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Small Modular Reactors: A Realist Approach to the Future of Nuclear Power

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Standard large nuclear reactors won't achieve scale or cost competitiveness with alternative energy sources. DOE should focus its resources on small modular reactors, which are a more promising technology with the potential to achieve price and performance parity.

KEY TAKEAWAYS

- Small modular reactors (SMRs) are the future of nuclear power, and they could become an important strategic export industry in the next two decades.
- SMRs must get to sufficient scale so they can become cost competitive with other energy sources including large reactors, renewables, and fossil fuels.
- DOE needs to develop independent assessment capabilities for SMRs (and other technologies) that focus on the pathway to price and performance parity (P3). All major investments must be reviewed through the P3 lens (see box).
- DOE should maintain and expand its strong support for basic and applied nuclear research through the Advanced Reactor Development Program (ARDP) and DOE's GenIII+ program, including new test and demonstration sites at INL.
- DOE's Office of Clean Energy Demonstrations (OCED) must provide critical funding to help provide commercial viability, and the Loan Program Office (LPO) will need reform and restructuring to focus specifically on scale-up.
- Nuclear Regulatory Commission (NRC) reform is under way, but more is needed. Innovation requires iteration, and that requires new thinking. NEPA reform is also needed, and so is improved interconnection of new energy sources to the grid.
- SMR markets will be global, so NRC and DOE must not ignore international regulation. United States, Europe, Japan, and other allies can align their regimes to help counter competition from Chinese and Russian state-backed enterprises.

EXECUTIVE SUMMARY

If nuclear power is the future, small modular reactors (SMRs) are the pathway, potentially offering a flexible, scalable, always-available, potentially cost-effective means of generating clean energy. U.S. companies are currently at the cutting edge of SMR development and deployment, but competition from China, Russia, South Korea, and certain European companies is intensifying. For SMRs to achieve widespread adoption, they must eventually reach price and performance parity (P3) with conventional energy sources, especially fossil fuels. And to do that, they need to scale.

Unlike large reactors, initially high SMR costs may fall because they are designed to be built—partly or completely—in a factory, rather than constructed on-site. Large-scale factory production can exploit economies of scale and can also lead to faster production, another key advantage. That is the endgame for SMRs. The question is how to get there, and the role the U.S. government should play along the way.

It's useful to think of technology development as following a four-phase pathway, although, of course, all the boundaries are fuzzy, and not all technologies go through all four phases:

- Initial basic and applied research eventually leads to a prototype or the equivalent.
- Testing and further development leads to a fully complete design whose components have been successfully tested.
- First-of-a-kind deployment demonstrates that the protype and related components can be scaled up to commercial size, and the first reactor of its kind can be built.
- During the scale-up phase, multiple copies are produced and sold, allowing costs to fall and eventually the technology to become competitive with existing energy sources. Scale-up requires finally settling on a design, developing a fully functioning factory, and building an order book deep enough to support production at scale.

Today, large reactors have reached the scale-up phase but have largely stalled there, and show no sign yet of successfully reaching P3. There are simply not enough orders in the United States to generate sufficient scale economies. Proponents hope that a coalescence of orders around the Westinghouse AP1000 design (which is now a standard model for large reactors) will get large reactors to scale, but that seems unlikely. SMRs are at a much earlier stage, only now reaching the end of the testing and further development phase, with leading-edge designs preparing for first-of-a-kind deployment in the United States and elsewhere.

As a result, we don't yet know whether SMRs will crack the scale-up problem; that question cannot be answered for at least a decade. But we can say that unlike large reactors, there is a greater *possibility* that SMRs will indeed scale, costs will fall, and P3 will be achieved. This is in part because SMRs have significant advantages, including that they may be able to expand the market for reactors very substantially. Because they can be sized from 1 megawatt (MW) to 300 MW or more, they can meet very different needs in different markets. Because some designs at least are well suited to the production of thermal energy, they can play a role in industrial decarbonization, and could also align well with desalination. Also, because they are modular, they can be aggregated to meet the specific amount of energy required. Some designs, for example those using molten salt and thorium promise cheaper fuel, lower refueling downtime requirements and have enhanced passive safety features that further reduce costs. In some cases, they use different fuels that are less expensive and easier to produce. And in contrast to wind and solar, they generate energy 24/7. That, combined with being clean, has attracted significant attention from Big Tech firms looking for power for their rapidly growing data centers.

