# Right-Sizing Reactors

## Balancing Trade-offs Between Economies of Scale and Volume

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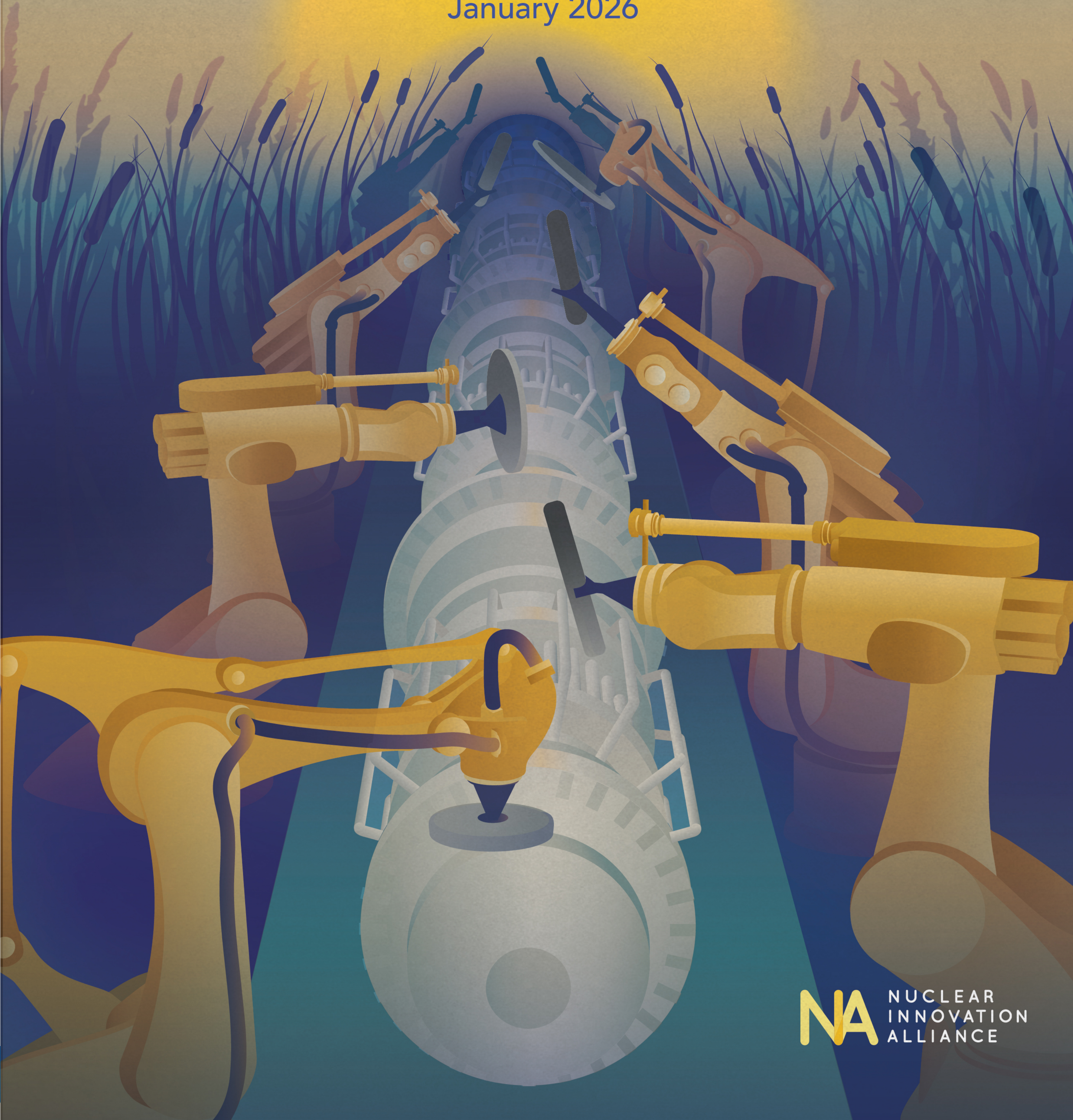

NUCLEAR INNOVATION ALLIANCE

# Right-Sizing Reactors:

Balancing trade-offs between economies of scale and volume

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# Table of Contents

## Executive Summary

In the past, nuclear energy programs pursued ever-larger reactors to capture economies of scale and meet rapidly growing demand for electricity in industrializing countries. But this trend often increased system complexity and exacerbated cost escalation—an effect documented across the U.S. and Europe in the late 20th century. More recent megaproject experience (e.g., Vogtle, Flamanville-3) strengthen the case that large bespoke plants carry substantial schedule risk and capital overruns. Yet some countries—South Korea, China—achieved cost declines with large reactors through standardization, serialization, and paced deployment, demonstrating that scale can succeed when accompanied by a comprehensive industrial strategy.

Modern Small Modular Reactors (SMRs) and microreactors invert the historical trend by emphasizing economies of volume rather than scale. Their smaller, standardized, often factory-fabricated units have the potential to reduce onsite labor, shorten construction timelines, enable iterative design improvements, and diversify supply chains. Learning-by-doing tends to proceed faster for smaller modular technologies, and modeling shows that even with higher first-of-a-kind costs, SMRs can surpass large reactors economically within the first dozen units. However, these benefits are contingent on vendors securing sufficient order books to justify manufacturing investment, on effective project execution, and on regulatory frameworks evolving to support high-volume licensing.

The current U.S. Nuclear Regulatory Commission (NRC) structure was optimized for large-scale light-water reactors and imposes disproportionately high licensing and annual fees on smaller reactors. Recent legislative reforms and NRC initiatives—such as technology-inclusive licensing, scalable emergency planning zones, and proposed factory-testing pathways—represent important progress. Still, enabling microreactors and SMRs to achieve cost and deployment advantages will require the more fundamental shifts now underway toward standardized reviews, scalable environmental processes, and elimination or streamlining of mandatory hearings.

The market for new nuclear is likely diverse enough to accommodate multiple sizes and deployment models. Microreactors (<50 MW) may serve off-grid communities, remote mining, defense installations, and oil and gas operations where reliability and transportability outweigh high capital costs. SMRs (50–300 MW) are gaining traction for data centers, industrial heat, repowering of retiring coal plants, and medium-sized grids. Medium reactors (300–1000 MW) align with municipal utilities and thermal plant replacements, while large reactors (>1 GW) remain suited to bulk electricity supply in countries with strong centralized institutions and robust supply chains.

Ultimately, the future of nuclear energy is not about choosing small or large reactors—it is about enabling the right technology for the right market. Achieving this requires coordinated actions across government, industry, finance, and civil society to support diverse reactor designs, promote serial deployment, reform regulation, execute projects effectively, and enable rapid learning. With appropriate enabling conditions, nuclear technologies—regardless of size—can follow the cost-decline trajectories seen in modular renewable and aerospace industries, unlocking the scale of low-carbon power needed for global decarbonization.

## 1. "Small is Beautiful" for Nuclear Power

The 1970s saw a boom in commercial nuclear power, with over 250 reactors beginning construction in 28 countries across North and South America, Europe, the Middle East, South and East Asia, and Africa.[1] These projects were primarily motivated by the desire for energy independence following successive oil crises and a rapid growth in demand for electricity in industrializing economies.

At the same time, a growing environmental movement was starting to critique not just the pollution from fossil fuels, but also the broader capitalist economic system and the military-industrial complex.[2] In 1973, E.F. Schumacher published *Small is Beautiful*, a critique of modern economic systems and a call for more human-centered, sustainable, and ethically grounded approaches to economics and technology. While Schumacher expressed the typical concerns for his time around atomic power – namely, safety and radiological risk — he specifically cited nuclear energy as being inconsistent with his principle of "appropriate technology," meaning it was too complex, too large, and too centralized. In contrast, he viewed renewable technologies as simpler and safer, and therefore more manageable for communities.[3]

What Schumacher called "appropriate technologies" were incorporated into what Amory Lovins called the "soft energy path" in a 1976 *Foreign Affairs* essay, which outlined an alternative path for U.S. energy focused on energy efficiency and renewable resources such as solar, wind, geothermal, and bioenergy—favoring decentralized, sustainable, and less environmentally damaging systems.[4]

Since the 1970s, the cultural and rhetorical focus of the environmental movement has stayed on these small-scale, low-impact energy technologies - as exemplified by the publications and campaigns of groups like Greenpeace and Environmental Defense Fund. Yet the physical size and capital cost of energy projects – even renewable energy – has grown significantly. For example, looking at onshore wind turbines in the U.S., the average height in the 1990s was just 30 meters and by 2020 they were close to 100 meters with the blades reaching 150 meters. The largest wind farm in the U.S., the Alta Wind Energy Center in California, has 600 wind turbines and covers five square miles.

Even nuclear technologies, which were already too large for Schumacher and Lovins in the 1970s – have grown significantly. The median gross capacity of a reactor built in the 1970s was over 950 MW, but by 2020, the median size had grown to 1,125 MW. Today, many countries are deploying these large reactors in fleets of 4 to 8 units, resulting in plants like the 8 GW Kashiwazaki-Kariwa Nuclear Power Plant in Japan.

Today, the focus on small-scale renewable technologies has moved beyond the aesthetic appeal of the 1970s. For example, Wilson et al. (2020) argue that so-called "granular" energy technologies – small in both size and cost, and modular – can deploy faster, decline in cost faster, and thus

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[1] International Atomic Energy Agency. (2025). Operational reactors by country – In Operation & Suspended Operation. PRIS. https://pris.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx
[2] Lovering, J., & Hobbs Baker, S. (2021). Can nuclear power go local? Issues in Science and Technology, 37(3), 50–55. https://issues.org/nuclear-power-local-democratic-progressive-lovering-hobbs-baker/
[3] Schumacher, E. F. Small is Beautiful: A Study of Economics as If People Mattered. (Harper & Row, 1973).
[4] Lovins, A. B. (1976). Energy strategy: The road not taken? *Foreign Affairs*, 55(1), 65–96.

accelerate decarbonization, hypothetically.[5] In their study, nuclear power is considered only in its very large, non-modular forms, and thus, not granular but "lumpy". Yet even with large nuclear power, the data tells a conflicting story. Cao et al. (2016) looked at a specific metric for real-world decarbonization: how much clean energy a country added per capita over a decade. They find that across all time periods and technologies, nuclear power has been the clean energy technology deployed the fastest. Specifically, the buildout of large nuclear reactors in Sweden, France, Belgium, Korea, and even Germany, added more clean kilowatt-hours over a decade than countries like Denmark, Spain, Germany, or even California were able to deploy with renewables in the 21st century.

