# JOINT STATE GOVERNMENT COMMISSION

General Assembly of the Commonwealth of Pennsylvania

## BENEFITS OF NUCLEAR ENERGY AND DEVELOPMENT OF SMALL MODULAR REACTORS

**Staff Study**

**February 2024**

*Serving the General Assembly of the Commonwealth of Pennsylvania Since 1937*

| **REPORT**<br><br>Benefits of Nuclear Energy and<br>Development of Small Modular Reactors | |
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| **JOINT STATE GOVERNMENT COMMISSION** | |
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The Joint State Government Commission was created in 1937 as the primary and central non-partisan, bicameral research and policy development agency for the General Assembly of Pennsylvania.[1]

A fourteen-member Executive Committee comprised of the leadership of both the House of Representatives and the Senate oversees the Commission. The seven Executive Committee members from the House of Representatives are the Speaker, the Majority and Minority Leaders, the Majority and Minority Whips, and the Majority and Minority Caucus Chairs. The seven Executive Committee members from the Senate are the President Pro Tempore, the Majority and Minority Leaders, the Majority and Minority Whips, and the Majority and Minority Caucus Chairs. By statute, the Executive Committee selects a chairman of the Commission from among the members of the General Assembly. Historically, the Executive Committee has also selected a Vice-Chair or Treasurer, or both, for the Commission.

The studies conducted by the Commission are authorized by statute or by a simple or joint resolution. In general, the Commission has the power to conduct investigations, study issues, and gather information as directed by the General Assembly. The Commission provides in-depth research on a variety of topics, crafts recommendations to improve public policy and statutory law, and works closely with legislators and their staff.

A Commission study may involve the appointment of a legislative task force, composed of a specified number of legislators from the House of Representatives or the Senate, or both, as set forth in the enabling statute or resolution. In addition to following the progress of a particular study, the principal role of a task force is to determine whether to authorize the publication of any report resulting from the study and the introduction of any proposed legislation contained in the report. However, task force authorization does not necessarily reflect endorsement of all the findings and recommendations contained in a report.

Some studies involve an appointed advisory committee of professionals or interested parties from across the Commonwealth with expertise in a particular topic; others are managed exclusively by Commission staff with the informal involvement of representatives of those entities that can provide insight and information regarding the particular topic. When a study involves an advisory committee, the Commission seeks consensus among the members.[2] Although an advisory committee member may represent a particular department, agency, association, or group, such representation does not necessarily reflect the endorsement of the department, agency, association, or group of all the findings and recommendations contained in a study report.

[1] Act of July 1, 1937 (P.L.2460, No.459); 46 P.S. §§ 65–69.

[2] Consensus does not necessarily reflect unanimity among the advisory committee members on each individual policy or legislative recommendation. At a minimum, it reflects the views of a substantial majority of the advisory committee, gained after lengthy review and discussion.

Over the years, nearly one thousand individuals from across the Commonwealth have served as members of the Commission's numerous advisory committees or have assisted the Commission with its studies. Members of advisory committees bring a wide range of knowledge and experience to deliberations involving a particular study. Individuals from countless backgrounds have contributed to the work of the Commission, such as attorneys, judges, professors and other educators, state and local officials, physicians and other health care professionals, business and community leaders, service providers, administrators and other professionals, law enforcement personnel, and concerned citizens. In addition, members of advisory committees donate their time to serve the public good; they are not compensated for their service as members. Consequently, the Commonwealth receives the financial benefit of such volunteerism, along with their shared expertise in developing statutory language and public policy recommendations to improve the law in Pennsylvania.

The Commission periodically reports its findings and recommendations, along with any proposed legislation, to the General Assembly. Certain studies have specific timelines for the publication of a report, as in the case of a discrete or timely topic; other studies, given their complex or considerable nature, are ongoing and involve the publication of periodic reports. Completion of a study, or a particular aspect of an ongoing study, generally results in the publication of a report setting forth background material, policy recommendations, and proposed legislation. However, the release of a report by the Commission does not necessarily reflect the endorsement by the members of the Executive Committee, or the Chair or Vice-Chair of the Commission, of all the findings, recommendations, or conclusions contained in the report. A report containing proposed legislation may also contain official comments, which may be used to construe or apply its provisions.[3]

Since its inception, the Commission has published over 450 reports on a sweeping range of topics, including administrative law and procedure; agriculture; athletics and sports; banks and banking; commerce and trade; the commercial code; crimes and offenses; decedents, estates, and fiduciaries; detectives and private police; domestic relations; education; elections; eminent domain; environmental resources; escheats; fish; forests, waters, and state parks; game; health and safety; historical sites and museums; insolvency and assignments; insurance; the judiciary and judicial procedure; labor; law and justice; the legislature; liquor; mechanics' liens; mental health; military affairs; mines and mining; municipalities; prisons and parole; procurement; state-licensed professions and occupations; public utilities; public welfare; real and personal property; state government; taxation and fiscal affairs; transportation; vehicles; and workers' compensation.

Following the completion of a report, subsequent action on the part of the Commission may be required, and, as necessary, the Commission will draft legislation and statutory amendments, update research, track legislation through the legislative process, attend hearings, and answer questions from legislators, legislative staff, interest groups, and constituents.

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[3] 1 Pa.C.S. § 1939.

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February 2024

To the Members of the General Assembly of Pennsylvania:

We are pleased to release *Benefits of Nuclear Energy and Development of Small Modular Reactors*, as directed by House Resolution 238 of 2022. The report presents a "holistic study on the benefits of nuclear energy and small modular reactors." It provides a detailed background on nuclear power development and use in the US and Pennsylvania and discusses the benefits, safety considerations, and the economics of the research, development, and construction of small modular reactors (SMR). Further, it presents case studies on other states' experiences with SMR. Information for this report was gathered from federal and state agencies, power industry reports, and university researchers, among others.

The full report is available on our website, http://jsg.legis.state.pa.us.

Respectfully submitted,

Glenn J. Pasewicz
Executive Director

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# INTRODUCTION

Electric generation from nuclear power has a long and conflicting history in Pennsylvania. The United States' first commercial nuclear power plant was built in Beaver County 66 years ago. Since that time, nuclear power plants have safely and efficiently powered millions of homes and businesses. Currently, nuclear power comprises a third of the electricity generated within the Commonwealth. Nuclear power is notable for a variety of positive traits such as providing base load power which supports grid stability, low refueling costs due to its high fuel density, efficient land use, low volume of waste per energy produced, and is our largest source of emission-less energy.

Pennsylvania was also home to the largest commercial nuclear power plant accident in the history of the United States at Three Mile Island in Dauphin County. While no deaths or illnesses are attributed to this incident by researchers, the legacy of the accident is still important. The accident incited panic locally and nationally, caused severe distrust of the industry, and led to an increase U.S. nuclear safety regulation that had a lasting effect on the way the public engages with nuclear energy. While spent nuclear fuel, a highly radioactive biproduct, can be safely contained within steel-lined concrete pools and casks on site, it is not a viable or cost-effective long-term waste solution. The primary challenge facing nuclear waste is its unpopularity, resulting in political inaction over locating the final site for its disposal in a deep geographic repository.

In recent years, nuclear power plants have struggled to compete with energy sources such as natural gas, wind, and solar, which have grown cheaper over time. In contrast, the construction of new nuclear power plants has grown significantly more expensive. Unreliable cost estimates and delays precede power plants costing billions of dollars more than projected. While these expenses are often blamed on Federal regulations, the source of the cost increases appears related to difficulties in project management and construction.

In response to these developments, House Resolution 238, Printer's No. 3602 was adopted on November 15, 2022 and directed the Joint State Government Commission to conduct a study on the benefits of nuclear energy and small modular reactors and how to maximize those benefits within the Commonwealth.

New small modular reactor (SMR) designs have the potential to change the way nuclear plants are constructed in the United States. Instead of enormous, difficult to build reactors, numerous small ones will be constructed inside factories and shipped on truck beds to sites where multiple units are joined together. Smaller, simpler designs also allow for new passive safety features capable of limiting the risk to nearby communities. SMRs could also unlock new ways to use nuclear power, such as industrial heat application, desalinization, or generating hydrogen. Detailed information on the cost effectiveness and practicality of SMR nuclear power plants is still limited. SMR are believed to be approximately six years away from commercial release in the U.S. and questions remain around their licensing, cost, and supply chains.

Regardless of advances in technology, nuclear energy will likely never be the best energy source to provide a quick return on investment or offer the cheapest energy to consumers. However, a case can be made for nuclear from the benefits of having a diversified energy portfolio, durable and long-lasting energy infrastructure, grid stability, and lack of harmful air emissions.

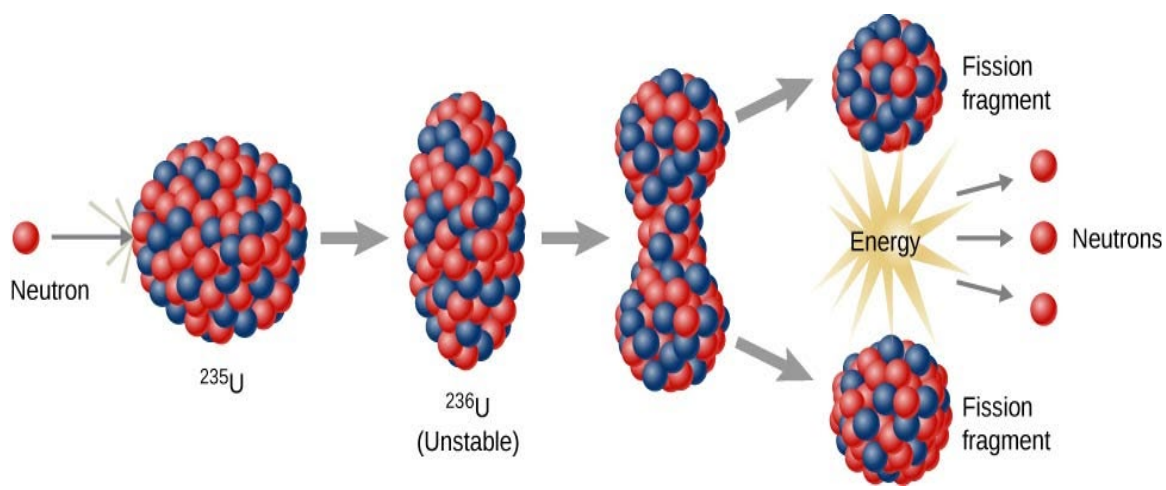
The staff would like to thank the Gateway for Accelerated Innovation in Nuclear, a project from the Idaho National Laboratory for providing information to assist in this study.

The principal method of generating electricity over the last century was burning fuel sources to create steam. In the case of traditional fossil fuels, such as oil and coal, resources are burned at a power plant to boil water, which generates the requisite steam. This steam is channeled to move large blades on a turbine. The spinning turbine blades turn magnets within a generator which creates electricity. Many nuclear power plants in operation today produce electricity through similar methods but differ primarily in the type of fuel used to produce steam.

Nuclear power plants are fueled by radioactive elements, typically an isotope of uranium known as U-235.[4] The uranium is stored in small ceramic pellets which are loaded into groups of vertical tubes called fuel assemblies. These fuel assemblies are placed inside a reactor, a room where nuclear reactions will occur. When a nuclear power plant begins operation, the fuel pellets are exposed to a stream of neutrons, causing the uranium atoms to split in a process known as fission. When an atom is split, the neutrons collide with more atoms, leading to a chain reaction within the reactor. Fission of uranium atoms is a continuous and controlled process which occurs when a nuclear power plant is operating.

**Figure 1**

**Model of Uranium Undergoing Nuclear Fission**[5]




Source: University Physics Vol. 3, Openstax.

[4] PA Dept. of Environmental Protection, *Nuclear Energy: Fact Sheet* (Harrisburg, Pennsylvania, 2015).
[5] Samuel J. Ling, William Moebs, and Jeff Sanny, *University Physics Volume 3*, Figure 10.19, OpenStax, September 29, 2016, https://openstax.org/details/books/university-physics-volume-3. Creative Commons License (CC BY-ND 4.0), https://creativecommons.org/licenses/by-nd/4.0/.

While undergoing fission, the fuel releases both heat and radiation. The power plants are carefully designed so that the heat can be released and used for productive purposes, while the radiation is kept contained within.[6] The type of commercial nuclear power plant most used today in the United States are called light-water reactors. The two main types of light-water reactor designs are pressurized-water reactors and boiling-water reactors. In the former, heat from the reactor is transferred through a series of loops, which can turn highly pressurized water into steam.[7] In the latter, the heat from the reactor is used to boil the water so that it evaporates water into steam. See Figures 3 and 4.

Regardless of how the steam is created, it is channeled into the turbine to create electricity. In the United States, nuclear power plant sites are typically comprised of between one and three reactors. The operations of a nuclear reactor can be scaled up or down by inserting control rods into a reactor which absorb neutrons and slow the rate of nuclear fission.[8] Control rods can also be removed to speed up the rate of fission.

One of the major components needed for a nuclear power plant to operate safely is coolant, typically water. The coolant is pumped into the plant to stop the reactor from becoming too hot and to keep the fission occurring at a controlled pace.[9] Excess heat is released into the air through oversized cooling towers, which have become a visual representation of the nuclear energy industry. Despite the similarity in appearance with smokestacks, cooling towers release only hot water vapor into the air, not carbon dioxide or other types of air pollution.

In traditional light water plant designs, the radioactive element uranium is used as fuel. While uranium is typically associated by the public with atomic weaponry, the type used in nuclear reactors is less enriched, it is not in as concentrated a form, and will not explode in the same way. While radiation dangerous to humans is a byproduct of nuclear fission, plants are constructed so that multiple barriers exist between the fuel and other parts of a nuclear power plant to prevent the release of radioactive material. Fuel is stored in ceramic pellets, fuel rods are made from zirconium, and reactor vessels are made of eight-inch-thick steel walls. Finally, the reactor is encased in a four-foot-thick concrete containment structure.

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[6] PA Dept. of Environmental Protection, *supra* n. 4.

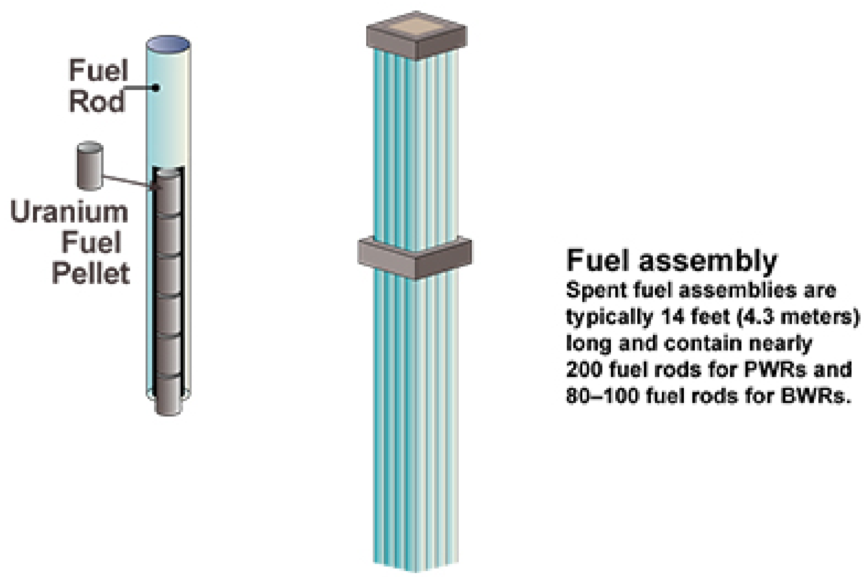
[7] "Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR)," Duke Energy | Nuclear Information Center, March 27, 2012, https://nuclear.duke-energy.com/2012/03/27/pressurized-water-reactors-pwr-and-boiling-water-reactors-bwr.

[8] PA Dept. of Environmental Protection, *supra* n. 4.

[9] *Id*.

**Figure 2**

**Nuclear Fuel Assembly**[10]




Source: NRC.

*Explanation of Units of Power*

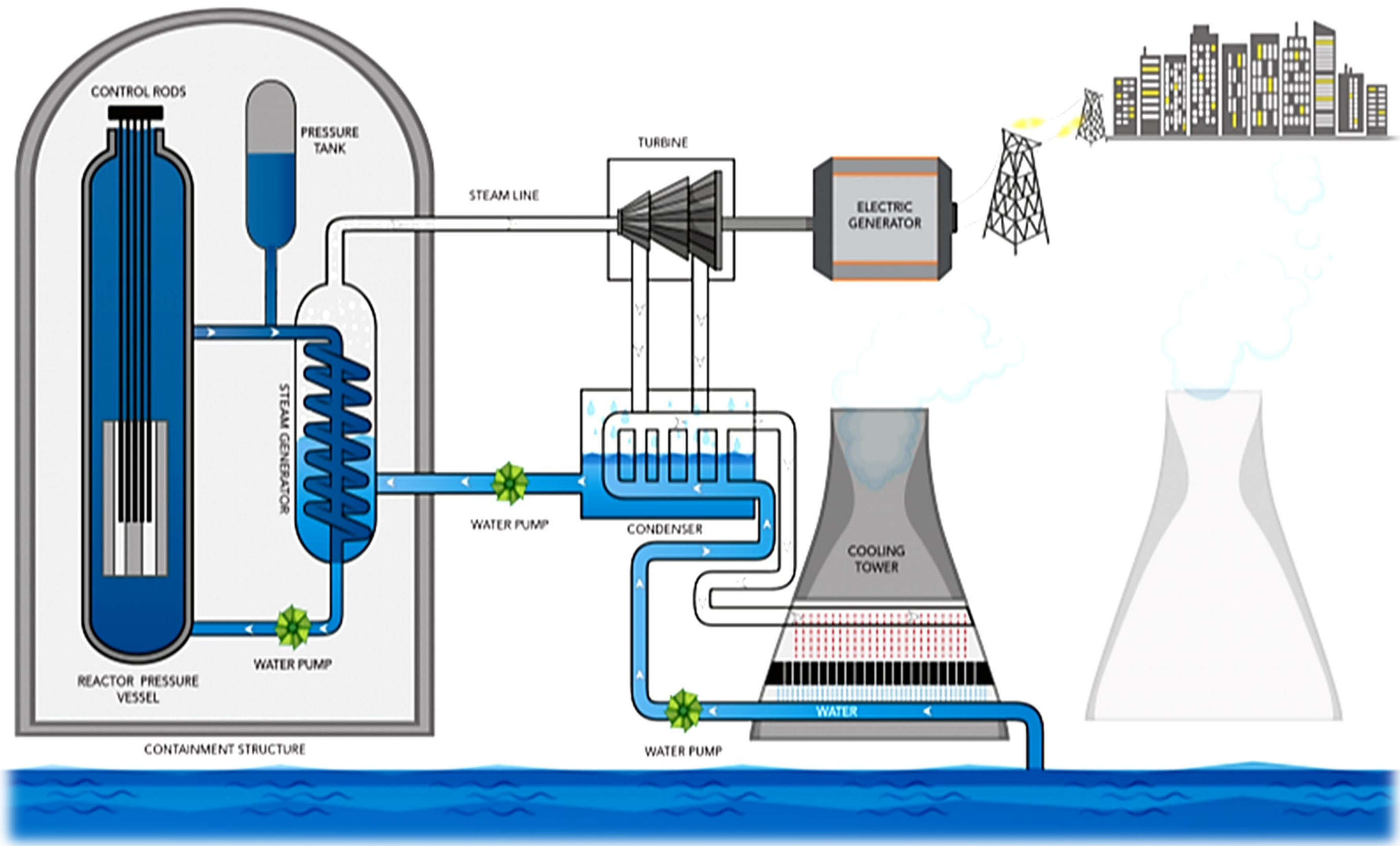
A Watt (W) is a basic unit of power, typically used to describe the rate of energy transfer of an appliance. For example, 18 W is enough to power an LED lightbulb for one second. A kilowatt (kW) is a thousand watts and is frequently used in discussions about electrical appliances. A kilowatt hour (kWh) is a measure of electricity defined as a unit of work or energy measured as one kilowatt of power expended for one hour. Frequently, the kWh is a measurement used for comparisons because it helps standardize electricity use kWh is the unit used when electricity is supplied to or taken from an electric circuit for one hour.

