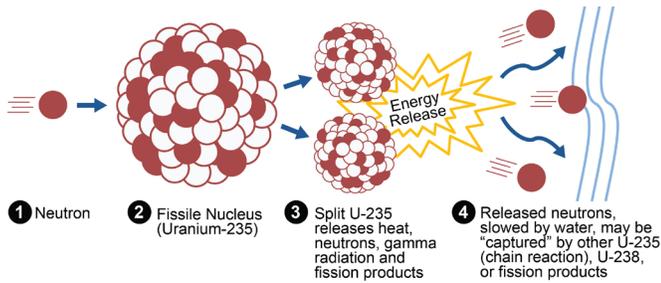


Nuclear Energy

Nuclear power plants generate electricity by using controlled nuclear fission chain reactions to heat water and produce steam that powers turbines. Nuclear is often labeled “clean” energy because no greenhouse gases (GHGs) or air emissions are released from the power plant. It has the highest capacity factor (92% in 2024) of any power plant type.^{1,2} As the U.S. and other nations seek low-emission energy sources, nuclear power’s benefits must be weighed against costs, operational risks, and challenges of storing fuel and managing radioactive waste.

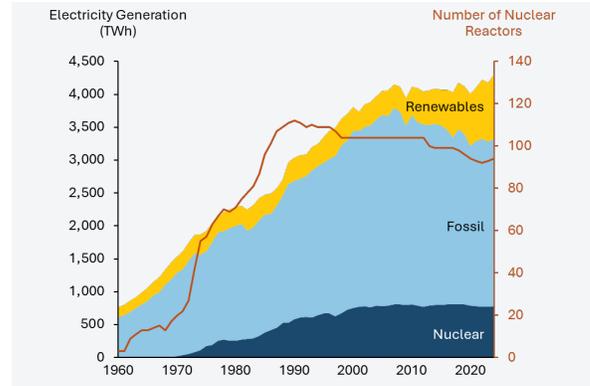
Fission of Uranium-235 in a Nuclear Reactor



Nuclear Resources and Energy Use

- Uranium is extracted primarily by in-situ leaching (60%), underground mining (18%), and open pit mining (16%).³
- Most nuclear reactors use enriched uranium with higher concentrations of uranium-235 (U-235) isotopes, which split more easily to produce energy. Mined uranium ore averages less than 1% U-235.⁴
- Total identified recoverable resources exceed 7.9 Mt, with 75% recoverable at reasonable cost (<\$130/kg).³ The largest deposits are in Australia (28%), Kazakhstan (14%), Canada (10%), Russia (8%), and Namibia (8%); only 1% is in the U.S.³
- U.S. nuclear plants purchased 23 kt of uranium in 2023, up 27% from 2022,⁵ importing from Canada (25%), Kazakhstan (21%), Australia (21%), and Russia (12%).⁵ The U.S. banned Russian uranium imports in 2024.⁶
- The first U.S. nuclear plant began commercial operations in 1958.¹ Over 50 reactors came online during the 1970s.² As of August 2023, 28 states operated 93 nuclear reactors at 54 plants with 95 GW net summer capacity.¹
- Nuclear provided 9% of global electricity in 2023, with the U.S. generating nearly one-third of this.⁹ Nuclear has provided about 18% of U.S. electricity annually since the 1990s.²
- Small modular reactors (SMRs) are advanced reactors producing up to 300 MW(e) per module, offering flexible power generation with cost and construction time savings.¹⁰
- Only one SMR plant has operated commercially since 2020 (Russia’s Akademik Lomonosov). Others are under construction or licensing in Argentina, Canada, China, Russia, South Korea, and the U.S.¹¹

U.S. Electricity Generation by Source²



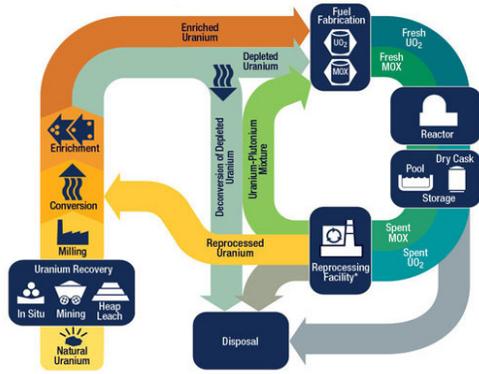
Economic Impacts

- Exploration and mine development expenditures for 2021-2023 totaled \$2.1B. Six countries accounted for 90% of expenditures, with Canada alone representing 34%.³
- Global uranium mine production increased 4% from 2020 to 2022. After five years of decline, production increased in 2022 following strong price recovery.³
- 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. However, nuclear has high levelized costs (LCOE)—about twice that of combined cycle natural gas and three times that of utility solar or onshore wind.¹²
- Final construction costs for U.S. nuclear plants typically exceed original estimates by 2-3 times due to delays. Plants begun after 1970 averaged cost overruns of 241%.¹³
- Only two new U.S. nuclear projects have begun since 1990, both requiring federal subsidies. The VC Summer dual reactor project in South Carolina was abandoned in 2017 with \$9B in sunk costs.¹³
- The Vogtle reactors in Georgia began operation in 2023 and 2024,¹⁴ seven years behind schedule, with total costs reaching \$35B, 2.5 times the projected cost of \$14B.¹³ Vogtle can power 500,000 buildings, and is expected to operate for 60-80 years.¹⁴
- Recent projects in the U.K., France, and Finland have experienced similar delays and cost overruns, while China, Japan, and South Korea have completed plants faster and closer to budget.^{13, 15}

