DOVETAIL PARTNERS

# SMALL-SCALE NUCLEAR ENERGY:

## U.S. PROSPECTS AND GLOBAL CONTEXT

By: Jim Bowyer, Ph.D and Kathryn Fernholz

July 2026

# TABLE OF CONTENTS

# Executive Summary

The U.S. nuclear power industry enjoyed 25 years of growth from its inception through early 1979. Then, an accident at the Three Mile Island nuclear plant changed everything, bringing nuclear power expansion in the U.S. to a halt for the next 45 years.

Despite early promises of low-cost electricity, low-cost nuclear power never came to be. Plagued by high capital costs and persistent cost overrun problems through its history, the nuclear industry has struggled to compete with other sources of power. The initial response of the industry was to build ever-larger reactors, seeking benefits from economies of scale. But construction costs continued to present a problem. Now, with added competition from wind and solar, delivered electricity price competition has become even more challenging.

As a potential partial solution to safety risks, as well as high up-front capital requirements, attention has turned to small modular reactors (SMRs). One third to one fourth or less the size of typical reactors, SMRs present less danger in the case of an accident, can more easily incorporate passive safety features, and may (aspirationally at least) lower costs of nuclear energy. Thousands of reactor years of accident-free experience with nuclear powered U.S. naval vessels provide confidence that fundamental technologies are sound.

SMR development is in its early stages, with only four operational SM reactors worldwide and none in the U.S. But more than 70 designs are on the drawing board, with orders already being placed by potential early adopters.

But many hurdles remain to be cleared before SMR deployment, including technical, regulatory, political, and public acceptance challenges that include finding a solution to long-term nuclear waste disposal.

Time will tell the story, but for now the future of SMRs is uncertain.


*"Time will tell the story, but for now the future of SMRs is uncertain.*

# A Brief History of Nuclear Power

## First Steps

The world's first nuclear power plant began operation near Moscow in 1954[1]. Two years later the first commercial power plant opened in Cumbria, England[2]. Many nuclear installations followed over the next several decades, with all of them small-scale by today's standards[3].

Accompanying the first nuclear power plants was unbridled optimism that this new technology would translate to incredibly inexpensive electricity. This view is reflected in a 1954 speech to the National Association of Science Writers by the Chairman of the U.S. Atomic Energy Commission (USAEC) wherein was uttered the memorable phrase:

> *"It is not too much to expect that our children will enjoy in their homes electrical energy too cheap to meter…"* [4]

Subsequent analysis, however, brought a dose of reality to the nascent industry. A 1961 USAEC analysis of nuclear vs fossil fuel generated power found nuclear at an economic disadvantage in every category evaluated – construction cost, fuel cost, and costs of operation and management. The report suggested that efforts to promote nuclear power be focused on areas of the country historically burdened by high electricity costs.[5]

In response to the unfavorable economics problem the nuclear energy industry began to build larger generating plants, seeking cost reductions through economies of scale. But larger created new problems. First, because larger scale reactors contained greater quantities of radioactive material, the consequential risk of accidents became larger. In addition, as plants increased in scale the upfront investment costs rose as well, creating difficulties in raising capital.[6] Public awareness of risks grew over time, and by the mid-1970s calls for greater regulation of the industry led to establishment of the Nuclear Regulatory Commission, an entity separate from the AEC that had previously been responsible for both promoting and regulating the industry.[7] Greater regulation and oversight also led to greater costs.

1 Schernikau (2024)
2 Black (2021)
3 World Nuclear Association (2026f)
4 Wellock (2026)
5 USAEC (1961)
6 Lee (2024)
7 Walker and Wellock (2024)

## A Reckoning

On March 28, 1979, the Three Mile Island (TMI) accident occurred at a nuclear generating station near Harrisburg, Pennsylvania.[8] The event triggered public alarm and accentuated calls for even greater regulation. At the time of the accident, about 50 reactors were under construction across the U.S. that had not yet received operating licenses. Mid-construction changes in design requirements including mandated incorporation of passive safety systems led to costly redesign and project delays. A study of final construction costs for nuclear plants that were under construction at the time of the TMI accident and completed afterward showed median increases in total construction periods and overall costs of 2.2 and 2.8 times compared to pre-TMI. Not coincidentally, TMI marked the end of new nuclear power plant construction starts in the U.S. for the following 30 years.[9]

The Chernobyl disaster[10] occurred seven years following TMI (1986) reminding people around the world of the risks of nuclear energy. A quarter century later (2011) an earthquake-triggered tsunami hit Fukushima, Japan, resulting in nuclear reactor meltdowns and again raising nuclear energy safety concerns.

What followed was continuation of a persistent history of project delays and cost overruns in the U.S. and elsewhere that has not abated with experience.[11] That the problem continues is evidenced by data showing that nuclear power plant projects that commenced construction in the U.S. between 2010 and 2020 experienced an average construction cost overrun of 102.5%, with delivery an average of three years behind schedule.[12] A more recent example (2024) is provided by a project in Georgia, USA. Contracted as a 7-year, $14 billion project, completion required 15 years, generating accumulated costs of almost $37 billion.[13] Investigations of causes of construction delays and cost overruns have identified regulatory changes, lack of standardized design, technical problems, supply chain disputes, litigation, and labor issues as key factors.[14]

With ongoing cost issues and periodic reminders of risks, nuclear energy not surprisingly declined in the world energy picture. Steady decline occurred from 1996 when nuclear accounted for 17.5 percent of electric generation globally to 2020 when the percentage had dropped to 9.2%.[15] Both economics and safety concerns have been identified as playing a role.[16] In the U.S. the share of nuclear in electricity generation remained over that same period at about 19.6%.[17]

Ongoing issues led to rethinking nuclear reactor design and engineering. What emerged was a focus on small-scale modular reactors that could be produced in plant settings. But how to regain public trust?

8 A failure in a reactor cooling system resulted in a partial meltdown of the central nuclear core and release of radioactive gases and iodine into the surrounding environment. It remains the worst U.S. nuclear accident in history. No deaths, injuries, or subsequent health impacts are known to have resulted from this incident.

9 Lovering et al. (2016)

10 This is recognized as the worst nuclear accident in history, an event that caused extensive release of radiation, 28 deaths, and longer-term adverse impacts to human health and the environment. Investigation revealed that flaws in reactor design and operator error were the cause.

