mostly deposited in the Pacific Ocean. About 150k people were evacuated. No deaths or radiation sickness have been directly linked to the accident.[38]
- The U.S. Price-Anderson Act limits the liability of nuclear plant owners if a radioactive release occurs to $500M for individual plants and $16.3M across all plants.[39]
- The Bipartisan Infrastructure Deal allocated $6B for the Civilian Nuclear Credit program to prevent premature retirement of existing nuclear plants.[40]
- Federal incentives for new nuclear plants include insurance against regulatory delays, a production tax credit (PTC), an investment tax credit (ITC) and federal loan guarantees.[41, 42, 43]
- The Inflation Reduction Act of 2022 offers up to a $15/MWh PTC for exsiting nuclear plants, and a $25/MWh PTC or a 30% ITC for new nuclear plants, as well as $700M to support the domestic uranium supply chain.[42]
- The U.S. DOE announced a $1.5B loan to reopen the 800 MW Palisades nuclear power plant in Michigan in 2024.[44]

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Sources for this factsheet are here, help with units and abbreviations is here.