Now, there are two seemingly divergent paradigms for the deployment of nuclear energy technology. If a country wants to build a lot of nuclear power fast, should they focus on small modular reactors, or even microreactors, to follow the promise of "granular" technologies? Or should they learn from the proven track-record of large-scale nuclear buildouts of the 1970s and 80s? During the Biden Administration, there was a legislative focus on large-scale clean energy infrastructure, but there were also many supportive policies for small modular reactors (SMRs) and microreactors. In President Trump's May 2025 Executive Orders in support of new nuclear energy, he endorsed all sizes and types of reactors, from large traditional designs, to SMRs, to microreactors.[6]

The successful completion of the two AP1000 reactors at Vogtle in Georgia did little to resolve this question. Some energy experts thought that the best next step would be to keep building AP1000s, to leverage the experience gained from the first two in the United States rather than start over with a new design. Others looked at the long delays and total cost for Vogtle and argued the U.S. would never build another large nuclear reactor. To resolve this question, it may be helpful to explore the literature on economies of scale in nuclear power.

## 1.1 The End of "Bigger is Better"

By the late 1970s, it was already clear that cost escalation was a serious concern for nuclear energy projects. Bupp and Derian's 1978 book *Light Water: How the Nuclear Dream Dissolved* was one of the first analyses to highlight cost escalation in nuclear power plants; they argued the cost escalation was primarily driven by the increasing size and complexity of designs.[7] Later, Charles Komanoff's 1981 book *Power Plant Cost Escalation* looked at both nuclear and coal power plants and laid the blame for rising costs more specifically on the increasing complexity of designs required to meet safety and environmental regulations.[8] The conclusions of these two books have come to be known in the academic literature as the Bupp-Derian-Komanoff hypothesis: that technology scale-up (increasing unit size) will lead to an inevitable increase in system complexity, resulting in inherent cost escalation trends that counteract potential learning-by-doing benefits.[9] Analysis of French

[5] Wilson, C., Grubler, A., Bento, N., Healey, S., De Stercke, S., & Zimm, C. (2020). Granular technologies to accelerate decarbonization. Science, 368(6486), 36–39. https://doi.org/10.1126/science.aaz8060
[6] https://www.whitehouse.gov/presidential-actions/2025/05/deploying-advanced-nuclear-reactor-technologies-for-national-security/
[7] Bupp, I. C. & Derian, J. *Light water: How the nuclear dream dissolved*. (Basic Books, Inc., 1978).
[8] Komanoff, C. *Power plant cost escalation*. (Van Nostrand Reinhold Company, Inc., 1981).
[9] Cooper, M. Policy Challenges of Nuclear Reactor Construction, Cost Escalation and Crowding Out Alternatives. Inst. Energy Environ. Vermont Law (2010).

nuclear costs have come to similar conclusions; however, the French data also shows that repeated builds of standardized designs at the same site leads to cost declines.[10]

More broadly, Bent Flyvbjerg's work highlights the significant challenges of managing costs and schedules for all kinds of "megaprojects," which are defined as projects exceeding $1 billion in construction costs.[11] Applying this framework to energy infrastructure projects, Sovacool et al. (2014) found that nuclear power plants – followed closely by hydroelectric dams – were the most likely projects to go over budget and experience construction delays,[12] with nuclear plants incurring a mean cost overrun of 117%.[13] In-depth studies of nuclear and hydro cost overruns reinforce this conclusion that any potential economies of scale are likely offset by the financial risk of project delays and cost overruns.[14,15]

There are several high-profile examples of nuclear projects being long-delayed and over-budget in western countries over the past decade. Vogtle 3 & 4 were about seven years late and $17 billion over budget, both about double the initial estimates.[16] The Olkiluoto-3 reactor in Finland – the first 1600 MW EPR reactor built by Areva – was 14 years late and €8 billion over budget, about three times the initial estimates for both time and budget.[17] These projects encouraged many nuclear developers and engineers to shift their focus to smaller, modular nuclear technology, which could have a better chance of coming in on-time and on-budget.

While the downsides to large nuclear reactors seem apparent, there are still strong advocates – both pro and anti-nuclear – who argue that SMRs will never be cost-competitive with large light-water reactors or that small nuclear will never be cheaper than renewables due to diseconomies of scale.[18,19] To understand these trade-offs for modern reactor designs, studies by Stewart (2022) and Stewart & Shirvan (2022, 2023) modeled the effects of different kinds of project risk on what they called nuclear "architectures": for example, a large passively safe Pressurized Water Reactor (PWR), a multi-unit SMR in a natural cooling pool (MMNC), a large modular Boiling Water Reactor (BWR), and a single unit 290MW BWR (SM-BWR). Their results were complicated but offer several important insights. The multi-unit SMR was the most vulnerable to construction delays, but the single-unit SMR was the least vulnerable. The multi-unit SMR project still required significant on-site labor because of the large cooling pool, so the potential project risk mitigation was offset by lost economies of scale.

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[10] Escobar Rangel, Lina, and F Lévêque. 2015. "Revisiting the Cost Escalation Curse of Nuclear Power New Lessons from the French Experience." *Economics of Energy & Environmental Policy* 4. https://www.jstor.org/stable/26189383?seq=1

[11] Flyvbjerg, Bent, Nils Bruzelius, and Werner Rothengatter. Megaprojects and Risk: An Anatomy of Ambition. Cambridge University Press, 2003.

[12] Sovacool, B. K., Gilbert, A. & Nugent, D. An international comparative assessment of construction cost overruns for electricity infrastructure. Energy Res. Soc. Sci. 3, 152–160 (2014).

[13] Sovacool, B. K., Nugent, D. & Gilbert, A. Construction cost overruns and electricity infrastructure: An unavoidable risk? Electr. J. 27, 112–120 (2014).

[14] Hultman, N. E., Koomey, J. G. & Kammen, D. M. What history can teach us about the future costs of U.S. nuclear power. Environ. Sci. Technol. 41, 2088–93 (2007).

[15] Callegari C, Szklo A, Schaeffer R (2018) Cost overruns and delays in energy megaprojects: How big is big enough? Energy Policy 114:211-220 doi:https://doi.org/10.1016/j.enpol.2017.11.059

[16] Amy, Jeff. "Georgia Nuclear Rebirth Arrives 7 Years Late, $17B Over Cost." AP News, 30 Jan. 2025, https://apnews.com/article/georgia-nuclear-power-plant-vogtle-rates-costs-75c7a413cda3935dd551be9115e88a64

[17] "Finland Commissions Olkiluoto 3 Nuclear Reactor – 13 Years Behind Schedule." *Enerdata*, 13 Apr. 2023, https://www.enerdata.net/publications/daily-energy-news/finland-commissions-olkiluoto-3-nuclear-reactor-13-years-behind-schedule.html

[18] Ramana, M.V., "The Forgotten History of Small Nuclear Reactors." *IEEE Spectrum*, 27 Apr 2015 https://spectrum.ieee.org/the-forgotten-history-of-small-nuclear-reactors

[19] Froese, S., Kunz, N. C., & Ramana, M. V. (2020). Too small to be viable? The potential market for small modular reactors in mining and remote communities in Canada. *Energy Policy*, 144(May), 111587. https://doi.org/10.1016/j.enpol.2020.111587

The single-unit SMR required the least person-hours of onsite labor, unsurprisingly, and avoided most of the usual cost and schedule overruns one would expect for a typical megaproject.[20]

Nonetheless, some countries have been quite successful at building large reactors. South Korea achieved absolute cost declines as it expanded its fleet of domestically designed OPR-1000 reactors.[21] Similarly, in China, reactor costs fell by half over the first 20 years of commercial deployment, due to standardization along with investment in domestic supply chains, workforce, and local project management.[22] France experienced very limited cost escalation within each series - or "palier" - of reactor models (although costs increased when a new, larger palier was introduced). While Japan did see modest cost escalation over time, it continued to build reactors at a record pace through the 1990s and 2000s, averaging 4.9 years for construction, while reactor size grew to over 1000 MWe.

Despite the many differences across these countries' nuclear programs, two similarities stand out that can contain cost escalation: a focus on standardization in reactor design and a more paced approach to deployment. China, Korea, and France had more centralized, state-supported nuclear industries and electric utilities, where vertical integration can facilitate learning-by-doing across the sector. Comparatively, the U.S. nuclear fleet rapidly increased reactor sizes and deployed a large variety of reactor designs, built by a diverse set of utilities, vendors, and architect-engineering firms.[23] The lesson here may be that scaling up reactor size can work if it is paced and paired with some level of design standardization.

## 2. Understanding Trade-offs Between Scale and Volume

The economic history of nuclear power is that of a technology that scaled up fast. These are some of the largest power plants in the world. Sophisticated econometric studies do find that nuclear reactors benefit from economies of scale, meaning that costs decrease per unit of capacity all else being equal. However, we also see evidence that nuclear energy has the worst experience globally going over budget and over schedule, especially for the largest projects. This is true for all kinds of large "megaprojects," not just nuclear. Nuclear has never been factory-fabricated to benefit from economies of volume, but we know from other technologies – even large, complex technologies - that this can lead to dramatic cost declines.

### 2.1 Economies of Scale

In a 2013 report, "*Approaches for Assessing the Economic Competitiveness of Small and Medium-Sized Reactors*," the International Atomic Energy Agency (IAEA) attempted to quantify the

[20] Stewart, W Robb. 2022. "Capital Cost Evaluation of Advanced Reactor Designs under Uncertainty and Risk." Massachusetts Institute of Technology.
Stewart, W. R. & Shirvan, K. Capital cost estimation for advanced nuclear power plants. *Renew. Sustain. Energy Rev.* 155, 111880 (2022).
Stewart, W Robb, and Koroush Shirvan. 2023. "Construction Schedule and Cost Risk for Large and Small Light Water Reactors." Nuclear Engineering and Design 407 (March): 112305. https://doi.org/10.1016/j.nucengdes.2023.112305.
[21] Lovering, J. R., Yip, A. & Nordhaus, T. Historical construction costs of global nuclear power reactors. Energy Policy 91, (2016).
[22] Liu, S., He, G., Qiu, M., & Kammen, D. M. (2025, July 28). *China reins in the spiralling construction costs of nuclear power — what can other countries learn?* Nature, 643, 1186-1188. https://doi.org/10.1038/d41586-025-02341-z
[23] Escobar Rangel, L. & Lévêque, F. Revisiting the cost escalation curse of nuclear power: New lessons from the French experience. *Econ. Energy Environ. Policy* 4, (2015).

trade-offs between economies of scale and other benefits for a generic Small Modular Reactor.[24] The report presents a standard scaling relation used in engineering, shown below, where the cost of the SMR is determined from the cost of a large nuclear power plant (*NPP* in the equation below) and the ratio between the unit capacities of the two reactors to the power of n-1, where n is the scaling factor. A scaling factor close to zero means that a technology benefits significantly from economies of scale, and a scaling factor of n=1 means that the cost is independent of size, or that there are no economies of scale.

$$Cost_{SMR} = Cost_{NPP} \times \left(\frac{SMR\ MW_e}{NPP\ MW_e}\right)^{n-1}$$

The uncertainty in applying this equation is determining the scaling factor, which must be observed from real-world engineering costs. Early studies of U.S. nuclear costs in the late-1970s found little-to-no economies of scale.[25] Bowers et al. (1983) surveyed 28 studies that measured scaling effects across various aspects of nuclear power plants and found scaling factors ranging from 0.25 to 1, with a mean factor of n=0.6. This is an important study, because that range of scaling factors, and the mean of n=0.6, still gets used in engineering models to this day, including in the IAEA report referenced above.