11 Ramana (2021), Eash-Gates et al. (2020), Grace (2025)

12 Eash-Gates et al. (2020)

13 Grace (2025)

14 Lovering et al. (2016), Savacool and Henne (2024), Stiegler et al. (2025)

15 Downing and Taylor (2024)

16 Ramana (2021, Downing and Taylor (2024)

17 USEIA (2026)

# Climate Concerns a Game Changer?

## Recognition of Nuclear Potential

In view of the ability of nuclear energy to provide carbon free electricity and heat it has long been viewed as a component of a zero-carbon solution even in the face of strong opposition from some groups. Nuclear power was recognized, for example, by the Intergovernmental Panel on Climate Change (IPCC) from the Second, and most prominently – Fifth[18], Assessment reports onward. As part of developing the IPCC Sixth Assessment Report, working group III conducted a series of modeling exercises in which nuclear energy was identified as a part of about 80% of scenarios that resulted in limiting change to a ≤ 1.5˚C increase threshold.[19]

This recognition provided impetus for continued investigation on the part of the scientific community into safer, less expensive nuclear energy. The topic of small modular reactors alone has generated more than 2,080 peer-reviewed publications, with most of these over the past decade.[20]

Seeking to gain the attention of policy-makers vis-a'-vis the climate change discussion a team of MIT nuclear scientists in 2003 highlighted the low-carbon aspect of nuclear power. Acknowledging the high up-front costs of establishing nuclear power plants, the team proposed use of tax credits to stimulate private investment while also noting as many had before, that were society to exact a price on carbon emissions the competitiveness of nuclear power would dramatically improve.[21]

A second MIT report on nuclear energy and the climate change problem was issued six years later.[22] The report emphasized the potential role of nuclear in addressing the climate change problem, concluding that:

> *In sum, compared to 2003, the motivation to make more use of nuclear power is greater, and more rapid progress is needed in enabling the option of nuclear power expansion to play a role in meeting the global warming challenge. The sober warning is that if more is not done, nuclear power will diminish as a practical and timely option for deployment at a scale that would constitute a material contribution to climate change risk mitigation.*

18 Bruckner (2014)
19 IPCC (2022)
20 Kim et al. (2025)
21 Ansolabehere et al. (2003)
22 Deutch (2009)

Subsequently a new push for nuclear energy expansion was initiated within COP 28[23] in 2023 in the form of a Declaration to Triple Nuclear Energy.[24] Signed initially by 22 countries, a number that had risen by early 2026 to 38, the declaration recognizes the "key role of nuclear energy in achieving global net zero greenhouse gas emissions/ carbon neutrality to mid-century . . ." and "commits to work together to advance a global aspirational goal of tripling nuclear energy capacity from 2020 to 2050".[25] The U.S. and Canada were among the first signatories.

Global data center and AI developments have added new urgency to nuclear energy expansion, in part because of unprecedented energy demands, but also because dramatic increases in power consumption are compromising progress toward reduction of fossil fuel reliance.[26]

## U.S. Policy Directives

In the U.S., nuclear energy entered the public policy arena as a potential emissions reduction solution at the turn of the 21st century. The election of President GW Bush in 2000 marked the beginning of a sustained effort to revitalize the U.S. nuclear energy industry. Bush was a proponent of nuclear energy expansion, signing into law the Energy Policy Act of 2005 that promoted U.S. nuclear reactor construction through incentives and subsidies, expanded nuclear technology research and development, and supported advanced reactor technology. All subsequent administrations similarly supported expansion of nuclear energy.

The Obama administration supported loan guarantees and significant R&D funding for advanced nuclear development. President Trump in his first term directed a thorough review of national nuclear energy policy to identify ways to revitalize the industry. He also sought to expedite licensing for new reactor designs. The Biden administration continued these programs, also launched Project Phoenix – an initiative supporting feasibility studies and technical assistance to convert coal-fired power plants to zero carbon small modular reactor energy generation – and gained passage of the ADVANCE (Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy) Act of 2024. The current Trump administration has aggressively acted through a series of Executive Orders to quadruple nuclear energy expansion, including rapid deployment of advanced demonstration reactors.[27]

As an indication of nuclear energy being back on the map in the U.S., the Commonwealth of Pennsylvania (home of TMI) recently released a Nuclear Energy Roadmap "to bolster Pennsylvania's national leadership in nuclear energy by mobilizing its existing fleet, industrial supply chain, and technical expertise.[28]

23 COP28 refers to the 28th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC).

24 USDOE (2023a)

25 USDOE (2023a), World Nuclear News (2026)

26 Altus (2025), Clancy (2025), Delgado (2026), Jack (2025), Jackson (2025), Nakhle (2025), Proctor (2023), Waltz (2024)

27 Hunt (2025)

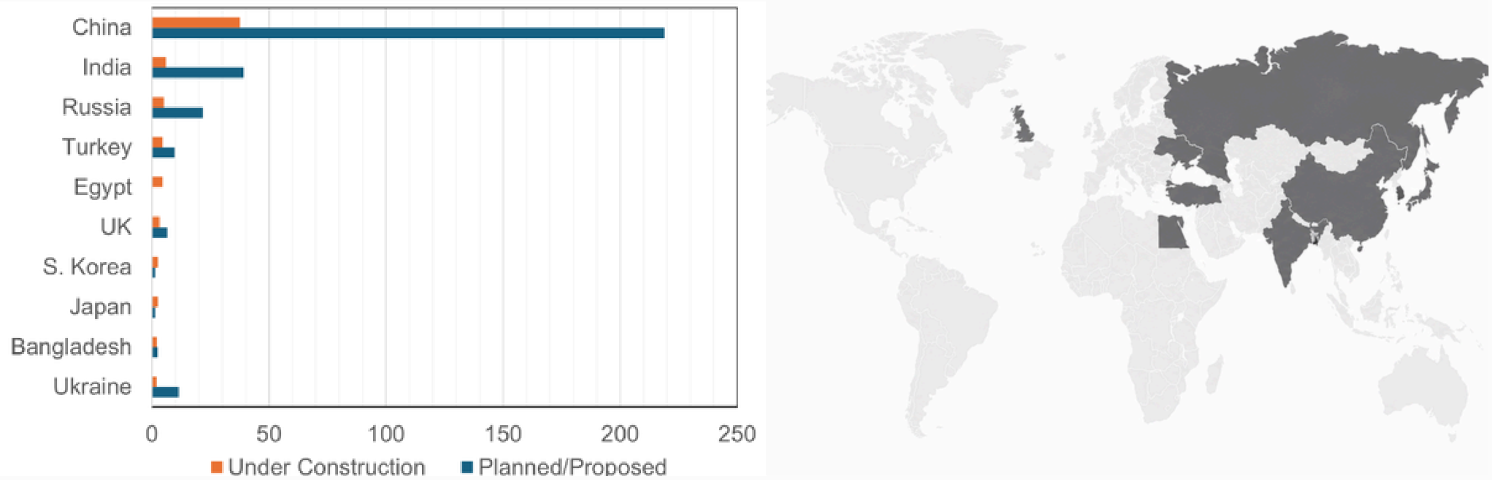
28 https://teampa.com/2026/05/team-pennsylvania-releases-pennsylvania-nuclear-energy-roadmap-to-advance-energy-leadership/

## Expanding Global Initiatives

In April 2026 an estimated 440 nuclear reactors operated in 31 countries, with a combined capacity of about 400 GWe. An additional 80 reactors totaling 75.5 MWe of capacity were under construction in 15 countries. It is in the category of planned and proposed nuclear facilities that the extent of interest in expanding nuclear power capacity is revealed.[29]

