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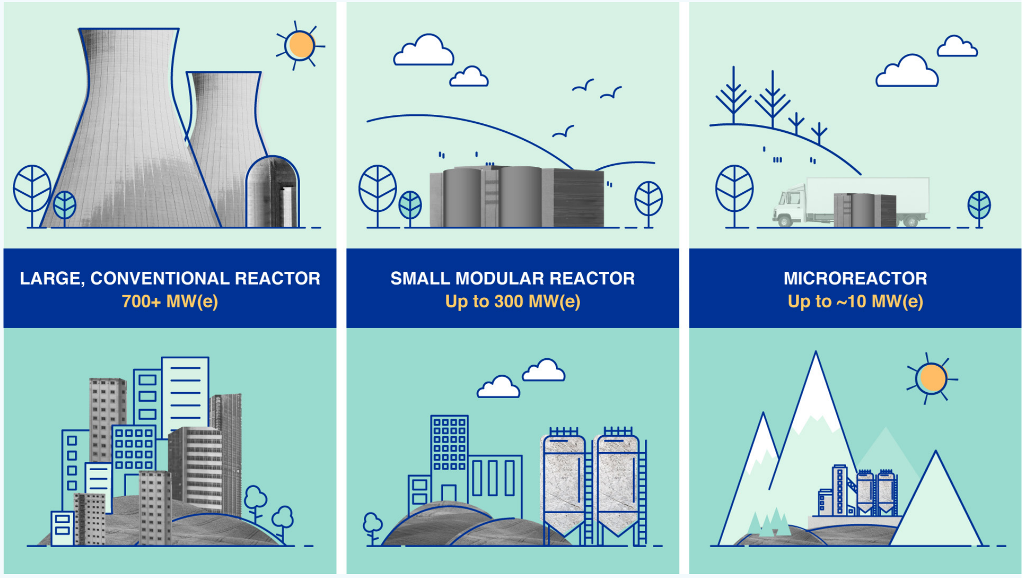
ISSUE BRIEF

SMALL MODULAR NUCLEAR REACTORS: MORE QUESTIONS THAN ANSWERS

To limit global warming to 1.5 degrees Celsius, the United States must rapidly transition from a fossil fuel-powered electricity grid to one based primarily on renewable energy and storage. Proponents of nuclear energy are now touting small modular reactors (SMRs) as safer, cleaner, and significantly cheaper to build and operate than present-day reactors. However, arguments in favor of SMRs are based on many questions as yet unanswered with data from real-world experience with this technology. Some deep decarbonization scenario modeling (including NRDC's) shows results that include new power generation with flexible, dispatchable technology. SMRs or other technology with similar characteristics may be needed particularly, from a modeling perspective, several decades from today. SMRs—none of which have yet been constructed in the United States—could receive billions of dollars in financial support under the Inflation Reduction Act (IRA).[1] While the federal government should continue to invest in a broad range of low-carbon power generation technology, it should double down on technologies where progress and cost-reductions are occurring, such as renewables and energy storage. To date the cost of nuclear power has only increased.

WHAT IS A SMALL MODULAR REACTOR?

Small modular reactors are nuclear reactors with an electrical power capacity of less than 300 megawatts (MW)—much smaller than typical present-day reactors, which are in the 1,000 to 1,600 MW range. *Modular* refers to two features: First, instead of one large nuclear plant, several units (or submodules) together produce the desired level of power generation; and second, a nuclear reactor comprising many submodules is factory assembled and transported to a location for installation. SMR designs include all the main reactor categories: water-cooled reactors; high-temperature gas-cooled reactors; liquid-metal, sodium, and gas-cooled reactors with fast neutron spectrum; and molten salt reactors.



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Proponents of SMRs argue that this technology would be safer and require fewer safety features than traditional nuclear power plants, but NRDC is concerned that some of the designs would pose increased environmental burdens, augment the nuclear waste problem, and add to nuclear weapons proliferation. In terms of economic feasibility, proponents argue that SMRs would be cheaper than traditional nuclear power plants because of the benefits of mass production, but there is no evidence to support this claim, because none have yet been manufactured at scale. And even if SMRs receive billions of dollars in financial support as part of the IRA, they cannot compete in the market against cheaper existing technologies such as wind, solar, and batteries.

A one-third-scale model of a NuScale Power module at the company's test facility.