When discussing large energy sources such as power plants that have large generation capacity, their power is labeled in megawatts (MW), which is equal to a million watts. When discussing the output of power plants, sometimes the amount of power generated is expressed as Megawatt Electric (MWe) to differentiate it from MW of thermal energy. A gigawatt (GW) is a billion watts, which is the unit of power used to describe electricity on a grid level, and the power output of some larger nuclear stations.

[10] U.S. Nuclear Regulatory Commission, "Fuel Assembly (Fuel Bundle, Fuel Element)", January 2023, NRC.gov, January 2023, https://www.nrc.gov/reading-rm/basic-ref/glossary/fuel-assembly-fuel-bundle-fuel-element.html.

**Figure 3**

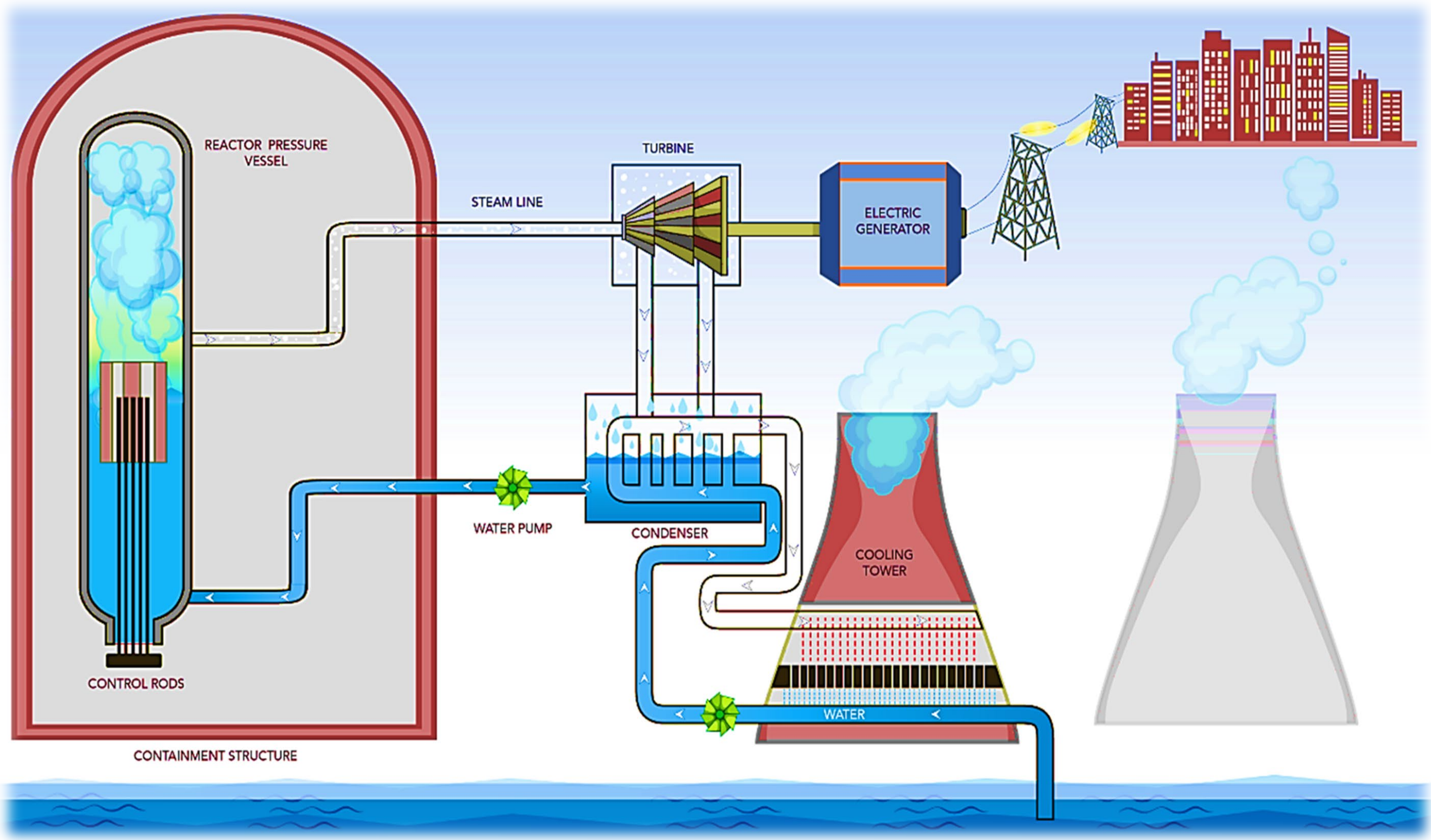
**Pressurized Water Reactor (PWR)**




Source: Figure by U.S. Dept. of Energy, Office of Nuclear Energy.

**Figure 4**

**Boiling Water Reactor (BWR)**




Source: Figure by U.S. Dept. of Energy, Office of Nuclear Energy.

# BENEFITS OF NUCLEAR POWER

*Background*

By the early 1950s, it was evident that nuclear technology posed an existential threat to the planet. Four countries, including the Soviet Union, had developed nuclear weapons, and the United States had moved on to successfully testing larger, more powerful nuclear weapons that use fusion, rather than fission, to operate. As part of his goal to reduce the threat of nuclear war, President Eisenhower proposed a policy of using nuclear technology for "effective peacetime uses" in a speech before the United Nations in 1953. A "special purpose" of this initiative would be to "provide abundant electrical energy in the power-starved areas of the world."[11]

Eisenhower's speech, known as the "Atoms for Peace" speech, was followed in 1954 by the Atomic Energy Act of 1954, which declared it to be the policy of the United States that:

> (a) the development, use, and control of atomic energy shall be directed so as to make the maximum contribution to the general welfare, subject at all times to the paramount objective of making the maximum contribution to the common defense and security; and
>
> (b) the development, use, and control of atomic energy shall be directed so as to promote world peace, improve the general welfare, increase the standard of living, and strengthen free competition in private enterprise.[12]

The promise of nuclear power was part of the optimism of the era, with the Chairman of the Atomic Energy Commission Lewis Strauss projecting in 1954 that nuclear power "too cheap to meter" would "not be too much to expect" for the coming era. Despite these predictions, nuclear power has not been without significant cost.[13] In fact, when that statement was made, it was panned by those in the electric utility industry who pointed out that fuel costs were a small part of an electric utility customer's bill.[14]

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[11] President Dwight D. Eisenhower, Address Delivered by the President of the United States before the General Assembly of the United Nations in New York City, December 8, 1953, *available at* https://www.eisenhowerlibrary.gov/sites/default/files/file/atoms_Binder13.pdf.

[12] Atomic Energy Act of 1954; Pub. L. 102-486, title IX, § 902(a)(8); 42 U.S.C. § 2011.

[13] U.S. Atomic Energy Commission, Remarks Prepared by Lewis L. Strauss, Chairman, United States Atomic Energy Commission, for Delivery at the Founders' Day Dinner, National Association of Science Writers, September 16, 1954, New York, New York, *available at* https://www.nrc.gov/docs/ML1613/ML16131A120.pdf.

[14] U.S. Nuclear Regulatory Commission, "'Too Cheap to Meter': A History of the Phrase," Sept. 24, 2021, https://www.nrc.gov/reading-rm/basic-ref/students/history-101/too-cheap-to-meter.html.

Although no source of energy has become "too cheap to meter," nuclear power is a part of our modern world, as envisioned 70 years ago. It is also true that residential electricity prices in the United States fell in real terms from 1960 to 2003.[15] It is unclear to what extent nuclear power influenced retail electricity prices — more coal capacity was added in this time frame and prices are influenced by more than the amount of electricity generated — but nuclear power generation reached 15 percent of total electricity generation in the United States in 1985 and approximately 20 percent over the last thirty years.[16]

*Benefits*

Irrespective of any effect on price, nuclear power provides other benefits. Nuclear power is the largest source of clean power in the United States. Not only is nuclear power generation free from carbon dioxide emissions, but it is also free from emissions of sulfur dioxide, nitrogen oxides, and mercury, thereby preserving the air quality from those hazardous byproducts of fossil fuel generation.

Nuclear energy also produces minimal waste per volume. This is because nuclear fuel is extremely energy dense. A one-inch-tall uranium pellet holds the same energy as 17,000 cubic feet of natural gas or one ton of coal. All of the fuel used in nuclear power plants in the entire United States could fit on a football field at a depth of less than 10 yards.[17]

Generating electricity from nuclear power also has additional advantages sources of renewable energy do not have. For one, nuclear power plants have a small footprint. A nuclear generating station requires about one square mile for a typical 1,000-megawatt facility. In comparison, to generate the same amount of electricity wind turbines would need 360 square miles, and 75 square miles of solar panels would be needed.[18]

Further, the nuclear industry supports nearly half a million jobs in the United States and contributes an estimated $60 billion to the U.S. gross domestic product every year. A typical nuclear power plant employs 700 people with salaries that are 30 percent higher than the local average. Nuclear power also has a national security aspect, as having a robust nuclear industry helps the United States influence the peaceful use of nuclear technology around the world.[19]

On the grid, the benefit of nuclear energy is the large baseload power it provides. Baseload power is the minimum amount of electric power required by the grid over a given period of time at a steady rate.[20] Baseload generating stations operate 24 hours a day year-round, with downtime only for maintenance. Without a baseload source of electricity, the grid could experience fluctuations in the amount of energy that can be delivered to end users. This could result in

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[15] U.S. Energy Information Administration, "Short Term Energy Outlook, Real Prices Viewer, Residential Electricity Prices," Jul. 11, 2023, https://www.eia.gov/outlooks/steo/realprices/.
[16] U.S Energy Information Administration, "Annual Energy Review 2011," Table 9.2 Nuclear Power Plant Operations, 1957-2011, p. 273, 2011, https://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf.
[17] U.S. Department of Energy, "3 reasons why nuclear is clean and sustainable," Mar. 31, 2021, https://www.energy.gov/ne/articles/3-reasons-why-nuclear-clean-and-sustainable.
[18] *Id.*
[19] *Id*.
[20] U.S. Energy Information Administration, Glossary, "Base load," https://www.eia.gov/tools/glossary/.

blackouts and damage to transmission equipment if there are not sufficient dispatchable sources of electricity. Traditionally, coal or nuclear plants have provided baseload power, but it is also possible to use natural gas, hydro, and geothermal power.[21]

This benefit is particularly relevant to Pennsylvania and the Pennsylvania, New Jersey, and Maryland (PJM) interconnection. According to a report by PJM, approximately 40 GW of fossil fuel generating capacity may be pressured to retire by 2027, with the majority of that capacity being shut down due to government policies. At the current low rates of entry of new renewables generation, the total capacity from generating resources would not meet projected peak loads.[22]

Discussing the impact this will have, PJM states that "PJM markets provide incentives for capacity resources…. As capacity reserve levels tighten, the markets will clear higher on VRR[23] curves [Variable Resource Requirement], sending price signals to build new generation for reliability needs."[24] However, should the trend of generating unit retirements outpacing the entry of new resources continue, PJM could face decreasing reserve margins and ultimately PJM's ability to maintain the reliability of the electric system.

In addition to providing baseload power, nuclear power plants provide grid resiliency, as they can operate in any weather condition and without reliance on trains or pipelines to transport fuel. Extreme weather has caused power generation outages in the past, as gas-fired plants ran into capacity constraints limiting the amount of gas they could access for power and frozen coal piles forced the shutdown of coal-fired generating units.

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[21] See Benjamin Matek and Karl Gawell, "The Benefits of Baseload Renewables: A Misunderstood Energy Technology," The Electricity Journal 28, Issue 2, Mar. 2015, 101-112, *available at* https://www.sciencedirect.com/science/article/pii/S104061901500024X#sec0010 (discussing renewable energy's impact on baseload power generation, overgeneration, and grid balancing).

[22] PJM Interconnection, "Energy Transition in PJM: Resource Retirements, Replacements & Risks," p. 16, Feb. 24, 2023, https://www.pjm.com/-/media/library/reports-notices/special-reports/2023/energy-transition-in-pjm-resource-retirements-replacements-and-risks.ashx.

[23] Variable Resource Requirement is PJM's administrative demand curve for capacity that establishes the maximum price that PJM would pay for a given quantity of capacity.

[24] PJM Interconnection, Energy Transition, *supra* n. 22 at p. 16.

*Current Status*

Nuclear power has been a part of Pennsylvania since 1953, when the Shippingport Atomic Power Station, the world's first large-scale commercial nuclear power plant, began operation just outside of Pittsburgh. Although the Department of Energy began decommissioning the Shippingport plant in June 1984[25] and finished in December 1989,[26] the Commonwealth is presently home to eight reactors across four nuclear power plants. See Table 1.

**Table 1**

**Pennsylvania Operating Nuclear Power Plants, 2024**

| Plant | Commissioning[27] | Licensed Through | Reactor Type | Operator |
|---|---|---|---|---|
| Susquehanna Steam Electric Station | **Unit 1**: June 8, 1983 **Unit 2**: February 12, 1985 | **Unit** 1: July 17, 2042 **Unit 2**: March 23, 2044 | General Electric BWR-4 | Talen Energy |
| Peach Bottom Atomic Power Station | **Unit 2**: July 5, 1974 **Unit 3**: December 23, 1974 | **Unit 2**: August 8, 2053 **Unit 3**: July 2, 2054 | General Electric BWR-4 | Constellation Energy |
| Limerick Generating Station | **Unit 1**: February 1, 1986 **Unit 2**: January 8, 1990 | **Unit 1**: October 26, 2024 **Unit 2**: June 22, 2029 | General Electric BWR-4 | Constellation Energy |
| Beaver Valley Power Station | **Unit 1**: October 1, 1976 **Unit 2**: November 17, 1987 | **Unit 1**: January 29, 2036 **Unit 2**: May 27, 2047[28] | Westinghouse PWR 3-Loop | Energy Harbor Nuclear |

Source: Compiled by Joint State Government Commission staff from the U.S. Nuclear Regulatory Commission and the U.S. Energy Information Administration.

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[25] International Atomic Energy Agency, "Decontamination and Decommissioning of Nuclear Facilities: Final Report of Three Research Co-ordination Meetings Held by the International Atomic Energy Agency and Held Between 1984 and 1987," 1989, p. 93, https://www-pub.iaea.org/MTCD/Publications/PDF/te_511_prn.pdf.

[26] Government Accountability Office, "Nuclear Research and Development: Shippingport Decommissioning — How Applicable are the Lessons Learned?," Sept. 1990, https://www.gao.gov/assets/rced-90-208.pdf.

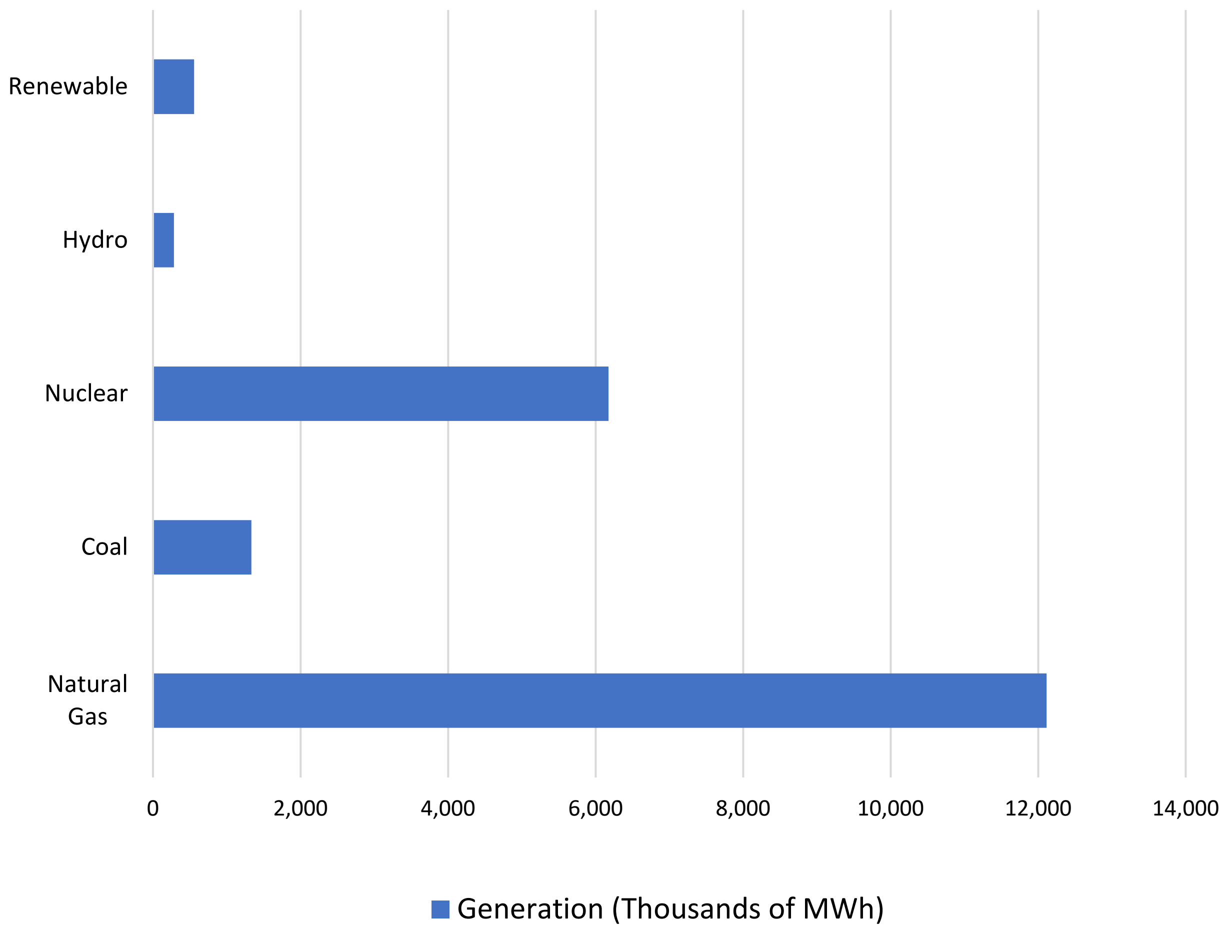
[27] U.S. Energy Information Administration, "State Nuclear Profiles 2010," n.d., https://www.eia.gov/nuclear/state/archive/2010/pennsylvania/pdf/pennsylvania.pdf. (source for the date of plant commissioning).

[28] U.S. Nuclear Regulatory Commission, "Beaver Valley Power Station, Unit 2," NRC.gov, July 5, 2023, https://www.nrc.gov/info-finder/reactors/bv2.html.

Nuclear power is the second-largest source of electricity in the Commonwealth, after natural gas. In March of 2023, the eight nuclear reactors in Pennsylvania generated 6,173,000 MWh of electricity, natural gas-fired plants generated 12,114,000 MWh, and coal-fired plants generated 1,335,000 MWh of electricity. These sources dwarf electricity produced by non-hydro renewable sources (559,000 MWh generated) and hydroelectric (284,000 MWh generated).[29] See Graph 1.

**Graph 1**

**Pennsylvania Net Electricity Generation by Source**
**March 2023**




Source: U.S. Energy Information Administration, Pennsylvania Profile Overview, Pennsylvania Net Electricity Generation by Source.