Within 25 countries planning is underway for an estimated 120 nuclear power reactors adding up to about 110 MWe of capacity. Over 300 more are proposed.[30] Figure 1 provides a partial summary of activity by country regarding nuclear power plant construction, planning, and proposed further development. China is clearly leading in all categories. In addition to the 10 countries listed in Figure 1 larger roles for nuclear energy are being pursued in Brazil, Hungary, Pakistan, Iran, Slovakia, Argentina, the United States. Canada, France, Indonesia, and South Africa.[31] Most recently a spate of Asian nations – Malaysia, Thailand, Vietnam, and the Philippines – have signaled interest in hosting nuclear power facilities through formal adoption of strategies to move in that direction.[32]

**Figure 1**
**New Nuclear Power Plants Under Construction and Planned/Proposed (GWe)**




Source: World Nuclear Association (2026d)

29 World Nuclear Association (2026d)
30 World Nuclear Association (2026d)
31 Black (2021), Nuclear Business Platform (2025), World Nuclear Association (2026b)
32 Delgado (2026)

# A New Direction

## The Vision

As of this writing, development of new nuclear energy capacity is overwhelmingly focused on facilities of traditional scale, i.e. 1200-1400 MWe. Within a few countries, however, the focus has shifted to smaller scale modular reactors. The United States, China, and Canada are leaders in this new area of development of nuclear power.

Envisioned are small modular reactors (SMRs) that complement renewable energy sources while providing back-up reliability, as well as large-scale nuclear generating facilities created by combining multiple small reactor modules. Now in the formative stage, the new technology is being promoted as lower cost and lower risk than current nuclear facilities, more reliable than wind and solar, and capable of providing essential back up to renewable energy.[33] Small is generally defined as 300 MW or smaller.[34]

Additional benefits of small-scale are:

- Improved siting flexibility
- Lower capital requirements
- Reduced up-front financing challenge via modular deployment
- Shorter construction duration
- Can be safely connected to micro grids[35]
- Allows for off-site production of key reactor components

## Long Experience Paves the Way

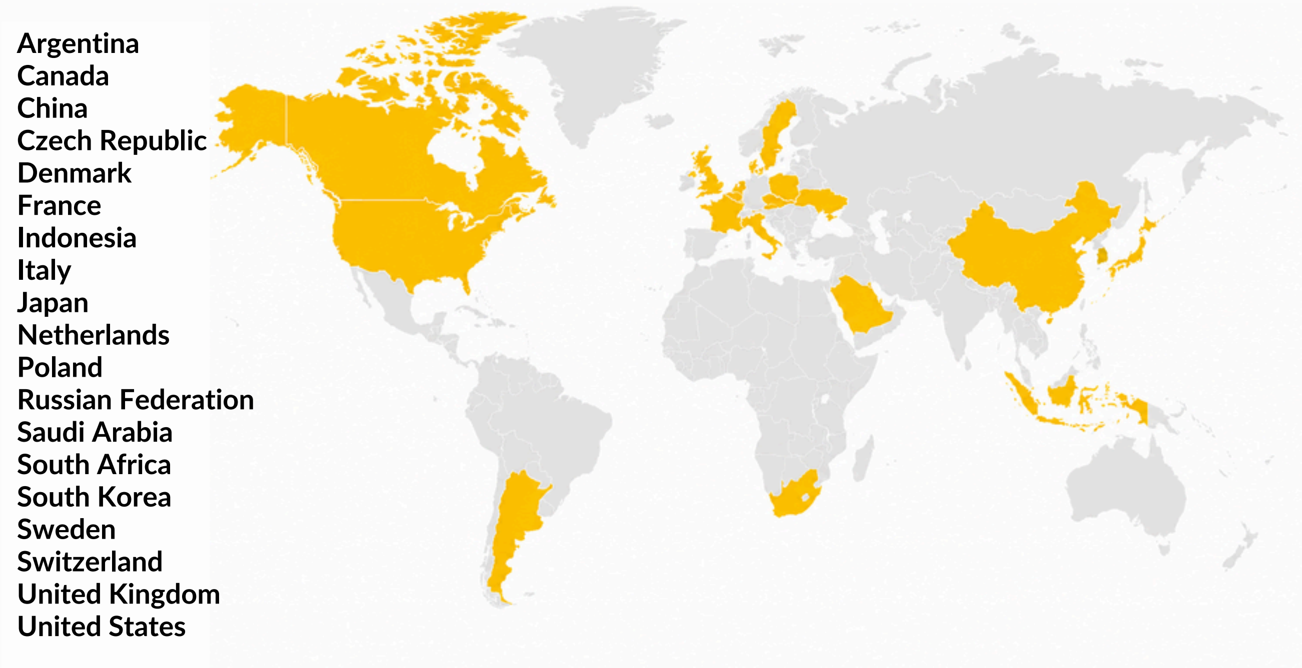
Small-scale factory-manufactured nuclear reactors are not a new concept, having been employed by the U.S. Navy for over 70 years. The nuclear-powered Nautilus submarine (SSN-571) was launched in 1954 powered by a Westinghouse manufactured 10 MW reactor. Seven years later the aircraft carrier Enterprise (CVN-65) went into service powered by eight 150 MW reactors – again factory produced units. Since those early days the Navy has continuously operated numerous nuclear-powered ships and submarines, logging over 7,600 nuclear years of serious incident-free operation during that period.[36] The accumulated experience of all the world's navies and nuclear-powered ships adds up to over 12,000 years of reactor years of service.[37] It is important to recognize that although naval reactors provide evidence that small reactors can be deployed safely, the reactor designs and technologies employed differ in several key aspects from those under consideration for civilian use.

33 Lee (2024), IAEA (2020), Hussein (2020), Chatzis (2020)
34 The world's largest nuclear reactor – at China's Taishan facility – has a gross capacity of 1,750 MW.
35 Microgrids are small-scale electrical grids that serve a specific local area such as a single manufacturing facility, business enterprise, neighborhood, or campus.
36 Naval Nuclear Propulsion Program (2025)
37 World Nuclear Association (2023)

## Widespread Interest, Multiple Designs

Increasing interest in small nuclear reactors has inspired designs from governments, universities, and the private sector worldwide. As of early 2026 there were 71 sustained SMR design, development, or deployment projects underway involving 19 countries (Figure 2).

**Figure 2**
**Countries Represented in New SMR Development**




Source: International Atomic Energy Agency (2024a)

## Various Reactor Technologies[38]

The 71 different designs span four basic technologies that are fundamentally defined by cooling mechanisms and variously described as: water cooled, high temperature gas cooled, molten salt, and fast neutron spectrum reactors.

### *Water Cooled Reactors*

Historically, more than 80% of commercial nuclear reactors have employed pressurized water-cooled technology using light water as the primary coolant. This is also the reactor technology used in all U.S. Navy nuclear-powered vessels throughout their history. Pressurized water-cooling accounts for a little more than one-fourth of designs proposed.

In the most common configuration of a water-cooled reactor, water in a primary loop is kept under extremely high pressure such that it can be heated to as much as 300˚C (570˚F) without boiling. This is used to heat a second loop of water to the boiling point, generating steam that runs a turbine, after which the steam is cooled and then recovered for reuse. The fuel employed is slightly enriched uranium in the form of thin rods or plates.