Of course, first-of-a-kind SMRs are going to be expensive. They will likely cost more per megawatt hour (MWh) than existing large reactors, and certainly more than competing fuels (solar, wind, and natural gas). Expensive new technologies that will take a decade or more to reach scale (if they ever do) are very high risk, and SMRs face four distinct kinds of risk:

- **Technology risks.** Until the reactors are up and running, we won't know whether in practice they meet the anticipated specs. Because we don't have operational experience yet, SMR technology could fail to translate from the drawing board on pilot projects to full commercial operation in multiple ways—they could generate less power, use more fuel, require more downtime; there is a long list of things that could go wrong.
- **Market risks.** SMRs as a business face risks on both the supply side and the demand side. Aside from the technical risks, SMR companies may find that the competition is more intense or effective than anticipated; that some assumptions about their supply chain are wrong; or even that key patents don't hold up. And of course—as with large reactors—companies may simply find that producing and siting SMRs is much more expensive than expected, or takes much longer, or that interest rates shift sharply upward, or indeed that inflation suddenly hits key inputs. On the demand side, it may be that expected markets simply don't materialize, or that there is no market for SMR energy at the price it needs to charge. It's hard to predict energy markets a decade out.
- **Regulatory risks.** SMRs must navigate multiple layers of regulation. They need to get their designs certified for safety (in the United States, by the Nuclear Regulatory Commission (NRC)). They need to get NRC safety approval for their operating plan for a specific site. They then need to get site approval via the National Environmental Protection Act (NEPA) process to ensure that environmental issues have been addressed. That may well also involve a defense against NIMBY ("not in my backyard") lawsuits. And as SMRs will need to scale globally, they will also need to address regulators in other countries.
- **Political risks.** The reality is most nuclear reactor purchases involve national governments in some way (the United States is perhaps an outlier here, although the U.S. Department of Energy's (DOE's) Office of Nuclear Energy (ONE), Office of Clean Energy Demonstrations (OCED), Loan Program Office (LPO), and other programs will still be key enablers for nuclear). Government commitments to nuclear power have been subject to intense political conflict in some countries, leading to reversals, as in Germany, and to a double reversal and then reapproval in Japan. Government support will likely be critical, but governments can also be fickle. And in the United States, while there now appears to be a growing bipartisan consensus at the federal level in support of nuclear power, that is not the case at the state level, where environmental concerns, NIMBY issues, and waste management continue to generate opposition.

It is therefore not surprising that derisking has been at the heart of policy discussions. How can governments mitigate or perhaps even eliminate these risks in ways that don't simply shift them entirely onto the backs of taxpayers?

It’s helpful to consider risk mitigation in terms of financial and nonfinancial risks, as the related policies are quite different.

Financial risk mitigation means finding ways to share risks between different stakeholders, including vendors (that sell reactors), constructors (that build plants), utilities (that usually own them), lenders, ratepayers, large end users, state and local governments, and national governments (and their taxpayers). Just listing the stakeholders indicates the complexity of possible risk-sharing models.

These stakeholders can also support nuclear construction through a wide variety of mechanisms. In the United States, funding comes from three primary sources: government grants for research and development (R&D) and eventually deployment; tax credits for either investment or production (Investment Tax Credits (ITC)/Production Tax Credits (PTC), with the latter currently set at $30/MWh; and—potentially though not yet in reality for SMRs—loan guarantees from LPO.

Other countries are using or exploring quite different approaches. The U.K. government has effectively been forced to become the owner of a plant being built at Hinkley Point, so taxpayers are largely on the hook there. The United Kingdom is also exploring rate-asset-based support, where ratepayers are required to pay a contribution during the construction period rather than just paying for electricity. In Finland, cooperative structures link vendors, construction companies, utilities, and large end users. In several European countries, Contracts for Difference (CfD) provide flexible operating subsidies that are tied tightly to market conditions, offering government subsidies where operating costs are higher than market prices. Many government have provided loans at below-market rates, while in Asia in particular, China has offered very attractive funding packages for new nuclear plants. The United States could clearly benefit from reviewing these options in a systematic way and aligning them with a much stronger emphasis on P3 assessment.

On the demand side, risk mitigation usually involves a long-term power purchase agreement (PPA), wherein a utility or large end user will agree to buy power at a more or less fixed price for a fixed number of years (often as long as 20 years). PPAs are effectively mandatory for large reactors; lenders will not take the risk of simply funding a huge speculative project. They will likely be mandatory for large SMRs, for the same reason. Microreactors—20 MW or less—may however be different; the amounts at stake are smaller and some microreactor companies aim to build and operate reactors themselves, simply delivering energy to clients.

The U.S. model for financial risk mitigation emerged largely because it was the approach that could get through Congress at the time, not because it was clearly the best approach. Indeed, it has many weaknesses especially over the long run, if only because it is exceptionally vulnerable to political risk.

Mitigating nonfinancial risks is also important. Technological risk is being mitigated by the close alignment between SMR companies and the National Labs, which provide critical expertise and capabilities in the form of facilities that can be shared by different SMR companies. Simulation, modeling, and physical test sites are all important, and can play especially helpful roles both at earlier stages of R&D and later in preparing designs for NRC certification. While this work is not glamorous or particularly visible, it is an important building block for the U.S. nuclear sector, and it would be devastating over the medium term if this work were not fully supported. Indeed, as SMR opportunities expand, it is likely that more SMR companies and designs will emerge, and they too will need access to and support from Idaho National Laboratory (INL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Lab (PNNL), and Argonne National Laboratory (ANL).

There are nonfinancial production risks to consider also. For example, many SMR designs require enriched uranium fuel (High-Assay Low-Enriched Uranium (HALEU)), and that supply chain is both global and insufficient. DOE is working on this, but other companies will likely have to follow TerraPower and cut their own deals with foreign entities and governments.

