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Small Modular Reactors
Still Too Expensive, Too Slow and Too Risky

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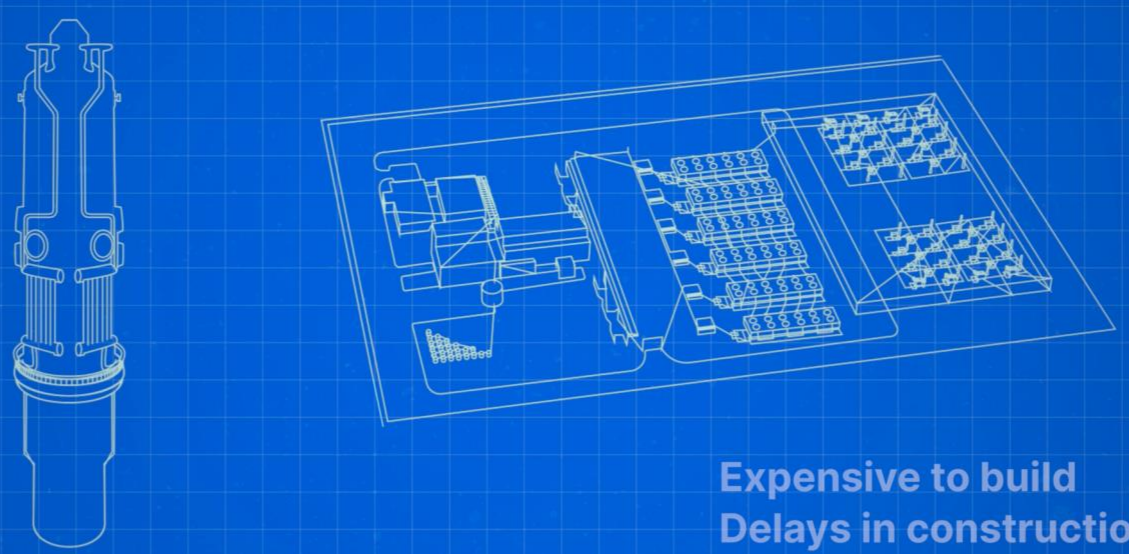

Expensive to build
Delays in construction
Financially risky
Not a good fit

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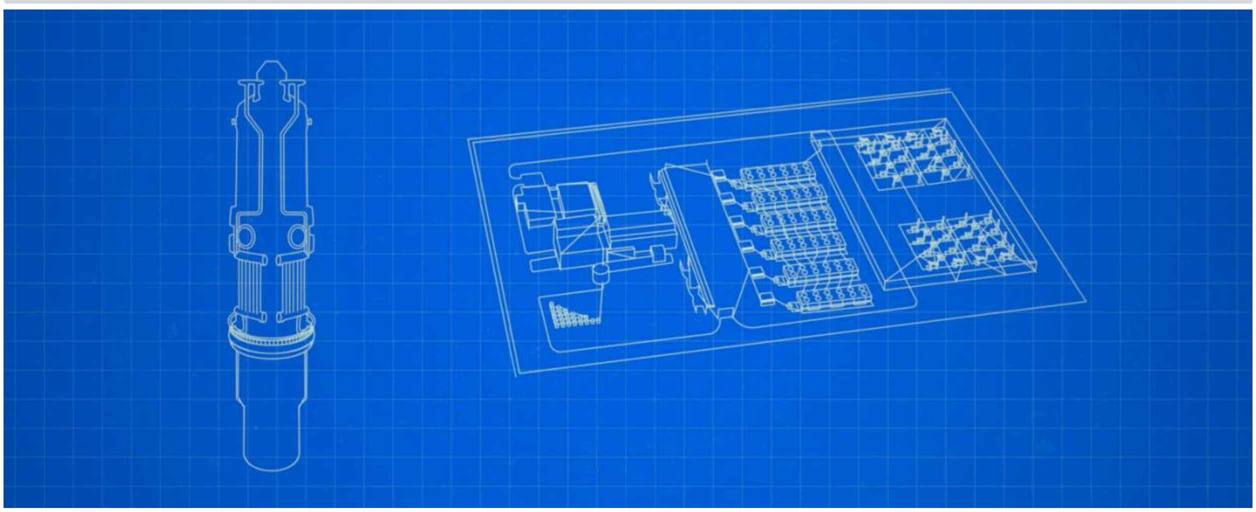
Key Findings

Small modular reactors still look to be too expensive, too slow to build, and too risky to play a significant role in transitioning from fossil fuels in the coming 10-15 years.