However, all the studies surveyed by Bowers were relying on the same data: U.S. reactors completed before Three-Mile Island. The large range in scaling factors across these studies comes from differences in study design; for example, including different variables in the linear regressions. Using a more complete dataset of nuclear construction costs across eight countries, including construction in the 21st century, Lovering (2020) performed a standard multi-factor regression including factors for unit size, leadtime (i.e. construction duration), country-level experience, and number of reactors on site.[26] This study found a similar range of scaling factors but also uncovered a new finding: countries that saw the largest economies of scale also had the greatest cost escalation and negative learning. This result suggests that there may be interactions between size, regulation, and leadtime that result in higher costs overall.

The evidence we have suggests that large reactors *do benefit* from economies of scale, but may also be vulnerable to cost escalation, depending on the specific deployment policies of the country, regulator, vendor, and utility. A separate question is whether the scaling equation above should be used to estimate the first-of-a-kind cost of an SMR, or a microreactor. As noted above, the IAEA does use this scaling relation to model the cost of SMRs. As a simple example, an SMR that's one-quarter the size of a large reactor (250MW compared to 1000MW) would be 74% more expensive per kilowatt to construct with the average scaling factor of n=0.6.

Where the equation starts to lose its applicability is with microreactors. For example, Moore (2016) used the scaling equation above with a scaling factor of n=0.45 to estimate the capital cost of

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[24] IAEA. Approaches for Assessing the Economic Competitiveness of Small and Medium Sized Reactors. Nuclear Energy Series NP-T-3.7, (2013).

[25] Mooz, William E. 1978. "Cost Analysis of Light Water Reactor Power Plants." Santa Monica: Rand Corporation.
Mooz, W. 1979. "A Second Cost Analysis of Light Water Reactor Power Plants." Santa Monica.
Paik, S, and W Schriver. 1980. "The Effect of Increased Regulation on Capital Costs and Manual Labor Requirements of Nuclear Power Plants." The Engineering Economist 26 (3).

[26] Lovering, J. R. *Evaluating changing paradigms across the nuclear industry*. (Carnegie Mellon University, 2020).

a 10MW microreactor from a 1,000MW LWR that cost $6,100/kW (in 2025USD). The result was $48,100/kW for the microreactor, which would likely be economically infeasible for any off-grid community.[27] Froese et al. (2020) made a similar estimate for a 3MW microreactor, and the result is even more expensive: $172,000/kW.[28] Their conclusion is that microreactors are uneconomic for off-grid applications, but this scaling equation should really not be used for this purpose. The scaling equation only applies for very similar designs, essentially a scaled-up or scaled-down version of the same reactor design. Microreactors are likely to be significantly different in their engineering from today's large light-water reactors. For starters, most of the designs are not light-water reactors, so scaling costs from a LWR makes very little sense. Some designs use heat pipes instead of pumps, which are much simpler and likely cheaper to manufacture. Bottom-up engineering cost estimates put the FOAK capital costs for microreactors at three to four times higher than a traditional large LWR, not ten to one hundred times higher.[29]

SMRs and especially microreactors will likely start at higher costs due to diseconomies of scale, but the hypothesis is that they will come down in cost with successive builds after only a handful of units. For example, a 2014 report from Idaho National Laboratory looked at a range of SMR sizes and deployment scenarios and estimated a levelized cost of electricity (LCOE) for a 7-unit, 180 MW SMR project to be $67-$84/MWh, which was lower than their estimate for a single 1260 MW light-water reactor.[30] That's because somewhere between the first and seventh unit of the SMR, it got cheaper than the large reactor on a per-kW basis. Of course, those cost declines are hypothetical, as commercial nuclear reactors have never been built in a factory setting. So, what can the literature tell us about mass-producing standardized reactors?

## 2.2 Evidence for Economies of Volume (Learning-By-Doing)

One of the main arguments for SMRs is that their small size and standardization could facilitate factory fabrication, which would enable faster learning-by-doing at the firm level, also known as economies of volume. Historically, there have been very few nuclear reactor designs that have had a successful series of standardized builds. Two studies by Mooz (1978 & 1979) found significant experiential learning at the level of the Architect-Engineering (A-E) firm of about 10% (i.e., costs decreased by 10% for every doubling of reactors built by a given A-E firm). Paik and Schriver (1980) performed a similar analysis to that of Mooz but with a different measure of regulatory effects; they found learning rates of 28% for the A-E firms.

More recently, Berthélemy and Escobar-Rangel (2015) performed a regression analysis to isolate hypothetical drivers of capital cost for a combined data set of French and U.S. reactors. They found that standardization of reactor design correlated significantly with decreasing lead times and costs.[31] Outside of nuclear technologies, Wilson et al. (2020) and Sweerts et al. (2020) examined the impact of unit size in energy technologies on economic and deployment metrics. They find that

[27] Moore, M. 2016. "The Economics of Very Small Modular Reactors in the North." In 4th International Technical Meeting on Small Reactors (ITMSR-4). Ottawa, Ontario, Canada. http://www.cnl.ca/site/media/Parent/Moore_ITMSR4.pdf.
[28] Froese, Sarah, Nadja C. Kunz, and M. V. Ramana. 2020. "Too Small to Be Viable? The Potential Market for Small Modular Reactors in Mining and Remote Communities in Canada." Energy Policy 144 (May): 111587. https://doi.org/10.1016/j.enpol.2020.111587.
[29] Hanna, B. N., Al-Dawood, K., Seurin, P. R. M., Abdelnasser, R., & Abou-Jaoude, A. (2025). A Bottom-Up Cost Estimation Tool for Nuclear Microreactors (INL/RPT-25-87273, Revision 0). Idaho National Laboratory. U.S. Department of Energy, Microreactor Program.
[30] Boldon, L. M. & Sabharwall, P. Small Modular Reactor: First-of-a-Kind (FOAK) and Nth-of-a-Kind (NOAK) Economic Analysis. (2014).
[31] Berthélemy, M. & Escobar, L. Nuclear reactors' construction costs: The role of lead-time, standardization and technological progress. *Energy Policy* 82, 118–130 (2015).

across energy supply, demand, and storage technologies, smaller unit sizes and standardization result in faster cost declines and deployment, and higher return on R&D investment.[32,33]

Importantly, economies of scale and economies of volume can overlap when multiple standardized reactors are located at a single site. Boarin and Ricotti (2014) found that SMRs can be cost-competitive with a traditional large reactor, only if they are built with multiple units co-located.[34] As a comparison, most U.S. nuclear power plants contain only one to two reactors on site, whereas in France, Canada, Japan, or South Korea, it is more common for sites to have four to eight reactors on site. DOE's 2024 *Liftoff* report states that multi-unit plants have significant economies of scale, with per MWh costs 30% lower than single unit plants.[35] SMRs can leverage this benefit by allowing for a scalable power plant size, e.g. NuScale's 6-pack and 12-pack designs. However, Stewart (2022) warns against deploying SMRs in this modality if it makes use of natural cooling, due to the larger amount of onsite construction needed (and labor), which compounds the diseconomies of scale for the individual reactors.[36]

In the DOE's updated *Liftoff* report, they note that if a utility built 7 GW of nuclear power, they would only get to 7th-of-a-kind for a 1 GW reactor, but the 23rd-of-a-kind for a 300 MW SMR.[37] That may seem obvious, but the implications are important: the SMR vendor will experience significantly more learning, and the design could decrease in cost substantially, possibly resulting in much lower cumulative construction costs. However, the actual results depend on the difference in starting capital costs and the difference in learning rates. Stewart (2022) makes clear that modularization on its own does not reduce capital costs, but it can serve as a catalyst for learning-by-doing effects when building units in a series. They also conclude that learning-by-doing is one of the most effective cost reduction strategies for nuclear projects.[38] On the other hand, the learning curves of different reactor technologies will likely asymptote at different absolute levels depending on fundamentals of the designs.

## 2.3 Innovation (Learning-By-Research)

*Incremental process improvements can only reduce costs for so long and will eventually stagnate. More significant reductions in cost often come from new innovations developed through R&D programs. However, once a reactor design is locked in, it can be detrimental to innovate in some cases.*

The historical cost data shows dramatic cost declines for the early periods of demonstration reactors in the U.S., France, and the U.K..[39] This is likely a combination of economies of scale and the effects of research and innovation. However, as firms gain experience building a certain design,

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[32] Wilson, C. et al. Granular technologies to accelerate decarbonization. Science (80-. ). 368, 36–39 (2020).
[33] Sweerts, B., Detz, R. J. & van der Zwaan, B. Evaluating the Role of Unit Size in Learning-by- Doing of Energy Technologies. Joule 1–4 (2020). doi:10.1016/j.joule.2020.03.010
[34] Boarin, S. & Ricotti, M. E. An Evaluation of SMR Economic Attractiveness. Sci. Technol. Nucl. Install. 2014, 1–8 (2014).
[35] Kozeracki, J. Vlahoplus, C. et al. *Pathways to Commercial Liftoff: Advanced Nuclear*. (2024).
[36] Stewart, W. R. Capital cost evaluation of advanced reactor designs under uncertainty and risk. (Massachusetts Institute of Technology, 2022).
[37] Bates, M. *et al. Pathways to Commercial Liftoff: Advanced Nuclear*. (2024). Department of Energy
[38] Stewart, W. R. Capital cost evaluation of advanced reactor designs under uncertainty and risk. (Massachusetts Institute of Technology, 2022).
[39] Lovering, J. R., Yip, A. & Nordhaus, T. Historical construction costs of global nuclear power reactors. *Energy Policy* 91, (2016).

utilities gain experience operating that design, and the supply chain develops, it can eventually become disruptive to make changes to the reactor design. For example, Berthélemy and Escobar-Rangel (2015) looked at nuclear cost data in the U.S. and France and concluded that standardization was important for cost reductions, and that unlike for other energy technologies, for nuclear, innovation led to cost escalation. Several studies of the AP1000 reactor conclude that passive safety features led to an unintended consequence of significantly higher costs for certain steel structures.[40,41] As a counter example, when the first Advanced Boiling Water Reactor (ABWR) was built by Toshiba in 1992 in Japan – the very first Gen III design in the world – it took only 3.2 years to complete the 1300 MWe reactor.

One important benefit of factory fabrication is the potential for costs to decline through process improvements and more frequent iterations in design.[42] We see this with most other energy technologies like solar panels, wind turbines, and batteries.[43] As an example of another complex, heavily-regulated industry, we can look at how SpaceX uses modularization in their rockets. Whereas other launch service companies use one large engine for each rocket, SpaceX chose to combine nine smaller engines into one for their Falcon 9 rocket. This had many advantages and parallels some of the promises of SMRs.[44] The smaller size of the individual engines allowed for easier transport and supply chains as well as faster iterations in design.

When new discoveries are made in the laboratory or at a university that could have important benefits for commercial nuclear technologies, it could be much easier and faster to implement if the component or the entire reactor is being fabricated in a central facility, rather than constructed bespoke on-site.