Regulatory risk is still substantial, despite recent efforts at NRC, where a new rulemaking aims to provide an optional alternative path for safety and operational certification for advanced reactors, replacing the existing model designed for existing GenIII large reactors. This pathway will however not be operational until at least 2027, although the current exemption-based process seems to be working better than SMR companies initially expected. More worrying, there has been no public discussion of a pathway for iteration: innovative products do not usually reach the market without substantial iteration and tweaking, or even full-scale pivots, and we simply have no idea how NRC will address a world that is so different from the "design once, build often" world that it is encouraging for large nuclear reactors. And regulatory risk is not limited to NRC: NEPA plays a significant role in delaying infrastructure projects (including SMRs), although fairly radical amendment is increasingly likely. State policy too impacts deployment, although antinuclear feeling is reversing, and this is being reflected in changes in state regulations for nuclear.

There are plenty of other regulatory concerns as well. SMR transportation and siting will be regulated and will likely need different approaches than those used for large reactors, and so will waste streams, all of which are in some state of flux.

Based on this analysis, the U.S. government has plenty still to do to support SMR development. Key recommendations cover the following areas:

- **Expanded funding for basic and applied research.** The Advanced Reactor Demonstration Program (ARDP), which spans several phases of development, has clearly been successful in supporting SMRs. Early funding—through this program or others—is critical, especially for a newly emerging sector such as SMRs; the discovery phase for this technology will require significant help in the form of grant funding and access to National Labs expertise and capabilities.
- **Testing, certification, and further development.** At this stage of development, new nuclear technologies are a decade or more from deployment at scale. They are therefore high-risk technologies, and federal funding in the form of matching grants will be crucial, as will access to testing and validating facilities at the National Labs and support for beginning the regulatory pathway.
- **First-of-a-kind commercial deployment.** This critical step marks the conclusion of the research and testing phase and the beginning of commercialization. Despite the missteps of OCED under the Biden administration, OCED funding will be absolutely critical for SMR deployment at this stage. We strongly recommend that OCED be reset to focus only on technologies that have reasonable prospects of reaching P3, but that support should

be renewed and possibly expanded. DOE must also fully accept the need for much improved transparency across contracts, milestones, and both technical and economic outcomes from supported projects. Public funding should generate publicly available results.

- **Scale-up.** Here too existing mechanisms will play a key role. LPO should also be reoriented, mandated to focus explicitly on scaling up promising new technologies that are within reach of P3. It should avoid funding projects on either the supply or demand side that have no pathway to sustainability, and subsidies should be explicitly designed to support projects in reaching scale and hence P3. Subsidized loans and tax credits are, however, not the only mechanisms available; the administration should explore multiple alternatives including, for example, risk tiering, the use of CfD, and vertically organized consortia.
- **Regulation is key to SMR success.** NRC must both find ways to reduce the time lag before designs are certified and—especially critical for SMRs—develop ways to support design iteration, a key feature of innovation. Distinguishing between iteration that has safety impacts and those that don't will be central, and NRC will also have to make significant strides in certifying factory-built reactors (and components) and addressing the need for new approaches to waste management and the transportation of SMR reactors, components, and fuel. SMRs will also need resolution of the current problems with interconnection, but it seems likely that these may be addressed before SMRs reach scale-up. Finally, international regulation matters; SMRs must work within global markets to achieve scale, so DOE should work to align certifications and safety regulations with other regulators.

SMRs are a promising technology with the potential to reach P3, in contrast to standard large nuclear reactors, which will not achieve scale or cost competitiveness with alternative energy sources. DOE should therefore focus its nuclear resources primarily on SMRs.

Box 1: Price/Performance Parity: "P3"

Climate change is global, so solutions must be global. In particular, they must meet the needs of low-income countries where demand for energy is rising fastest, and where ability and willingness to pay a green premium is low to nonexistent.

There is no evidence that forcing change with regulation, subsidies, or exhortation will work. Low-income countries will not adopt clean energy at the expense of growth. Neither will richer countries.

The market is the only lever powerful enough to drive the transition at the scale needed—and it will only work when clean energy technologies can outcompete dirty ones without subsidies or regulations. They must reach P3.[1]

Renewable energy is inherently variable. To succeed, especially in lower-income countries, Variable Renewable Energy (VRE) must deliver with reliability and costs that are broadly similar to fossil-generated energy. The United Kingdom recently announced that it is the first Organization for Economic Cooperation and Development (OECD) country to halve its emissions by effectively replacing coal-fired power generation with wind and solar. Nuclear and gas have remained largely constant over the past decade, but gas has now become the backup to VRE.

About the Author

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ENDNOTES

1. Robin Gaster, "Mend It, Don't End It: It's Time to Reset Clean Energy Policy by Focusing on Price/Performance Parity (P3)" (ITIF, January 2025), https://itif.org/publications/2025/01/27/time-reset-clean-energy-policy-focusing-price-performance-parity-p3/; Robin Gaster, Robert D. Atkinson, and Ed Rightor. "Beyond Force: A Realist Pathway Through the Green Transition" (ITIF, July 2023), https://itif.org/publications/2023/07/10/beyond-force-a-realist-pathway-through-the-green-transition/.