Investment in SMRs will take resources away from carbon-free and lower-cost renewable technologies that are available today and can push the transition from fossil fuels forward significantly in the coming 10 years.

Experience with operating and proposed SMRs shows that the reactors will continue to cost far more and take much longer to build than promised by proponents.

Regulators, utilities, investors and government officials should embrace the reality that renewables, not SMRs, are the near-term solution to the energy transition.



Executive Summary

The rhetoric from small modular reactor (SMR) advocates is loud and persistent: This time will be different because the cost overruns and schedule delays that have plagued large reactor construction projects will not be repeated with the new designs. But the few SMRs that have been built (or have been started) paint a different picture—one that looks startingly similar to the past. Significant construction delays are still the norm and costs have continued to climb.

Factbox: Small Modular Reactors

- Generally defined as reactors that are no more than 300 megawatts (MW)[1], although several so-called SMRs are larger.
- The International Atomic Energy Agency says there are more than 80 SMR concepts at some phase of development worldwide.
- SMR proposals span the technology gamut, from scaled-down conventional boiling and pressurized water reactors (BWRs and PWRs) to first-of-a-kind technologies, as well as designs that have been tried previously and have failed.

[1] All megawatt numbers in this paper are megawatts-electric (MW) unless otherwise noted.

IEEFA has taken a close look at the data available from the four SMRs currently in operation or under construction, as well as new information about projected costs from some of the leading SMR developers in the U.S. The results of the analysis show little has changed from our previous work. SMRs still are too expensive, too slow to build, and too risky to play a significant role in transitioning from fossil fuels in the coming 10 to 15 years.

We believe these findings should serve as a cautionary flag for all energy industry participants. In particular, we recommend that:

- Regulators who will be asked to approve utility or developer-backed SMR proposals should craft restrictions to prevent delays and cost increases from being pushed onto ratepayers.

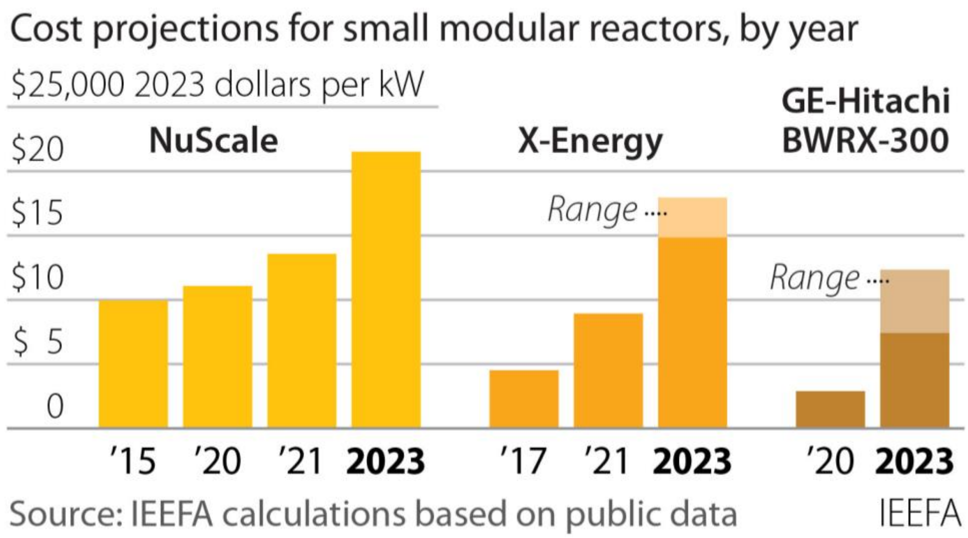
- Utilities that are considering SMRs should be required to compare the technology's uncertain costs and completion dates with the known costs and construction timetables of renewable alternatives. Utilities that still opt for the SMR option should be required to put shareholder funds at risk if costs and construction times exceed utility estimates.