## 2.4 Supply Chain Economies (Learning-By-Searching)

*Nuclear firms may be able to reduce costs by sourcing cheaper components from alternative suppliers, and smaller reactors have smaller components that can be supplied by more diverse manufacturers. Smaller components also enable faster iterations in process innovations.*

Smaller reactors may also open the supply chain to a more diverse range of suppliers for certain components, a process sometimes referred to as "learning-by-searching". Reactor Pressure Vessels (RPVs) are a great example. In the 1960s and 70s, when the major nuclear vendors were building fleets of nuclear reactors, almost everything was supplied in-house, including RPVs, which at the time were produced using traditional welding techniques. Most RPVs were built in the U.S., France, or the U.K. However, the welding process uses a filler material at the joints that is prone to embrittlement from radiation over time and needs regular inspections. For this reason, the industry moved to forging the entire vessel in large sections using fewer welds (ideally, the entire RPV is forged as a

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[40] Eash-gates, P. *et al.* Sources of Cost Overrun in Nuclear Power Plant Construction Call for a New Approach to Engineering Design. *Joule* 4, 2348–2373 (2020).
[41] Stewart, W. R. Capital cost evaluation of advanced reactor designs under uncertainty and risk. (Massachusetts Institute of Technology, 2022).
[42] Flyvbjerg, B., & Gardner, D. (2023). *How Big Things Get Done: The Surprising Factors that Determine the Fate of Every Project, from Home Renovations to Space Exploration, and Everything in Between*. New York: Currency.
[43] Wilson, C., Grubler, A., Bento, N., Healey, S., De Stercke, S., & Zimm, C. (2020). Granular technologies to accelerate decarbonization. Science, 368(6486), 36–39. https://doi.org/10.1126/science.aaz8060
[44] Bowen, M. *In Search of a SpaceX for Nuclear Energy*. Nuclear Innovation Alliance (2019).

single component with no joints). But as reactors – and RPVs – got bigger, the forges that could do this kind of work were limited to just a few places. Vessel production moved to Japan, Korea, and China as the steel industry (and the nuclear industry) collapsed in the U.S., but even today, the throughput at these large forges is limited to roughly four RPVs per year.

Moving to smaller reactors means smaller RPVs, and that creates an opportunity for new suppliers to compete in the market. Just as one example, in 2016, DOE funded the Electric Power Research Institute (EPRI) to conduct a four-year RPV "moonshot" project, aiming to demonstrate three new enabling technologies that could dramatically reduce the costs and manufacturing timelines of RPVs.[45] They chose to demonstrate these enabling technologies on a 2/3-scale model of NuScale's 50 MW reactor design because the components could be manufactured in existing facilities in a reasonable amount of time.

Learning-by-searching is an important lesson from the airline industry. While a Boeing wide-body aircraft will be assembled in a factory in Everett, Washington, the parts will be flown in from suppliers all over the world. This allows Boeing to "search" for the cheapest suppliers and build redundancy into its supply chain. Yet, Boeing's 777X is now the most delayed aircraft in aviation history. As a counter example, Kairos has a strategic focus on vertical integration in its supply chain, developing in-house capabilities to manufacture its own components.[46] At this point, nuclear vendors will likely take different paths in diversifying their supply chains and each carries different benefits and risks.

## 2.5 Potential Financing and Risk-Management Benefits of SMRs

> *A significant share of the cost overrun for a large nuclear project could be due to poor estimation by project planners in the first place. Studies have found that the nuclear industry has consistently over-estimated labor productivity by a wide margin, leading to predictable cost overruns. On-site construction has notoriously low labor productivity.*

Even when SMRs have higher capital costs, they may be more attractive than large-scale reactors for several reasons. Boarin and Ricotti (2014) found additional benefits to SMRs, including reduced risk of construction delays and cost overruns.[47] Mignacca and Locatelli (2020) performed a systematic review of SMR economic studies. They found a diverse array of potential financial benefits: reduced costs from factory fabrication, incremental capacity additions (and incremental shutdowns), economies of co-siting multiple units, cogeneration and better load-following, faster learning, shorter construction duration (and thus lower interest costs during construction), higher availability due to less frequent refueling outages, and shorter licensing time for subsequent units.[48] Additionally, Stewart (2022) found that modularization, both for small and large reactors, could

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[45] Barker, B. (2017, May 9). A "Moonshot" for Reactor Vessel Production. EPRI Journal. https://eprijournal.com/a-moonshot-for-reactor-vessel-production/

[46] Pierpoint, L. (2025, September 24). Shortening the nuclear development cycle from decades to years. Latitude Media. https://www.latitudemedia.com/news/green-blueprint-the-non-nuclear-route-to-cheaper-reactors/

[47] Boarin, S., Locatelli, G., Mancini, M. & Ricotti, M. Financial case studies on small-and medium-size modular reactors. Nuclear Technologies 178, (2012).

[48] Mignacca, B. & Locatelli, G. Economics and finance of Small Modular Reactors: A systematic review and research agenda. Renew. Sustain. Energy Rev. 118, 109519 (2020).

dramatically reduce financing costs by reducing the construction duration by 65-75%, or 15-25% of total costs.[49]

Recent studies out of MIT also look at managing the uncertainty around construction schedule of nuclear projects. Eash-Gates et al. (2020) looked at cost escalation in U.S. nuclear plants for standardized designs from 1976 to 1987 and found that over half of the cost escalation was due to soft factors like poor labor productivity. Specifically, projects that depend heavily on commodities (e.g. concrete and steel) and onsite labor are more vulnerable to labor productivity and delays. They recommend designing reactors that use less commodities and have less onsite labor, i.e. more offsite fabrication.[50] Similarly, Stewart (2020) found that large reactors experienced greater sensitivity to tighter labor markets and were prone to construction delays unlike smaller reactors, which were less sensitive to labor conditions and experienced fewer delays overall.[51] Interestingly, they found that nuclear industry estimates consistently over-estimated labor productivity by a wide margin, leading to predictable cost overruns.

## 2.6 Right-Sizing Regulations for SMRs and Microreactors

*Small and very small modular reactors may have numerous potential benefits in terms of cost and timelines. Still, these benefits will only be realized if the regulatory process can be right-sized for these new designs. The next two sections will focus on the licensing challenges and progress at the Nuclear Regulatory Commission (NRC) in the U.S., although many other countries that are considering advanced nuclear have identified updating licensing paradigms as essential to innovation and commercialization of new technologies as well.*

### 2.6.1 Licensing Fees in the U.S.

The fee structure at the NRC for license applications was designed for large reactors and does not scale with size. For example, the NRC estimated several years ago that, on average, the total fees charged to a vendor were as follows: $32 million for a Combined Operating License, $12 million for an Early Site Permit, and $54 million for a Design Certification.[52] That may not be a lot of money if you're planning to build two 1,000 MW reactors at your project site, but those same fees for a single 5 MW microreactor would be completely unrealistic. The current system of annual NRC fees for operating reactors is also a challenge. For example, a 5 MW microreactor could face annual fees representing 18% of its annual operating and maintenance costs, rendering business models inviable.[53]

In January of 2019, the Nuclear Energy Innovation and Modernization Act (NEIMA) was enacted into law, and it included several provisions to improve licensing for advanced reactors. Overall, NEIMA tasked NRC to develop a "technology-inclusive" regulatory framework by the end of 2026

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[49] Stewart, W. R. Capital cost evaluation of advanced reactor designs under uncertainty and risk. (Massachusetts Institute of Technology, 2022).
[50] Eash-gates, P. *et al.* Sources of Cost Overrun in Nuclear Power Plant Construction Call for a New Approach to Engineering Design. *Joule* 4, 2348–2373 (2020).
[51] Stewart, W. R. Capital cost evaluation of advanced reactor designs under uncertainty and risk. (Massachusetts Institute of Technology, 2022).
[52] Lutz, B. & White, P. *Nuclear Reactor Licensing 101*. Nuclear Innovation Alliance (2024).
[53] Nuclear Energy Institute. *Regulation of Rapid High-Volume Deployable Reactors in Remote Applications (RHDRA) and Other Advanced Reactors*. (2024).

and make the fee structure and budget more transparent, predictable, and equitably allocated. In the summer of 2024, the Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy (ADVANCE) Act became law in the U.S. and included many improvements to the nuclear licensing process. Under the Act, licensing fees are reduced by 55% from $323/hour to $146/hour, effective for FY2026.

While these reductions in fees are a step in the right direction, they stand in stark contrast to the more innovation-friendly fee structure of the Federal Aviation Administration, for example. The FAA does not charge any fees for licensing new aircraft designs. Instead, most of the FAA's annual budget comes from a trust fund that is financed through user fees, such as taxes on airline tickets.[54]

### 2.6.2 NRC Improvements for High-Volume Licensing

There are many ways that NRC's safety regulations do not scale appropriately with reactor size. When the NRC was founded in 1975, the average capacity of a reactor that began construction in the U.S. was over 1,100 MWe. As such, most of the Commission's regulations are optimized for very large reactors that are built as bespoke projects. Current regulations regarding operator staffing and control room designs are tailored to large LWRs, not to SMRs that might incorporate minimal staffing, autonomous operations, or remote monitoring. This is especially true for many microreactor designs.

Requirements for physical security and emergency preparedness were also established for large LWRs, and may not provide the necessary flexibility for SMRs with lower risk profiles and smaller potential consequences. As an example, requirements for a certain number of on-site security guards would be excessive for a 1 MW microreactor that fits in a shipping container. Not to mention, the cost would be untenable.

Some of these challenges have been addressed through NRC rulemaking based on whitepapers submitted by first-mover license applicants. For example, when licensing new reactors, historically applicants had to submit plans for two emergency planning zones around the project: a plume exposure pathway fixed at a 10-mile radius, and one for an ingestion exposure pathway fixed at a 50-mile radius. However, in 2022, the SMR vendor NuScale had their alternative methodology approved for determining an EPZ that could be limited to the site boundary.[55] Later in 2023, the NRC expanded the ruling so that all SMRs and advanced reactors could apply a consequence-based, scalable methodology to determine the size of the EPZ based on risk.[56] Similarly, the NRC is in the process of developing and implementing risk-informed licensing strategies for microreactors, as required by the ADVANCE Act.[57]

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[54] Gilbert, A., Greenwald, J., & Ibarra, V. Jr. (2021, May). Unlocking advanced nuclear innovation: The role of fee reform and public investment (Nuclear Innovation Alliance). https://www.nuclearinnovationalliance.org/sites/default/files/2021-08/NIA%20Unlocking%20Nuclear%20Innovation%20through%20NRC%20Fee%20Reform.pdf

[55] NuScale Power LLC. (2022, October 20). *NuScale's Emergency Planning Zone boundary methodology validated by the U.S. Nuclear Regulatory Commission Advisory Committee on Reactor Safeguards*. https://www.nuscalepower.com/press-releases/2022/nuscales-epz-boundary-methodology-validated-by-the-nrc-advisory-committee-on-reactor-safeguards

[56] Accomando, J., Pennella, P., & Polonsky, A. (2023, September 13). *NRC finalizing emergency preparedness rule for new reactor designs*. Morgan Lewis – Up & Atom. https://www.jdsupra.com/legalnews/nrc-finalizing-emergency-preparedness-9209273

[57] Nuclear Innovation Alliance. (2025, September 8). *Regulatory implementation summary: NRC progress under the ADVANCE Act*. https://nuclearinnovationalliance.org/index.php/regulatory-implementation-summary-nrc-progress-under-advance-act

Factory-fabrication is also a relatively new concept for the NRC, at least for a whole reactor (there is currently a Manufacture License available under 10 CFR Part 52 subsection F).[58] However, the current framework does not consider aspects such as fuel loading, conducting operational testing, or closing Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC) at the factory. In January 2024, the NRC staff presented a set of recommendations and different policy options to the commissioners regarding some of these questions, particularly fuel loading and pre-shipment operational testing.[59] The staff's recommendations included:

- Separate licensing constructs for factory fueling vs. operational testing
- Define when "operations" begin. For example, the disabling of physical mechanisms that prevent criticality (in a factory) as the start of "operations", rather than when fuel is loaded.
- Propose a new licensing category under 10 CFR Part 53, § 53.1480, called "combined license for testing of manufactured reactors" (COL-TMR), which would permit limited operational testing (i.e., low power, short duration) of factory-manufactured reactors.