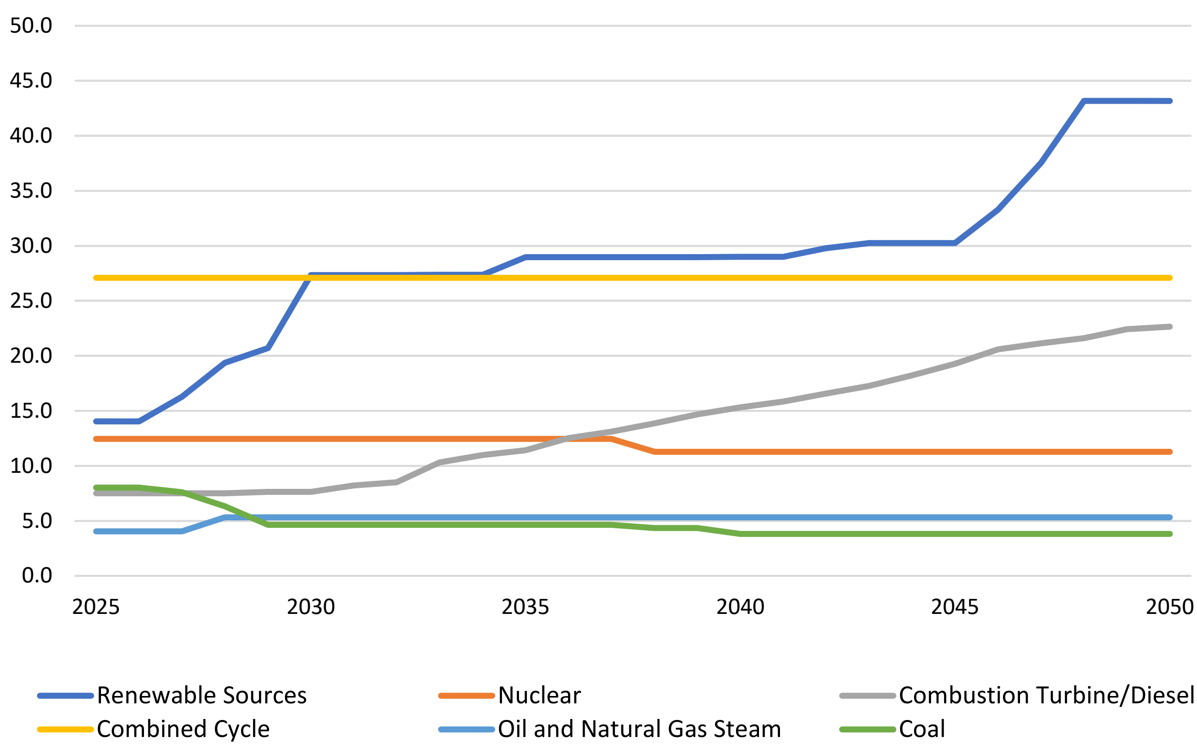
[29] U.S. Energy Information Administration, "Pennsylvania Profile Overview," accessed July 6, 2023, https://www.eia.gov/state/?sid=PA#tabs-4.

Pennsylvania is the third-largest producer of electricity behind only Texas and Florida and is the first among all states in electricity exports.[30] As part of the PJM Interconnection, Pennsylvania shares its electricity with 13 other states as far west as Illinois and as far south as North Carolina, plus Washington, D.C.

This electricity comes chiefly from natural gas, which comprises 53 percent of all electricity generated per year. This percentage is set to expand with new natural gas plants scheduled to come online by 2025 and the retirement of the coal-fired Homer City Generating Station. Nuclear energy accounts for about 30 percent of Pennsylvania's annual electricity generation.[31] Over the next 28 years, nuclear capacity is currently forecasted to decrease by 1GW of capacity in the PJM Region and while over 29 GW of renewable energy sources are expected to be installed. See Graph 2.

**Graph 2**

**Installed Electric Power Capacity in GW: PJM /East Region 2025-2050**




Source: U.S. EIA Annual Energy Outlook March 2023.

[30] *Id.*
[31] U.S. Energy Information Administration, "Pennsylvania Profile Analysis," Nov. 17, 2022, https://www.eia.gov/state/analysis.php?sid=PA.

*Three Mile Island Accident*

Three Mile Island (TMI) Nuclear Generating Station in Londonderry Township, a few miles south of Harrisburg, is perhaps the best-known nuclear power plant in the United States. Unfortunately, this is because Unit 2 experienced a partial core meltdown in 1979. It occurred when a malfunction in the secondary coolant system caused the temperature of the primary coolant to rise. This caused the reactor to shut down and release a valve to get rid of some of the overheated cooling liquid.

However, the relief valve failed to close. Instrumentation on the Unit 2 reactor did not reveal that the relief valve had failed to close. The failure of this valve caused the primary coolant to drain away. Another automatic system continued to pump water into the pressurizer, raising the water level in it. Because the instrumentation failed, operators at the plant did not know that the relief valve was still open and draining cooling water away from the core. As a consequence, they reduced the flow of replacement water to the pressurizer to avoid over-pressurization in the cooling system. The reactor coolant water boiled away, and uncovered fuel core overheated, partially melting and releasing radioactive material.

The incident shook public confidence in nuclear power and was a cause of the decline of nuclear power plant construction in the 1980s and 1990s. TMI Unit 1 was also shut down for over half a decade while regulators determined the best course of action regarding safety and training. After being restarted in 1985, TMI's Unit 1 operated safely until its shutdown in 2019.[32]

*Causes for Three Mile Island Shutdown*

In the years prior to the shutdown of Three Mile Island Unit 1, nuclear power provided 42 percent of the Commonwealth's electricity production.[33] The plant shut down September 2019 as a result of a poor financial outlook, as the price of the electricity it was able to sell was below the cost of maintaining and operating the plant.

Since energy deregulation in 1996, nuclear power plants have had to compete with other energy sources in annual wholesale energy auctions to determine who will provide power.[34] Local power plants compete with other energy sources in the Pennsylvania, New Jersey, Maryland (PJM) region. Energy auctions typically favor the cheapest energy options and in many ways this method is friendly to energy consumers by keeping costs low but have proven an obstacle to selling electricity produced by nuclear power.

The main reason TMI closed was that it could not economically compete in the energy market due to a surplus of cheap natural gas following the Marcellus shale boom. Renewable energy sources were insulated from this market disruption due to State policy choices, but nuclear

[32] World Nuclear Association, "Three Mile Island Accident," Apr. 2022, https://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/three-mile-island-accident.aspx.
[33] Bicameral Nuclear Energy Caucus Report, 2017-2018 Session, Nov. 2018, p.3, https://nuclearenergy.pasenategop.com/wp-content/uploads/sites/90/2018/11/Nuclear-Energy-Caucus-Report-November-2018.pdf.
[34] Hannah Pell, Ryan Hearty, David Allard, *Why did the Three Mile Island Unit 1 Reactor Close? Physics Today* 75 (6), 46–52 (2022).

was not. Credits were only provided to renewable energy sources, so nuclear is counted the same as natural gas, coal and other energy sources that emit carbon. Proponents of nuclear argue that this market system promotes cheap energy over grid reliability, jobs, and air quality.[35] From this point of view, closing nuclear plants may be short sighted and as closed plants cannot be restarted without great expense.

A variety of legislative solutions were proposed in the past to make nuclear power plants more solvent, but a coalition could not garner the necessary support before the closure of TMI.[36]

While environmentally conscious Pennsylvanians might advocate that shuttered nuclear power plants be replaced with renewable energy sources, that is unlikely given the current market incentives. When TMI closed, the percent of nuclear power generated by Pennsylvania dropped by eight percent from 2018 to 2021.[37] The amount of power coming from renewable energy sources did not significantly change, resting at three to four percent. Over that same four-year period, electricity produced by natural gas rose from 35 to 53 percent, as natural gas replaced the energy previously supplied by coal and nuclear sources.

While some nuclear may be offset with new solar and wind, the rest of the shortfall would likely be made up of natural gas which will increase the total amount of carbon produced. Due to the current reality of storing spent nuclear waste on site, they present environmental risks whether they are functioning or not. Premature closure means that communities that already host these sites continue to bear the risk of storing nuclear waste with little benefit to offset it. Additionally, closing nuclear power plants also carries risks for communities, from losing jobs to increasing the amount of carbon in the air.

*Alternative Energy Portfolio Standard*

In 2004, Pennsylvania adopted an alternative energy portfolio standard (AEPS) that required the state to use alternative energy sources for 18 percent of the state's electricity retail sales by 2021, with at least 0.5 percent from solar energy.[38] The definition of alternative energy includes solar, wind, low-impact hydropower, large-scale hydropower, coal mine methane, biologically derived methane gas, municipal solid waste, and wood and paper pulping by-products, among others. Nuclear power is not included.[39]

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[35] *Id.*
[36] *Id.*
[37] PA Public Utility Commission and PA Dept of Environmental Protection, "Alternative Energy Portfolio Standards Act of 2004: Compliance for Reporting Year 2021 - 22," *PA PUC.Gov*, March 22, 2023, p. 23, https://www.puc.pa.gov/media/2332/aeps-2022-report-final-032223-_dm.pdf.
[38] Act of November 30, 2004 (P.L. 1672, No. 213, § 3); 73 P.S. § 1648.3 (hereinafter Alternative Energy Portfolio Standards Act).
[39] Alternative Energy Portfolio Standards Act §2; 73 P.S. § 1648.2.

Renewable energy sources as counted by the U.S. Energy Information Administration — hydroelectric, wind, and solar — accounted for three percent of the Commonwealth's energy production in 2021.[40] However, using the AEPS definition, the Commonwealth has met the 18 percent consumption of alternative energy by retail customers benchmark as of 2021.[41] This is because the AEPS standard is a measure of retail electricity consumption — not production — and (with certain exceptions) the AEPS standard can be met by purchasing electricity generated by renewable sources outside of Pennsylvania.

*Pennsylvania Climate Action Plan*

Although nuclear power is excluded from the Alternative Energy Portfolio Standard, there is some support for nuclear power generation in the Governor's announced Climate Action Plan (CAP). As a "near-term" goal, the CAP aims to maintain nuclear power generation at current levels, with creating a carbon emissions-free grid as a long-term policy goal. To create this grid, the DEP believes that the AEPS requirement for retail electricity consumption should be expanded from the current 18 percent to 100 percent and that the eligible sources should be expanded to include nuclear as a generating source.[42] The CAP recognizes that the vast majority of Pennsylvania's zero emission electricity production currently is from nuclear power plants.[43]

*Recent Action*

While TMI's closure was a preventable and potentially wasteful use of Pennsylvania's existing energy infrastructure, it is unlikely to be repeated. The announced closure of Beaver Valley was forestalled by Pennsylvania joining Regional Greenhouse Gas Initiative in 2019. While cap and trade programs can be politically contentious, they benefit nuclear power plants by charging other energy sources for carbon released into the air. In November of 2023, the Pennsylvania Commonwealth Court ruled that Pennsylvania's participation in the RGGI amounted to an unconstitutional tax, since it was not approved by the Pennsylvania General Assembly.[44] Due to an appeal, this decision will be reviewed by the Pennsylvania Supreme Court at later date.

Even without participating in the RGGI, more nuclear power plant closures are unlikely to occur over the next decade due to recent federal intervention. In November of 2021, the U.S. Congress passed the Bipartisan Infrastructure Investment and Jobs Act. This law provided six billion dollars in relief in the form of credits for nuclear power plants in economic distress. The act is funded through fiscal year 2026 and can provide $1.2 billion a year. The plan will prioritize plants that use domestically sourced uranium. In the first round of funding, it saved the California power plant Diablo Canyon from closure. Also included was a U.S. Dept. of Energy loan program

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[40] Pennsylvania Profile Analysis, *supra* n. 31.

[41] Pennsylvania Public Utilities Commission, "Electric Power Outlook for Pennsylvania 2020-2025," Aug. 2021, p. 14, https://www.puc.pa.gov/media/1604/epo-report2021.pdf.

[42] "Pennsylvania Climate Action Plan" (Harrisburg: PA. Dept. of Environmental Protection, 2021), pp. 85-86.

[43] *Id*. at p. 19.

[44] *Ziadeh v. Pa. Legislative Reference Bureau et al.* 41 MD 2022 (Pa. Cmwlth. November 1, 2023).

to help reduce investor risk in nuclear power plants as well as funding for demonstration projects for hydrogen fuel production.[45]

In 2022, the Inflation Reduction Act created tax credits available through 2032 for existing nuclear reactors. These credits will subsidize 50 percent of the capital costs of new nuclear reactors. Also includes a production subsidy worth up to double the value for existing reactors, which will go into effect in 2024. An estimated 22 nuclear power plants have avoided closure, and no new nuclear power plants have announced retirements as result of these actions.[46]

[45] Hogan Lovells, Stephanie Fishman, and Amy Roma, "Summary of Nuclear Energy Provisions in the Infrastructure Bill," JD Supra, November 16, 2021, https://www.jdsupra.com/legalnews/summary-of-nuclear-energy-provisions-in-4352559/.
[46] Daniel Esposito, "How Policy Saved America's Nuclear Power Plants," Forbes, November 9, 2023, https://www.forbes.com/sites/energyinnovation/2023/11/08/how-policy-saved-americas-nuclear-power-plants/.

*Background*

The chief concern of the public relating to nuclear energy is its role in producing radioactive waste as a byproduct of generating electricity. There are two primary types of nuclear waste which differ based on their levels of radioactivity. Low-level waste from nuclear power plants could be any item that has been contaminated with neutron radiation. Waste could include protective coverings, cleaning supplies, tools, or parts from inside a reactor vessel. Typically, this low-level waste is stored on site until it is not as radioactive and can be disposed of through regular means. Another possibility is the waste may be shipped to one of four low-level disposal sites throughout the country in U.S. Dept. of Transportation approved containers capable of withstanding most major traffic accidents.[47] It should be noted that nuclear power plants are the second largest source of low-level waste in the region behind the industrial section.

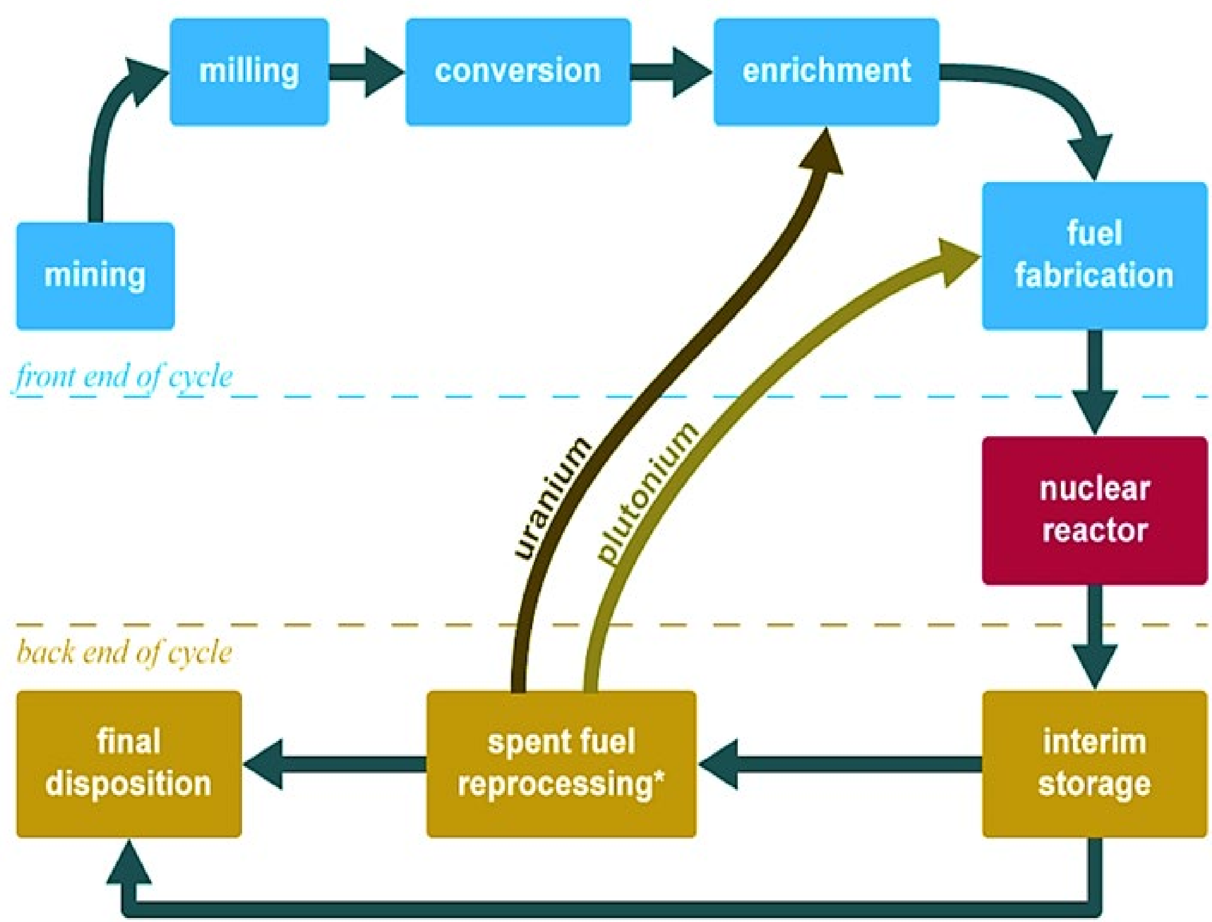
While low-level nuclear waste must be tracked and disposed of properly, high-level radioactive waste (HLRW) presents a much greater risk to human health if mishandled and requires extreme precautions because this type of waste produces levels of radiation that decay over hundreds of human life spans. The main source of this HLRW is spent nuclear fuel. Over time fuel loaded into a reactor becomes less efficient for generating electricity and must be replaced. In the U.S. nuclear power plants, fuel typically lasts every three to six years. About once a year, a quarter of a reactor's fuel is replaced.[48] Spent nuclear fuel does not appear visually different from when it entered reactors in the fuel assembly, and contrary to its depictions in media, is solid rather than liquid. Over 95 percent of the spent fuel consists of uranium 238. Spent fuel also contains one percent of uranium-235 and the remaining four percent fissile plutonium and other radioactive elements.[49] Spent fuel removed from the reactor is not only radioactive but also produces thermal heat in excess of 1,000 degrees Fahrenheit.[50]

[47] U.S. Nuclear Regulatory Commission "Low-Level Waste," NRC Web, 2020, https://www.nrc.gov/waste/low-level-waste.html.
[48] "The Nuclear Fuel Cycle," U.S. Energy Information Administration (EIA), October 2023, https://www.eia.gov/energyexplained/nuclear/the-nuclear-fuel-cycle.php.
[49] "Nuclear Fuel Cycle Overview," World Nuclear Association, April 2021, https://world-nuclear.org/information-library/nuclear-fuel-cycle/introduction/nuclear-fuel-cycle-overview.aspx.
[50] Jeff Johnson, "Radioactive Waste Safety," Chemical & Engineering News, March 27, 2023, https://cen.acs.org/articles/91/i44/Radioactive-Waste-Safety.html.

Unlike some types of industrial waste like heavy metals, which are permanently dangerous, HLRW has the potential to become less dangerous over long periods time as it decays.[51] It takes between 1,000 and 10,000 years for HLRW to revert to the radioactivity of mined uranium ore. Direct exposure to high levels of radiation is harmful to the tissue and DNA of humans and animals, and can be lethal. There is also a risk of indirect exposure if HLRW is improperly stored and contaminates the environment and enters the food chain.[52] Due to these concerns, HLRW is a highly regulated substance which must be carefully contained by plant owners and monitored by the NRC.

**Figure 5**

**Nuclear Fuel Cycle**




*Spent Fuel reprocessing is omitted from the cycle in most counties, including the United States.

Source: U.S. Energy Information Administration.