- Investors and bankers weighing any SMR proposal should carefully conduct their due diligence. Things will go wrong, imperiling the chances for full recovery of any invested funds.

- State and federal governments should require that estimated SMR construction costs and schedules be publicly available so that utility ratepayers, taxpayers and investors are better able to assess the magnitude of the SMR-related financial risks that they may be forced to bear.

- Finally, it is vital that this debate consider the opportunity costs associated with the SMR push. The dollars invested in SMRs will not be available for use in building out a wind, solar and battery storage resource base. These carbon-free and lower-cost technologies are available today and can push the transition from fossil fuels forward significantly in the coming 10 years—years when SMRs will still be looking for licensing approval and construction funding.

Figure ES 1: SMR Construction Cost Estimates Keep Rising

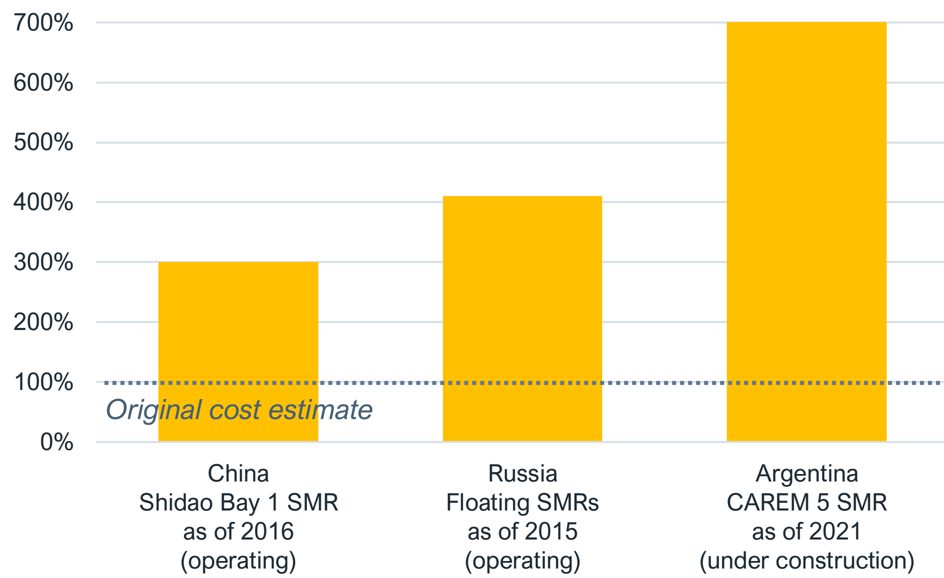


Too Expensive

A key tenet for SMR proponents is that the new reactors will be economically competitive. But the on-the-ground experience with the initial SMRs that have been built or that are currently under construction shows that this simply is not true.

There currently are three operating SMRs worldwide—two in Russia and one in China, plus a fourth under construction in Argentina. Costs for all four have been significantly higher than originally forecast (see below).

Figure 1: Cost Escalation Experienced by SMRs in Operation or Under Construction



Source: IEEFA calculations from data in the 2023 World Nuclear Industry Status Report and Bellona Environmental Foundation.

The takeaway is that the projected costs significantly understated actual construction expenditures. Projected costs for the Russian SMRs climbed more than 300% from initial estimates, according to the last available information.[1] Since the estimate is from 2015, it is likely the final costs were even higher since the two units did not enter commercial service until 2019. Likewise, it has been reported that the cost for China's Shidao Bay 1 SMR, a 150MW high-temperature gas-cooled reactor (HTGR), was triple initial cost projections.[2]

The example from Argentina is even more extreme. Projected costs for the CAREM 25 (*Central Argentina de Elementos Modulares*), a 25MW research reactor designed to serve as the prototype for 100MW models, have climbed 600% since initial work began on the project in 2013.[3] According

[1] Bellona Environmental Foundation. New documents show cost of Russian floating nuclear power plant skyrockets. May 25, 2015.
[2] World Nuclear Association. Nuclear Power in China. Accessed May 12, 2024. Nuclear Engineering and Design. Current status and technical description of Chinese 2 × 250 MWth HTR-PM demonstration plant. 2009.
[3] IEEFA calculations based on data in 2023 World Nuclear Industry Status Report, pp. 438-439.