ARGUMENTS IN FAVOR OF SMRS ARE LARGELY THEORETICAL

Because development and deployment of SMRs worldwide are limited, the safety and economic arguments in their favor are largely theoretical. Even with the recent U.S. Nuclear Regulatory Commission's approval of one of the many SMR designs, expansion of nuclear energy in the United States via SMR deployment could not happen until the 2030s at the earliest.

According to a 2022 International Atomic Energy Agency (IAEA) assessment, more than 80 SMR designs are at different stages of development and deployment in 18 IAEA member nations other than the United States.[2] For a commercial nuclear power plant to operate within the United States, the owner/operators must obtain a license from the Nuclear Regulatory Commission (NRC). The NRC has engaged with various SMR designs in pre-application and standard design approval activities (see Table 1). Of these designs, NuScale is farthest along in the reactor licensing process and received conditional NRC approval for a 50 MW module in the United States earlier this year.[3] However, NuScale now plans to build a 77 MW design instead, which will require a new approval and certification.

Contingent on that approval, developers of the Carbon Free Power Project (CFPP) facility in Idaho were supposed to deploy six 77 MWe NuScale VOYGR SMR plant modules to generate 462 megawatts of electricity.[4] However, On November 8, 2023, NuScale announced that the CFPP project had been terminated. This project was expected to be the first SMR to begin operation in the United States. Developers estimated that the resulting energy would cost $89 per megawatt-hour (MWh) based on operating costs; however, that evaluation includes an anticipated $1.4 billion subsidy from the Department of Energy and a new subsidy from the IRA on the order of $30 per MWh.[5] The unsubsidized price of the power from CFPP would be more than $100 per MWh, which is significantly higher than the $24 per MWh from onshore wind and utility-scale solar.[6]

TABLE 1: SMR DESIGNS UNDERGOING THE NRC DESIGN APPROVAL PROCESS

Design	Electrical Capacity MW(e)	Reactor Type	Coolant	Technology Developer
NuScale-VOYGR[7]	77	Integral Pressurized Water Reactor	Light Water	NuScale Power Corporation
SMR-160[8]	160	Pressurized Water Reactor	Light Water	Holtec International
BWRX-300[9]	270-290	Boiling Water Reactor	Light Water	GE-Hitachi Nuclear Energy
Xe-100[10]	82.5	High-Temperature Gas-Cooled Reactor	Helium	X-Energy LLC

ARGUMENTS IN FAVOR OF SMRS ARE NOT BACKED BY EVIDENCE

Proponents of SMRs claim that this technology will safely deliver competitively priced electricity through a combination of economies of scale and improved construction schedule. However, these claims are not realistic.

- **Economies of scale:** Studies suggest that scaling down from 1,000 megawatt nuclear power plants to SMRs would result in a significant loss of scale economies, with a resulting increase in overnight cost (the cost of a construction project, not counting accrued interest) and operation and maintenance costs.[11] Advocates of SMRs argue that it is possible to replace economies of scale with the "economy of multiples" offered by SMRs, such as cost savings due to modularization and mass manufacturing. However, there is no history of the nuclear industry realizing these sorts of cost savings in any of its past projects or reactors.
- **Construction schedule:** Estimated shorter construction schedules are said by proponents to be a key driver of SMR cost savings. According to SMR advocates, construction time for an SMR is reduced because the components may be manufactured on a factory assembly line and transported to the site for installation. Historically, nuclear construction schedules have been very long and highly uncertain. For example, when Georgia approved the expansion of the Vogtle nuclear facility, the two new 1,117-megawatt reactors were expected to cost about $14 billion.[12] The project started in 2009, and the reactors were projected to enter service in 2016/2017; however, one of the units did not reach full power until 2023.[13] The project is not yet completed, and construction costs are expected to rise to more than $35 billion.[14]

  Thus far, all the SMRs built or under construction in other countries have followed this same pattern, with time and cost overruns during construction. These include the two KLT-40S reactors in Russia, which took 12.7 years to complete instead of the expected 3.7 years, and the two high-temperature gas-cooled reactors in China, which were supposed to be built in 4 years but took 9 years.[15] Compared with other countries that use nuclear power, there is a much higher degree of variation across power plant designs and construction methods in the United States.[16] Construction schedules are also significantly longer and more variable in this country. If SMRs are running into delays abroad, it is more than likely they will face those same construction obstacles here.