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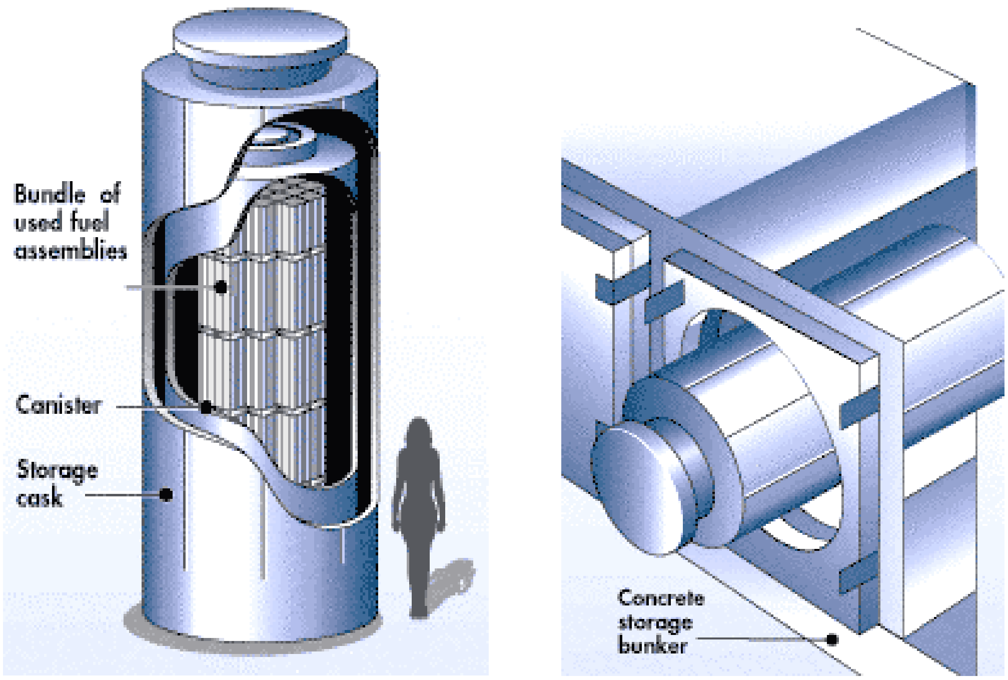
[51] "Radioactive Waste - Myths and Realities," World Nuclear Association, January 2022, https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx.
[52] U.S. Nuclear Regulatory Commission, "Backgrounder on Radioactive Waste," NRC Web, January 2024, https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/radwaste.html.

Once it is time to refuel a reactor, old fuel assemblies are removed and brought to large steel lined concrete storage pools located on plant grounds. These pools are full of cool circulating water to dissipate heat and shield plant workers against radioactivity. The pools are kept under guard by security personnel. The HLRW is stored in the pools for a minimum of a year to over a decade.[53]

The cooled fuel assemblies are brought out of the pool and loaded into steel cylinders containing inert gases to prevent corrosion and are either bolted or welded shut to prevent leakage. These casks are then covered with additional steel or concrete to provide additional radiation shielding.[54] While some dry casks are designed for transport, currently nuclear waste remains onsite even after a plant closure. Currently there is no place in the US to store HLRW until the Department of Energy builds a permanent repository or a consolidated interim storage facility becomes available.

**Figure 6**

**Dry Cask Storage**[55]




Source: Nuclear Regulatory Commission.

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[53] U.S. Nuclear Regulatory Commission, "What Is Spent Nuclear Fuel?," NRC Web, June 16, 2023, https://www.nrc.gov/reading-rm/basic-ref/students/science-101/what-is-an-spent-fuel.html.
[54] U.S. Nuclear Regulatory Commission "Dry Cask Storage," NRC Web, June 2023, https://www.nrc.gov/waste/spent-fuel-storage/dry-cask-storage.html.
[55] U.S. Nuclear Regulatory Commission" Typical Dry Cask Storage System", July 2020 https://www.nrc.gov/waste/spent-fuel-storage/diagram-typical-dry-cask-system.html.

While nuclear waste can be a source of great concern for nearby communities, the main risk caused by spent fuel is the nation's lack of a permanent disposal site. The Nuclear Waste Policy Act of 1982 is one of the most important laws in the United States surrounding the storage of HLRW. The intention of the act was to build a storage facility far underground called a deep geologic repository which would house the nation's supply of HLRW generated from its power plants. [56] In 1987, the act was amended once Yucca Mountain in Nevada was selected for this site.[57] The U.S. Dept. of Energy (DOE) had been charged with constructing and operating the Yucca Mountain facility by 1998.[58]

For this effort, 40 billion dollars was raised using a surcharge of power plant customers.[59] However, the selection of the site was opposed by local, state, tribal, and environmental groups, and the project was stalled for over a decade before ceasing in 2009.[60] At the time millions of dollars had already been spent preparing to build the deep geologic repository. In 2023, an estimated 86,000 metric tons of spent fuel are stored at 70 reactor sites throughout 35 states.[61] An additional two thousand tons of HLRW are generated each year, about half the size of an Olympic-size swimming pool.[62] In 2021, Pennsylvania stored 8,140 metric tons of spent fuel within its borders.[63] By 2016, Pennsylvania had raised over nearly two billion dollars for the nuclear waste disposal fund for the construction of a permanent waste disposal.[64]

Texas and New Mexico were once considered possible interim consolidated disposal sites, that could accept waste until the construction of a final repository. After extensive application and review process, the NRC had granted both locations 40-year licenses to operate.[65] However, nuclear waste storage can be extremely unpopular among local communities, and state official have voiced opposition to the plans. In both state legislatures laws preventing HLRW from other states being transported or stored have passed.[66] Additionally, there are two lawsuits in federal court to block the operations of these interim disposal sites.[67] In Texas a circuit court has currently

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[56] 42 U.S.C. §10101 *et seq*. (1982).
[57] "Summary of the Nuclear Waste Policy Act," EPA, June 2023, https://www.epa.gov/laws-regulations/summary-nuclear-waste-policy-act..
[58] *Id.*
[59] Nicole Feldman, "The Steep Costs of Nuclear Waste in the U.S.," Stanford Doerr School of Sustainability, July 2, 2018, https://sustainability.stanford.edu/news/steep-costs-nuclear-waste-us#gs.1xy0op.
[60] "Yucca Mountain Research Collection: 2000-2016: The Yucca Mountain Project Grinds to a Halt," University Libraries, University of Nevada, Reno, accessed February 5, 2024, https://guides.library.unr.edu/yuccamountain/timeline2000-2016.
[61] "Used Nuclear Fuel," Nuclear Energy Institute, accessed February 5, 2024, https://www.nei.org/advocacy/make-regulations-smarter/used-nuclear-fuel.
[62] Office of Nuclear Energy, "5 Fast Facts about Spent Nuclear Fuel," Energy.gov, October 3, 2022, https://www.energy.gov/ne/articles/5-fast-facts-about-spent-nuclear-fuel.
[63] "Used Fuel Storage and Nuclear Waste Fund Payments by State," Nuclear Energy Institute, August 2022, https://www.nei.org/resources/statistics/used-fuel-storage-and-nuclear-waste-fund-payments.
[64] *Id*.
[65] U.S. Nuclear Regulatory Commission, "Consolidated Interim Storage Facility (CISF)," NRC Web, December 2020, https://www.nrc.gov/waste/spent-fuel-storage/cis.html.
[66] N.M. Ch. 25, Signed by the Governor March 17, 2023, & Texas House Bill 7, Signed by the Governos Sept. 9, 2021.
[67] New Mexico v. U.S. Nuclear Regulatory Commission, No. 21-9593 (10th Cir. Feb. 10, 2023).

ruled against the facility and revoking the permit.[68] The dispute centers on whether NRCs has the authority to enact temporary waste solutions.

HLRW was never meant to be indefinitely stored at plant sites, and dissatisfied owners successfully sued the US government for being unable to meet its disposal commitment.[69] So far taxpayers have paid plant operators $9 billion for on-site storage of HLRW. This is an ongoing expense that costs U.S. taxpayers approximately $500 million a year.[70] Expansion of the nuclear industry will bring more spent fuel, which may be unadvisable due to the current stalemate over where to house spent fuel and the current expense of the temporary solution.

*Consent-Based Waste Siting*

While the federal impasse over a long-term storage solution is unlikely to be resolved in the near term, consent-based processes offer a potential path forward. By 2012, the federal government began to advocate to use transparency to demystify nuclear waste disposal and help educate and engage communities who might one day volunteer to store spent fuel.[71] In 2021, the federal government showed renewed interest using consent-based waste siting processes to encourage private storage facilities. Currently DOE is permitted to use consent-based sitting process and negotiate agreements for host communities to get a license, but Congressional approval would eventually be needed to build and run any interim storage facility.

In 2021, the DOE sought community input on using consent-based siting processes to locate federal interim storage facilities. Responses indicated that DOE had much work to do to build trust and relationships with host communities.[72] By 2023, the consent-based processes were still being refined by DOE it was continuing to work to educate communities. DOE awarded $26 million to support consent-based siting educational and community engagement programs through 12 states and the District of Columbia.[73] Pennsylvania was one of 21 states that did not house any awardees or their engagement partners.

*Fuel Recycling*

Reusing nuclear fuel is another potential use for the stockpile of nuclear waste, one that has not been substantially explored in the United States to date. While it is called spent nuclear fuel, in some ways this misleading because it still contains more than 90 percent of its potential energy after use.[74] In order to make the fuel usable once more, it must be reprocessed, meaning

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[68] State of Texas et al v. Nuclear Regulatory Commission, No. 21-60743 (5th Cir. Aug. 25, 2023).
[69] Aiken County, S.C., et al. v. NRC et al., No. 11-1271 (DC Cir. Aug. 13, 2013).
[70] Feldman, *supra* n. 59.
[71] "Blue Ribbon Commission on America's Nuclear Future" (Washington D.C.: U.S. Dept. of Energy, January 2012).
[72] Consent-Based Siting: Request for Information Comment Summary and Analysis, September 2022 U.S. Department of Energy, office of nuclear energy.
[73] U.S. Dept. of Energy, "DOE Awards $26 Million to Support Consent-Based Siting for Spent Nuclear Fuel," Energy.gov, June 9, 2023, https://www.energy.gov/articles/doe-awards-26-million-support-consent-based-siting-spent-nuclear-fuel.
[74] Office of Nuclear Energy, *supra* n. 62.

the plutonium and uranium within are separated.[75] After reprocessing, the recycled elements can be put into new fuel assemblies and fed through reactors a second time. While this recycling process it can only be done once, sodium-cooled fast reactors being developed have the potential to generate electricity using spent fuel.[76]

In the 1970s the United States has home to programs pioneering fuel recycling. At the time security officials worried over the danger of isolating plutonium that could be made into weapons if it was acquired by terrorist factions. U.S. fuel recycling programs were suspended, while other nations continued to safely recycle their fuel. While no U.S. law currently prevents nuclear fuel recycling, another reason why it has not been pursued is its expense. A 2003 report estimated that fuel created from reprocessing would be 25 times greater per kilogram than uranium prices at that time.[77] The economics could change if the price of uranium continues to increase or becomes difficult to source.

France is the worldwide leader of nuclear recycling, reprocessing 1700 metric tons which allow it to power 10 percent of its reactors. France has demonstrated the ability to bring down the cost of their fuel reprocessing by 40 percent over the last decade yet requires public subsidies to stay in operation. Russia and Japan both reprocess nuclear fuel as well. The U.K. once had a fuel reprocessing facility called Stellafield which closed in 2022, after 45 years of operation and reprocessing 55,000 metric tons of fuel.[78] In the U.S., recycling spent fuel the lacks economic incentives to make this process attractive to private companies for use refueling conventional LWR. It is possible that fuel reprocessing, used to make HALEU, a type of fuel used to power fast reactors discussed in a later chapter of this report. Oklo, a California based company has submitted plans to the NRC to construct a fuel recycling facility.[79]

It should be noted that while it may reduce waste volume, recycling spent fuel does not negate the need for an eventual permanent storage site. The Arkansas legislature passed Act 259 in 2023 promoting fuel reprocessing, recycling and interim storage. Overall, the state is looking to explore technical and economic feasibility, federal funding opportunities associated with these actions.[80]

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[75] Cleo Schroer, "FAQ: Recycling Nuclear Waste," Good Energy Collective, October 12, 2023, https://www.goodenergycollective.org/policy/faq-recycling-nuclear-waste.

[76] Office of Nuclear Energy, "3 Advanced Reactor Systems to Watch by 2030," Energy.gov, April 12, 2021, https://www.energy.gov/ne/articles/3-advanced-reactor-systems-watch-2030.

[77] Matthew Bunn et al., The Economics of Reprocessing Versus Direct Disposal of Spent Nuclear Fuel, December 13, 2004.

[78] World Nuclear News, Sellafield ends nuclear fuel reprocessing after 58 years, July 21, 2022, https://www.world-nuclear-news.org/Articles/Sellafield-ends-nuclear-fuel-reprocessing-after-58.

[79] "Oklo Sets out Plans for Licensing of Fuel Recycling Plant," World Nuclear News, July 21, 2022, https://www.world-nuclear-news.org/Articles/Oklo-sets-out-plans-for-licensing-of-fuel-recyclin.

[80] Arkansas Act Number 259 of 2023, https://www.arkleg.state.ar.us/Home/FTPDocument?path=%2FACTS%2F2023R%2FPublic%2FACT259.pdf.

*Safety*

To ensure these strict safety measures are met, the U.S. Nuclear Regulatory Commission (NRC) is charged with licensing of sites, power plants, and operators. The NRC also performs inspection of these nuclear power plants and ensures those operating them have the correct qualifications.

In Pennsylvania, safety around nuclear power plants is taken seriously. As an example, near Limerick Generating Station there are planning and training in the 21 municipalities within a ten-mile emergency training zone (ETZ). Part of this preparation is testing the siren every month.[81] Title 35 requires every municipality in the Commonwealth to have an emergency operations plan. Municipalities within ETZ of a nuclear power plant must also have an up-to-date Radiological Emergency Response Plan. Annual training for responding agencies is required and the plan is practiced every two years. Actions in the plan listed include shelter-in-place descriptions, evacuation routes, and dispersing potassium iodide tablets.

[81] Jason Wilson, "Limerick Generating Station," Montgomery County, PA - Official Website, accessed February 5, 2024, https://www.montgomerycountypa.gov/3316/Limerick-Generating-Station.

# ECONOMICS OF NUCLEAR POWER

There are many ways to measure the cost of energy. For the everyday Pennsylvanian, the market price of electricity is likely their most common point of reference. Market price includes the costs associated with generating electrical power from the beginning of a project all the way to the homes and businesses of the consumer. However, there may also be external costs that are not reflected in the market price such as damage to the environment, public health, property, or in the case of nuclear, sociopolitical concerns like proliferation. Whether the usefulness of an energy source outweighs its cost largely depends on what criteria it is being judged by. The cost of a particular energy source costs can change based on whether the cost to environment, transmission, taxes, or credits are included.

In the U.S. energy demand has not grown in recent years, and while deregulating energy has benefited consumers by making electricity cheaper, it has also made prices volatile, making it harder to plan long term energy infrastructure investments.[82] The cost to construct and fund a nuclear power plant is significantly higher than all other costs associated with its operation and maintenance, fuel, and waste disposal combined.

**Table 2**
**Breakdown of Nuclear Power Costs**[83]

| Economics of Nuclear power | Category |
|---|---|
| Project Investment | 66% |
| Operations and maintenance | 16 |
| Fuel and waste | 17 |

Source: Nuclear Engineering International.

[82] "Financing Nuclear Energy," World Nuclear Association, October 2020, https://world-nuclear.org/information-library/economic-aspects/financing-nuclear-energy.aspx.
[83] Tony Roulstone, Economies of scale vs. economies of volume", Nuclear Energy Magazine, August 6, 2015, https://www.neimagazine.com/features/featureeconomies-of-scale-vs-economies-of-volume-4639914/.

One of the most frequent ways of comparing energy sources used by policy makers is the levelized cost of electricity (LCOE). This number estimates the cost to build and run a generation source over a given period. In the table below, data on average LCOE are compared for thirty-years starting in 2028. LCOE comparisons can be limited because they measure cost rather than value. In addition to other energy statistics, the U.S. Energy Information Administration (EIA) publishes data about avoided costs that might result from adopting a new power source, with higher amounts of avoided costs associated with more value. By dividing value by its cost, the DoE estimates which energy sources have the highest value for their cost. Based on this criteria, geothermal power had the highest value for its cost, and new designs in steam natural gas also performed well above other dispatchable energy sources. Of the resource-constrained, or renewable, energy sources solar and onshore wind had the highest value to cost ratio.

**Table 3**

**Levelized Cost, Avoided Costs and Value to Cost Ratio for new resources starting in 2028**

| Resource Type | Technology Name | Levelized Cost $/MWh | Levelized Avoided costs $/MWh | Average Value-cost Ratio |
|---|---|---|---|---|
| Dispatchable | Ultra-super critical coal | $89.34 | $34.81 | 0.39 |
| | Biomass | $77.15 | $36.25 | 0.48 |
| | Advanced nuclear | $70.99 | $34.41 | 0.49 |
| | Combined-cycle (Gas) | $39.14 | $32.69 | 0.84 |
| | Geothermal | $37.29 | $40.06 | 1.08 |
| Resource-constrained | Wind, offshore | $100.33 | $30.56 | 0.31 |
| | Hydroelectric | $57.12 | $35.50 | 0.63 |
| | Solar, Hybrid | $36.27 | $31.57 | 0.87 |
| | Wind, onshore | $28.06 | $27.63 | 0.98 |
| | Solar, Photovoltaic | $23.32 | $22.95 | 0.98 |
| Capacity resource | Combustion turbine | $128.82 | $108.55 | 0.84 |
| | Battery storage | $117.28 | $104.50 | 0.89 |

Source: U.S. E.I.A. Annual Energy Outlook 2023.

While LCOE can be useful for quick comparisons it does not capture all the data necessary to make site specific determinations over whether a particular energy source is cost effective. “LCOE estimates have proven to be a limited way of estimating overall system costs for generating electricity" and that “It is primarily relevant for comparison against similar firm generation sources with equivalent $CO_2$ emissions”. Overall, it is difficult to compare the costs of intermittent power sources like solar and wind with more dispatchable power sources that can more easily respond to demand. The cost of generating electricity can also vary significantly based on the characteristics of a particular location.

It should be noted that economic estimates used by the DoE cover a thirty-year time span and nuclear plants have an expected 40-year service life, so the LCOE decreases the longer the power plant operates. At this time in the U.S., Nuclear power plants can apply for additional license renewals in increments of twenty years, with 94 percent of operating nuclear reactors extending their service to 60 years.[84] Six reactors have completed applications for a subsequent license renewal to extend their operations to eighty years. There are 11 more renewal applications under review by the NRC, including Pennsylvania's own Peach Bottom Atomic Power Stations.[85] While nuclear power plants may have the highest up-front cost, they also last the longest.

One way of comparing costs of energy types is looking at overnight costs, which represents the cost of an energy source if it was built instantaneously and excludes financing costs. In 2023 the EIA provided an outlook, which showed the projected overnight costs of new energy source as seen in the table below. Base prices have been adjusted to account for the newness and track record of certain types of technologies.

**Table 4**

**Cost and Performance Characteristics of New Electricity Sources 2023**

| Technology Name | First Year Available | Size (MW) | Lead Time | Total Overnight Cost 2022$/kW | Heat Rate (Btu/kWh) |
|---|---|---|---|---|---|
| Ultra-supercritical coal (USC) | 2026 | 650 | 4 | $4,507 | 8,638 |
| USC with 30% carbon capture and sequestration (CCS) | 2026 | 650 | 4 | $5,633 | 9,751 |
| USC with 90% CCS | 2026 | 650 | 4 | $7,319 | 12,507 |
| Combined-cycle —single-shaft (gas) | 2025 | 418 | 3 | $1,330 | 6,431 |
| Combined-cycle —multi-shaft (gas) | 2025 | 1,083 | 3 | $1,176 | 6,370 |
| Combined-cycle with 90% CCS (gas) | 2025 | 377 | 3 | $3,140 | 7,124 |
| Internal combustion engine | 2024 | 21 | 2 | $2,240 | 8,295 |
| Combustion turbine —aeroderivative | 2024 | 105 | 2 | $1,428 | 9,124 |
| Combustion turbine —industrial frame | 2024 | 237 | 2 | $867 | 9,905 |
| Fuel cells | 2025 | 10 | 3 | $7,291 | 6,469 |
| Nuclear— light water reactor | 2028 | 2,156 | 6 | $7,777 | 10,447 |
| Nuclear —small modular reactor | 2028 | 600 | 6 | $8,349 | 10,447 |

[84] Aaron Larson, "Subsequent License Renewal: Extending Nuclear Power Reactors to 80 Years of Operation (and Maybe More)," POWER Magazine, June 15, 2023, https://www.powermag.com/subsequent-license-renewal-extending-nuclear-power-reactors-to-80-years-of-operation-and-maybe-more/.