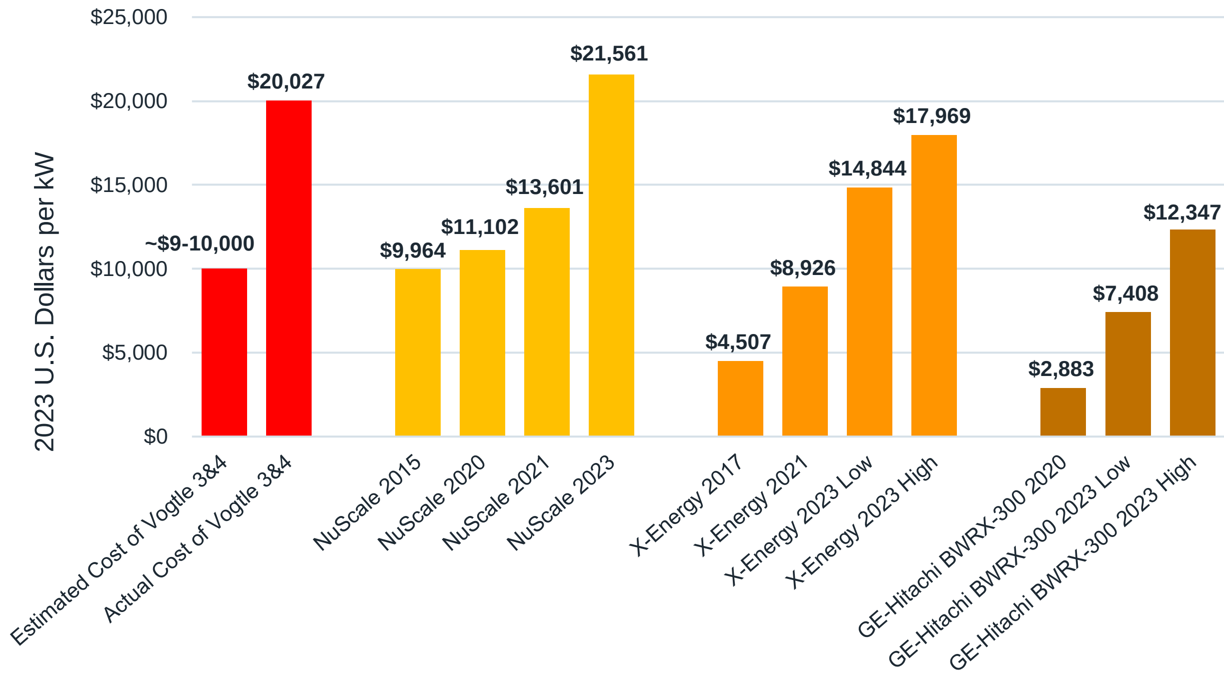
to the World Nuclear Association, the plant will not begin operation until 2027,[4] which makes additional cost increases a real possibility.

Similar significant cost increases have occurred at proposed projects in the U.S. IEEFA has previously documented the problems at NuScale.[5] Costs for that company's SMR more than doubled from 2015-2023, rising from $9,964 per kilowatt (kW) to $21,561 per kW, prompting the cancellation of the company's signature project, a planned six-reactor, 462MW facility to be built in Idaho in cooperation with the Utah Associated Municipal Power Systems (UAMPS).

NuScale's problems are not unique. U.S. SMR developers have consistently sought to shield their construction cost estimates, but information about two other prominent projects shows that the estimated costs for these projects also have skyrocketed. The cost increases for the X-Energy and GE-Hitachi SMR projects (see graphic below) occurred well before either had secured licensing approval from NRC, let alone begun construction. IEEFA believes this should be a red flag for utilities, regulators and investors. The costs, already high, are likely to climb even higher.

