The Role of Small Modular Reactors in Decarbonization

Paul A. DeCotis and Echo D. Cartwright

INTRODUCTION

Decarbonization efforts underway to meet climate mitigation goals worldwide are forcing regulators, policymakers, electric grid operators, and parts of the scientific community to reconsider the role of nuclear power in the transition. Many proponents of nuclear power argue that nuclear technologies can play a role in advancing a clean energy economy, while others argue that it has no role in such an economy until treatment and disposal of nuclear waste can be safely managed. The US Department of Energy (DOE), for example, has been supporting research and development (R&D) in advanced small modular nuclear reactors (SMRs) for some time and is hopeful that nuclear power in the form of SMRs can play a role.

SMRs are a key part of DOE's goal to develop safe, clean, and affordable nuclear power options. SMRs currently under development in the United States represent a variety of sizes, technology options, capabilities, and have a role in different deployment scenarios. DOE claims these advanced reactors, envisioned to vary in size from tens of megawatts up to hundreds of megawatts, can be used for power generation, heat processing, desalination, green hydrogen production, or for other industrial uses. SMR designs are testing light water as a coolant and other non-light water coolants, such as a gas, liquid metal, or molten salt. DOE recognized the transformational value SMRs can provide to the nation's energy security, and economic and environmental outlook and is looking to have SMRs deployed in the late 2020s to the early 2030s.[1]

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It is widely recognized that the electrification of transportation and buildings will require more power generation and investment in the transmission and distribution grid. In line with clean energy and decarbonization goals, power generation will need to come from low- or

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[1] Office of Nuclear Energy, US Department of Energy. (n.d.) *Advanced small modular reactors (SMRs)*. Energy.gov. https://bit.ly/3uPFB6t

non-carbon-emitting sources. And as world events of late have demonstrated the need for countries to be more energy independent, domestic energy production is gaining importance. The United States is a net exporter of petroleum, natural gas, and coal, when not long ago, it was a net importer of petroleum and natural gas. The United States is on a path to remain energy independent when it comes to fossil fuels, ensuring a continuous and reliable supply. Further, the United States is investing in clean energy technologies, like renewable energy generation—including the domestic production of offshore wind—to be energy independent in a low-carbon economy. Energy independence and energy supply chain security are the most challenging national and international issues now facing nearly every country.

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Discussions on alternative pathways to meet decarbonization goals, maintain reliability, and secure energy independence are now increasingly including the use of nuclear power. Just a few years ago, nuclear power was fraught with controversy. Large central station nuclear power plants like Southern Company's Vogtle electricity-generating plant under construction in Georgia has been plagued with cost overruns and construction delays. The Georgia plant represents the first of its kind large-scale nuclear power plant built in the United States in over three decades. Cost overruns and construction delays have plagued the nuclear power industry for years, causing some owners to discontinue plant construction and several others to discontinue nuclear plant operations due to the high costs of maintenance and compliance with stricter regulations. Public perception, safety concerns, and issues disposing of nuclear waste have also resulted in plans to shut down and decommission nuclear power plants.

The use of SMRs, as an integral part of the future low-carbon and energy security mix, is becoming increasingly discussed as states recognize the need for an "all solutions" approach to decarbonization. Included in these discussions are issues surrounding the use of nuclear power and weighing whether society would simply be trading one environmental concern and issue for another. This article briefly explores the potential advantages and disadvantages to integrating SMRs into a broader energy portfolio to meet clean energy and decarbonization goals. These authors are not taking a position on the use of nuclear power as part of our future energy mix, simply advancing some of the arguments in favor and in opposition to SMRs.