[85] U.S. Nuclear Regulatory Commission, "Status of Subsequent License Renewal Applications," NRC Web, December 2023, https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html.

| Table 4<br><br>Cost and Performance Characteristics of New Electricity Sources<br>2023 | | | | | |
|---|---|---|---|---|---|
| **Technology Name** | **First Year Available** | **Size (MW)** | **Lead Time** | **Total Overnight Cost 2022$/kW** | **Heat Rate (Btu/kWh)** |
| Distributed generation —base | 2025 | 2 | 3 | $1,915 | 8,912 |
| Distributed generation—peak | 2024 | 1 | 2 | $2,300 | 9,894 |
| Battery storage | 2023 | 50 | 1 | $1,270 | NA |
| Biomass | 2026 | 50 | 4 | $4,998 | 13,500 |
| Geothermal | 2026 | 50 | 4 | $3,403 | 8,881 |
| Conventional hydropower | 2026 | 100 | 4 | $3,421 | NA |
| Wind, onshore | 2025 | 200 | 3 | $2,098 | NA |
| Solar photovoltaic (PV) with tracking | 2024 | 150 | 2 | $1,448 | NA |
| Solar PV with storage | 2024 | 150 | 2 | $1,808 | NA |

Source: U.S. E.I.A. Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2023.

Compared with other energy sources, nuclear is the most expensive in terms of total overnight cost. This is before interest accrual, a major cost driver in nuclear projects. Nuclear power plants have the longest lead time of the available options, meaning it takes the longest to build. It has been estimated that advanced nuclear would be highly competitive with other power sources at an overnight capital cost of $2000/kWe but if other energy costs rise it could also compete in the $4000-$5000/kWe range.[86] Based on current EIA estimates, advanced nuclear could significantly exceed this price range.

Nuclear power plant capital costs include site preparation, engineering, manufacturing, construction, and financing. One of the difficulties of building a nuclear power plant is the high financing costs and large sunk cost burden; money that has already been invested which cannot be recovered. If difficulties arise late in a project after billions of dollars have already been invested, developers can be faced with tough decisions over whether to finish the project. Because there are frequently uncertainties in build and developments times these plants have limited financing options and high interest rates.[87] These conditions can create a cycle of ratcheting, as previous construction projects face issues, raising interest rates on new projects, which drives construction cost up even further and puts additional strain on new nuclear construction.

[86] National Academies of Sciences, Engineering, and Medicine. 2023. Laying the Foundation for New and Advanced Nuclear Reactors in the United States. Washington, DC: The National Academies Press., p. 3, https://doi.org/10.17226/26630.
[87] *Id.*, p.63.

Even on the low end of estimates, nuclear power is currently the most expensive in terms of capital costs. A one GW nuclear plant could cost 8.4 to 14 billion dollars in capital costs.[88] The amount of time to pay back initial investments of construction and installation through the sale of power generated is also important. Payback time can vary and is determined by energy prices, demand, type of technology, and location. Because the initial investments required to build nuclear is much higher than other energy sources, a new nuclear plant can take over a decade to repay.

*Construction Cost and Build Time*

Despite the common perceptions of high costs of nuclear relating to its rare fuel, stringent safety enforcement rules, and costs disposing radioactive waste, the bulk of the expense is tied to construction and financing. As a type of energy source is used, typically the costs to produce decline as demand rises, as greater efficiencies are discovered and technological advances aid in this transition.[89] In the U.S., building nuclear power plant has grown more expensive over time, however this is not a universal experience, and researchers have found that policy and choices and regulatory environment play a large role in determining the cost of nuclear energy.[90]

Countries that regularly construct nuclear power plants and have trained and experienced work forces have lower costs. In recent years the United States construction of nuclear power plants has dwindled and those that have been built have faced cost overruns and delays, and more recently supply chain issues with steel and concrete and workforce issues have driven up costs further.[91] In the case of global nuclear leaders, such as France, that have continued to build nuclear power plants on a regular basis are able to do so at lower costs. These nations also have differing priorities compared to the United States energy market, relying public financing through state-owned energy companies which own and operate plants and frequently reusing the same designs to bring consistency to projects.

As a general rule, the longer it takes to build a power plant, the more it will cost. A natural gas plant can be built in about two years and quickly start paying off the costs of its construction and financing.[92] In the U.S. construction of a nuclear power plant frequently takes over ten years. In France, the average construction time five to eight years, and a plant in Japan can be built in three to four years.[93] One aspect that makes nuclear power plants expensive to build is their unique security concerns that drive up the price of its construction compared with other energy sources. For example, solar and wind generating plants do not need to be secured against earthquakes or be

[88] Lucia Fernandex, Capital Cost of Energy Production in the U.S 2023 by technology, Statistica, November 24, 2023, https://www.statista.com/statistics/654401/estimated-capital-cost-of-energy-generation-in-the-us-by-technology/

[89] "Unit 2: Renewable Energy Use in Your Life, Section B: Comparing Renewable and Non-Renewable Energy Costs," UWSP, accessed February 5, 2024, https://www3.uwsp.edu/cnr-ap/KEEP/nres635/Pages/Unit2/Section-B-Comparing-Renewable-and-Non-Renewable-Energy-Costs.aspx.

[90] Jessica R. Lovering, Arthur Yip, and Ted Nordhaus, "Historical Construction Costs of Global Nuclear Power Reactors," *Energy Policy* 91 (April 2016): 371–82, https://doi.org/10.1016/j.enpol.2016.01.011.

[91] Jeff McMahon, "3 Reasons Nuclear Power Plants Are More Expensive in the West (It's Not Regulation)," Forbes, October 2, 2018, https://www.forbes.com/sites/jeffmcmahon/2018/10/01/3-reasons-nuclear-reactors-are-more-expensive-in-the-west-hint-its-not-regulation/.

[92] World Nuclear Association, *supra* n. 82,

[93] Joshua Antonini, "Nuclear Wasted: Why the Cost of Nuclear Energy Is Misunderstood," Mackinac Center for Public Policy, July 25, 2022, https://www.mackinac.org/blog/2022/nuclear-wasted-why-the-cost-of-nuclear-energy-is-misunderstood.

able to withstand a terrorist attack from a plane. However, without these safeguards in place, there could be greater risks to environmental and public health.

It has long been speculated the U.S. safety regulation were to blame for the rising cost of constructing new nuclear plants. The regulation process which can up to 10 years in total to approve construction and operational licenses and cost millions of dollars in licensing fees.[94] For example, “The two reactor designs most recently certified by the NRC resulted in fees of between $45 million and $70 million.” [95] While licensing a nuclear power plant can certainly be expensive, increasing regulations are not entirely why nuclear plants are more costly to build in the U.S. When reviewing historical cost data, an MIT study found that decreasing labor productivity was also a significant factor and that many of the increases seen between 1976 and 1987 were not directly attributable to increased safety requirements. Many indirect costs relating to construction support were responsible for the 70 percent in the rise of nuclear construction and the largest increases were seen in engineering services, on-site job supervision, and temporary construction facilities.[96]

Therefore, the leading reason why nuclear construction costs twice as much as in other countries is thought not to be exclusively tied to regulation but underestimating project costs, and issues in project design and management.[97] Project delays are a major reason for exploding costs as large sums of money borrowed accrue interest and contractors hired charge fees for delays. This is why companies constructing nuclear power plants must be able to adapt plans quickly as the costs associated with stalling a project may be great enough to cancel it.

The size and cost of nuclear stations have grown larger over the decades as nuclear power plants sought to make energy generation cheaper through economies of scale. All the commercial LWR nuclear reactor units completed in the U.S. since 1975 have had over 800MW of generation capacity, with the majority being over 1,000MW.[98] There are some required safety and personnel related costs, which all US nuclear power plants must bear regardless of size, so it incentivizes construction of large power plant. Most plants which have closed in the United States within the last ten years have been under 1,000MW.[99] The paradox is while larger nuclear power plants are more efficient, they are also more complex to build and if projects are not managed correctly, can substantially inflate the cost of the project.

As noted before, countries that build nuclear power plants frequently are better at it. These countries have been able to create a standardized process developing multi-unit sites and doing so quickly, so there is minimal workforce turnover.[100] A strong supply chain and workers who are

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[94] Duke Energy, “NRC New Nuclear Licensing Process,” Duke Energy | Nuclear Information Center, January 17, 2012, https://nuclear.duke-energy.com/2012/01/17/nrc-new-nuclear-licensing-process.
[95] “General Questions about NRC Fees,” NRC Web, accessed February 5, 2024, https://www.nrc.gov/about-nrc/regulatory/licensing/general-fee-questions.pdf.
[96] Nancy W. Stauffer, “Building Nuclear Power Plants,” Building nuclear power plants, November 25, 2020, https://energy.mit.edu/news/building-nuclear-power-plants/.
[97] McMahon, *supra* n. 91.
[98]“List of Commercial Nuclear Reactors: United States,” in *Wikipedia*, accessed February 5, 2024, https://en.wikipedia.org/wiki/List_of_commercial_nuclear_reactors#United_States.
[99] *Id.,* Analysis by JSGC Staff
[100] Jeff McMahon, “4 Ways to Lower Nuclear Plant Construction Costs, according to MIT,” Forbes, October 2, 2018, https://www.forbes.com/sites/jeffmcmahon/2018/10/02/4-ways-to-lower-nuclear-plant-construction-costs/?sh=26121aea54b8.

trained specifically to build the plants are also an asset. Expert ideas on how to lower cost of nuclear power plants construction have identified a number of approaches for keeping costs under control for nuclear power plants:

- National Consensus around long-term energy plan
- Strong public engagement
- Standardized design
- Centralized construction
- Built big to maximize economies of scale
- Fixed cost of construction
- Financed with low-cost loan[101]

Reviewing these criteria, they are rarely enacted in the United State and may explain why some countries with more a direct role in planning and investment in power production have had more success in building nuclear power plants. If nuclear power plants are to be built economically, they will need to be planned in advance, to have a stable energy market, and access to low-cost financing options.

New materials are another method through which the construction of new nuclear power plants could become more cost effective. For example the cost of pouring rebar-enforced concrete could be avoided by pursing alternative construction techniques such as self-consolidating concrete.[102] The Advanced Construction Technology Initiative has proposed vertical shaft construction which could save $50 million in project costs, steel bricks which could decrease labor costs, advanced monitoring, and creating digital twin of the power plant using computer modeling.[103] It is also widely noted that it's easier to build power plants when building multiple reactors because this builds a trained and experienced workforce. It is also important for the design of a power plant to be completed prior to the start of construction. Ideally those who will be fabricating parts and constructing the power plant are included in the design phase of the project, so they can anticipate and avoid potential issues.[104]

*Recent U.S. Nuclear Construction*

For the first decade of the millennium, several nuclear reactors were proposed and then abandoned. One such proposed plant was to be on a new site on the Bell Bend of the Susquehanna River in Luzerne County. The owner of the site, PPL Electric, could not secure the necessary financing to begin construction. Several of the planned reactors throughout the country being developed were expansions of existing nuclear power plant sites; however, many of these projects never progressed further than design stage.

[101] Michael Shellenberger, "The Seven Secrets to Cheap Nuclear Energy," IAEA Bulletin 58–4 (October 25, 2017).
[102] McMahon, *supra* n. 100.
[103] Office of Nuclear Energy, *supra* n. 76.
[104] McMahon, *supra* n. 91.

The most notable recent U.S. nuclear cancelation was an expansion of the V.C. Summer Power Plant in South Carolina. The construction of two new reactors at the site was terminated after the expected cost of the project rose from $11 to $25 billion dollars.[105] While it was suggested that some of the effort could be salvaged by only completing one reactor, project investors could not be convinced. At the time of the cancelation, $9 billion had already been spent on the project.

A South Carolina state law known as the Base Load Review Act had allowed plant owners to charge customers based on the costs of constructing nuclear power plants prior completion.[106] The act was intended to decrease costs of financing and constructing and encourage investment by allowing owners to receive money before plant operations commenced. Instead, the new reactors were never completed and consequently led to nine rate hikes for their customers. The law was repealed in 2018. The two abandoned nuclear reactors in South Carolina will cost rate payers $2.3 billion over the next two decades.[107]

In Georgia, the Vogtle Power Plant built a new reactor at a preexisting nuclear site in 2023, with another near completion. This pair of reactors represents the first entirely new reactors built in the United States over the last thirty years. While the reactors were originally quoted at $14 billion, the total cost is expected to amount to $35 billion.[108] The second is still being constructed and the project is currently seven years behind their initial schedule.[109] State regulators and independent consults have criticized issues of quality control, record keeping, missing deadlines, and determined that those involved with the project misjudging length and cost of project milestones.[110]

These troubled projects in South Carolina and Georgia were the primary cause of Westinghouse's Bankruptcy in 2017.[111] Both projects were using a new construction process to prefabricate parts in a central factory for the Westinghouse AP1000 design before assembly at site to standardize construction. However, the company chosen did not have the necessary experience or technical skills to produce acceptable modules on what was later determined to be an aggressive time schedule and tight budget.[112] This chapter is relevant to small modular reactors which plan on using factory construction to lower costs of nuclear. Even if the new nuclear designs are improved, projects could still face these same quality control and project management issues if the wrong manufacturing partner is chosen.

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[105] Scoppe, Cindi Ross. "SC Nuclear Debacle, by the Numbers." The State, September 4, 2017. https://www.thestate.com/opinion/opn-columns-blogs/cindi-ross-scoppe/article170003262.html.
[106] S.C. 2007 Act No. 16, adding section 58-33-210 *et saq*.
[107] Alex Crees, "The Failed V.C. Summer Nuclear Project: A Timeline," Choose Energy, December 4, 2018, https://www.chooseenergy.com/news/article/failed-v-c-summer-nuclear-project-timeline/.
[108] Stanley Dunlap, "After Years of Setbacks, New Plant Vogtle Unit Hits '100 Percent Power' for First Time - Georgia Recorder," Georgia Recorder, May 30, 2023, https://georgiarecorder.com/brief/after-years-of-setbacks-new-plant-vogtle-unit-hits-100-percent-power-for-first-time.
[109] *Id*.
[110] Stanley Dunlap, "Plant Vogtle Delays and Ballooning Costs since 2012 Unveiling like 'Groundhog Day'," Georgia Recorder, February 18, 2022, https://georgiarecorder.com/2022/02/18/plant-vogtle-delays-and-ballooning-costs-since-2012-unveiling-like-groundhog-day/.
[111] Tom Hals and Emily Flitter, "How Two Cutting Edge U.S. Nuclear Projects Bankrupted Westinghouse," *Reuters*, May 2, 2017, https://www.reuters.com/article/idUSKBN17Y0C7/.
[112] *Id*.

*Historical Construction Costs*

While these recent events are disappointing for those hoping for a nuclear resurgence, building nuclear power plants in the United States has a history of cost overruns and project delays. The Watts Bar plant in Tennessee was planned to have two units costing a combined $825 million for both in 1977. The first reactor, Unit 1 was completed for $6.8 billion in 1996.[113] After a decade long delay, work on the second reactor was eventually resumed in 2007 with an estimated $2.5 billion cost to complete. This project finished in 2016 and for a total of $6.1 billion. Other nuclear power plants in the U.S. had constructions costs that significantly exceeded initial estimates and were met with project delays as well. Two reactors at Comanche Peak in Texas took an additional ten years to build and over $8.3 billion more than initially forecasted. [114]

Even if a project is properly managed, the sheer scale of nuclear projects can lead projects to be long and costly. In 1976 construction began on three reactors at Palo Verde Generating Station in Arizona, which is the largest nuclear power plant in the U.S..[115] The first reactor came online after a decade, with the second being completed two years later, in 1986. The total cost of the project was 5.9 billion dollars, the equivalent to 16.5 billion in 2023 dollars.[116] An audit of the construction project indicated that less than one perfect of the projects cost were unreasonably spent, and that actions taken by project managers had likely saved rate payers $300 million.[117]

While generating capacity of units in the United States has stayed around 1000MW, the price of construction has climbed steadily over the last 40 years.[118] Comparing recent constructions to historical ones built in Pennsylvania illustrate that the cost to construct a nuclear power plant have risen dramatically over inflation. Of the nuclear power plants with publicly available information, Beaver Valley appears to be the most expensive plant completed in Pennsylvania. As with the new reactors at Vogtle in Georgia, both plants are Pressurized Water Reactors designed by Westinghouse, although the Vogtle design is four decades newer. When completed, the new units at Vogtle will cost nearly two and a half times more than the units at Beaver Valley, adjusted in 2023 dollars. However, the total capacity of the new reactors will only be 23 percent higher. The cost of other Pennsylvania reactors in 2023 dollars and construction times are shown in the table below.

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[113] Dan Drollette, "Watts Bar Unit 2, Last Old Reactor of the 20th Century: A Cautionary Tale - Bulletin of the Atomic Scientists," Bulletin of the Atomic Scientists, June 28, 2018, https://thebulletin.org/2015/10/watts-bar-unit-2-last-old-reactor-of-the-20th-century-a-cautionary-tale/.

[114] "Comanche Peak Nuclear Power Plant Turns 20, Uneventfully," *Dallas News*, August 15, 2010, accessed February 6, 2024, https://www.dallasnews.com/business/2010/08/15/comanche-peak-nuclear-power-plant-turns-20-uneventfully/.

[115] Robert Peltier, "TOP PLANTS: Palo Verde Nuclear Generating Station, Wintersburg, Arizona," *POWER Magazine*, November 6, 2015, https://www.powermag.com/palo-verde-nuclear-generating-station-wintersburg-arizona/

[116] S.H. Shepherd, T.F. Quan, and D W.T. Carroll, "Winning a Prudence Audit," OSTI.gov, November 1, 1989, https://www.osti.gov/biblio/5486744.

[117] *Id*.

[118] The Associated Press, "After 36 Years, Nuclear Plant in Tennessee Nears Completion," *The New York Times*, May 11, 2015, https://www.nytimes.com/2015/05/11/us/after-36-years-nuclear-plant-nears-completion.html.

| Table 5<br>Construction Costs of Pennsylvania Nuclear Power Plants<br>adjusted to 2023 Dollars[119] | | |
|---|---|---|
| **Name** | **Adjusted Cost (in billions of dollars)** | **Approximate build time (years)** |
| Beaver Valley Unit 1&2 | $12.6 | 13 |
| Limerick Unit 1 | 10.8 | 12 |
| Peach Bottom Unit 2 & 3 | 4.4 | 6 |
| PPL Susquehanna Unit 1 & 2 | 11.8 | 11 |
| Three Mile Island Unit 1 | 2.3 | 6 |

Source: U.S. E.I.A. 2010.