[4] World Nuclear Association. Nuclear Power in Argentina. April 17, 2024.
[5] See IEEFA, NuScale's small modular reactor and Eye-popping new cost estimates release for NuScale small modular reactor.

Figure 2: Projected Cost Increases for Proposed U.S. SMRs



Source: IEEFA calculations based on public data for each of the projects converted to 2023-year U.S. dollars. For example, see the GE Hitachi website, Four reactors could cost Saskatchewan $12 to $20 billion,, X-Energy and ARES Acquisition Corporation Announce Strategic Update, Georgia Power Company's monthly and Quarterly Reports to the Georgia Public Service Commission on construction of the Vogtle Nuclear Project and IEEFA reports on NuScale.

This chart illustrates two key important points.

First, when NuScale's proposed SMR project with UAMPS was cancelled in November 2023, years before it even would have had a license from the NRC, its estimated construction cost was already higher (on a per-kW basis using 2023 dollars) than the actual cost of the two new reactors at Georgia Power's Vogtle nuclear plant.

Second, evidence is now starting to come out showing that the estimated construction costs of other leading SMR developers are also rising significantly, even before companies have secured licenses from the Nuclear Regulatory Commission and well ahead of any actual construction activity.

It is also important to note that these price increases aren't design-specific. For example, when X-Energy raised the projected all-in price of its SMR in July 2023 (effectively doubling the cost from $2.5 billion to $4.75 billion to $5.75 billion), the company cited the following factors: Inflationary pressures for construction materials, higher labor costs, increased interest rates and supply chain constraints for equipment, among others.[6]

NuScale attributed the significant cost increases at its UAMPS project to similar factors including rising interest rates and higher prices for steel and other construction commodities.[7]

These types of generic increases almost certainly have been felt by all SMR developers, pushing up the projected prices of their projects as well.

Harder to forecast, but certainly an issue that should concern regulators and potential customers, is the likelihood of future price increases as proposed projects inch closer to construction. At that point, developers will be competing against one another for skilled labor, design resources and reactor-related construction materials. This competition, with many developers chasing scarce labor and material in a still-nascent market, is bound to lead to significant upward pressure on project costs.

The BWRX-300

The BWRX-300 is a planned 300MW boiling water reactor that is being developed by GE-Hitachi Nuclear Energy. It is based on the companies' 1,600MW economic simplified boiling water reactor (ESBWR); the ESBWR has been licensed by the U.S. Nuclear Regulatory Commission (NRC) but not built.

The BWRX-300 still has not been licensed in the U.S., but the company signed a contract with Ontario Power Generation (OPG) in 2023 to build the first unit at OPG's Darlington nuclear facility in Canada.[1] The companies have begun work and say they plan to have the first unit online by the end of 2028.

The Tennessee Valley Authority is also considering building one or more of the reactors in its service territory and has invested in a joint effort to help fund licensing activities at the NRC.

[1] Utility Dive. GE Hitachi and 3 partners announce first commercial contract for grid-scale SMR in North America. January 30, 2023.

The cost debate inevitably includes Westinghouse, the developer of the two AP1000 reactors recently brought online at Georgia Power's Vogtle nuclear facility. That project, which led to Westinghouse's bankruptcy, was more than $20 billion over budget and took more than six years longer to complete than forecast.[8] Undaunted by that debacle, Westinghouse has now jumped into the SMR market, introducing a 300MW unit (the AP300) that it says it can build for $3,333 per kW—even though the final cost of the Vogtle reactors was more than $20,000 per kW in 2023-year dollars. Even if Westinghouse's projected AP300 cost is just an overnight estimate that excludes escalation and financing costs, that is a spectacular projected cost reduction for a facility that is still not licensed and far from breaking ground for construction.

[6] EE Power. Inflation-Ridden Supply Chains, Interest Rates Dampen SMR Development. July 13, 2023.
[7] UAMPS Talking Points. January 2, 2023.
[8] For more details, see IEEFA, Southern Company's Troubled Vogtle Nuclear Project.