SMRS ARE UNPROVEN AND COME WITH REAL TECHNICAL, ECONOMIC, AND ENVIRONMENTAL CONCERNS

While light-water nuclear technology—using regular water, as opposed to heavy water with large amounts of deuterium—is not new, the proposed modular construction aspects and all the varying designs of SMRs are all first-of-their-kind. To the extent that utilities' decarbonization plans and state and federal climate policies involve SMRs, environmental progress and meeting the demands of the climate crisis will rely on untested technology that raises technical, economic, environmental, and public health concerns.

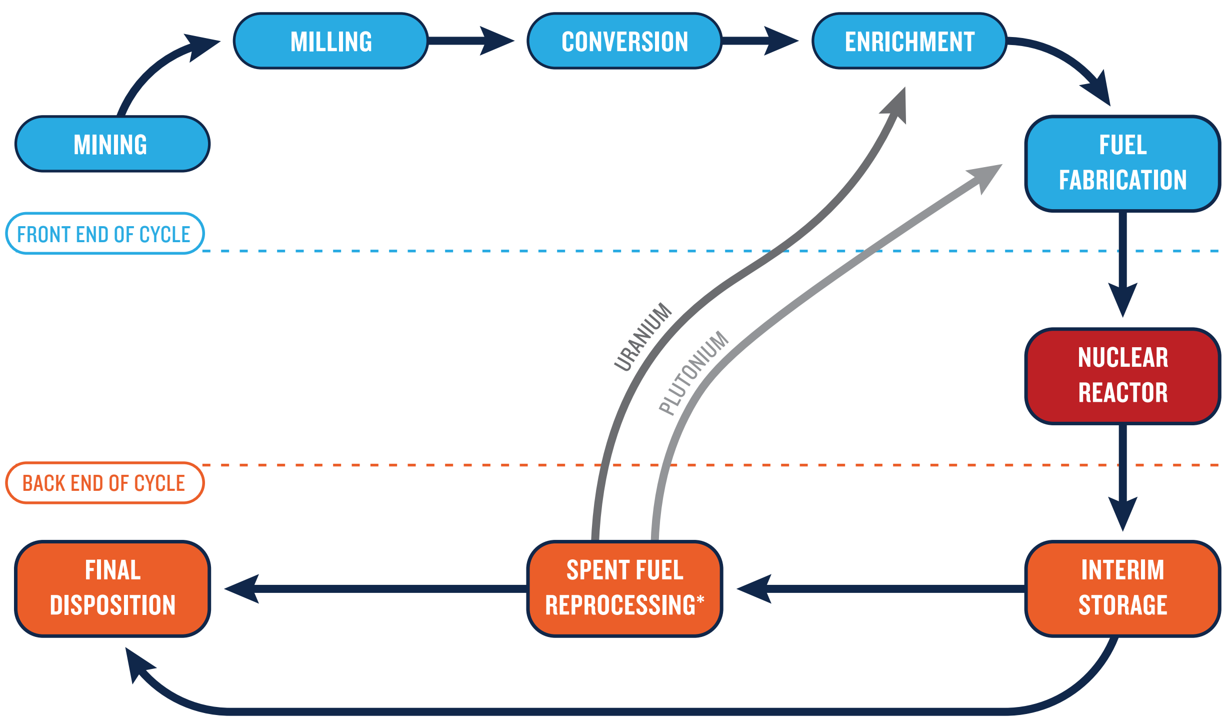
TECHNICAL AND ECONOMIC CONCERNS

- **Supply chain:** The strategy of modularization may see significant challenges in licensing and regulation, transportation cost, more complex logistics, supplier management, and, perhaps most significant, high factory infrastructure and supply chain start-up costs.
- **Lack of safety record:** The lack of performance data on the passive safety design aspects of SMRs is a source of technical and regulatory uncertainty.
- **Societal acceptance:** As discussed below, proposed regulations for SMR facilities would relax the current 10- and 50-mile emergency planning boundaries around a facility. Especially when dealing with the untested, new technology of an SMR, local communities may find this an unacceptable level of risk.
- **Potential threats:** Significantly reduced control and security staffing at SMR plants as a cost-savings measure would increase cyber and physical threats.[17]
- **Operational inflexibility:** In a world with renewables, load following (altering power plant output based on fluctuations in demand for electricity) will be key. No nuclear reactor in the United States has demonstrated the technical capability to load follow, nor demonstrated economic viability when operating at less than maximum capacity.