The cost of operating a nuclear power plant includes fuel (mining uranium), maintenance, decommissioning, and waste disposal. Operational costs can further be divided into fixed and variable. Fixed costs include labor, materials, contract services for routine operations and maintenance as well as administration and general costs.[120] Nuclear power plants had the second highest fixed costs behind only biomass. Nuclear energy sources had lower variable operations and maintenance than other dispatchable energy fuel sources such as gas and coal. This is the parts and labor necessary to keep a power source running.

| Table 6<br>Fixed and Variable Operations and Maintenance<br>per energy source<br>2023 | | |
|---|---|---|
| **Type of Technology** | **Variable Operations & Maintenance ($/MWh)** | **Fixed Operations & Maintenance ($/KW per year)** |
| Nuclear - LWR | $2.34 | $136.91 |
| Nuclear - SMR | $3.38 | $106.92 |
| Ultra-supercritical Coal | $5.06 | $45.68 |
| USC with 90% CCS | $11.49 | $62.34 |

[119] "State Nuclear Profiles: Pennsylvania," U.S. Energy Information Administration, April 26, 2012, https://www.eia.gov/nuclear/state/archive/2010/pennsylvania/.Adjusted for inflation by JSGC staff.
[120] Thomas Hauske, "Variable Operations and Maintenance (VOM) Costs Education," Slideshow, PJM, July 25, 2017.

| Table 6<br>Fixed and Variable Operations and Maintenance<br>per energy source<br>2023 | | |
|---|---|---|
| **Type of Technology** | **Variable Operations & Maintenance ($/MWh)** | **Fixed Operations & Maintenance ($/KW per year)** |
| Natural Gas Combined-Cycle | $2.10 | $13.73 |
| Natural Gas w/90% CCS | $6.57 | $31.06 |
| Conventional Hydroelectric | $1.57 | $47.06 |
| Wind, onshore | $0.00 | $29.64 |
| Solar PV w/Storage | $0.00 | $17.16 |
| Biomass | $5.44 | $141.50 |

Source: U.S. E.I.A. Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2023.

New technology may also be able to help reduce the cost of operating reactors. A.I. technology may lead to cost saving in existing reactors by working to detect any cracks in concrete that could cause leaks of radioactive material as well as finding ways to optimize a plants fuel strategies to reduce waste and maintenance.[121] These improvements in fuel efficiency could lead each rod to last 5 percent longer and lead to a saving of $3 million dollars a year in savings.[122]

[121] Priya Aggarwal, "How AI Can Make Nuclear Energy Cheaper | The Kernel," *Medium*, December 16, 2021, https://medium.com/generation-atomic/how-ai-can-make-nuclear-energy-cheaper-d2d2c1e4ab3.
[122] Kim Martineau, "Want Cheaper Nuclear Energy? Turn the Design Process into a Game," MIT News | Massachusetts Institute of Technology, December 17, 2020, https://news.mit.edu/2020/want-cheaper-nuclear-energy-turn-design-process-game-1217.

*Background*

Today, nuclear power plants conjure images of massive concrete structures with iconic radial cooling towers, capable of generating enough electricity to power thousands of homes. Nuclear power stations did not start this large in either size or generation capacity but were built up over time. The smallest nuclear power plants in the country were typically the oldest, many of them closed as the cost of future repairs outweighed their profitability. There are some instances where smaller reactors proved advantageous, such as the U.S. Navy's use of small reactors to power its submarines.

In the private sector, nuclear power plants generation had grown larger throughout the 70s and 80s during the peak of their construction in the United States. Siting requirements, low public approval, and a strict regulatory review process limited the number of plants developed, because any one of those concerns could be enough to halt a project. Perhaps the most important reason for power plants growing larger was a desire to achieve economies of scale to make nuclear power more competitive with other energy sources.[123] While efficiencies due to large size were achieved, a downside is that the total capital costs grew and deterred investors. As indicated in the previous section, nuclear projects in the U.S. have been consistently late and over budget for decades which has further eroded confidence of investors and banks. In recent years, decreasing costs of renewable energy sources and a boom of cheap natural gas have also discouraged investment in new plants.

*Definition of Small Modular Reactors* (SMR)

As construction continue to rise, it has become vital for the U.S. nuclear industry to reassess how their reactors are built and make designs less complex, safer, and cheaper. The current solution proposed is to shrink the size of the reactors so that they can be built inside factories, while increasing passive safety features as a way of winning back public and investor confidence. These reactors are known as Small Modular Reactors, or SMR. It is important to note that SMRs are not just one design, but a whole classification of designs that tend to meet the following criteria:

- Small - reactors that take up less space on a site.
- Modular - design that allows prefabrication at a factory and units that can be shipped to the site.
- Reactors – Fission-based units with a capacity of generating between 10-300 MWe.[124]

[123] Ernest Moniz "Why We Still Need Nuclear Power," MIT Energy Initiative, Nov. 2, 2011, https://energy.mit.edu/news/why-we-still-need-nuclear-power/.
[124] Joanne Liou, "What Are Small Modular Reactors (SMRs)?," IAEA, September 13, 2023, https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs.

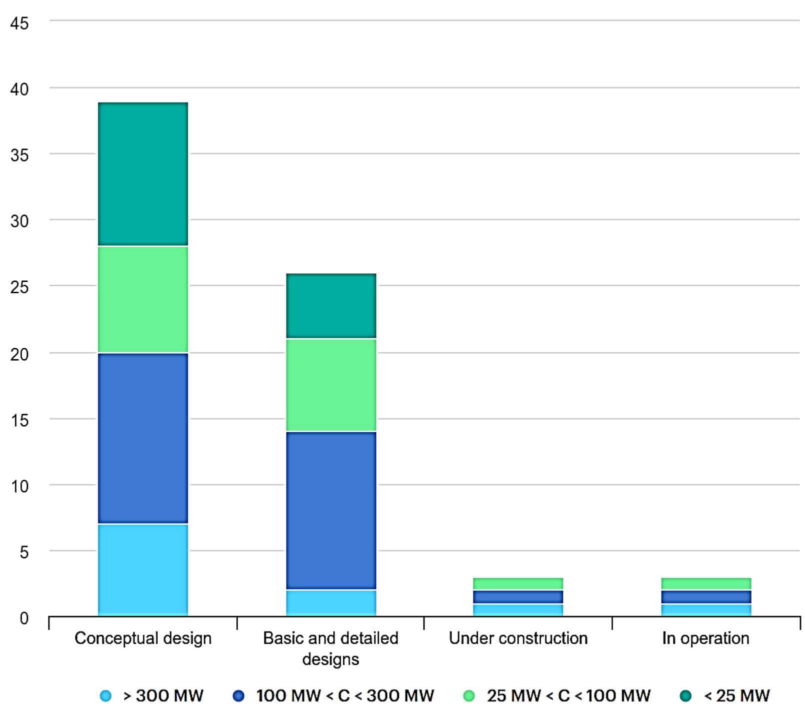
It is the hope of those designing SMRs that these characteristics will result in nuclear reactors twice as fast to build and assemble, easier to site, more versatile, at a total cost more affordable than large light-water reactors. While these elements do represent innovations, they are also a financial necessity if new nuclear construction is to continue in the U.S. As mentioned previously, the concept of small reactors has been tried before and found economically inefficient, but what is novel about SMR is the enhanced safety features and modular, prefabricated elements. The crucial factor that remains undetermined is whether this can be implemented in a way that is economical when compared to other available energy options.

*Current Status of SMR*

As of 2022, there were over 80 commercial SMR designs in development around the world.[125] Nearly 40 of these designs were in the concept phase and 26 had progressed to basic or detailed designs.[126] The majority of the designs were found between two capacity sizes: those between 100-300MW and those under 25MW. It is likely that many of these designs will never reach the market due to either not meeting regulatory standards or not securing sufficient investment to proceed with construction.

**Graph 3**

**Number of SMR Designs in Development Globally 2022**




[125] *Id.*
[126] IEA, Global number of small modular reactor projects by status of development, 2022, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-number-of-small-modular-reactor-projects-by-status-of-development-2022, IEA. License: CC BY 4.0.

So far, only a small number of SMR plants have been built worldwide. The Chinese HTR-PM is a high-temperature gas-cooled pebble bed reactor that started producing electricity in 2021 and began operation in 2023.[127] China is also currently constructing an SMR demonstration of its ACP100 model at an existing nuclear power site in Changjiang region.[128] Russia has built a floating SMR plant out at sea which started providing power to the grid in 2019, and in 2023 announced plans to build a land-based SMR plant in an artic region.[129]

In the United States SMR are still largely in the design and testing phase and are not expected to reach market until sometime in the 2030s.[130] Due to their compact size, SMR are typically classified as advanced nuclear reactors within the industry, meaning they have improvements over the previous generation of designs. SMRs are placed within two categories by the NRC: light-water reactors and non-light water reactors. The first group uses uranium fuel and water as a coolant like the traditional reactors outlined in previous sections of the report. The second category includes reactors that experiment with alternate systems of fueling and cooling such as gases, salts, and liquid metals.

**Table 7**

**Advanced and SMR Nuclear Designs Engaging in Preapplication Activities with NRC**

| Design Name | Reactor Type | Estimated Unit Output | Company | Additional Notes |
|---|---|---|---|---|
| Energy Multiplier Module | Non-LWR | 66 MWe | General Atomics | Helium Cooled Reactor |
| Kairos Design | Non-LWR | 35 MWe | Kairos Power | Fluoride salt-cooled high -temperature reactor |
| Natrium Reactor | Non-LWR | 345 MWe | TerraPower, LLC and GE Hitachi | Pool-type sodium fast reactor using HALEU metal fuel |
| eVinci Microreactor | Non-LWR | 200 kWe - 5 MWe | Westinghouse Electric Co. | -- |
| Integral Molten Salt Reactor | Non-LWR | 190 MWe | Terrestrial Energy USA | -- |
| XE-100 | Non-LWR | 80 MWe | X-Energy, LLC | High-Temperature Gas -cooled Reactor using TRISO-X Fuel |

[127] World Nuclear News, "China's Demonstration HTR-PM Enters Commercial Operation," December 6, 2023, accessed February 6, 2024, https://world-nuclear-news.org/Articles/Chinese-HTR-PM-Demo-begins-commercial-operation.

[128] World Nuclear News, "Containment Shell in Place for Chinese SMR," November 6, 2023, accessed February 6, 2024, https://www.world-nuclear-news.org/Articles/Containment-shell-in-place-for-Chinese-SMR.

[129] World Nuclear News, "License Issued for Russia's First Land-Based SMR: New Nuclear," April 24, 2023, https://world-nuclear-news.org/Articles/Licence-issued-for-Russia-s-first-land-based-SMR.

[130] Oliver Gordon, "Small Modular Reactors: What Is Taking so Long?," *Energy Monitor*, September 20, 2022, https://www.energymonitor.ai/sectors/power/small-modular-reactors-smrs-what-is-taking-so-long/.

| **Table 7**<br>**Advanced and SMR Nuclear Designs Engaging in Preapplication Activities with NRC** | | | | |
|---|---|---|---|---|
| **Design Name** | **Reactor Type** | **Estimated Unit Output** | **Company** | **Additional Notes** |
| Molten Chloride Fast Reactor | Non-LWR | NA | TerraPower, LLC | -- |
| Fast Modular Reactor | Non-LWR | 50 MWe | General Atomics-Electromagnetic Systems | Helium Cooled Reactor |
| ARC-100 Sodium-Cooled Fast Reactor | Non-LWR | 100 MWe | ARC Clean Technology | -- |
| Oklo Auroa Powerhouse | Non-LWR | 15 MWe | Oklo Inc. | Liquid metal-cooled, metal -fueled fast reactor |
| High-Temperature Gas Cooled Test Reactor | Non-LWR | 15 MWe | University of Illinois at Urbana-Champaign and Ultra Safe Nuclear Corp. | TRISO Fueled, Helium -cooled microreactor |
| Kaleidos Microreactor | Non-LWR | 1 MWe | Radiant Industries, Inc. | High Temperature Gas Reactor, a microreactor designed to replace diesel engine |
| SMR-300 | LWR | 300 MWe | Holtec, Int. Co. | -- |
| BWRX-300 | LWR | 300 MWe | GE-Hitachi Nuclear Energy (GEH) | Additional application for construction permit at Clinch River Nuclear site, filed by Tennessee Valley Authority |

Source NRC SMR Pre-Application Activities.

So far, light-water SMR designs are considered more mature by some analysts and may be closer to reaching the U.S. market.[131] This is due in part to the similarity in design to large LWR, meaning they may not have the same development and regulatory obstacles as newer reactor designs which in theory make them easier to commercialize. For example, these SMR design may use existing fuel and infrastructure and may be more familiar to regulators at the NRC.[132] While NuScale's design is one of the most well-known SMR designs, other light-water SMR designs include the Holtec's SMR-300 reactor and the GE-Hitachi is making the BWRX-300, and

[131] Kenneth Thomas, Chuck Gunzel, and Nicole Lahaye, "Emerging Technologies Review: Small Modular Reactors" (Pacific Northwest National Laboratory, April 2023), https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-34156.pdf.

[132] John Volkoff to U.S. Nuclear Regulatory Commission, January 28, 2022, *NuScale Power, LLC Letter of Intent Providing the Carbon Free Power Project (CFPP) Combined License Application (COLA) Response to NRC Regulatory Issue Summary 2020-02 and Regulatory Engagement Plan*, https://www.nrc.gov/docs/ML2202/ML22028A277.pdf.

Westinghouse's AP300. Some SMR projects have already been abandoned, like the "Generation mPower" design by Babcock & Wilcox which could not secure adequate funding.

The first and only SMR design approved by the NRC thus far is the NuScale US600. A detailed analysis of the general NuScale SMR design can be found in the chapter succeeding this one. While the only current NRC approved design will likely never be built in the U.S., the company has already redesigned their reactor for a higher power output and must undergo additional regulatory review. Holtec has also raised the output of their modules signally that companies with designs chaining together multiple small reactors together may be having difficulty balancing the cost to make SMRs while delivering targeted electricity prices.

*Passive Safety*

A major goal of SMR-based nuclear power plants is to improve safety compared to older generations. By making reactors smaller and simpler, they can use passive safety features based on physics to minimize possible mechanical and human errors that have led to reactor meltdowns in the past. Pumps powered by electricity have been known to fail. For example, a broken pump could lead to a reactor overheating. Similar to the incident at Fukushima, but several SMR include system will use water convection instead. An example is in the standard NuScale SMR design that house multiple reactors within a pool of water. This cooling pool would be enough to absorb heat and prevent them from going critical.

However, there can sometimes be tradeoffs when pursuing a particular safety design. For example, at Fukushima, the power plant was located underground to protect it from earthquakes, which inadvertently made it more vulnerable to flooding. Early in its design phase, some concern with the NuScale was noted that whether the backup pumps were adequate because they were not designated as safety-related, so they can have more lax standards.[133] There is also some caution being raised against using multiple small reactors that share cooling systems because the failure of one could cause multiple reactors to break. While passive systems emphasize prevention over containment, scientists critical of nuclear designs advocate that SMR still must be able to contain radiation in the event of an unforeseen situation.[134]

Other SMR designs such as X-Energy and are pursing TRISO fuel pebbles to increase plant safety. These Uranium pellets are coated in multiple layers of carbon and ceramic which could eliminate the possibility of a reactor meltdown and withstand high temperatures.[135]

[133] Edwin Lyman, "Small Isn't Always Beautiful," *Union of Concerned Scientists* (Union of Concerned Scientists, September 2013), accessed February 6, 2024, https://www.ucsusa.org/sites/default/files/2019-10/small-isnt-always-beautiful.pdf.
[134] *Id*.
[135] Office of Nuclear Energy, "TRISO Particles: The Most Robust Nuclear Fuel on Earth," Energy.gov, July 9, 2019, https://www.energy.gov/ne/articles/triso-particles-most-robust-nuclear-fuel-earth.

*Size and Location*

Another goal with SMRs is that their smaller land footprints may make it easier to site reactors in new places. With the example of NuScale, physically the reactors are one third the size of traditional reactors. Hypothetically, this could allow reactors to be in used in places like islands, cities, factories, or at preexisting power plants. There would be smaller emergency zones allowing SMRs to be sited closer to areas of high population density.[136] There is also potential for SMRs to be used in geographically remote locations such as mining operations and replace diesel generators.

*Flexibility*

Because SMRs are still being designed there is a whole host of possible applications beyond energy production. Traditionally, nuclear power plants provide baseload energy that take a lot of time and planning to scale energy production up or down.[137] This has led the energy source to be labeled as inflexible. With SMRs, designers claim that this problem can be solved using multiple independently controlled smaller reactors which can be adjusted at a more rapid pace However, a possible downside is they must know ahead of time to plan for this, and it doesn't work as well near the end of a fuel cycle. [138]

Part of that flexibility is hoping to make plants more versatile, so that they could be used for a range of things beyond just the production of electricity. Steam from a plant can be used to generate hydrogen in addition to electricity.[139] This hydrogen can be used to store energy and is an important product in chemical industries, plastics, and synthetic fuel. Currently natural gas is more commonly used in hydrogen production. Some SMRs produce large amounts of heat that could have a use in warming homes, desalinating water, or even oil refining. When placed inside factories SMR could deliver power to their operations and depending on the model, produce enough heat for industrial purposes.

Initial research suggests that SMRs could even be co-located at other power plants, to power negative emissions systems, such as carbon capture negative emissions system like direct carbon capture work by taking carbon out of the air. While these systems are often regarded as impractical due to high energy costs, powering these systems with an SMR could lead to a 13 percent lower cost.[140]

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[136] World Nuclear News, "US Regulator Approves Methodology for SMR Emergency Planning," October 28, 2022, https://world-nuclear-news.org/Articles/US-regulator-approves-methodology-for-SMR-emergenc.
[137] "3 Ways Nuclear Is More Flexible Than You Might Think," Energy.gov, June 23, 2020, accessed February 6, 2024, https://www.energy.gov/ne/articles/3-ways-nuclear-more-flexible-you-might-think.
[138] *Id.*
[139] *Id*.
[140] Miachael Goff, "Could Advanced Reactors Make Carbon Capture Systems More Viable?," Office of Nuclear Energy, September 7, 2023, accessed February 6, 2024, https://www.energy.gov/ne/articles/could-advanced-reactors-make-carbon-capture-systems-more-viable.

*SMR Cost*

As noted in a previous chapter, construction is where new power plants often experience delays and overruns. SMRs are intended to produce built in factories and then shipped to location where they will be assembled Some SMR manufacturers believe they could construct modules twice as fast as traditional power plants because work on the reactor could be done in factories at the same time as on-site construction.[141] Cost saving from mass production could be substantial if enough buyers were found. A common point of comparison used by industry representatives is that airplanes once made the transition between being built piecemeal to factory manufacture and they contend that the consistency this creates may be enough to outweigh negative economies of scale. It could take between 10 to 15 first of a kind SMR projects between 2030-2040 to lower SMR costs between 2040-2050.[142]

Overall, it is too soon to tell how much SMRs will cost or whether they will be affordable, however it is likely they will still be at the higher end of electricity production. In 2022 GE Hitachi reported that a levelized cost of $60/MWh would be possible for their design.[143] NuScale originally predicted a LCOE could reach $58/ MWh, but January of 2023 price estimates to $89 per MWh.[144] In November of 2023, it was announced that NuScale Power's contract to build six SMR units in Utah was cancelled, due to rising costs associated with the plant, which is notable because it was the only SMR design currently approved by the NRC.[145]

To be practical, SMRs need to be both simple and be designed with factory construction in mind.[146] Only at high volumes of construction will they be cost effective which means international regulations must be harmonized so they can be sold to as many countries as possible. To construct reactors cheaply, as many parts as possible must be factory created, not only reactors and turbines. The difference in cost between the first of a kind reactor and those that will follow later are critical to determining the future of SMR. One estimate assumes that an unsubsidized NuScale reactor would have a LCOE of $120 MWh and that it could can only get down to $51 cost per MWh if highly successful and would still need subsidies to compete with the low price of electricity generated from wind.[147]

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141 Jeff Brady, "This Company Says the Future of Nuclear Energy Is Smaller, Cheaper and Safer," NPR, May 8, 2019, https://www.npr.org/2019/05/08/720728055/this-company-says-the-future-of-nuclear-energy-is-smaller-cheaper-and-safer.

142David Brown, "The Nuclear Option: Making New Nuclear Power Viable in the Energy Transition" (Wood Mackenzie, May 2023), https://www.woodmac.com/horizons/making-new-nuclear-power-viable-in-the-energy-transition/.