Westinghouse's cost projections for the AP300 are notable given two framing points—one recent and the other from the early 2000s. In the first data point, from 2002, Westinghouse executives were discussing the company's decision to stop development of its AP600 reactor and pursue commercialization of the AP1000.[9]

"Industry executives indicate that any new nuclear plant must be able to compete in the deregulated generation wholesale marketplace and provide a return to the shareholders," they wrote.[10] "Against this standard, the costs of advanced nuclear power plants currently are still too high. This includes the AP600, Westinghouse's 600 MWe advanced passive plant … Although the AP600 is the most cost-effective nuclear power plant ready for deployment, it is still more expensive than other new generation options in the U.S."

That was 20 years ago, and the situation has become even more tenuous since with the significant decline in the costs of wind, solar and battery storage.

The other development, from February, was the announcement by the Czech utility CEZ that Westinghouse had been eliminated from a bidding process to build four large nuclear reactors in the country because it refused to offer a fixed bid proposal for the project.[11] A fixed bid process resulted in Westinghouse's bankruptcy in 2017 due to the rising costs of the Vogtle and Summer projects, so maybe the company, now owned by private equity firm Brookfield Energy Partners and the

The Xe-100

X-Energy is planning to build an 80MW high temperature gas reactor that will be capable of delivering electricity or steam to customers. The company says the modules usually will be bundled in fours as a 320MW facility.

The two previous HTGRs in the U.S. were the 40MW Peach Bottom 1 reactor in Pennsylvania, which operated from 1966-74, and the 330MW Fort St. Vrain facility in Colorado, which operated from 1976-89.[1] Fort St. Vrain had significant operating issues, recording a lifetime capacity factor of only roughly 17% before its closure years ahead of schedule.[2]

X-Energy's planned SMR will use a different fueling system than Fort St. Vrain, a so-called pebble bed process in which the fuel is fed continuously into the reactor in the form of small spheres, or pebbles.[3] The only currently operating reactor using this system is China's Shidao SMR, mentioned previously.[4]

The company announced plans in 2023 to build four of the reactors at a Dow Chemical manufacturing facility in Seadrift, Texas.

[1] High Temperature Gas Reactors: Assessment of Applicable Codes and Standards. Pacific Northwest National Laboratory. October 2015.
[2] Ibid. PNNL data with IEEFA calculations.
[3] Pebble Bed – The Nuclear Gumball Machine. Dec. 14, 2022.
[4] World's first HTR-PM nuclear power plant connected to grid. Dec. 20, 2021.

[9] As its name suggests, the AP600 reactor was 600 MW in size. While not literally an SMR, the AP600 was Westinghouse's first effort to market a reactor smaller than those the nuclear industry had generally built in the U.S.
[10] International Atomic Energy Agency. AP1000: Meeting economic goals in a competitive world. May 2002.
[11] Neutron Bytes. Westinghouse Eliminated from Czech Nuclear Project. February 10, 2024.

uranium miner Cameco, has learned its lesson. But what does that say about its cost estimates, either for the AP1000 or the AP300?

IEEFA also does not believe these will be the last cost increases, either for the SMRs referenced here or the many other designs under development. All the proposed SMRs still need additional design work, licensing by the U.S. Nuclear Regulatory Commission, the scaling up of SMR designs to commercial-size projects during construction and pre-operational testing. The experience of other reactor projects has repeatedly shown that further significant cost increases and substantial schedule delays should be anticipated at future stages of project development.

Finally, IEEFA questions the assertion by SMR advocates that costs will decline as more reactors of a given design are brought online, leading to what is known as a positive learning curve. The U.S. nuclear industry has never shown a positive learning curve. Instead, it has repeatedly shown a negative learning curve where the cost of new reactors continued to rise, even as more were built.