---

38 Hussein (2020), OECD (2021), Wang et al. (2023), Rogalev (2023), CRS (2023), Lee (2024), IAEA (2024a)

*High Temperature Gas Cooled Reactors*

Helium is used as the coolant in a high temperature gas cooled reactor. The gas absorbs heat from the fission reaction – as high as 750-950˚C (1380-1750˚F) before passing through a heat exchanger where heat is transferred to water that produces steam to run a turbine. The helium is cooled in the exchanger before circulating back to again serve as a coolant. These reactors use what is known as TRISO fuel – poppy seed sized kernels of uranium coated by three layers of carbon and ceramic materials that are combined either into billiard ball-sized spheres or cylindrical pellets about 1mm (1/25th inch) in diameter. TRISO fuels are an important element of modern reactor design in that they can withstand extreme temperatures without melting, providing a critical safety feature in the event of an accident.[39]

*Molten Salt Reactors*

Molten salt reactors, another form of advanced reactor, are both powered and cooled by the same material – molten salt. The molten material is pumped through a core, then to a heat exchanger and back again in a continuous loop, with heat transferred to a secondary salt loop that is used to generate steam to power a turbine. The molten salt is composed of uranium or thorium compounds that are mixed with fluorides or sometimes chlorine.

*Fast Neutron Spectrum Reactors*

These are the most advanced reactors, utilizing liquid metals (sodium or lead) as coolant that provide for unrestrained movement of neutrons (thus the word fast in the name). As in other reactors, heat produced is used to make steam to run turbines. Powered by enriched uranium, plutonium, or even spent nuclear fuel[40], these reactors are highly efficient, gaining more energy (as much as 70 times more energy) from the same fuel as other nuclear technologies while producing little waste.[41]

Some fast neutron reactors are classified as “breeder” reactors, with a ratio of final to initial fissile content greater than one. Others are “iso-breeders” with a burn ratio of exactly one. These reactors can theoretically run indefinitely, although technical and safety issues dictate longevity limits.

The high efficiency of fast neutron reactors, coupled with the ability to use spent nuclear waste as fuel, provides a potential solution to the longstanding nuclear waste problem.[42] Radioactive waste is still created by these reactors, but in far smaller quantities than with other technologies. In addition, the waste that does result remains radioactive for several hundred years rather than thousands.[43]

Fast neutron reactor technology is not new, having been developed in the 1950s. However, light water reactors became the dominant technology at a time when uranium supplies were viewed as abundant. Attention has shifted back to fast neutron technology over the past several decades, with active development underway in a number of countries.

39 USDOE (2019), Lee (2021)

40 Spent nuclear fuel is reactor fuel that has been used to the extent that it can no longer effectively sustain a chain reaction (NRC).

41 Donovan (2020).

42 Wakabayashi (2021), Donovan (2020), World Nuclear Association (2026c)

43 Donovan (2020), Ashton (2023)

## Specific Reactor Designs

Potential applications are reflected in concepts being advanced. Some are envisioned as stand-alone land-based plants serving a specific facility or remote area where periodic fuel replenishment is difficult or unduly expensive. Others are intended for installation on barges or other watercraft, others yet as micro-scale units mounted on mobile vehicles. Another approach involves placement of multiple SMRs on a common site allowing incremental or single project development of a facility similar in size to traditional nuclear power plants.

Of the small-scale nuclear designs in various stages of development, over 40% were described by the International Atomic Energy Agency (IAEA) in 2024 as conceptual, with another 18% in the basic design stage. The remainder were in the detailed design stage (24%), under construction or development (8%), or in operation – four units (6%).[44]

Of the four units in operation, two are in Russia, providing heat and electricity in a remote Arctic region. Other operating SMRs are in China and Japan, the Chinese unit operating commercially, that in Japan a small unit used for research purposes.

It is noted that relatively few of the designs being considered are expected to advance to an operational stage. Those that are now in operation, or become advanced to that stage, can provide proof of scale operationally, economically, and from a regulatory standpoint. Evidence of performance is needed in the areas of public acceptance and licensing and at-scale production of components, on-site construction, regulatory approvals, and delivered energy costs. It is only at that point that mass production and broad deployment of SMRs are likely to be allowed to proceed.[45]

## A Significant Setback

In 2014 the Department of Energy, Office of Nuclear Energy announced a cooperative agreement with an Oregon-based company – NuScale Power – wherein funding would be provided for further development of its small nuclear reactor design.[46] The following year NuScale and Utah Associated Municipal Power Systems (UAMPS) announced the Carbon Free Project. The goal was to construct a 600 MW nuclear power plant made up of 12 small (50MW) nuclear reactor modules of the design then undergoing refinement. Costs were estimated at $3 billion, with project completion slated for 2023. NuScale's design was described as offering the benefits of carbon-free nuclear power without the issues presented by the high cost of installing large capacity reactors.

By 2020 the NuScale reactor concept appeared sufficiently promising that DOE awarded up to $1.355 billion to the company to assist in development of the Utah project, an undertaking that was also viewed as a demonstration project. A revision of the original project plans resulted in a target capacity of 720 MW (each module 60MW), with estimated total project costs raised to $6.1 billion.[47] The new announcement indicated project launch in 2025 and completion to the point of having the first power module operational by 2029.

44 International Atomic Energy Agency (2024a)
45 Tuler and Webler (2024), Gaster (2025)
46 USDOE (2014)
47 UAMPS/SmartEnergy (2020), Ramana (2024)

But early optimism soon gave way to growing concerns. In 2021 the project was scaled back to 462 MW even as estimated project costs continued to rise. As corresponding projections of the cost of power that the plant would produce rose as well, subscriptions in the plant from member utilities lagged far behind needed levels. Then in 2023 estimated project costs were increased to $9.3 billion in what turned out to be fatal to project viability. A few months later what had been hailed as a cornerstone of America's nuclear future ended in project cancellation.[48]

Described as having "cast a shadow of uncertainty over the pace of SMR deployment", the NuScale/UAMPS project failure has been variously interpreted as evidence that SMR development should cease, or as a learning opportunity that could benefit developers of different reactor technologies.[49]

Meanwhile, unrelated to the NuScale/UAMPS project, the Nuclear Regulator Commission certified the NuScale VOYGRTM power module, the first US certification for small reactors of any kind.[50] This is an advanced light-water small nuclear reactor design with passive cooling features. In as much as UAMP issues had nothing to do with reactor performance, the certification is unaffected by termination of that project. It was subsequently reported that NuScale had 19 signed agreements to deploy SMR plants in 12 countries, as well as an agreement with the Tennessee Valley Authority to deploy six 6 MW reactors across the TVA service area.[51] More recently (March 2026) the company TerraPower obtained approval for construction of a 345MWe commercial nuclear plant in Wyoming. Located at the site of coal-fired power facility in the process of closure, the reactor will be a fast neutron spectrum sodium cooled unit equipped with a molten salt storage system. Needed prior to beginning operation is a license from the Nuclear Regulatory Commission.[52]