143 Robert Walton, "$60/MWh for Advanced Nuclear Electricity Is Achievable, Says GE Hitachi Executive," Utility Dive, August 22, 2022, https://www.utilitydive.com/news/advanced-nuclear-ge-hitachi-mwh-nuscale-smr-small-modular-reactor/630154/.

144 David Schlissel, "Eye-Popping New Cost Estimates Released for NuScale Small Modular Reactor," Institute for Energy Economics and Financial Analysis, January 11, 2023, accessed February 6, 2024, https://ieefa.org/resources/eye-popping-new-cost-estimates-released-nuscale-small-modular-reactor.

145 Timothy Gardner and Manas Mishra, "NuScale Ends Utah Project, in Blow to US Nuclear Power Ambitions," Reuters, November 9, 2023, https://www.reuters.com/business/energy/nuscale-power-uamps-agree-terminate-nuclear-project-2023-11-08/.

146 McMahon, *supra* n. 91.

147 Michael Barnard, "Shoveling Money Into Small Modular Nuclear Reactors Won't Make Their Electricity Cheap," *Clean Technica*, March 28, 2023, https://cleantechnica.com/2023/03/28/shoveling-money-into-small-modular-nuclear-reactors-wont-make-their-electricity-cheap/.

A review of existing literature from the Idaho National Laboratory found that SMR costs were not found to be substantially different from larger reactors. The study estimated the costs for advanced nuclear was between $4000 and $7000/kWe with an operating expense between $15-$35 /MWh.[148] Only SMR under 15MW, sometimes called microreactors, were found to have a higher cost per kWe and were excluded from the estimate. Additionally, the review indicated that depending on the type of reactor, a first of a kind SMR plants could be anywhere from 30 percent to 110 percent more expensive than subsequent units.

*Potential Downsides of SMR*

In spring of 2022, a study by Standford University review of three types of SMR found they would produce between two to 30 times as much waste as a conventional LWR.[149] The research sparked discussion within the industry about the level of waste produced by SMR, as developers contested the findings. In the fall of 2022, a study sponsored by the Idaho National Laboratory found that it is expected for SMR to have the same waste generation per KWh of a traditional plant.[150]

While the nuclear industry contends that the total amount of waste will have a low volume for power produced, as noted in a previous chapter there is no central waste depository so waste would be placed in cooling pools on site and possible moved to casks later. Despite producing a similar output of waste as large reactors, for SMR to be economically viable in a factory model it is projected that they will need to generate many additional reactor units, which would in turn increase both the total volume of waste and number of sites needed to store them. Until interim or permanent storage solutions can be agreed upon this will remain an issue.

Utilization rates of nuclear power plants remain a consideration. While many new SMR designs are said to be more compatible with intermittent energy sources like wind and sun, this pairing may not be very cost effective since nuclear plants operate at peak efficient to sell as much energy as possible to pay back their high cost of investment. Ramping up and down an SMR to load follow intermittent energy sources will make them take longer to pay off and may decrease its fuel efficiency.

There have also been difficulties in sourcing a new type of fuel known as High Assay Low Enriched Uranium (HALEU), due to the politically contentious relationship between the U.S. and Russia in recent years. The first domestic nuclear fuel producer in over 70 years opened in Ohio in 2023 will create HALEU fuel, but it will take time for it and other new companies to meet projected demand.[151]

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[148] Abdalla Abou-Jaoude et al., "Literature Review of Advanced Reactor Cost Estimates," *Integrated Energy Systems* (Idaho National Laboratory, October 2023).

[149] Mark Shwartz, "Stanford-Led Research Finds Small Modular Reactors Will Exacerbate Challenges of Highly Radioactive Nuclear Waste," Stanford News, May 30, 2022, https://news.stanford.edu/2022/05/30/small-modular-reactors-produce-high-levels-nuclear-waste.

[150] T.K. Kim et al., "Nuclear Waste Attributes of SMRs Scheduled for Near-Term Deployment" (Argonne National Laboratory, November 18, 2022), https://www.osti.gov/biblio/1900154.

[151] Prachi Patel, "U.S. Re-Enters the Nuclear Fuel Game," IEEE Spectrum, November 13, 2023, https://spectrum.ieee.org/nuclear-power-plant-2666199640.

*Legislative and Regulation Obstacles*

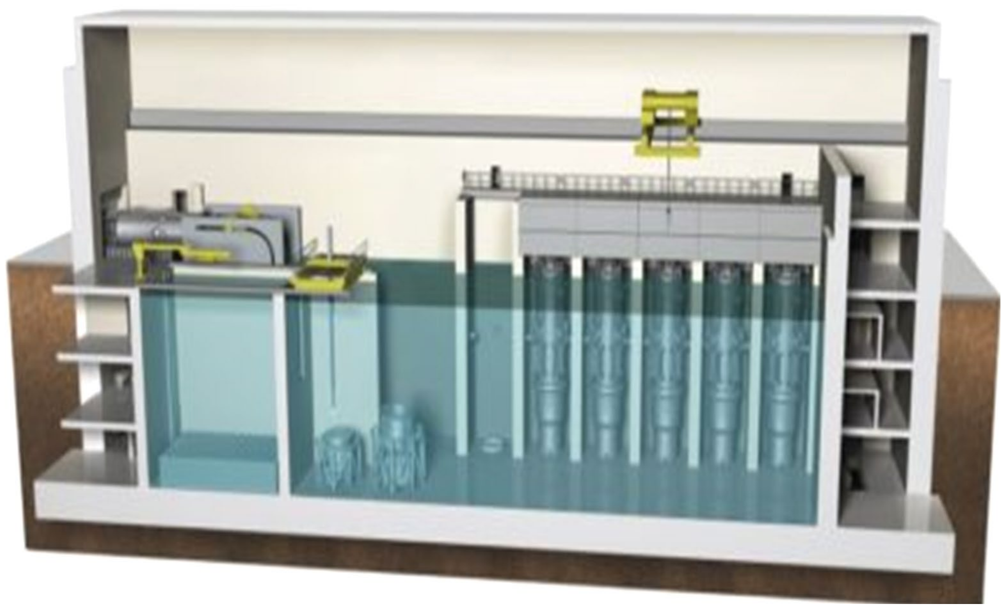
Currently, twelve states have legislative barriers to nuclear development.[152] These restrictions may take the form of moratoriums until the nation waste repository is built, voter or legislative approval to build new plants, or total bans nuclear new constructions. Within the last eight years four states have repealed barriers to nuclear development. Pennsylvania has no laws preventing the construction of LWR or SMRs. This is not to say that PA has no obstacles to SMR development. The Pennsylvania Radiation Protection Act was passed after Three-Mile Island accident in 1979.[153] The law applies fees to operators of nuclear power plants and waste storage sites.[154] The act outlines the duties of the PA DEP to create radiation protection programs. Currently, the program is funded based on the number of reactors. To better prepare for SMR, Pennsylvania should consider reexamining the fee structure which would have to pay proportionally higher fines due to having large numbers of smaller reactors.

[152] Office of Nuclear Energy, "What Is a Nuclear Moratorium?," Energy.gov, October 23, 2023, https://www.energy.gov/ne/articles/what-nuclear-moratorium.
[153] The Act of July 10 1984 (P.L. 688, No. 147), known as the Radiation Protection Act.
[154] 35 P.S. § 7110.402.

One of the examples that outlines both the potential and pitfalls of SMR in the United States is the work of the NuScale Power Corporation. NuScale's SMR design is somewhat different from competitors like the now defunct mPower design which sought to mimic traditional large light water reactor plants. NuScale's design has up to 12 reactors submerged in a pool of water.

**Figure 6**

**NuScale SMR Plant**



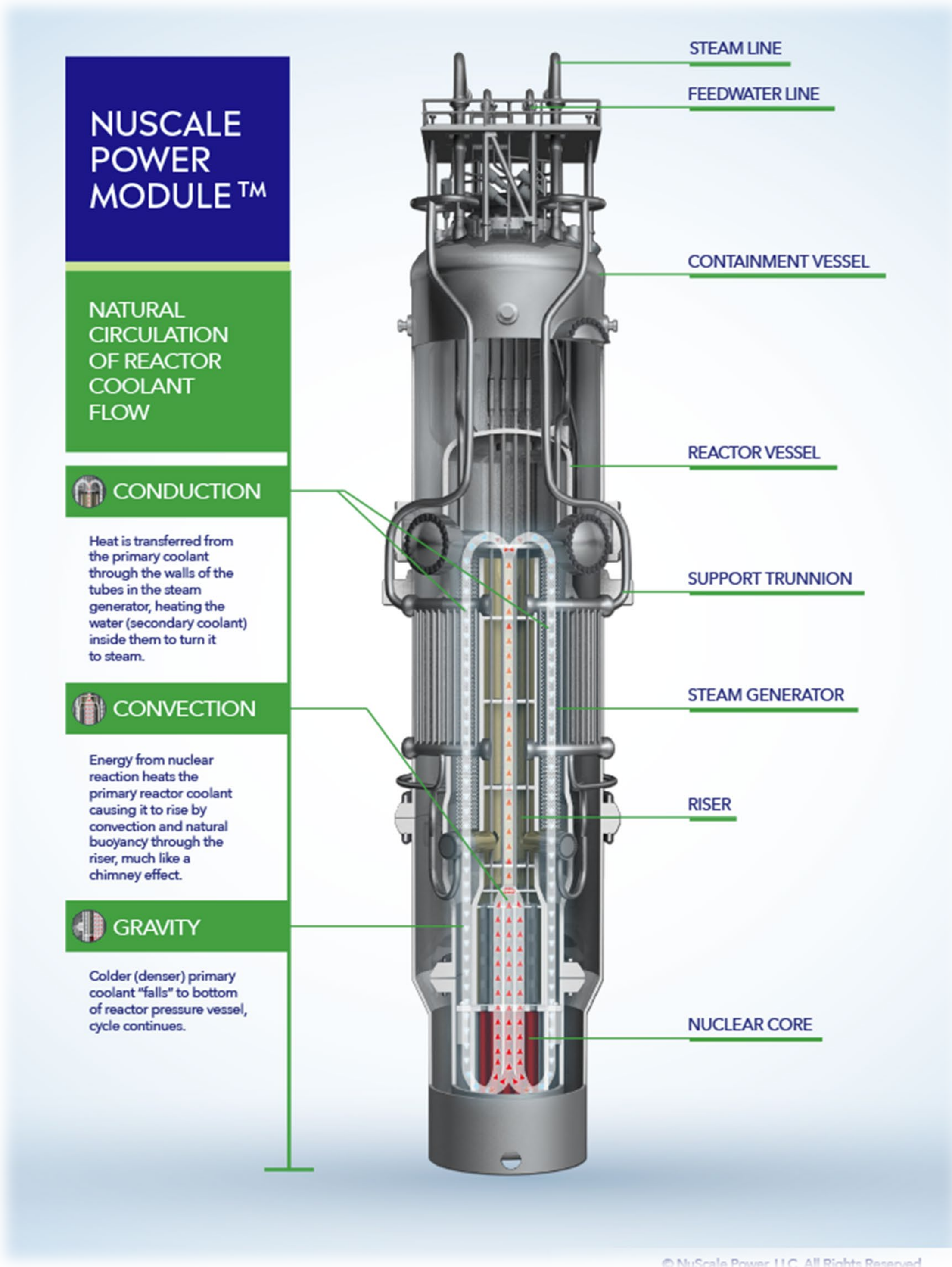
Source: NuScale.

Each vessel was 65 feet tall by a 9-foot diameter, all nested in 82 ft long, 15 feet wide containment structure.[155] The control rod drive is external. As part of its passive safety features, it uses natural convection cooling for routine and emergency. Because of this, the NuScale design had no coolant pumps in the primary reactor coolant system to carry heat from core to the steam generators. A second loop which carries steam from generators to turbines would need motor-driven pumps. This is different from other pressurized water reactors design because the primary coolant is not pumped through the steam generators, instead it flows around outside them. Emergency cooling could be maintained indefinitely through a backout by using valves. See figure 6.

[155] Lyman, *supra* n. 133.

**Figure 7**

**NuScale Power Module**




Source: NuScale.

*NuScale Early Efforts*

The NuScale company started as Oregon State University research project in 2007.[156] Since then, the path to constructing small modular reactors has been littered with obstacles. NuScale's SMR design was primarily based around traditional light water reactors, with the goal of making them small enough that the reactor could fit into containment vessels on a bed of a large truck. These modules could be linked together at the site of the power plant and shared cooling resources that would function even if power was lost.

In 2011, NuScale's primary source of funding, the Michael Kenwood group was investigated by the Securities and Exchange Commission and accused of misappropriating $53 million.[157] While NuScale had no role in these misdeeds, the loss of its funding led the developer to lay off over 100 employees and stalled its projects. NuScale was rescued by the publicly traded construction company Fluor who acquired a majority interest and became its primary source of funding which allowed NuScale to rehire its employees and resume its work on SMRs.[158]

*Carbon Free Power Project*

In 2014, it was first proposed that the Utah Associated Municipal Power Systems (UAMPS), an energy company serving the western parts of the countries, would construct a power plant using the NuScale SMR design. The site of the project would have been on federal lands in the desert of Idaho owned the U.S. Department of Energy. These plans were further developed in 2015 to become the Carbon Free Power Project, Idaho known as CFPP.[159] The original goal was to link together twelve 60 MW reactors for a combined total of up to 720MW generation potential. Idaho National Laboratory, an energy research facility with ties to the U.S. Dept of Energy was to provide technical assistance for the project.

One reason for the optimism of the CFPP was confidence that the similarity of NuScale's design to traditional power plants meant it had the best chance to pass NRC review. As noted in the previous chapter, these predictions were well founded in 2020, when the 50MWe version of its design became the first SMR design to be approved in the United States. Originally estimated for 2027, by the time the project received approval from the NRC, its start date was pushed back to 2029 with all reactors being online by 2030.[160]

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[156] Eric Wesoff, "NuScale: The Rise, Fall, and Rebirth of a Nuclear Startup," *Green Tech Media*, October 13, 2011, https://https:/www.greentechmedia.com/articles/read/nuscale-the-rise-fall-and-rebirth-of-a-nuclear-startup.

[157] U.S. Securities and Exchange Commission, "Sec Charges Connecticut-Based Hedge Fund Manager For Fraudulent Misuse Of Investor Assets," January 28, 2011, http://www.sec.gov/litigation/litreleases/2011/lr21828.htm.

[158] Wesoff, *supra* n. 156.

[159] Idaho National Laboratory, "FAQs Carbon Free Power Project," *Idaho National Laboratory*, November 9, 2023, https://inl.gov/trending-topics/faqs-carbon-free-power-project/.

[160] David Schlissel and Dennis Wamstead, "Small Modular Reactor 'Too Late, Too Expensive, Too Risky and Too Uncertain' | IEEFA," Institute for Energy Economics and Financial Analysis, February 17, 2022, https://ieefa.org/articles/ieefa-us-small-modular-reactor-too-late-too-expensive-too-risky-and-too-uncertain.

While supporting new technology comes with many unforeseen issues that could increase costs, the downfall of CFPP appears rooted in the economics of energy production rather than a particular flaw in its design. At the start of the project, it was expected that NuScale's SMR would cost about the same as a traditional nuclear power plant, 6-8 cents per kWh.[161] This would have been on the expensive end of the energy generation spectrum, but interested communities were willing to take the chance on a novel technology. The first sign of trouble started in 2021 when UAMPS announced that the CFPP would shrink to only six reactors, but that it would raise the power of each unit to 77MWe, so there would only be a modest reduction in the amount of power being offered by the plant. At the time, it was claimed this would lead to an increase in cost from $55/MWh to $58/MWh. Additionally, the number of participants signed on to the project had diminished.[162]

In 2022, reports began to circulate that inflation and shortages of materials such as steel and copper that would be used to construct the plant, and rising interest rates would bring the cost of the project up to $100/MWh and that the UAMPS was having difficulty getting its composite members to sign up to buy energy from the CFPP.[163]

It has been noted that the cost of this project would have been even higher without federal subsidies from the Inflation Reduction Act. From the inception of NuScale's original university research, the Department of Energy provided $400 million to assist the project over a period of twenty years.[164] In 2020, the DOE announced that they would provide up to $1.4 billion in cost sharing over multiple years, provided the plan received congressional approval. Despite assistance, overall cost of the plant rose from $5.3 billion in 2021 to $9.3 billion in 2023 for a 6-unit 77MW plant.[165]

By spring of 2023, the CFPP outlook appeared dire. Its projected cost of electricity projection had risen, and the company announced it needed to triple the numbers of subscribing communities for the project to remain viable.[166] One of the factors that caused subscribers to avoid signing on to the project is they were not convinced the power it generated would be affordable to

[161] Eric Wesoff, "NuScale Progresses with Small Modular Nuclear Reactors," *Wood Mackenzie*, May 26, 2010, https://www.greentechmedia.com/articles/read/nuscale-progresses-with-small-modular-nuclear-reactors.
[162] Nuclear Engineering International, "UAMPS Downsizes NuScale SMR Project," NEI Magazine, July 27, 2021, https://www.neimagazine.com/news/newsuamps-downsizes-nuscale-smr-project-8937920.
[163] Robert Walton, "Rising Steel Prices, Interest Rates Could Push NuScale Utah Project Cost to $100/MWh, but Support Remains," Utility Dive, November 16, 2022, https://www.utilitydive.com/news/nuscale-nuclear-reactor-smr-uamps-rising-steel-prices-interest-rates/636619/.
[164] Lyman, *supra* n. 133.
[165] Grant Smith and Anthony Lacey, "Small Size, Big Problems: NuScale's Troublesome Small Modular Nuclear Reactor Plan," Environmental Working Group, July 11, 2023, https://www.ewg.org/news-insights/news/2023/07/small-size-big-problems-nuscales-troublesome-small-modular-nuclear.
[166] Stephen Singer, "NuScale Must Triple Subscription Level for Small Modular Reactor in Idaho by Early 2024, Company Says," Utility Dive, March 17, 2023, https://www.utilitydive.com/news/nuscale-smr-uamps-funding-nrc-doe-idaho-lab/645262/.

their communities, and if agreed to its power purchase agreement, they would be committed to further price increases, which seemed likely.[167] In November of 2023, the CFPP was cancelled.[168]

*NuScale Future*

While NuScale was unable to realize the CFPP in Idaho, it remains to be seen how this cancellation will affect its other projects. The 77MW version of their standard design is still undergoing the NRC review process.[169] The NuScale company currently has plans to sell power plants internationally in configurations of four, six, and twelve reactors, and the company has hopes to build power plants in Romania, South Africa, and South Korea.[170] In October of 2023, Standard Power announced it would use NuScale technology to power two data centers located in Ohio and Pennsylvania.[171]

While the fate of SMR has not yet been decided, if built this technology has the potential to make nuclear power generation initially more affordable, safer, and flexible than current nuclear power plants. Unfortunately, the cost of SMRs is expected to rise, and they are competing with cheap natural gas and renewables whose prices are falling.

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[167] Robert Walton, "Rising Steel Prices, Interest Rates Could Push NuScale Utah Project Cost to $100/MWh, but Support Remains," Utility Dive, November 16, 2022, https://www.utilitydive.com/news/nuscale-nuclear-reactor-smr-uamps-rising-steel-prices-interest-rates/636619/.
[168] Zach Bright, "NuScale Cancels First-of-a-Kind Nuclear Project as Costs Surge," E&E News by POLITICO, November 16, 2023, https://www.eenews.net/articles/nuscale-cancels-first-of-a-kind-nuclear-project-as-costs-surge.
[169] *Id.*
[170] Timothy Gardner, "NuScale CEO Defends Modular Nuclear Plants after Project Cancellation," *Reuters.Com*, November 14, 2023, https://www.reuters.com/business/energy/nuscale-ceo-defends-modular-nuclear-plants-after-project-cancellation-2023-11-14/.
[171] Aaron Larson, "NuScale Gets a Win with SMRs for Data Centers in Ohio and Pennsylvania," *POWER Magazine*, October 6, 2023, https://www.powermag.com/nuscale-gets-a-win-with-smrs-for-data-centers-in-ohio-and-pennsylvania/.