Whether the benefits of Small Modular Reactors – including standardization and factory fabrication – can be realized will depend on whether the regulations can be reformed to meet the needs of high-volume licensing.[60] In early 2024, the Nuclear Innovation Alliance published a report with three main recommendations for how the NRC's current licensing system—optimized for a few large light-water reactors—must evolve into a scalable, standardized, and performance-based process capable of handling hundreds of advanced reactor applications annually without compromising safety or transparency:

1. **Standardize Safety and Technical Reviews.** Expand the use of Standard Design Certifications (SDCs), Standard Design Approvals (SDAs), and other NRC tools that allow repeated use of previously approved designs. Use site-independent safety analyses so the NRC doesn't have to re-review identical technical content for each new site. Limit reviews by the Advisory Committee on Reactor Safeguards (ACRS) to first-of-a-kind or safety-significant cases, with expedited or consolidated reviews for standardized reactors.
2. **Create Scalable Environmental Review Processes.** Allow categorical exclusions (CATEX) and environmental assessments (EAs) in place of full Environmental Impact Statements (EISs) when justified. Implement performance-based reviews that scale NRC efforts to demonstrate impact levels. Let applicants prepare draft environmental documents under NRC supervision (as permitted under the Fiscal Responsibility Act of 2023). Develop generic environmental impact statements (GEIS) for standardized technologies to reduce repetitive analyses.
3. **Modernize or Eliminate the Mandatory Hearing Requirement.** Allow the NRC Commission to use alternative, less formal processes—such as public meetings, staff briefings, or informal adjudications—instead of mandatory hearings for every license. Retain the option for contested hearings if stakeholders have specific contentions.

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[58] https://www.ecfr.gov/current/title-10/chapter-I/part-52/subpart-F
[59] U.S. Nuclear Regulatory Commission. (2024, January 24). Micro-Reactor Licensing and Deployment Considerations: Fuel Loading and Operational Testing at a Factory (SECY-24-0008, ML23207A250) https://www.nrc.gov/docs/ML2320/ML23207A250.pdf
[60] White, P., Ponangi, R. T. & Reserved, A. R. *Enabling High Volume Licensing of Advanced Nuclear Energy*. Nuclear Innovation Alliance (2024).

NEIMA and the ADVANCE Act directed the NRC to make progress on some of these issues. In addition, in May of 2025, President Trump signed four Executive Orders aimed at accelerating deployment of nuclear power in the United States. Executive Order (EO) 14300 Section 5(e) directed the NRC to establish a new process for licensing modular reactors, including microreactors. In response, the NRC held a series of public meetings in the summer of 2025 and is now in the process of developing draft rulemaking for so-called "low-consequence reactors."[61] Draft rulemaking is due to the Commission in February 2026.

However, some companies would like to move even faster than the NRC. For example, Shepherd Power is a nuclear project developer that is hoping to deploy thousands of microreactors for the oil and gas industry. They have partnered with the Nuclear Energy Institute to identify and mitigate regulatory challenges, and reduce fees and timelines, such that a reactor can be licensed within 180 days of site identification, and that licensing is less than 1% of capital costs.[62]

## 3. Right-Sizing Nuclear Reactors for Markets

*There likely won't be a single best reactor design for all markets. Thus, the question becomes how to "right-size" reactors to potential markets and match reactor attributes to customer needs.*

As detailed in the previous sections, there has been a general trend towards larger reactor capacities over time in pursuit of economies of scale (and to meet the robust demand for electricity in industrializing economies). But with the challenging economics of large nuclear projects, and significant cost overruns and construction delays, in recent years there has been growing interest in moving toward smaller reactors with the hope that they will become cheaper through standardization, modularization, and factory fabrication. The smaller size could also open new markets and applications that were not available to large reactors.

The total cost of a smaller reactor may be lower, but the levelized cost of electricity may be higher, at least initially. Yet, different aspects of cost may be relevant to different markets. Some customers might value a reactor that can operate flexibly, ramping up and down to match demand. Other customers might be looking for a specific capacity to replace a retiring coal plant, or a specific physical footprint to fit onto the site of an existing nuclear reactor. Still others want to manage project financial risk by choosing smaller reactors. Certain industrial customers may need products other than electricity; and certain utilities may want to add capacity gradually over time so as not to overwhelm their grid (or their balance sheets).

Among the countries interested in starting commercial nuclear power programs,[63] many have existing power grids with limited capacity. For example, the total capacity of all power plants on Jordan's and Puerto Rico's grids is about 7 GW; Ghana and Uruguay each have less than 6 GW,

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[61] U.S. Nuclear Regulatory Commission. (2025). *Public meeting announcement – ADAMS Accession No. ML25192A134*. Retrieved from https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML25192A134

[62] Shepherd Power. (2025). *Our approach*. https://www.shepherdpower.com/our-approach

[63] World Nuclear Association. (2025). Emerging nuclear energy countries. https://world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries

Kenya and Nigeria less than 4 GW.[64] For these countries, adding a single reactor with 1 GW capacity would leave the grid too vulnerable to reactor outages; even a 300 MW SMR might be pushing the limits of what the grid can reliably handle.

There likely won't be a single best reactor design for all markets. Thus, the question becomes how to "right-size" reactors to potential markets and match reactor attributes to customer needs. The airline industry has already seen this kind of rightsizing. For a long time, aircraft were slowly moving toward larger designs, as the cost per passenger-mile benefited from economies of scale. But after the airlines were deregulated in the late-1970s and competition increased, the industry underwent market segmentation. The largest, wide-body aircraft are reserved for international, long-haul flights like London-Beijing.  Smaller, regional jets are more popular for shorter flights because they can be flown more frequently and use more airports, allowing airlines to adjust service rapidly to meet changes in demand. Different aircraft manufacturers dominate these different markets as well, with Boeing and Airbus covering widebody aircraft, and Bombardier and Embraer producing most regional jets.

When SpaceX was first able to offer commercial launch services with its Falcon 1 rocket, the cost to launch something (per kilogram) was higher than its NASA competitor, the Delta IV Heavy. However, the SpaceX rocket was much smaller overall, such that the total cost to launch was over thirty times cheaper. This meant that more customers could afford to launch satellites into space using SpaceX, and the company could have more frequent launches.[65] In the following case studies, we'll explore the different size classes of nuclear and the potential markets for each.

### 3.1 The Market for Microreactors (<50 MW)

The history of nuclear power began with microreactors in the 1950s: the GE Vallecitos reactor that came online in California in 1957 was 24 MWe, the first Soviet power reactor was 5 MWe, and the UK built a fleet of eight gas-cooled reactors in the 1950s that were all under 50 MWe. But those were all prototypes of designs that quickly grew in size as companies gained experience with the technology. Some SMR developers are following a similar path today: for example, Kairos Power is building a pair of scaled down molten-salt cooled reactors (about one-tenth the size of their ultimate commercial model) to gain operational data and help with development.[66]

[64] U.S. Energy Information Administration. (2025). International energy data – Electricity Capacity. https://www.eia.gov/international/data/world

[65] Roberts, T. G. (2022, September 1). Space launch to low Earth orbit: How much does it cost? Center for Strategic and International Studies, The Aerospace Security Project. https://aerospace.csis.org/data/space-launch-to-low-earth-orbit-how-much-does-it-cost/

[66] World Nuclear News. (2024, November 21). Hermes 2 construction permits approved by US Nuclear Regulatory Commission. World Nuclear Association. https://www.world-nuclear-news.org/articles/regulator-oks-hermes-2-construction-permit

Most of today's microreactors are *intentionally* small, often less than 10 MWe, and are targeting very different markets than traditional, large reactors. Specifically, there is an expectation that microreactors will have higher capital costs, but that certain customers will be willing to pay a premium for reliable electricity. While some companies are pursuing microreactors as a way to accelerate entry into the commercial market for advanced nuclear technology, most are offering microreactors for unique attributes like:

- Radically simplified engineering with minimal moving parts, enabling significant factory fabrication and higher learning rates.
- Minimal staffing or even autonomous operations.
- Simpler transportation by rail, truck, or barge.
- Longer fuel lifetime, and even "lifetime cores," meaning the reactor is delivered fully fueled and runs for 10-30 years without refueling.
- Ability for owners to arbitrage prices by coming on and off the grid as needed.

Essentially, microreactors offer an electricity product that looks more like a battery than a diesel generator in terms of how it operates. And their potential markets reflect these novel aspects.

### 3.1.1 Off-Grid and Microgrid Applications

While the term "off-grid" may be culturally associated with low energy consumption, like a cabin in the woods, there are several specific off-grid markets that require large and reliable amounts of energy: Arctic and island communities, mining and extractive industries, and defense installations. Currently, these markets are most likely to be powered by diesel generators, which are both expensive and vulnerable to supply disruptions. Diesel exhaust also has significant environmental and public health impacts. For these reason, in 2018, U.S. Senator Lisa Murkowski (R-AK) co-authored an op-ed arguing for policies to accelerate the deployment of microreactors, especially for rural Alaska where over 200 communities rely on expensive diesel microgrids for electricity.[67] In neighboring Canada, a 2011 study by the Canadian government found over 290 off-grid communities, with an average population around 700, and average fossil-fueled power capacity of just 1.8 MWe.[68] While that total market may seem small, only twenty to thirty 10-MW microreactors, that is likely enough for serial production for developers to invest in fabrication facilities and see some cost declines from learning.