ENVIRONMENTAL AND PUBLIC HEALTH CONCERNS

- **Environmental radiation risks:** Light-water SMRs follow the same nuclear fuel cycle as existing water-cooled nuclear reactors (front-end steps that prepare uranium for use in nuclear reactors and back-end steps to safely manage, prepare, and dispose of used but still highly radioactive fuel).[18] This nuclear fuel cycle (Figure 1) has associated environmental radiation risks resulting from released contaminants.[19] This poses hazards for both public and worker health.

FIGURE 1: NUCLEAR FUEL CYCLE



*Spent fuel reprocessing is omitted from the cycle in most countries, including the United States.

Source: Pennsylvania State University Radiation Science and Engineering Center (public domain)

NUCLEAR FUEL CYCLE

Worker-related concerns include internal and external radiation exposure during primary component maintenance during operations and power outages, steam generator surveillance and repair, spent fuel pool work activities, refueling operations, waste processing operations, component decontamination, and spill cleanup.

Public radiation risks depend on implementing appropriate emergency planning zones (EPZs), within which measures are taken to protect people from radiation exposure. Currently the NRC defines two EPZs around each nuclear power plant. The first is a *plume exposure pathway* extending about 10 miles in radius around the reactor site. Protective action plans within this area are designed to avoid or reduce dose from potential exposures such as inhaling radioactive waste. The second is an *ingestion exposure pathway* extending about 50 miles in radius around the reactor site. Protective action plans for this area are designed to avoid or reduce dose from eating or drinking radioactive materials.

Designing appropriate methodology for SMR EPZs is an essential element of practical emergency preparedness and response. Some SMR plant developers claim that SMR designs have advanced safety features and should have a reduced EPZ size.[20] NuScale, for example, is seeking an EPZ that ends at the site security fence, arguing that the change provides the same level of protection to the public as a 10-mile radius.[21] The NRC's Advisory Committee on Reactor Safeguards recently approved NuScale's methodology to calculate the EPZ.[22] This will have major implications for future SMR license applications.

- **Nuclear waste management and disposal:** A 2022 study led by researchers at Stanford's Center for International Security and Cooperation showed that SMRs exacerbate the challenges of nuclear waste management and disposal and that most SMR designs will increase the volume of nuclear waste in need of management and disposal by a factor of 2 to 30 compared with traditional reactors in the case study.[23] Researchers at Argonne

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A Holtec HI-STORM UMAX dry storage system at the shuttered San Onofre Nuclear Generating Station.

National Laboratory also recently published a study to evaluate the nuclear waste attributed to SMRs scheduled for deployment within this decade compared with waste from a reference large pressurized water reactor (PWR). The result showed that the volume of nuclear waste from SMRs is roughly comparable to that from conventional PWRs.[24] These studies indicate that managing and disposing of SMR nuclear waste is a critical safety matter, as some of the waste products remain radioactive for a long time.

- **Nuclear proliferation risks:** The most substantial hurdle to achieving new nuclear weapons capability for a state or subnational organization is access to nuclear material—or access to highly enriched uranium or plutonium. Nuclear proliferation risks for any future deployment of SMRs will depend on how the SMR systems integrate safety, physical security, safeguards, and material control and accounting into their designs. Non-light-water reactor SMR designs, or designs that incorporate high-assay low-enriched uranium, substantially increase the environmental harm and nuclear weapons proliferation risk from nuclear energy.[25]

CONCLUSION

Proponents of SMRs claim that SMR technology will safely deliver competitive electricity generation through a combination of passive safety, modularization, and smaller plant size. They also argue that it is possible to offset economies of scale achieved by large nuclear plants with economy of multiples. However, there is no history of the nuclear industry realizing those claims. SMRs could receive financial support as part of the IRA, but even with those subsidies, SMRs can't reasonably compete in the electricity market against cheaper and proven renewable energy technologies. For SMRs to play any role in the future, the technology must address the following challenges: cost, environmental radiation, nuclear waste, and nuclear weapons proliferation. Absent meeting these challenges, the technology is unlikely to succeed.

ENDNOTES

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