48 World Nuclear News (2023), Ramana (2024), Market Minute (2025)
49 Market Minute (2025), Ramana (2024)
50 USDOE (2023b)
51 NuScale (2025)
52 NRC (News 2026)

## Economic Uncertainties

### Industry Portrays Nuclear as Competitive

The nuclear industry acknowledges that capital costs of nuclear reactors represent a problem. One view is that these costs are high primarily because of the infrequency of nuclear plant construction and lack of standardized design. Projections suggest dramatic reductions in cost of traditional nuclear plants through changes in procedures and application of lessons learned.[53] The same strategies are seen as reducing costs of SMR installations. In addition, prospects of mass factory production of SMRs and related reduction of on-site construction time, construction delays and cost overruns are viewed as having potential for significant reduction of capital costs.[54] The potential for building out plants in modular fashion can further reduce funding challenges. The potential for changes in procedures and standardization notwithstanding, the U.S. nuclear industry is counting on a substantial subsidy contained in the Trump administration's "Great Big Beautiful Bill" in the form of a substantial (40%) investment tax credit for plant construction to bring nuclear energy to a competitive position.

### Analysts Skeptical of Nuclear Economics

Despite international enthusiasm for expanding nuclear power, some scientists and analysts are expressing the view that nuclear is likely to remain a high cost alternative and that if there is a future for nuclear energy it will be in isolated areas or regions where energy is historically expensive, or built to serve specific purposes such as large chemical plants or data centers that require large quantities of uninterruptable power.[55] One report described the prospects for wide adoption of nuclear power as "decidedly dim in many parts of the world.[56]

## Nuclear Fuels

### Fuel Options

Fuel used in SMRs ranges from natural uranium, binary uranium compounds such as uranium carbide and uranium nitride, uranium and other actinium fluorides, plutonium, and thorium.

Many of the advanced SMR designs call for use of what is known as HALEU (High-Assay Low-Enriched Uranium) fuel;[57] this is uranium enriched to 5-20% U-235 as compared to a 5% enrichment level common for fuels of most nuclear plants in operation. Many designs also specify TRISO fuel. Uranium, plutonium, and thorium can all be used in making TRISO, as can HALEU fuels.

53 Spangler et al. (2025)
54 Chatzis (2020), Stewart et al. (2022), Liou (2023), World Nuclear Association (2023, 2026a), Larsen et al. (2024)
55 Bettenhausen (2023), Josephs et al. (2023), Jin and Bang (2024), Daigle et al. (2024)
56 MIT 2018
57 Ashton (2023)

## World Resources

The US Geological Survey reported that as of 2023 at least 21 countries operated uranium mines, had prospective or planned mines on the drawing board, or idled mines that could be restarted. Of these, 17 were actively mining. Additionally, more than 50 countries were reported as having spent nuclear fuel in temporary storage.[58]

Uranium is commonly found in the earth's crust. However, ore concentrations that can be legally and economically extracted, defined as metal reserves, are concentrated in only a few countries. Five nations account for 68% of known world reserves of uranium: Australia (28%), Kazakhstan (14%), Canada (10%), Namibia (8%), and Russia (8%). The U.S. accounts for about 1%.[59] Six nations (all the above plus Uzbekistan) account for about 90% of global production. In view of this, and the fact that the U.S. is the world's largest uranium consumer, the USGS in April 2026 reported that *"The dependency on production from a small number of countries and mines creates a supply risk. In addition, global geopolitical instability, regulatory and financial uncertainties, small enrichment and fuel fabrication capacity and logistical challenges in transporting radioactive materials add to these vulnerabilities for the United States."*

In contrast to uranium, thorium is 3-4 times as abundant as uranium in the lithosphere and reserves are more widely distributed globally. Eleven nations hold 68% of known reserves and no-one country accounts for more than 13% of reserves.[60] The U.S. has an estimated 9.4% share of world thorium reserves. A decided advantage of thorium is that it is very difficult to weaponize, thereby essentially eliminating proliferation concerns.[61] A downside of thorium as a fuel is that compared to uranium more mining and ore processing is required to recover it on comparable scales.[62]

Only trace amounts of plutonium occur in nature. Almost all plutonium now in existence was created as a by-product of nuclear fission within reactors. About 70 metric tons are generated per year as spent nuclear fuel. All Western and Russian light water reactors can use plutonium in mixed oxide fuel, providing an option for managing this material.[63]

## Security/Safety

## Operational Risk

SMRs are promoted as lower risk than traditional nuclear reactors based largely on relative size. Small-scale reactors contain less, and in some cases much less, nuclear material than a traditional reactor, thereby posing radiological less risk in case of an accident.[64] In addition, the small size also accommodates incorporation of passive safety systems that automatically and safely shut down and cool a reactor without power or human intervention;[65] many of the proposed SNR designs incorporate this feature.[66] Safety can be further enhanced by use of TRISO fuel which is compatible with some of the proposed SMR designs.[67]

---

58 USGS (2026)
59 OECD (2025), World Nuclear Association (2025)
60 World Nuclear Association (2024)
61 NS Energy (2018)
62 Degueldre and Joyce (2020)
63 World Nuclear Association (2026e)
64 Hussein (2020), World Nuclear Association (2023), Budnitz (2024), Lee (2024), UN (2025)
65 Budnitz (2024), Lee (2024)
66 Black (2021)
67 USDOE (2019), IAEA (2024)

## Regulatory Oversight Challenges

For all nuclear reactors – large and small – the IAEA establishes specific safety requirements for reactor design, construction, and operation as well as for handling and accounting for all types of nuclear fuel.[68] Regulatory enforcement is the responsibility of nations in which reactors are located. IAEA requirements cover reactor and plant design from the first conceptual stage through final design and construction, and reactor start-up and operation. Independent verification is required throughout all stages of reactor design and construction, and periodically of operation. There are also strict requirements for tracking all types of nuclear fuels for purposes of ensuring that all are accounted for.[69]

Some of the SMR designs are for battery-type reactors wherein fuel is added as a final step in reactor manufacture, with the unit then sealed; these are designed such that fuel does not need to be replaced for many years (10-20 years or more), or for the expected life of the reactor. These types of reactors pose significant challenges to verification of safety requirement compliance, as do at some level all types of factory manufactured reactors. Consequently, a review of existing protocols is needed, particularly in the case of what are referred to as "battery-type reactors.[70]

## Security

As with any nuclear facility, there are concerns about theft, malicious intrusion, and terrorism.[71] These concerns are magnified by the apparent intent of some SMR developers to site such units in isolated areas relying on remote operation and monitoring by licensed operators. This is far different from current operation wherein protected zones are required around nuclear facilities, with controls located well within these zones.[72] Further, visions of remote control raise concerns about cybersecurity that strongly suggest need for more robust control-site-to-reactor data control models than reflected in proposed SMR designs.[73]

In view of the fact that some SMR designs incorporate use of enriched uranium or plutonium, and that deployment of SMRs to many more countries than now operating nuclear facilities is envisioned, risks of nuclear weapons proliferation are heightened. Thoughtful development of new regulatory and enforcement measures will be needed, measures that would require proactive involvement of governmental bodies of all countries in which location of reactors are proposed.[74]

68 Hosyan (2025)
69 National Nuclear Safety Administration (2026)
70 International Atomic Energy Agency (2024b)
71 Budnitz et al. (2024), UN (2025)
72 Siserman-Gray and Landine (2023)
73 Siserman-Gray and Landine (2023), (NRDC 2023)
74 Gao et al. 2024, UN (2025)

# What's Next?

As of this writing there are no operating SMRs in the United States other than those located on naval vessels, and only one has gained approval for construction (though not operation). This contributes to uncertainty regarding the future of SMRs.