*Overview*

Electricity production from burning coal has dropped precipitously in recent years due to cheap natural gas, as well as concerns over air pollution and its contributions to global warming. Currently it is estimated that a quarter of U.S. coal power plants will retire by 2029.[172] In Pennsylvania, coal was once the primary source of electricity, but has declined every year since 2010 dropping by 36 percent over a period of 12 years.[173] The Commonwealth's largest coal-fired plant, Homer City closed in July of 2023.[174]

In 2022, the U.S. DOE conducted a study examining which coal plants had the potential to house nuclear reactors. Across the country, the report noted 157 retied coal and 237 operating plants that could be potential candidates for conversion into SMR plants.[175] Approximately 80 percent of these sites would be good to host advanced nuclear smaller than a 1GB of installed capacity. Of the Pennsylvania sites reviewed, 11 plants closed within ten years of 2021. While the specific locations were not listed, the study noted there were two sites with no siting barriers and eight additional sites with only one siting issue.[176] GAIN officials contacted by Commission staff in October of 2023 estimated that of the 15 currently operating coal power plants in Pennsylvania, six could potentially be reused as SMRs sites, while three could either house large or small reactors.

*Potential Benefits of Coal to Nuclear Conversion*

There are remaining questions over what to do with these energy production sites once they are shuttered and the void that could be left in communities that have depended on power plants for employment. Siting SMR inside the grounds of coal power plants that have either closed recently or will in the future is an option currently being explored by numerous industry organizations and researchers. There are multiple reasons why citing coal in nuclear plants appear to be a beneficial match. SMR plants can fulfill a similar energy production niche, have the potential to reuse some aspects of the old site, and could bring jobs and increasing economic activity that mitigate the loss of coal plants.

[172] M. Tyson Brown, "Nearly a Quarter of the Operating U.S. Coal-Fired Fleet Scheduled to Retire by 2029 - U.S. Energy Information Administration (EIA)," U.S. Energy Information Administration, November 7, 2022, https://www.eia.gov/todayinenergy/detail.php?id=54559.
[173] PA Public Utility Commission, *supra* n. 37.
[174] David Fritsch, "The Largest Coal-Fired Power Plant in Pennsylvania Will Close by July 2023," U.S. Energy Information Administration, June 5, 2023, https://www.eia.gov/todayinenergy/detail.php?id=56700.
[175] J. Hansen *et al.*, "Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants" (U.S. Department of Energy, September 13, 2022), p 87, https://fuelcycleoptions.inl.gov/SiteAssets/SitePages/Home/C2N2022Report.pdf.
[176] *Id.* p 25.

Comparing the power output of coal plants with SMR, they could produce similar output which is useful for filling its place in the energy grid. In PA the installed capacity of coal plants is frequently above frequently above 50MWe, but only the five largest plants were above 135 MWe so SMR plant configurations could be scaled to a similar level.[177] One of the chief differences lies with SMR's higher utilization rate. SMR would likely be running at capacity 90 percent of the time compared with coal's 50 percent.[178] So, while they have similar total capacity SMR would be producing more energy, at higher costs when compared to the coal plant its replacing. In one example used in the report, replacing a coal plant with SMR led to an 86 percent reduction in greenhouse gases regionally, similar to taking 500,000 cars off the road.[179]

There is also potential to reuse existing elements of coal plants to reduce the cost of the overall project of hosting SMR at coal plants. Through repurposing existing infrastructure at these plants such as grid connections, cooling towers and water access, office buildings, and roads they could potentially 15 to 35 percent in costs when compared to building an entirely new plant.[180] A less optimistic scenario in which they would only be able to use administrative buildings, roads, and transmission lines reduces the savings to around 10 percent.[181]

If correctly managed, coal to nuclear conversion could significantly mitigating the loss of jobs resulting from a plant closure is potential benefit of a coal to nuclear conversion, with 77 percent of coal jobs could be transferred to nuclear power plants according to the DoE report.[182] In a scenario examined, converting the coal plant to nuclear site led to a net increase of 650 jobs, many of which may be stable and high paying. Additionally, this time of construction could bring $275 million in economic activity from plant operation, $102 million of which would be wages brought home by the additional jobs the plant would generate.[183]

*Potential Barriers to Coal to Nuclear Conversion*

While the DoE study explored the likely benefits for coal to nuclear conversion, another study examined the possibility of siting SMR at a coal site in Maryland offers insight on the type of issues that could arise when attempting to make the switch. The owner, X-energy, provided an economic analysis using its four-reactor XE 100 design in Maryland. At the examined coal site, the converted power plant would not be able to reuse existing equipment or cooling tower, as it was found that steam from the XE-100 plant design operates at a higher temperature than the equipment was originally built for.[184] While the four-reactor plant could potentially fit on the site, it was noted it would involve changes to its layout or even reducing the number of reactors.[185]

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[177] "List of Coal-Fired Power Stations in the United States," in *Wikipedia*, accessed February 7, 2024, https://en.wikipedia.org/wiki/List_of_coal-fired_power_stations_in_the_United_States.
[178] Mark Morey and Alex Gorski, "As U.S. Coal-Fired Capacity and Utilization Decline, Operators Consider Seasonal Operation," eia.gov, September 1, 2020, https://www.eia.gov/todayinenergy/detail.php?id=44976.
[179] Hansen, *supra* n. 175 at p. 62.
[180] *Id.* pg. 71.
[181] *Id.* pg. 30.
[182] *Id.* pg. 56.
[183] *Id*. pg. 72.
[184] X-Energy, LLC, "Feasibility and Assessment and Economic Evaluation: Repurposing a Coal Power Plant Site to Deploy an Advanced Small Modular Reactor Power Plant," November 30, 2022, Pg. 5.
[185] *Id.* pgs. 4-5.

This type of adjustment is not ideal when looking to move toward standardizing designs to lower costs.

One of the largest concerns discussed was the need to upgrade the existing transmission infrastructure to be able to handle the output 320MWe provided by the new plant. This upgrade would take $10 to $20 million investment. Additionally, the regulatory authority in charge of transmission upgrades was not accepting any applications. Finally, the report noted uncertainty whether evacuation route nearby of highway had the capacity to support evacuation requirements.

The report projected that construction and operating costs of the Xe-100 SMR plant could be competitive but recommended additional economic analysis before selecting the site.[186] Some caveats of their analysis is that was assumed the plant at this site would not be a first of a kind model and relied on savings related to production and learning rates. However, until SMR are more widespread and the initial investment on early plants is made, analysis over the cost effectiveness of later plants is of limited value. Additionally, the report noted it had not considered how recent increases in the supply chain would affect its affordability, and that the plant would require a separate analysis to determine whether a two-reactor plant would be more cost effective.

Perhaps the two largest barriers to citing SMR in coal plants are related to product cost and timeliness. Early studies project that savings related to reusing coal sites could be between 10 to 33 percent. It is quite possible that these site-based savings could make later SMRs more profitable in the future but may not be enough to encourage initial investment. Until large investments are made and early SMR plants are built, the savings identified from site reuse is likely not enough to make SMRs cheaper than other energy options.

There may be difficulty aligning coal closures and with the start of SMR operation. SMRs have not yet passed necessary regulatory steps to operate in the United States, and once they do, there is no guarantee that the old coal sites will still be viable. After a decade, most of the useful parts will have been scrapped, or repurposed or the site has been transitioned to other uses. Transmission lines are reported to be one of the most valuable components of reusing coal sites, that could save a project millions of dollars if reused. In some places, nuclear would need to compete with other power sources who might also seek to use transmission lines, such as a solar farm which opened at a closed coal site in New Mexico.[187]

To be able to make use of the existing workforce, SMR would need to begin operation close to the closure of coal plants before they relocate or find new positions elsewhere. Approximately 23 percent of positions would require significant retraining or licensing: operators, managers, and technicians. Questionable practice of extending plant operations to line up with SMR construction would not be guaranteed. Based on this preliminary evidence the limiting issue is that SMR have not progressed to a point where they may be able to capitalize on the closure of coal plants.

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[186] *Id.* p. 23.

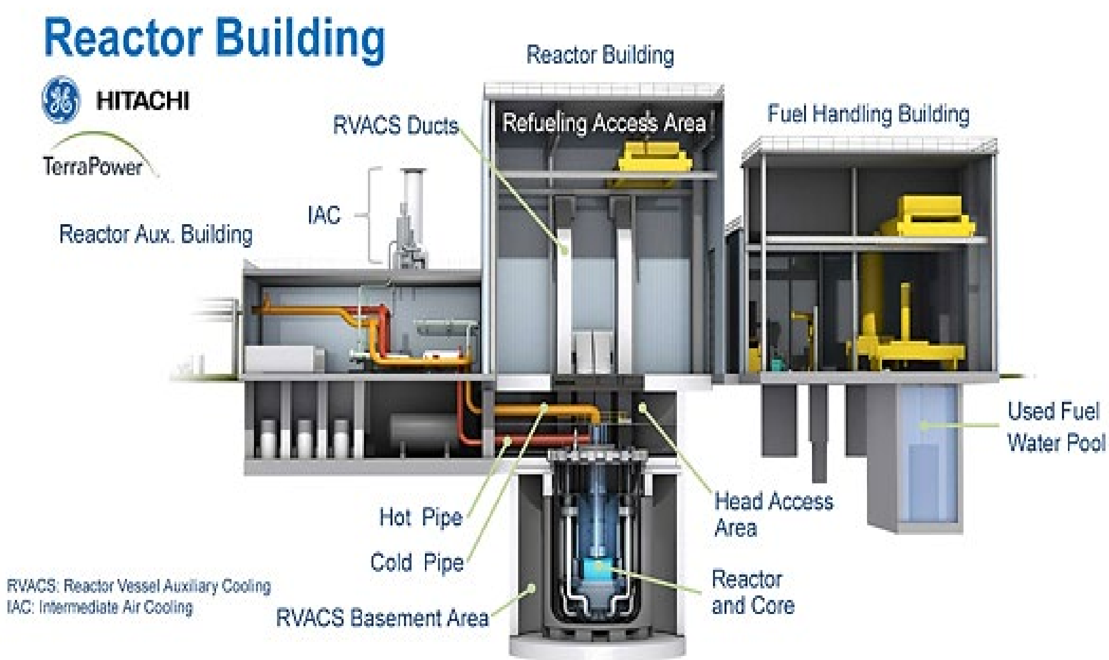
[187] Ryan Kennedy, "New Mexico Solar Project Sites 200 MW on Former Coal Plant," Pv Magazine USA, August 30, 2023, https://pv-magazine-usa.com/2023/08/30/new-mexico-solar-project-sites-200-mw-on-former-coal-plant/.

*Case Study: Natrium*

Perhaps the highest profile instance of an advanced reactor project reusing a coal plant is in Kemmerer Wyoming. In 2021, Pacificorp, a multistate utility company, and Terrapower, a nuclear developer founded by Bill Gates, announced a partnership to build a 345 MW nuclear reactor in a region known for its coal development. The proposed power plant would use the Natrium reactor design, which is a pool type sodium fast reactor. The design for the power plant is currently undergoing pre-license activities by the NRC.[188] See figure 8.

**Figure 8**

**Natrium Power Plant Design**




Source: TerraPower.

Part of what makes the Natrium design unique compared to other SMR, is it can store energy like a battery in addition to its generating capacity. Heat from the reactor is stored in molten salt which can act as 1GWh of thermal storage. When needed, the plant can temporarily ramp up production to 500MW by dropping the molten salt into a turbine to produce electricity for up to five hours. This design is meant to complement renewable resources so that natrium reactors can easily ramp up product during peak hours where solar or wind may not be generating.

[188] Nuclear Regulatory Commission, "Natrium," NRC Web, February 1, 2024, https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/licensing-activities/pre-application-activities/natrium.html.

The Natrium reactor uses a specialized type of fuel known as High-Assay Low Enriched Uranium (HALEU) metal fuel. HALEU is enriched to level of between 5-20 percent which is greater than the five percent used at traditional light water reactor.[189] Originally Terrapower was looking to source its fuel from Russia. Due to complications involving the Invasion of Ukraine, Terrapower has lost its primary source of fuel. As a result of these fuel shortages, the opening of the Natrium plant has been delayed until 2030 at minimum.[190] Since the delay, start-up companies have begun to produce HALEU domestically.

Terrapower currently estimated that the Kemmerer plant would cost $4 billion, with the company aiming for future plants to cost closer to $1 billion.[191] So far, this project has been awarded $80 million in funding by the DOE,[192] while also attracting $750 million in private equity investment.[193] The company is currently examining whether five coal plants could be equipped with natrium reactors by 2035, and is looking to cite two reactors in Utah.[194] Critics say uncertainty exists over the financial risk to communities, which is not well understood.

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[189] Office of Nuclear Energy, "What Is High-Assay Low-Enriched Uranium (HALEU)?," Energy.gov, April 7, 2020, https://www.energy.gov/ne/articles/what-high-assay-low-enriched-uranium-haleu.

[190] Dustin Bleizeffer, "Wyoming Nuclear Plant on Track Despite Industry Setback, Developer Says," *WyoFile*, November 20, 2023, https://wyofile.com/wyoming-nuclear-plant-on-track-despite-industry-setback-developer-says/.

[191] Cat Clifford, "Bill Gates' TerraPower Aims to Build Its First Advanced Nuclear Reactor in a Coal Town in Wyoming," *CNBC*, November 18, 2021, https://www.cnbc.com/2021/11/17/bill-gates-terrapower-builds-its-first-nuclear-reactor-in-a-coal-town.html.

[192] Office of Nuclear Energy, "U.S. Department of Energy Announces $160 Million in First Awards Under Advanced Reactor Demonstration Program," Energy.gov, October 13, 2020, https://www.energy.gov/ne/articles/us-department-energy-announces-160-million-first-awards-under-advanced-reactor.

[193] TerraPower, "TerraPower Announces $750 Million Secured in Fundraise," August 15, 2022, https://www.terrapower.com/fundraise/.

[194] TerraPower, "PacifiCorp Forecasts Need for Two Additional Natrium Reactors in New Regulatory Filing," March 31, 2023, https://www.terrapower.com/pacificorp-forecasts-need-for-two-additional-natrium-reactors-in-new-regulatory-filing/

# REPORT FINDINGS

Nuclear energy has many positive attributes such as no carbon emission or harmful air pollution, support of electrical grid stability, and has a high-capacity factor due to its infrequent need for fuel. Despite these benefits, nuclear energy faces numerous obstacles including negative public perception, reliance on foreign fuel sources, lack of a centralized waste repository, and is a highly regulated industry that must meet strict safety requirements which other energy sources do not.

1. For many years light water reactors have proven prohibitively expensive to construct and slow to build in the United States. The two most recent reactors being built at the Vogtle Electric Generating Plant in Georgia have had a combined cost of $31 billion and are still unfinished. In South Carolina, rate payers are responsible for $2.3 billion in costs associated with two nuclear reactors despite the reactors having been abandoned.

2. Small Modular Reactors (SMR) show promise in their ability to deliver the aforementioned benefits of nuclear power at more affordable costs. In addition to electric generation, some models of SMR could provide process heat, desalinated water, or produce hydrogen, all of which could be an asset to industrial businesses. SMR designs are capable of load follow other energy sources giving them greater flexibility. New passive safety features based on reactor size or novel fuel sources could make SMR significantly safer than past iterations.

3. Despite industry, media, and investor optimism, however, SMR development has yet to reach maturity. While a small handful of SMRs in China and Russia have been completed, few, if any U.S.-based reactors will be brought to market before 2030. Only a single SMR design from NuScale has applied for licensure and been approved by the NRC to date. This reactor was subsequently redesigned to have a higher power output and will need at minimum another year of regulatory review. While thirteen other companies have engaged in pre-license activities with the NRC, none of them have filed formal applications for licensure. The previous SMR approval from the NRC took five years to review from the date of filing.

4. Current research suggests that new SMR models will produce an amount of high-level radioactive waste comparable to other reactors per KW. While this waste has been safely contained in cooling pools and concrete casks at other nuclear sites for decades, it is nonetheless considered a temporary solution that costs U.S. taxpayers $500 million annually. The commonwealth should explore ways of supporting U.S. Department of Energy efforts to develop a consent-based nuclear waste siting process.

5. Building SMR prototypes will require significant investment. Depending on the type of reactor, a first-of-kind SMR plant could cost from 30 to 110 percent more than subsequent units. Before its cancelation, a six-reactor SMR project in Idaho was projected to cost a total of $9.3 billion, or $89 per MWh. A delayed Natrium reactor in Wyoming is expected to cost a minimum of $4 billion. It could take from 10 to 15 first-of-kind SMR projects constructed between 2030 and 2040 to achieve lower SMR costs between 2040 and 2050.

6. To fulfill the promise of low-cost nuclear energy, SMR will need to be mass produced in factories. Many current estimates show what costs might be after manufacturers have learned how to make the units more cheaply. After expensive first-of-kind projects are completed, SMRs could cost between $4,000-$7,000 per kilowatt of capacity installed and between $15-35 per MWh in operating expenses. Previous efforts to mass produce parts for larger nuclear power plants in South Carolina and Georgia faced significant challenges; SMR production could result in similar setbacks while factory assembly is perfected.

7. The potential exists for coal-fired power plants to be replaced with SMRs due to their similar power output and potential for SMRs to reuse old sites and materials. Coal to nuclear conversion could potentially result in 15-35 percent cost savings in SMR construction and provide communities facing plant closures with hundreds of new jobs and millions of dollars in economic development. Coal plant sites must be reused within a decade of closure for cost savings to occur. For job retention benefits to occur, SMR construction would have to align with future coal plant closures. In Pennsylvania, it is estimated that 11 closed and 9 operating coal plants could be repurposed to site SMR.

8. When SMRs arrive in Pennsylvania, communities must carefully consider the terms of power purchase agreements to try to balance potential value to communities in the form of investment and stable jobs they could bring against the financial risk of a project.

9. Given the exorbitant cost of new construction for large light-water reactors and the nascent status of SMRs, existing nuclear power plants should be maintained given their reliable output of baseload power and generation of carbon-free electricity. Past efforts to phase out nuclear power plants with renewable energy sources have thus far instead led to an increase in use of fossil fuels.

10. Federal intervention has saved Pennsylvania's remaining nuclear power plants from premature closure in the short term. If a nuclear power plant becomes financially at risk in the future, the General Assembly should consider expanding on economic incentives to continue their operation if it is deemed both practical and safe to do so.

PRINTER'S NO. 3602

THE GENERAL ASSEMBLY OF PENNSYLVANIA

# HOUSE RESOLUTION

No. 238 Session of 2022

INTRODUCED BY MEHAFFIE AND STRUZZI, OCTOBER 25, 2022

REFERRED TO COMMITTEE ON CONSUMER AFFAIRS, OCTOBER 25, 2022

A RESOLUTION

Directing the Joint State Government Commission to conduct a holistic study on the benefits of nuclear energy and small modular reactors.

WHEREAS, Nuclear energy is a reliable source of zero carbon-emitting energy; and

WHEREAS, Nuclear energy requires refueling less than once per year; and

WHEREAS, Nuclear energy has a vital role in the diverse energy portfolio of this Commonwealth; and

WHEREAS, Small modular reactors are a relatively novel and innovative method of creating nuclear energy; and

WHEREAS, It would benefit the General Assembly to have a comprehensive overview of nuclear energy and small modular reactors and the benefits derived from nuclear energy and small modular reactors; therefore be it

RESOLVED, That the House of Representatives direct the Joint State Government Commission to conduct a holistic study on the benefits of nuclear energy and small modular reactors; and be it further

RESOLVED, That the study include findings and recommendations on how to maximize the benefits of nuclear energy and small modular reactors in this Commonwealth; and be it further

RESOLVED, That the Joint State Government Commission issue a report of its findings and recommendations and submit the report to the General Assembly no later than 12 months after the adoption of this resolution.