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CHARACTERISTICS OF SMALL MODULAR REACTORS

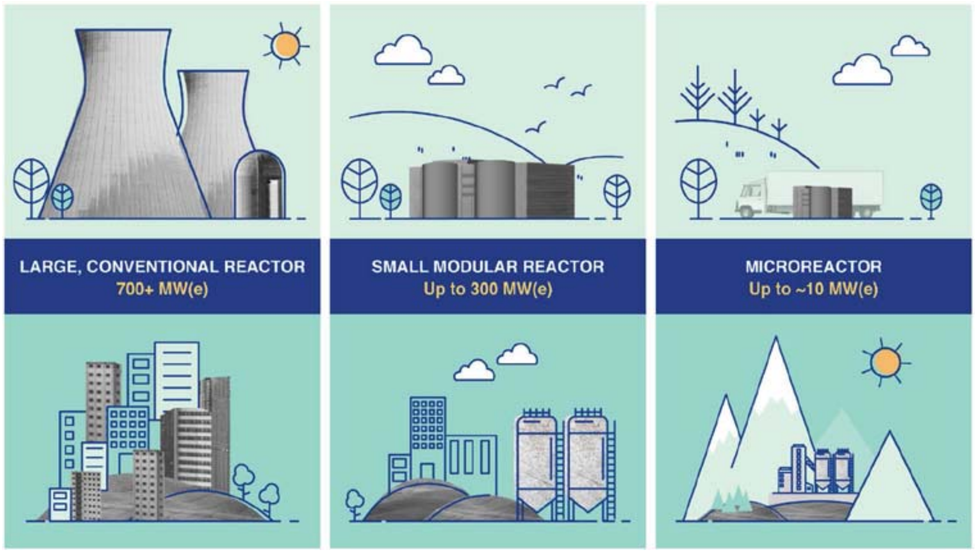
The International Atomic Energy Agency (IAEA) describes SMRs as advanced nuclear reactors with a power-generating capacity of up to 300 megawatts (MW) per unit and the ability to produce a large amount of low-carbon electricity.[2] SMRs can be factory-assembled and transported to a location for installation and are envisioned for markets such as industrial applications or remote areas with limited electric grid capacity. The units are referred to as "SMR" based on their technology characteristics:

- **Small** – physically a fraction of the size of a conventional nuclear power reactor
- **Modular –** making it possible for systems and components to be factory-assembled and transported as a unit to a location for installation
- **Reactors –** harnessing nuclear fission to generate heat to produce energy[3]

[2] Liou, J. (2021). *What are small modular reactors (SMRs)?* International Atomic Energy Agency. https://bit.ly/3viAcns

[3] Ibid.

Figure 1. Comparison of SMRs to Traditional Nuclear Energy Designs



Source: Liou, J. (2021). *What are small modular reactors (SMRs)?* International Atomic Energy Agency. https://bit.ly/3viAcns

Unlike traditional large-scale nuclear power plants that need to be located near major water sources, such as rivers, lakes, or the coasts because they need large volumes of water for cooling, SMRs could be deployed in many situations where a full-scale nuclear plant would not be feasible. SMRs currently under development in the United States are of various sizes, technology options, capabilities and deployment scenarios, and can vary in size from tens to hundreds of megawatts.[4] SMRs can also be designed with the latest safety features, allowing them to be located in previously disturbed lands, such as brownfield sites, or closer to population centers, and used to generate power for remote towns and other industrial uses.[5] **Figure 1** illustrates the comparisons between SMRs and more traditional designs of large nuclear energy generation.

SMR technology has been advancing for over a decade as more R&D is invested into the technology. In 2012, DOE established the SMR Licensing Technical Support (LTS) program to work through collaborative public–private partnerships with industry, research institutions, the national laboratories and academia to promote the advanced safety, operational and security features of SMR technology.[6] According to DOE, the use of SMR is a key component of the department's goal "to develop safe, clean, and affordable nuclear power options," and has "long recognized the transformational value that advanced SMRs can provide to the nation's economic, energy security, and environmental outlook."[7] Building off of the success of the LTS program, in 2019, DOE launched the Advanced SMR R&D program, which "supports research, development, and deployment activities to accelerate the availability of US-based SMR technologies into domestic and international markets".[8] With this as a backdrop, the following will provide a highlight of the benefits and potential risks of deploying SMR technology.