A 2019 study by the Nuclear Energy Institute estimated that the average electricity cost from diesel generators in these off-grid markets was \$0.15-\$0.60/kWh, depending on the price of diesel and how it was delivered. In the same report, they estimated that a first-of-a-kind microreactor could generate electricity at a cost of \$0.14-\$0.41/kWh, demonstrating that such technology could already be cost-competitive for this niche market.[69] Similarly, a microgrid optimization study of two large off-grid communities in northern Canada found that a microreactor plus battery system could be cheaper than existing diesel costs if the reactor's capital cost was under \$15,000/kW.[70]

### 3.1.2 Remote Extractive Industries

Another promising market for microreactors could be off-grid mining sites. Mining operations consume substantial amounts of energy, and the costs for off-grid mining installations can be a significant barrier for project development. Froese et al (2020) estimated the potential market for SMRs for off-grid mining across Canada, looking only at mines operating past 2030 or still in development. They found that the total market was 685 MW, but with the average load ranging from 4 MW to 125 MW.[71]

In addition to mining, oil and gas extraction and processing could be a potentially large initial market for microreactors. It may seem counter-productive to use a low-carbon technology to extract fossil fuels, but doing so can help reduce the overall carbon intensity of these fuels. More importantly, the oil and gas industry could serve as an early adopter, or niche market, for this new technology. They have high energy demand and capital to invest.

BWXT says that their 50 MWth BANR microreactor could be used to provide process heat for mining or the oil and gas industries.[72] In a 2023 DOE report, *Microreactor Applications in U.S. Markets*, the authors suggest that the oil and gas industries in Alaska and Wyoming could benefit from microreactor deployment, but further market research is needed.[73]

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[71] Froese, S., Kunz, N. C. & Ramana, M. V. Too small to be viable? The potential market for small modular reactors in mining and remote communities in Canada. *Energy Policy* **144**, 111587 (2020).
[72] BWX Technologies, Inc. (n.d.). BWXT Advanced Nuclear Reactor (BANR). Retrieved December 11, 2025, from https://www.bwxt.com/sectors/nuclear-energy/smrs-microreactors/bwxt-advanced-nuclear-reactor-banr/
[73] Aumeier, S., Shropshire, D., Araújo, K., Koerner, C., Bell, C., Fauske, G., Johnson, R., Parsons, J., Gerace, S., Holubynak, E., & Righetti, T. (2023). Microreactor Applications in U.S. Markets. Idaho National Laboratory. https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_65488.pdf

### 3.1.3 Defense Installations

Beginning in the mid-2000s with the Bush Administration, concerns have grown about the vulnerabilities posed to military installations by fuel dependence. For domestic installations, maintaining reliable power requires large diesel generators for backup power, with frequent inspections, and a huge supply of diesel onsite. For forward operating bases, like those in Afghanistan and Iraq, fuel is mostly delivered by convoy, which accounted for half of all fatalities of U.S. troops in both conflicts from 2001 to 2010.[74] For these reasons, DOE and DoD commissioned several studies looking into the feasibility of deploying SMRs at fixed and mobile defense installations. However, most SMR designs under commercial development were too large for defense applications. Of the 500 fixed defense installations that the U.S. has worldwide, over 90 percent could have their annual electricity consumption met by a 40MW power plant or smaller.[75]

Shifting their focus to microreactors, the Department of Defense (DoD) announced Project Pele in 2016, led by the Strategic Capabilities Office. The goal of the initiative is to develop a transportable microreactor that could provide 1-5 MWe for at least three years continuously. Unique for defense applications, Project Pele also wanted a reactor that could be assembled in less than three days and disassembled for relocation in less than seven days. In 2022, BWXT was awarded the first contract to build a prototype high-temperature gas-cooled microreactor using High-Assay Low-Enriched Uranium (HALEU) fuel. A few years later, the U.S. Department of the Air Force announced the selection of Eielson Air Force Base for its microreactor pilot program. While contract negotiations had a rocky start,[76] a Notice of Intent to Award was granted to Oklo in June 2025 to build its 75MW Aurora microreactor, which is based on the historic Experimental Breeder Reactor-II design.

Interest in SMR deployment has continued to heighten across different parts of the DoD. The U.S. Army, U.S. Navy, and Joint Base San Antonio, have all issued solicitations to meet energy needs ranging from base or installation power, targeted technology use, and even data center sustainment.[77] In June 2024, the Department of Defense's Defense Innovation Unit, along with the Department of the Army and the Department of the Air Force, announced the Advanced Nuclear Power for Installations (ANPI) program, which aims to partner with nuclear vendors to design and build microreactors at military installations. In April 2025, DoD announced that eight companies had been selected to move forward with providing microreactors to U.S. military installations.[78] In October 2025, the army announced the Janus Program, which aims to have a microreactor come online at U.S. military base by September 2028,[79] with many of the same microreactor vendors in the running as the ANPI program.[80]

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[74] Andrew Holland. *Micro Nuclear Reactors: Prospects for Deploying Land-Based Nuclear Energy for the US Military*. (2019).

[75] King, M., Huntzinger, L., & Nguyen, T. (2011, March). *Feasibility of nuclear power on U.S. military installations* (CRM D0023932.A5/2REV). Center for Naval Analyses. Approved for public release under authority N00014-05-D-0500.

[76] Eric Wesoff, "Air Force Rescinds $100 M Award for Oklo Microreactor," *Canary Media*, November 22, 2023, https://www.canarymedia.com/articles/nuclear/air-force-rescinds-100m-award-for-oklo-microreactor.

[77] Lutz, B. (2025, December 19). New nuclear reactors for military purposes. Nuclear Innovation Alliance. https://nuclearinnovationalliance.org/new-nuclear-reactors-military-purposes

[78] Defense Innovation Unit. (2025, April 10). DOD selects eligible companies for the Advanced Nuclear Power for Installations Program. Retrieved from https://www.diu.mil/latest/DOD-selects-eligible-companies-for-the-Advanced-Nuclear-Power-for-Installations-Program

[79] U.S. Army Public Affairs. (2025, October 14). Army announces Janus Program for next-generation nuclear energy. https://www.army.mil/article/288903/army_announces_janus_program_for_next_generation_nuclear_energy

[80] Zisk, R. (2025, October 15). The Army goes nuclear. Tectonic Defense. Retrieved from https://www.tectonicdefense.com/the-army-goes-nuclear/

## 3.2 The Market for SMRs (50 – 300 MW)

For the most part, Small Modular Reactors are a business model innovation more than a technical innovation, with modular components and factory fabrication aimed at reducing capital costs and providing cheaper electricity. However, their smaller capacity and physical size also provide some unique use cases. Generally, SMRs are attractive to customers who have high energy needs and require extreme reliability (greater than 99.99% uptime).

### 3.2.1 Data Centers

Over the last few years, there has been a meteoric rise in interest from tech companies in SMRs to power data centers. Data centers require a lot of power, 24/7, year-round, and that power must be reliable. More importantly, many of these companies have commitments to reduce their greenhouse gas emissions, regardless of whether the data center is in the U.S. or elsewhere in the world. In October 2024, Google announced that it would procure several SMRs from Kairos Power totaling 500 MW, to power both data centers and offices.[81] Amazon invested in X-energy and is partnering with them to deploy 5 GW of their SMR by 2039 to power Amazon operations.[82] Switch and Equinix, both data center operators, have made agreements with Oklo for future Power Purchase Agreements (PPAs). Data4 and Westinghouse are exploring the use of its AP300 SMR to power data centers across Europe. In September 2024, Oracle announced that its next data center - which will consume more than 1 GW - will be powered by three SMRs.[83]

### 3.2.2 Industrial Process Heat

One of the most promising first-mover applications of SMRs is for industrial applications, specifically co-location at industrial sites for the production of both heat and electricity. That was the goal of the Next Generation Nuclear Plant (NGNP) project authorized by the Energy Act of 2005, to develop and demonstrate a high-temperature gas-cooled reactor (HTGR) capable of producing both electricity and process heat for industrial applications, including hydrogen production.

A 2016 study from INL looked at low-carbon options for existing industrial facilities in the U.S. that require thermal energy. Below is a table of the industries that were highlighted as being a good fit (based on necessary temperature) for potential SMRs.[84] Note that many of the average heat needs, given in MWth, would be on the small end for an SMR, and could be more appropriate for a microreactor.

The interest in industrial process heat didn't stop with NGNP. The nuclear vendor, X-energy, has partnered with the chemical company, Dow, to develop a four-unit high-temperature gas-cooled reactor (HTGR) at a Dow chemical facility in Texas.

[81] Terrell, M. (2024, October 14). Google signs advanced nuclear clean energy agreement with Kairos Power. Google Blog. https://blog.google/outreach-initiatives/sustainability/google-kairos-power-nuclear-energy-agreement/

| Target Industry | Number of Plants | Industry Process Heat Type | Average Heat Use (MWth) | Total Industry (GWth) |
|---|---|---|---|---|
| Petroleum Refineries | 140 | Combustion gases | 100 | 14 |
| Iron and Steel Mills | 115 | Combustion gases<br>Electricity | 30 | 3.5 |
| Paper Mills | 116 | Steam | 245 | 28 |
| Paperboard Mills | 73 | Steam | 245 | 18 |
| Pulp Mill | 30 | Combustion Gases<br>Steam | 10-30 | ~1 |
| Ethyl Alcohol Manufacturing | 168 | Combustion Gases<br>Steam | 20 | 3.3 |
| Alkalies & Chlorine Manufacturing | 11 | Steam | 50 | 0.5 |
| Nitrogenous Fertilizer | 30 | Combustion Gases | 80 | 2.4 |
| Wet Corn | 24 | Steam | 95 | 2.3 |
| Potash, Soda and Borate Mining | 11 | Steam | 300 | 3.3 |
| **Total Industrial Market Upper Limit (GWth)** | | | | 76 |
| Data from: McMillan, C., Boardman, R., McKellar, M., Sabharwall, P., Ruth, M., & Bragg-Sitton, S. (2016, December). Generation and use of thermal energy in the U.S. industrial sector and opportunities to reduce its carbon emissions (Technical Report NREL/TP-6A50-66763; INL/EXT-16-39680). National Renewable Energy Laboratory; Idaho National Laboratory. | | | | |

[82] X-Energy Reactor Company, LLC. (2024, October 16). Amazon Invests in X-Energy to Support Advanced Small Modular Nuclear Reactors and Expand Carbon-Free Power. https://x-energy.com/media/news-releases/amazon-invests-in-x-energy-to-support-advanced-small-modular-nuclear-reactors-and-expand-carbon-free-power

[83] Butler, G. (2024, September 10). Oracle to build nuclear SMR-powered gigawatt data center. DataCenterDynamics. Retrieved from https://www.datacenterdynamics.com/en/news/oracle-to-build-nuclear-smr-powered-gigawatt-data-center/

[84] McMillan, C., Boardman, R., McKellar, M., Sabharwall, P., Ruth, M., & Bragg-Sitton, S. (2016, December). Generation and use of thermal energy in the U.S. industrial sector and opportunities to reduce its carbon emissions (Technical Report NREL/TP-6A50-66763; INL/EXT-16-39680). National Renewable Energy Laboratory; Idaho National Laboratory. Retrieved from https://docs.nrel.gov/docs/fy17osti/66763.pdf

### 3.2.3 Granular Additions

Even for larger grids, accommodating a sudden addition of one gigawatt of power can be challenging. A benefit of SMRs is that they can provide more granular additions of power. For example, if a utility needs three gigawatts of new capacity over the next decade, they could build three 1- GW traditional reactors, or twelve 250 MW SMRs, which they could stagger in construction start such that they come online every six months. This also distributes capital costs over a longer timeline.