As time passes in the process of gaining various approvals, risks to further development increase. Those risks fall in the categories of technology, market, regulatory, and political:[75]

- Technology: Challenges arise partly from the lack of operational SMRs that could serve to demonstrate functionality, potential needs for modification, maintenance needs, operational costs, and so on. Without that, evaluation is limited to a paper exercise – a limitation not likely to inspire high dollar commitment of capital.
- Market: The SMR market today is being defined by potential early adopters such as Amazon and Google. But whether a market of the size needed to achieve economies of factory mass production will develop is an open question. Wider adoption will likely require that technologies are proven, public acceptance assured, and costs demonstrated to be within acceptable limits.
- Regulatory: At this point, new or modified rules that might apply to SMRs within the U.S. or other countries are completely unknown. In addition, the possibility of regulations changing rapidly should an SMR accident occur anywhere in the world contributes to risk.
- Political: In recent years, political support for nuclear development at the federal level has been bipartisan. But as players change from election to election and history unfolds there is no assurance of continued support.

An additional risk, that in the United States ranks as both technical and political, is that despite the passage of over four decades since being recognized as a problem, there is still no resolution of the long-term nuclear waste disposal issue.

Determination of what path future SMR development might take is extremely difficult. The greatest likelihood is that a few of the reactor designs and project concepts that are now under consideration will advance to the demonstration phase, most probably on military reservations or at federal government research installations, with demonstrated performance at these sites providing guidance for further development.

75 Gaster (2025)

# Summary

Nuclear energy has a 70+ year history characterized by cost challenges, waxing and waning public confidence and support, and most recently renewed technological innovation and future potential. Inspired by need for carbon free energy and rapidly rising data center energy demands, nuclear energy has gained newfound interest in the United States and around the world. Concurrently, interest in small modular commercial nuclear reactors has emerged based on over 70 years of experience with nuclear powered naval vessels.

With many small modular reactor designs, representing four or more basic technologies under development and financed by numerous government entities, it is unclear at this point which, if any, might emerge as best options for further advancement. Experience gained through operation of demonstration reactors, perhaps located on military reservations or government research sites may pave the way for entry to commercial markets.

Chances of success in penetrating commercial energy markets are difficult to judge. With development as of this point largely in conceptual to late design stages, there is a total lack of experience-based cost, performance, regulatory, and political and public acceptance information needed prior to any realistic possibility of SMR deployment. Also, the lack of a solution to long-term nuclear waste storage represents an ongoing problem for and risk to the nuclear industry. Due to all of these factors, the long-term outlook for SMRs is highly uncertain.