[4] See Note 1.
[5] Deign, J. (2020). *So, what exactly are small modular nuclear reactors?* Greentech Media. https://bit.ly/3JROYXs
[6] See Note 2.
[7] See Note 1.
[8] Ibid.

ADVANTAGES OF SMRS

The accelerated pace of R&D into SMRs has resulted in several benefits that are inherently linked to the small and modular design of the systems. SMRs have a lower initial capital investment, greater scalability and siting flexibility for locations unable to accommodate more traditional larger reactors. They also have the potential for enhanced safety and security compared to earlier designs, and their deployment can help drive economic growth. These benefits are highlighted below.[9]

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Modularity and Lower Capital Investment

We've already discussed how the size of SMRs allows for more flexibility in how and where these systems can be deployed. As the technology continues to advance, SMRs are anticipated to require limited on-site preparation, which will significantly reduce the typical lengthy construction times associated with larger nuclear units. It is expected that the ability to transport prefabricated modules to their required locations will lower project capital costs and ultimately reduce costs associated with their deployment. As the demand for energy increases, additional modules can be incrementally added, increasing the duration of the system's life cycle.

Greater Siting Flexibility and Efficiency

Ensuring adequate grid infrastructure to deliver electricity to remote locations remains a significant challenge in reducing greenhouse gas (GHG) emissions and meeting our energy security needs. SMRs can provide power in locations where larger traditional units are not needed or lack the infrastructure to support a large unit, including smaller electrical markets, remote areas, smaller grids, sites with limited water and acreage, or unique industrial applications. SMRs can also be used for replacement power at aging or retiring fossil-fueled generation sites. Likewise, SMRs can supplement existing industrial processes or generation sites with a carbon-free emitting energy source. When used with other generation sources, such as renewable and fossil-fueled energy, SMRs can leverage resources and produce higher efficiencies and multiple energy end products while increasing grid resiliency and security. Some advanced SMRs can produce higher temperature process heat for either electricity generation or high energy-intensive industrial applications.

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Increased Safeguards

SMRs include increased safeguards and security requirements as part of the "security by design" engineering process applied to new SMR design. DOE indicates that new SMR design facility protection systems include "barriers that can withstand design basis aircraft crash scenarios and other specific threats,"[10] and further "provide safety and potential nonproliferation benefits to the United States and the wider international community."[11] DOE further states that "most SMRs will be built below grade for safety and security enhancements, addressing vulnerabilities to both sabotage and natural phenomena hazard scenarios. Some SMRs will be designed to operate for extended periods without refueling."[12] With the ability to be manufactured and fueled within a factory, then sealed and transported to a location, advanced SMRs could be returned to

[9] Ibid.

[10] Ibid.
[11] Ibid.
[12] Ibid.

the factory at the end of their life cycle for defueling, thereby minimizing the transport and handling of nuclear material. According to DOE, advanced SMRs "based on non-light water reactor coolants could be more effective at dispositioning plutonium while minimizing the wastes requiring disposal."[13]

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Industry Growth and Economic Development

The increasing use of any technology results in increased economic growth. It is anticipated that mass manufacturing SMRs will reduce the cost per kilowatt of electricity equal to current generation sources. SMR proponents say that a factory approach to manufacturing could help the sector cut costs and remain competitive as the costs of renewables decline. With the existence of both domestic and international markets for SMRs, DOE is hopeful that as the development of standardized SMR designs takes hold, US companies will have an increased presence in the global energy markets.[14] As with any technology, the increased use of SMRs will provide the necessary incentive to increase manufacturing capacity to meet demand, resulting in further growth of both domestic and international sales of SMR units. Coupled with the deployment of SMR units to replace retiring power plants or meet growing electricity generation needs, this will result in significant growth in domestic manufacturing, the tax base, and factory, construction and operating jobs.

DISADVANTAGES OF SMRS

The deployment of more SMRs into the US energy portfolio mix would need to address the issues and potential risks associated with their use, not unlike dealing with nuclear power sources of any size. These include the current high cost of the technology relative to other alternatives, lengthy licensing and regulatory timelines for project approval and construction, and the fact it is still nuclear power with the need to address public approval as well as the disposal of nuclear waste at the end of the project's life. These issues are discussed below.