Because of the SMR's small footprint, they could also be a good option for additions to an existing power plant, either a retiring fossil fuel plant or operating nuclear power plant. For example, across the coal power plants that have retired in the U.S. in the last ten years, the average unit size was under 300 MW in every region except the Southwestern U.S. The average capacity of the whole power plant site was under 500 MW in every region except the Southwest.[85]

### 3.2.4 Medium-Sized Grids

Some power grids are just smaller, and an SMR could be a better fit. These might be municipal utilities, industrial parks, research campuses, or universities. For example, the average power demand at the University of Wisconsin-Madison campus is about 210 MW, with an additional 100 MW thermal demand.[86] SMRs could be a good fit for on-site generation if these facilities wanted more control over their power supply.

### 3.2.5 Traditional Utility Markets?

One of the original hopes of SMRs is that modularization would bring down costs through learning-by-doing. Almost every other energy technology is fabricated from modular components – wind turbines, solar panels, gas turbines – so it is not unrealistic to assume that nuclear reactors could also benefit from factory fabrication.

New nuclear energy needs to have overnight capital costs in the range of $2,000 to $4,000/kW to be cost-competitive with natural gas in the U.S.[87] The question is: do serially produced SMRs have a better chance of reaching that target than traditional, large reactors?

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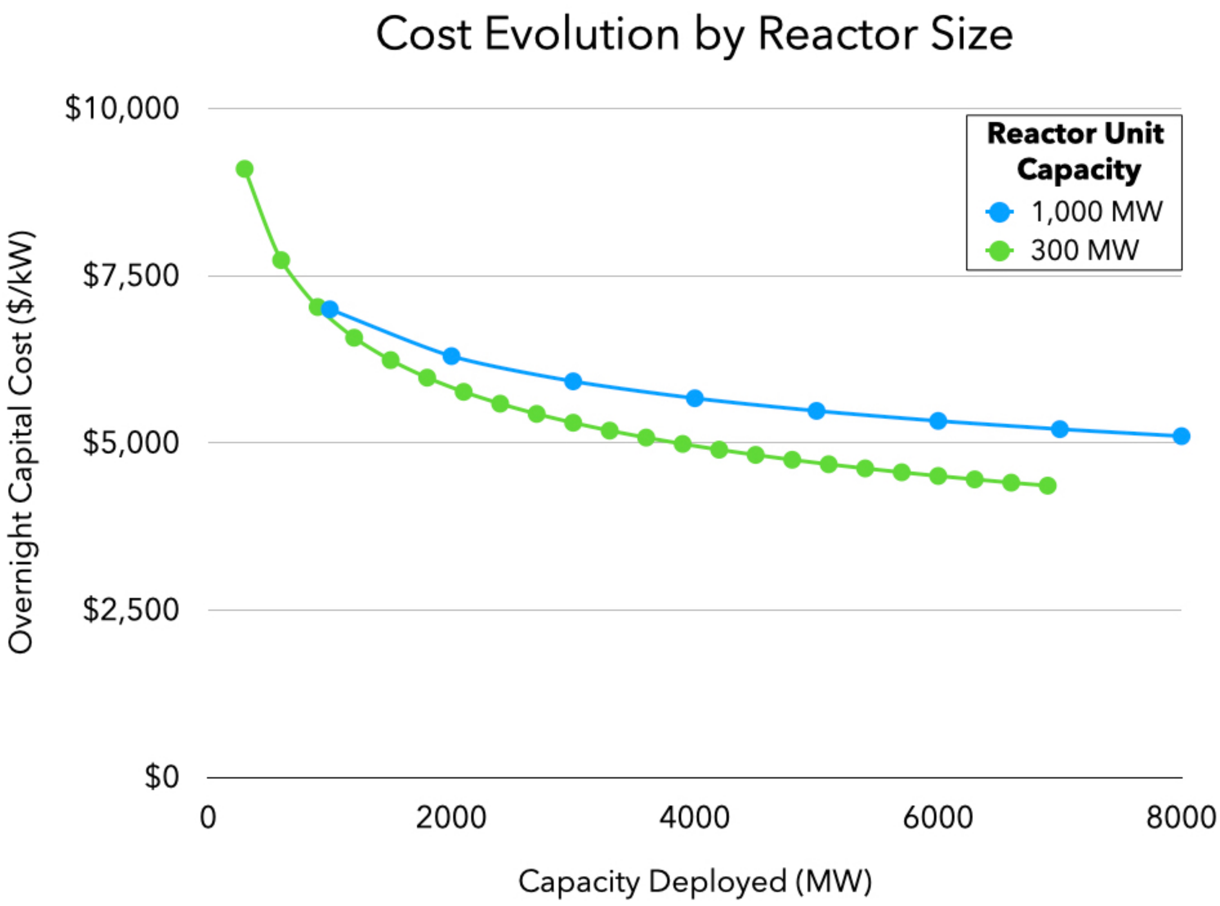
[85] Hansen, J., Jenson, W., Wrobel, A., et al. (2022). Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants. Idaho National Laboratory. Retrieved from https://sai.inl.gov/content/uploads/29/2024/11/c2n2022report.pdf

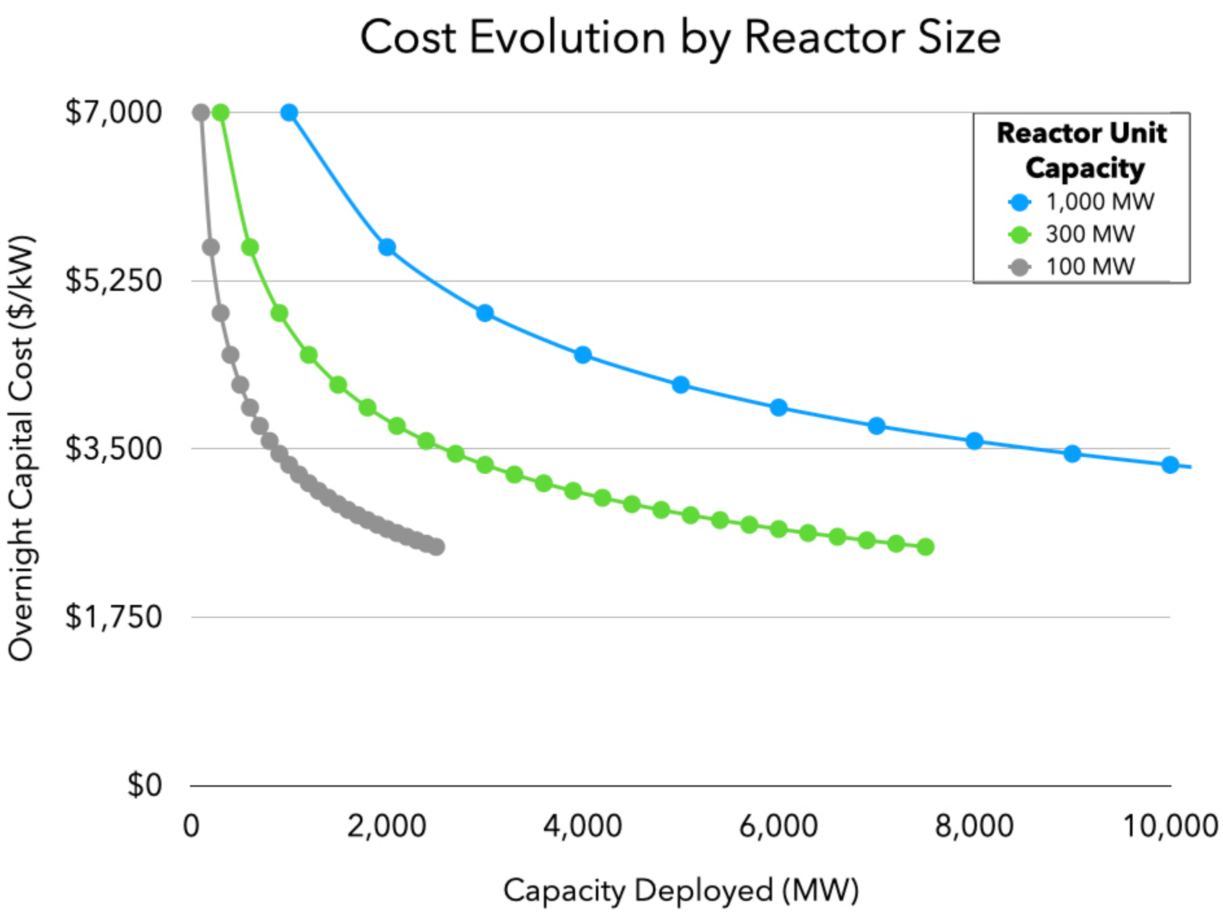
[86] Lovering, J. R. Evaluating changing paradigms across the nuclear industry. (Carnegie Mellon University, 2020).

[87] U.S. Department of Energy. 2016. "Task Force on the Future Nuclear Power."

The answer depends on many factors including the difference in starting capital cost and learning rates between the large and small reactor. The DOE Liftoff report suggests that SMRs likely will have FOAK costs 30-50% higher than a large reactor. But we know from other energy technologies that smaller unit sizes experience faster cost declines through learning (higher learning rates). As a simple illustration, below is a comparison of two learning curves: the blue line is the overnight cost trend for a 1,000 MW reactor that has a FOAK cost of $7,000/kW and a 10% learning rate, and the green line is the same curve for a 300 MW SMR that starts at $9,100/kW and a 15% learning rate. The SMR quickly becomes cheaper than the larger unit, even by the first build of the large reactor. Of course, it may not be realistic that a given reactor would continue to benefit from continuous learning. There may be physical limits that imply asymptotes earlier and at different levels for different technologies. More realistically, a reactor will follow a learning curve until a new model is introduced, and then the curve will start fresh.



Another way to look at learning curves is to analyze how much capacity must be built before the unit cost reaches a target value, say $2,500/kW. The initial capital cost and learning rates will be different for different sizes and kinds of reactors. But if we assume everything is equal except size, it is clear how just size alone makes a big difference. If a generic reactor starts at FOAK costs of $7,000/kW and has a learning rate of 25%, you need to build 25 reactor units to get costs below $2,500/kW. Twenty-five units would only be 2.5 GW of the 100 MW reactor, but 25 GW of the 1,000 MW reactor. That's a significant difference in terms of total investment cost: reaching this cost target would cost close to $90 billion if you built 25 1,000 MW reactors, but only $9 billion if you were building 100 MW reactors ($26 billion total if you built 300 MW reactors). See the chart below for the cost evolution curves.




There is still an open question of what the most economic or successful deployment "architectures" for SMRs will be. Will they be built stand-alone as a distributed energy resource? Or will they be built in multi-unit packs where the units can share operating infrastructure like control rooms and cooling pools? Might there even be a day when a developer builds 10 or 50 SMRs at one site like how wind turbines are deployed today?