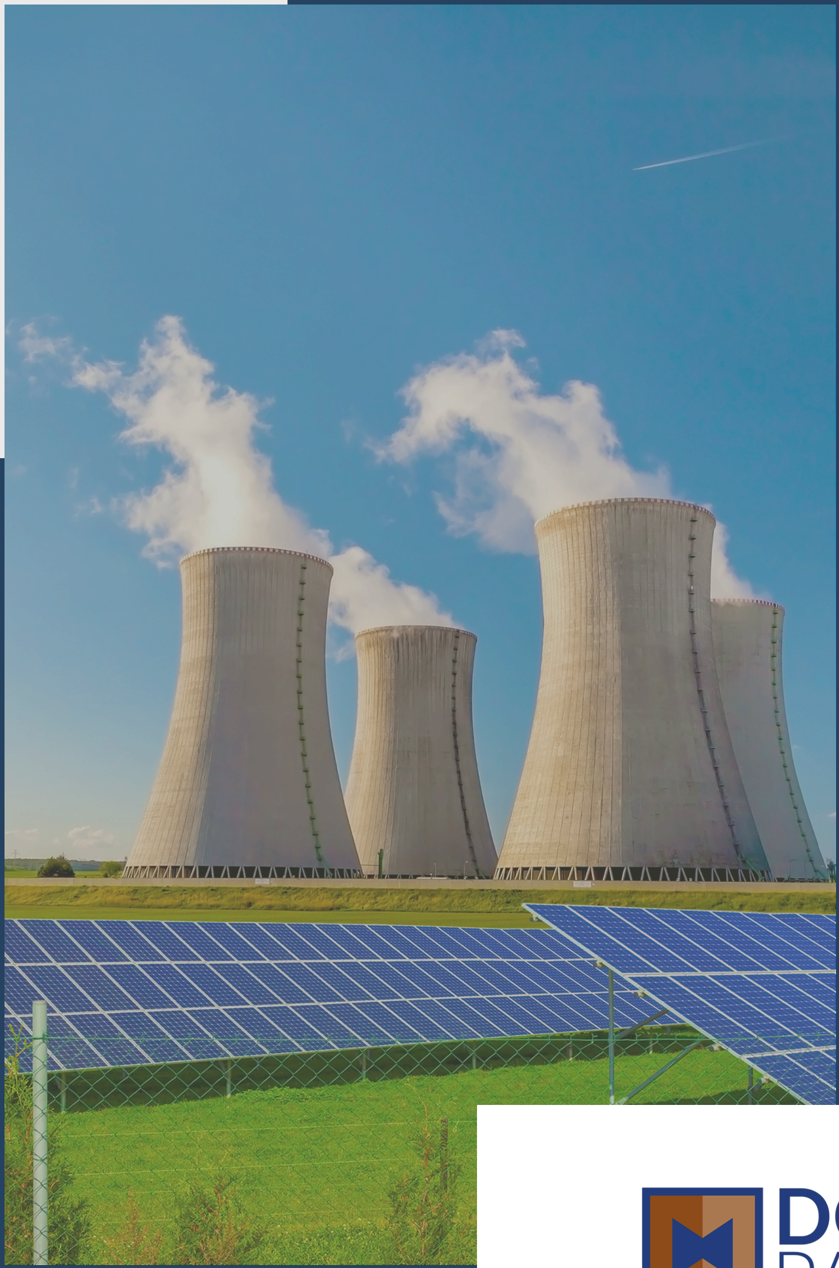
# Literature Cited


1. Altus, K. 2025. Google Teams Up with Energy Giant to Revive a Long-Shuttered Nuclear Plant. Fox Business, Oct. 28.
2. Ansolabehere, S., Deutch, J., Moniz, E., Driscoll, M., Gray, P., Holdren, J., Joskov, P., Lester, R. and Todreas, N. 2003. The Future of Nuclear Power - An Interdisciplinary MIT Study. Massachusetts Institute of Technology.
3. Ashton, L. 2023. Fueling the Future: Building Fuel Supply for SMRs and Advanced Reactors. Nuclear Innovations for Net Zero, 2023, Sept., Vol. 64-3.
4. Bettenhausen, C. 2023. Can Small Modular Reactors Save Nuclear Energy? Chemical and Engineering News, 2023, 101(30): 30–36.
5. Black, R. 2021. Small Modular Nuclear Reactors. Energy & Climate Intelligence Unit, April 2.
6. Bruckner T., Bashmakov, I., Mulugetta, Y., Chum, H., de la Vega Navarro, A., Edmonds, J., Faaij, A., Fungtammasan, B., Garg, A., Hertwich, E.,Honnery, D., Infield, D., Kainuma, M.,Khennas, S., Kim, S., Nimir, H., Riahi, K., Strachan, N., Wiser, R. and Zhang, X. 2014: Energy Systems. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
7. Budnitz, R., Heinonen, O. and Nilsson, A. 2024. Safety, Security, and Safeguards for Small Modular Reactors. In: The Oxford Institute for Energy Studies. Forum 139 (February): 29-32.
8. Chatzis, I. 2020. Small Reactors, Great Potential. IAEA. October 22.
9. Clancy, H. 2025. 7 Companies Helping Amazon, Google, Meta, and Microsoft Go Nuclear. Trellis, June 12.
10. Congressional Research Service (CRS). 2023. Advanced Nuclear Reactors: Technology Overview and Current Issues. CRS Report R4570, Feb. 17.
11. Daigle, B., DeCarlo, S. and Lotze, N. 2024. Big Change Goes Small: Are Small Modular Reactors (SMRs) the Future of Nuclear Energy? U.S. International Trade Commission, Office of Industry and Competitiveness Analysis. March.
12. Delgado, A. 2026. Southeast Asia Revisits Nuclear Power Plans for AI Data Centers as Iran War Disrupts Energy Supplies. Associated Press, Mar. 26.
13. Degueldre, C. and Joyce, M. 2020. Evidence and uncertainty for uranium and thorium abundance: A review. Progress in Nuclear Energy, Volume 124, June.
14. Deutch, J., Forsberg, C., Kadak, A., Kazini, M., Moniz, E. and Parsons, J. 2009. Update of the MIT 2003 Future of Nuclear Power An Interdisciplinary MIT Study.
15. Donovan, J. 2020. Shrinking Nuclear Waste and Increasing Efficiency for a Sustainable Energy Future. IAEA Bulletin Vol. 61-3 (Sept): 14-21.
16. Downing, D. and Taylor, B. 2024. A Split-Second Look at Nuclear Energy Around the World. USITC Office of Industry and Competitiveness, Executive Briefing on Trade, March.
17. Eash-Gates P, Klemun M, Kavlak G., McNerney, J., Buongiorno, J. and Trancik, J. 2020. Sources of Cost Overrun in Nuclear Power Plant Construction Call for a New Approach to Engineering Design. Joule, 4(11): 2348-2373.
18. Gao, B. Kuznetsova, K., Zhiqiu Ma, Z. and Miller, K. 2024. Nuclear Small Modular Reactors (SMRs): Key Considerations for Deployment. International Energy Forum.

19. Gaster, R. 2025. Small Modular Reactors: A Realist Approach to the Future of Nuclear Power. Information Technology and & Innovation Foundation, Center for Clean Energy Innovation. April.
20. Grace, D. 2025. What Was Learned From Building New Nuclear Reactors? Power Magazine, April 1.
21. Hosyan, S. 2025. IAEA Specific Safety Requirements SSR 2/1. Safety of Nuclear Power Plant Design. International Atomic Energy Agency.
22. Hunt, A. 2025. Trump Sets Out Aim to Quadruple U.S. Nuclear Capacity. World Nuclear News, May 24.
23. Hussein, M. 2020. Emerging Small Modular Nuclear Power Reactors: A Critical Review. Physics Open, Volume 5, December.
24. Intergovernmental Panel on Climate Change (IPCC). 2022. Annex III: Scenarios of Modelling Methods in Climate Change: Mitigation of Climate Change, Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
25. International Atomic Energy Agency (IAEA). 2024a. Small Modular Reactor Technology Catalogue. A Supplement to Small Modular Reactors: Developments 2024. IAEA Advanced Reactors Information System (ARIS).
26. International Atomic Energy Agency (IAEA). 2024b. Policy Documents and Complete Collection of Safety Standards. (Most recent update Dec. 23, 2024)
27. Jack, S. 2025.UK Needs More Nuclear to Power AI, Says Amazon Boss. BBC, May 15.
28. Jackson, A. 2025. Amazon Secures 1,920 MW Power Deal with Tallon Energy. Data Cener Magazine, June 11.
29. Jin, I. and Bang, I. 2024. The Time for Revolutionizing Small Modular Reactors: Cost Reduction Strategies from Innovations in Operations and Maintenance. Progress in Energy 174(Sept: 105288.
30. Josephs, R., Yap, T., Alamooti, M., Omojiba, T., Benarbia, A., Tomomewo, O. and Ouadi, H. 2025. Regulation of Small Modular Reactors (SMRs): Innovative Strategies and Economic Insights. Eng. 2025; 6(4):61.
31. Kim, B-K, Bae, Y. and Kim, P. 2025. Decades of Development: A Bibliometric Analysis of Small Modular Reactor Research. Nuclear Engineering and Technology 57(12): 1-9.
32. Larsen, L., Abou-Jaoude, A., Guaita, N. and Stauff, N. 2024. Nuclear Energy Cost Estimates for Net Zero World Initiative. Idaho National Laboratory. INL/RPT-23-74378.
33. Lee, J. 2024. Review of Small Modular Reactors: Challenges in Safety and Economy to Success. Korean J. Chem. Eng. 41, 2761-2780.
34. Liou, J. 2023. What Are Small Modular Reactors? International Atomic Energy Administration. Office of Public Information and Communication, September 13.
35. Lovering, J., Yip, A. and Nordhaus, T. 2016. Historical Construction Costs of Global Nuclear Power Reactors. Energy Policy 91(2016): 371-82.
36. Market Minute. 2025. NuScale Power's Flagship SMR Project Crumbles, Sending Ripples Through the Nuclear Energy Sector. Aug. 4.
37. MIT. The Future of Nuclear Energy in a Carbon-Constrained World. 2018. MIT Energy Initiative.
38. Nakhle, C. 2025. What is Holding Up Progress on Small Modular Reactors? GIS Reporting, Nov. 25.
39. National Nuclear Security Administration. nd. Nuclear Nexus: International Nuclear Safeguards.