Energy and Environmental Impacts

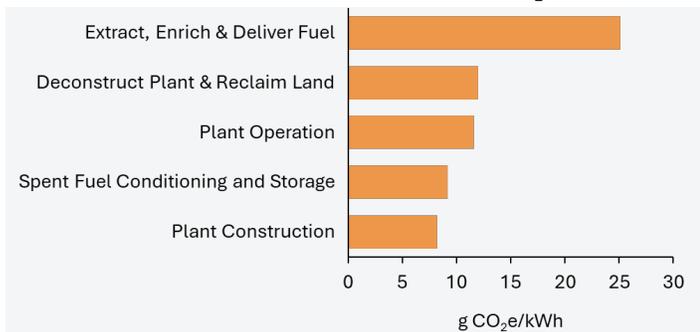
- A uranium fuel pellet (~0.5” in height and diameter) contains energy equivalent to 1 t of coal or 149 gal of oil.¹⁷ A typical 1 GW reactor holds 18M pellets.¹⁸
- The nuclear fuel cycle encompasses producing, using, and disposing of uranium fuel. Powering a 1 GW plant annually requires mining 20-40 kt of ore, processing it into uranium fuel, and disposing of spent fuel.¹⁹

Nuclear Fuel Cycle¹⁶



- 3% of this waste 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. Life cycle GHG intensity ranges from 5.4-122 g CO₂e/kWh,^{22, 46} far below other baseload sources like coal (1,001 g CO₂e/kWh).²⁴ Mining and milling represent nearly 50% of emissions.⁴⁶

Life Cycle GHG Emissions of Nuclear (g CO₂e/kWh)²³

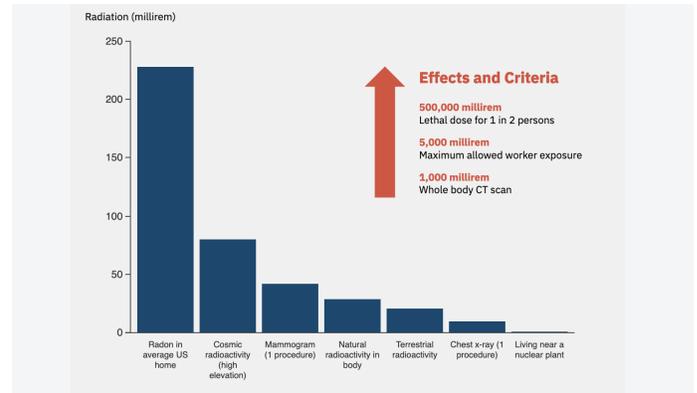


- Nuclear power plants use 270-670 gal/MWh of water, depending on operating efficiency and site conditions.²⁵ For pressurized and boiling water reactors, most environmental impacts stem from fuel element extraction and production.²⁶
- Advanced reactor designs like SMRs and closed fuel cycles with recycling capabilities could improve nuclear energy's long-term sustainability.³

Nuclear Waste

- The U.S. generated 89,178 t of commercial spent fuel and reprocessing waste, stored at over 100 sites in 39 states as of 2021.²⁷ Reprocessing used nuclear fuel can reduce waste and extract 25-30% more energy.²⁸
- Spent fuel is stored in wet pools or dry casks in the U.S. While wet pools were more common, many sites are reaching capacity. Dry cask storage is increasingly used, storing 50% of spent fuel in 2021, up from 27% in 2011.^{27, 29}
- 10 years after use, spent fuel assemblies release 10,000 rem/hr of radiation, far exceeding the fatal whole-body dose of 500 rem for humans.³⁰

Dose from Common Radiation Sources (mrem)³⁶



- Managing nuclear waste requires very long-term planning. U.S. EPA set radiation exposure limits in permanent storage facilities over an unprecedented 1 million-year timeframe.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 due to political pressure and local opposition.³³
- The Nuclear Waste Policy Act required the U.S. federal government to begin controlling spent nuclear fuel in 1998. When this did not occur, the government became liable for reactor site storage costs.³⁴

Safety and Public Policy

- In 1986, explosions at the Chernobyl nuclear plant in Ukraine resulted in 134 workers and emergency responders diagnosed with acute radiation syndrome. 28 died within weeks. 350k people were evacuated and/or permanently resettled, and a 1,000 mi² Chernobyl Exclusion Zone was established to restrict public access.³⁷
- On March 11, 2011, an M9.0 earthquake near Fukushima, Japan triggered a tsunami that damaged reactor cooling systems, causing meltdowns. Radiation releases were lower than Chernobyl and mostly deposited in the Pacific Ocean. About 150k people were evacuated, with no deaths or radiation sickness directly linked to the accident.³⁸
- The U.S. Price-Anderson Act limits nuclear plant owner liability to \$500M for individual plants and \$16.3B across all plants for radioactive releases.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} After 2027, new projects using nuclear fuel from countries like Russia or China will no longer qualify for these tax credits.⁴⁵
- The U.S. DOE announced a \$1.5B loan to reopen the 800 MW Palisades nuclear power plant in Michigan in 2024.⁴⁴