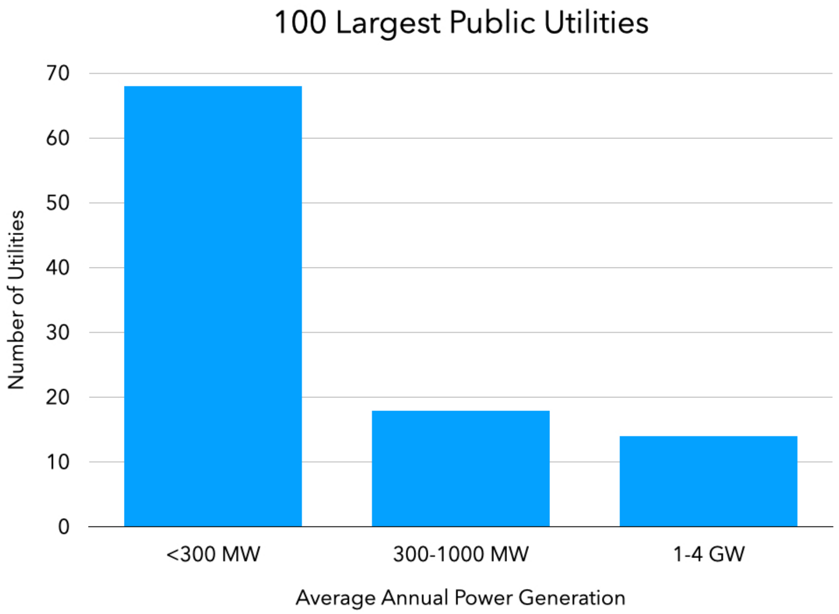
A lot depends on how much on-site construction is still needed to support the factory-built modules. NuScale's design had a significant cost challenge because all its modules will be submerged in the same cooling pool that is built below grade. This complex civil engineering project adds improved safety but also high costs. And as mentioned in the regulatory section, many of the potential cost savings from standardization and factory fabrication will greatly depend on how SMRs are regulated.

## 3.3 The Market for Medium (300-1000MW)

Reactors in this size range were very common from 1970-1990 around the world. Now, some non-LWR reactors are targeting this size and the market looks a bit different than SMRs. Medium-sized reactors could incorporate some modular components and fabrication techniques, if not full factory fabrication. Due to their somewhat traditional size, their target markets also tend to be more traditional.

### 3.3.1 Municipal Utilities

Publicly owned utilities in the U.S. tend to be smaller than investor-owned utilities, and only a third own any generating facilities of their own. Of the one hundred largest public power utilities in the U.S. - measured by annual electricity generation – only 14 have annual average power consumption in the 1-4 GW range, and 18 in the 300-1000 MW range.[88] Their peak power demands will be higher than their average, and they need system reliability, so their actual owned capacity is generally larger than this. Still, a medium-sized reactor could be a good fit for these public utilities, while an SMR or microreactor would be better for the smaller ones. Importantly, many municipal utilities would have difficulty raising the capital for a large nuclear project.



### 3.3.2 Thermal Power Plant Repowering

Whether it is public or investor-owned, utilities likely have many thermal power plants retiring in the next decade. As of this publication, the United States has about 260 operating coal units with capacities in the range of 300-1000MW (that's two-thirds of operating coal units, with the other third being smaller than 300 MW).[89]

Medium-sized reactors could also be an option for replacing retiring nuclear reactors, as they are a good match for capacity. Most operating reactors' licenses have been renewed, and plants can now operate to 60 years. Even with subsequent license renewals – operating to 80 years - there will be a sharp decline in capacity due to retirements starting in 2050.[90] Whether this happens or not, utilities often have land available adjacent to existing nuclear power plants where they could add additional units. Indeed, many nuclear power plants were originally planned to have more units than they do now, as additional units were cancelled.

## 3.4 The Market for Large (1000 MW+)

The primary market for traditional, large reactors is going to be bulk electricity supply, or the traditional utility market. In the U.S., operating nuclear reactors provide the second cheapest source of electricity after hydroelectric, producing electricity for 2.2 cents per kilowatt-hour, less than coal or natural gas.[91] But the latest estimate for the recently completed reactors at Vogtle gives a levelized cost of $189/MWh or 18.9 cents per kWh,[92] significantly more expensive than a new gas plant that can range from 5 to 10 cents per kWh.[93]

However, in many other countries, the price of electricity from fossil fuels is much higher and the price of recent nuclear builds is much lower (or is projected to be much lower), for example, in South Korea and China, but also in newcomer countries like Bangladesh and Turkey. One might argue that the demand for electricity will grow so much by 2050 that industry should focus on deploying the largest reactors. As of July 2025, thirty-one countries have signed a pledge to triple global nuclear capacity by 2050, which implies adding 750 GW of new reactors in addition to replacing any reactors that retire before 2050.

The market could be even larger, though, if nuclear were to play a more central role in decarbonization. The IEA projects that global demand for electricity could grow by 25-75% by 2050. But a more granular projection from Third Way and the Energy for Growth Hub found that among countries that will be ready for nuclear energy by 2030 or likely ready by 2030, there will be an additional 22,800 terawatt-hours of annual demand for electricity by 2050. Meeting that additional demand entirely with nuclear power would require about 2,500x 1,100 MW nuclear reactors.

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[89] RePower Score. (2025). RePower Score. https://repowerscore.org/
[90] U.S. Nuclear Regulatory Commission. (2025). Subsequent license renewal. https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html
[91] EIA. Frequently Asked Questions (FAQs): How much does it cost to generate electricity with different types of power plants? https://www.eia.gov/tools/faqs/faq.php?id=19&t=3
[92] American Nuclear Society. "*Liftoff* Report Lifts the Lid on Cost and Risk in Push to nth-of-a-Kind Reactors." ANS Newswire, 10 July 2024, https://www.ans.org/news/article-6463/iliftoffi-report-lifts-the-lid-on-cost-and-risk-in-push-to-nthofakind-reactors/.
[93] U.S. Energy Information Administration. *Levelized Costs of New Generation Resources in the Annual Energy Outlook 2025*. April 2025, U.S. Energy Information Administration, https://www.eia.gov/outlooks/aeo/electricity_generation/pdf/AEO2025_LCOE_report.pdf

On the other hand, building 2,500 reactors by 2050 is more than 100 reactors per year. During the peaks of nuclear deployment, from 1970-1990, the world was averaging about 20 reactors (or 16 GW) coming online every year. That is significantly more than the world is building currently and therefore 100 reactors per year would require a massive ramp-up in the labor force and supply chain. Even in China, over the last decade, the country only had about three reactors come online every year. In 2024, only *seven* reactors were brought online worldwide. For such complicated infrastructure projects, with high labor demand and a history of going over budget and over schedule, this pathway seems impractical with large reactors. In contrast, Boeing can produce about 600 aircraft annually in its factories.

### 3.4.1 How Large is Too Large?

While the recent history with reactors around 1,000 MW has been successful in East Asia, the results of even larger reactors has been mixed. While the APR1400s have been relatively cost-competitive in both Korea and the UAE (under $3,000/kW), construction has been averaging about nine years in both countries. The even larger EPR, which is 1600MW, has a poor record in Europe, although has fared better in China.

For example, the first EPR to start construction in 2005 in Finland, took close to 18 years to finish, at a cost of $7,500/kW.[94] The first and only EPR built in France took 17 years to complete and cost ~$8,700/kW.[95] On the other hand, the two EPRs built in China only took nine years to complete and only cost $3,400/kW. This was still high for China, which had been averaging $2,200/kW for domestic designs built around this time.[96] In Russia, the largest reactors they have built to date are approximately 1,100 MW, and cost data is difficult to obtain; however, even here, the construction time has averaged about nine years.

One challenge for these large reactors is the limited supply chain for forged components. The EPR and AP1000 require almost twice as many forgings as the Generation II reactors built in the late 1970s, but the number of suppliers was much larger then and more diverse.[97] The few forges that do exist can only produce a few components per year at the required size and quality required for large nuclear power plants. Beyond the supply chain, onsite construction for these projects are massive endeavors, which can easily be set back by disruptions due to labor, weather, or logistics.

Yet, there is still demand for even these largest reactors. Two EPRs are under construction at Hinkley Point C in the UK, with another two units planned for the Sizewell C site, and another two are in consideration for another site. The French utility EDF has an agreement with Nuclear Power Corporation of India to provide six EPRs for the Jaitapur site in India, which would provide 9.6 GW of power once complete. Outside of South Korea and the UAE - which already have operating Korean APR-1400s -Poland and the Czech Republic have agreements with KHNP to procure multiple APR-1400s.

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[94] Veselov, D. (2023, April 17). Olkiluoto 3 finally online in Finland; Germany closes last three nuclear plants. POWER Magazine. https://www.powermag.com/olkiluoto-3-finally-online-in-finland-germany-closes-last-three-nuclear-plants/
[95] Veselov, D. (2023, May 1). Flamanville 3 reactor online in France after 12-year delay. POWER Magazine. https://www.powermag.com/flamanville-3-reactor-online-in-france-after-12-year-delay/
[96] Liu, Shangwei, et al. "Can China Break the 'Cost Curse' of Nuclear Power?" *Nature*, vol. 643, 28 July 2025, pp. 1186–1188. https://doi.org/10.1038/d41586-025-02341-z

# Conclusion

The economic case for commercial Small Modular Reactors has yet to be proven. Outside of Russia and China, the first projects are just breaking ground. Will these vendors secure enough orders to justify capital-intensive investments in manufacturing facilities? Will the benefits of learning-by-doing outweigh diseconomies of scale for individual units? The evidence from most other energy technologies is that small and modular enables more iterative learning and innovation in a factory setting, thus leading to more rapid cost declines and faster deployment. But time will tell if this is also true for nuclear power, or if the engineering is just too complicated, order books too hard to achieve, or the regulatory structures are unable to scale to match reactor size and risk profiles.

However, it is likely not the case that one size, large or small, will win the whole nuclear power market. What we see is that there are specific markets for each class of reactor size, and more than enough energy demand in each market to accommodate multiple vendors. The island nation of Jamaica does not need a 1600 MW EPR, but supplying a 1 GW data center with a fleet of microreactors might be just as inappropriate. Yet as governments around the world consider renewed public investment in commercial nuclear power, where should they put their limited budgets? How can they get the most power for the least cost?

The challenge now is to create enabling conditions that allow different customers to procure the right reactor for their unique and specific needs. The conditions for success include a set of public and private actions that encourage a portfolio of reactor designs and sizes. Such actions include effective and efficient public-private demonstration programs, public and private financing, project development, willing customers, risk sharing mechanisms and order books. Importantly, all these actions need to support vendors and project developers such that, regardless of reactor size, it is easy to quickly implement lessons learned, make improvements to design and process, and compete on performance and cost. If industry, government, the financial community, and civil society can create these conditions for success, there is reason to expect significant cost declines similar to those of solar panels or wind turbines over the last few decades.

[97] World Nuclear Association. (2024). Heavy manufacturing of power plants. https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/heavy-manufacturing-of-power-plants