Even the French nuclear program, which relied on a high degree of standardization in the design of its 58 reactors built between 1970 and 2000, failed to achieve a positive learning curve. Rather, costs continued to increase over time despite the program's design standardization.[12]

And any positive learning curve achieved in building SMRs will depend heavily on how many of each design are built. The International Atomic Energy Agency (IAEA) estimates that there are about 80 SMR designs currently being proposed and marketed worldwide,[13] making it highly uncertain how many of each design will be constructed. Too few, and there may not be any cost savings over time, and there may also be no economic justification for modular construction in a factory.

With these concerns in mind, IEEFA believes companies considering the Westinghouse AP300 (or any other SMR) should insist on a fixed price contract in any development agreements. A developer's willingness to sign one would say volumes about their confidence in their own estimates, and keep risks down for the buyer.

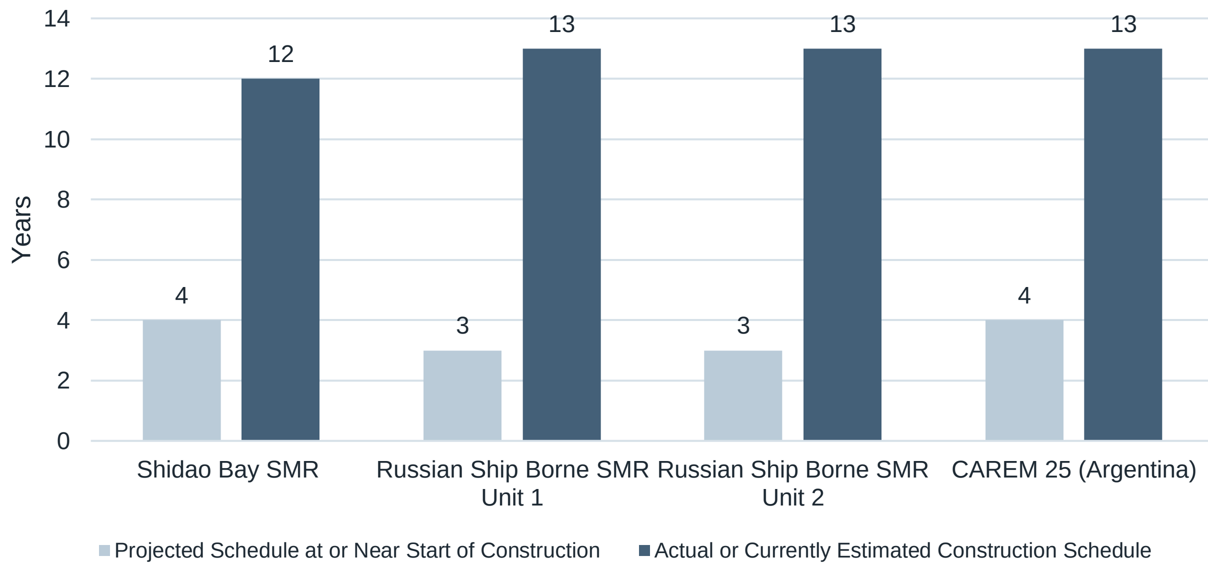
[12] Energy Policy. The Costs of the French nuclear scale-up: a case of negative learning by doing. September 2010.
[13] IAEA. Small modular reactors. Accessed May 14, 2024.

Too Slow

A second tenet for SMR backers is that the reactors can be built quickly—in sharp contrast to recent history with larger units. But just as with the cost claims, the rhetoric here does not match reality.

Turning again to the results in Russia, China and Argentina, long construction delays have been the norm, not the exception. As the graphic below shows, not one of these SMRs has come close to meeting its projected three- to four-year construction schedule.

Figure 3: Projected vs. Actual SMR Construction Schedules



Source: IEEFA calculations based on data in the 2023 World Nuclear Industry Status Report and IAEA's Power Reactor Information System.

Two other SMRs currently under construction in China and Russia are also years behind schedule. Russia's BREST-300 lead-cooled reactor is now scheduled for completion in 2026, even though announcements in the early 2010s had indicated it would be operational by 2018.[14] Similarly, China's ACP100, a 125MW pressurized water SMR that has been under development since the early 2010s, is now not scheduled to begin commercial operation until 2026.[15]

Similarly optimistic construction estimates have consistently shown up in U.S. SMR project development presentations.