High Costs and Lengthy Licensing and Regulatory Timeframe

A disadvantage of SMRs remains its cost. To bring first-cost down, SMRs would need production scale, much like every other distributed energy resource did before becoming widely commercially available and economic. Licensing and permitting might also be a barrier adding to cost and timing delays. "In regulating the design, siting, construction, and operation of new commercial nuclear power facilities, the Nuclear Regulatory Commission (NRC) currently employs a combination of regulatory requirements, licensing, and oversight. Historically, the licensing process was developed for large commercial reactors. The licensing process for new reactor designs is a lengthy and costly process."[15]

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The Soviet Union built eight reactors with a capacity of less than 300 MW. Of the eight, four have been permanently shut down and the remaining four soon will be and replaced by a floating nuclear power plant. The US Army built and operated eight small power reactors beginning in the 1950s, but they proved unreliable and expensive, and the program was shut down in 1977. Small Magnox

[13] Ibid.

[14] Ibid.

[15] Nuclear Power. (2022). *Advantages and disadvantages of small modular reactors.* nuclear-power.com. https://bit.ly/3uSBhU8

reactors in the UK have also all been shut down.[16] With limited operating experience, much is still unknown.

Supply Chain

No company, utility, consortium, or national government is currently considering building the massive supply chain that is at the very essence of the concept of SMRs—mass modular factory construction. Yet without that supply chain, SMRs will continue to be expensive. In early 2019, North American Project Director for Nuclear Energy Insider Kevin Anderson, said that there "is unprecedented growth in companies proposing design alternatives for the future of nuclear, but precious little progress in terms of market-ready solutions."[17] Anderson argued that it is time to convince investors that the SMR sector is ready for scale-up financing but that it will not be easy. A 2018 DOE report stated that to make a meaningful impact, about $10 billion of government subsidies would be needed to deploy 6 GW of SMR capacity by 2035. But there's no indication or likelihood that the US government will subsidize the industry to that extent.[18]

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Community Acceptance, Siting and Environmental Concerns

Another disadvantage to SMR deployment will likely come from community opposition to the installations of these units near population centers. While advanced SMR units are envisioned to be much smaller, much like other energy project siting issues, community acceptance will be key to successfully incorporating SMRs into a broader energy portfolio mix. Environmental impact statements will be required for the siting of these units, which will review the footprint of the project, potential impacts on local species and habitats, soil and water use, potential particulate matter release during construction and decommissioning, and detailing the transportation and disposal of the nuclear waste upon defueling the units at their end-of-life cycle. It is likely that communities will still express concern over any nuclear unit, regardless of the size, located in close proximity to population centers.

> SMRs can serve as distributed energy resources used to generate green hydrogen as a lower-carbon alternative to natural gas, help electrify buildings using fuel cells, and to support microgrid development serving industrial and commercial loads.

CONCLUSION

SMRs are being discussed in some states as a technology worth considering given their advantages and disadvantages, and the need to take some risks and demonstrate progress toward decarbonization goals. Renewable energy resources continue to receive the necessary levels of financial support from the government to continue driving down costs and demonstrate success. Offshore wind, for example, is receiving significant attention in US coastal states with aggressive targets and public–private partnerships in support of garnering public support and financing. SMRs can serve as distributed energy resources used to generate green hydrogen as a lower-carbon alternative to natural gas, help electrify buildings using fuel cells, and to support microgrid development serving industrial and commercial loads. If decarbonization and clean energy goals are to be met, complete with job growth and social equity and a broad portfolio of energy options, perhaps including SMRs should not be ruled out just yet.

[16] Green, J. (2019). *Small modular reactors: An introduction and an obituary.* World Information Service on Energy. https://bit.ly/3vukVjo
[17] Green, J. (2019). *Small modular reactors are dead on non-arrival.* Beyond Nuclear International. https://bit.ly/3OvS9b4
[18] Ibid.