40. Natural Resources Defense Council. 2023. Small Modular Nuclear Reactors: More Questions Than Answers. Issue Brief IB-23-11-A.
41. Naval Nuclear Propulsion Program. 2025. Occupational Radiation Exposure from U.S. Naval Nuclear Plants and Their Support Facilities. Department of the Navy, Report Nt-25-2, May.
42. NRC News. 2026. NRC Issues First Commercial Reactor Construction Approval in 10 Years for TerraPower in Wyoming. March 4.
43. NS Energy. 2018. Major Pros and Cons of Thorium Nuclear Power Reactor. Feb. 16.
44. Nuclear Business Platform. 2025. Indonesia's Nuclear Ambitions: Harnessing Uranium for a Green 2060. Aug. 5.
45. NuScale. 2025. NuScale Proudly Supports TVA and Entra Energy Announcement of Landmark 6-Gigawatt Small Modular Reactor Program. Sept. 3
46. Organization for Economic Co-operation and Development (OECD). 2021. Small Modular Reactors: Challenges and Opportunities. NEA No. 7560.
47. OECD. 2025. Uranium 2024: Resources, Production and Demand. OECD Nuclear Energy Agency/International Atomic Energy Agency Report NEA 7683.
48. Proctor, D. 2023. Hydrogen Production, SMRs Touted for Virginia Data Center Hub. Power Magazine, Aug. 20.
49. Ramana, M. 2021. Small Modular and Advanced Nuclear Reactors: A Reality Check. In IEEE Access, vol. 9, pp. 42090-42099.
50. Ramana, M. 2024. The Collapse of Nuscale's Project Should Spell the End dor Small Modular Nuclear Reactors. UtilityDive, Jan. 31.
51. Rogalev N., Rogalev A., Kindra V., Zlyvko, O., and Osipov, S. 2023. An Overview of Small Nuclear Power Plants for Clean Energy Production: Comparative Analysis of Distributed Generation Technologies and Future Perspectives. Energies 2023, 16, 4899.
52. Schernikau, L. 2024. The Role of Nuclear in the Global World of Energy. In: The Oxford Institute for Energy Studies. Forum 139 (February): 18-19.
53. Siserman-Gray, C. and Guy Landine, G. 2023. Cybersecurity for Small Modular Reactors (SMRs): Regulatory Challenges and Opportunities. Pacific Northwest National Laboratory (PNNL).
54. Sovacool, B. and Hanee, R. 2025. Beyond Economies of Scale: Learning from Construction Cost Overrun Risks and Time Delays in Global Energy Infrastructure Projects. (May 2025) Energy Research & Social Science, vol. 123.
55. Spangler, R., Qun, S., Larsen, L., Bolisetti, C., Abou-Jaoude, A., Asgari, M., Shirvan, K., Stewart, W.R., Krellenstein, J. and Wilkinson, G. 2025. Potential Cost Reduction in New Nuclear Deployments Based on Recent AP1000 Experience. U.S. Department of Energy, Systems Analysis of Integration Campaign, Report INL/RPT-25-89701.
56. Stewart, W.R, Gregory, J. and Shirvan, K. 2022. Impact of Modularization and Site Staffing on Construction Schedule of Small and Large Water Reactors. Nuclear Engineering and Design, Vol. 397 (Oct).
57. Stiegler, S., Parrott, L-E. and Osbom, T. 2025. Nuclear Power Plants: Mitigating Risks of Claims and Delay. Insight, Oct. 28. Vinson & Elkins.
58. Tuler, S. and Webler, T. 2024. The Challenge of Community Acceptance of Small Nuclear Reactors. Energy Research & Social Science, Volume 118, December.
59. UAMPS/Smart Energy. 2020. DOE Cost-Share Award of $1.355 Billion is Approved for Carbon Free Power Project. Oct. 16.

60. United Nations. 2025. Nuclear Small Modular Reactors. Brief of the Secretary-General's Scientific Advisory Board.
61. U.S. Atomic Energy Commission (USAEC). 1961. Costs of Nuclear Power. Replacement of Report TID-8506 of July 1959. Jan.
62. U.S. Department of Energy. 2014. NuScale Power Design Certification Project. Office of Nuclear Energy.
63. U.S. Department of Energy. 2019. TRISO Particles: The Most Robust Nuclear Fuel on Earth.
64. U.S. Department of Energy. 2023a. Declaration to Triple Nuclear Energy Capacity by 2050, Recognizing the Key Role of Nuclear Energy in Reaching Net Zero. December 1.
65. U.S. Department of Energy. 2023b. NRC Certifies First U.S. Small Modular Reactor Design: NuScale Power Module Becomes the First SMR Design Certified by the NRC.
66. U.S. Energy Information Administration (USEIA). 2026. Monthly Energy Review, March, p.
67. U.S. Geological Survey. 2026. Uranium – Deposits, Production and Resources, Market Dynamics, and Supply Chain Risks. Fact Sheet 2025-3057. April.
68. U.S. Government Accounting Office (GAO). 2023. NRC Needs to Take Additional Actions to Prepare to License Advanced Reactors. GAO-23-105997. July.
69. U.S. Government Accounting Office. 2025. Nuclear Waste. June 24.
70. U.S. Nuclear Regulatory Commission. 2024. Backgrounder on Radioactive Waste. Office of Public Affairs, Jan.
71. Wakabayashi T. 2021. Concept of a fast breeder reactor to transmute MAs and LLFPs. Scientific Reports 11(1):22443.
72. Walker, J. and Wellock, T. 2024. A Short History of Nuclear Regulation1946-2024. NUREG/BR-0175, Revision 3. U.S. Nuclear Regulatory Commission, July.
73. Waltz, E. 2024. Big Tech Backs Small Nuclear: Google and Amazon Invest in Small Modular Reactors to Power Data Centers. IEEE Spectrum, Dec. 10.
74. Wang, Y., Chen, W., Zhang, L., Zhao, X., Gao, Y. and Dinavahi, V. 2024. Small Modular Reactors: An Overview of Modeling, Control, Simulation, and Applications. IEEE 12(2024): 39628-39650.
75. Wellock, T. 2026. "Too Cheap to Monitor: A History of the Phrase. U.S. National Regulatory Commission, Feb. 2.
76. World Nuclear Association. 2023. Small Nuclear Power Reactors. March.
77. World Nuclear Association. 2024. Thorium. May 2.
78. World Nuclear Association. 2025. Supply of Uranium. December 9.
79. World Nuclear Association. 2026a. Economics of Nuclear Power. March 24.
80. World Nuclear Association. 2026b. Emerging Nuclear Countries. March 30.
81. World Nuclear Association. 2026c. Fast Neutron Reactors, March 31.
82. World Nuclear Association. 2026d. Plans for New Reactors Worldwide. April 4.
83. World Nuclear Association. 2026e. Plutonium. March 30.
84. World Nuclear Association. 2026b. Fast Neutron Reactors. Mar. 31.
85. World Nuclear Association. 2026f. Small Modular Reactors. March 24.
86. World Nuclear News. 2023. Idaho SMR Project Terminated. Nov. 9.
87. World Nuclear News 2026. China and Brazil Among New Signatories to Tripling Nuclear Goal. March 10.



DOVETAIL PARTNERS

Dovetail Partners' mission is to provide authoritative information about the impacts and trade-offs of environmental decisions, including consumption choices, land use and policy alternatives.

Dovetail Partners is a non-profit 501(c)(3) organization

Connect with us.

www.dovetailinc.org