One of the first planned SMRs in the U.S., the 195MW mPower PWR design backed by Babcock & Wilcox and Bechtel, was launched in 2009 with plans to have the first two units operational by

14 Mycle Schneider Consulting. World Nuclear Industry Status Report 2023. December 2023, p. 325.
15 *Ibid*, p. 322.

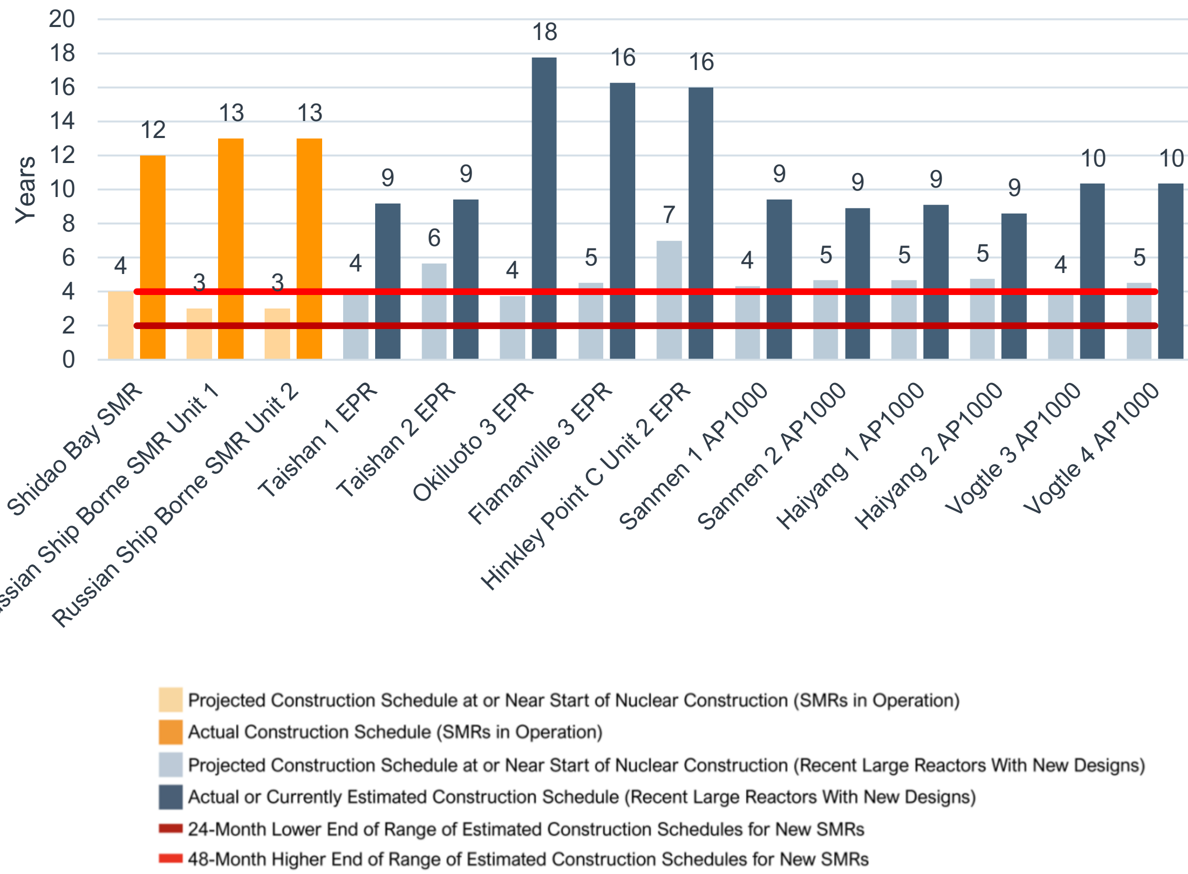
2022.[16] The development effort was shelved in 2017 after the companies and the U.S. Department of Energy had spent almost $500 million on the reactor design. In announcing the cancellation, Bechtel's Fred deSousa hit on one of the key issues facing all SMR developers—cost. "However, bringing a new reactor program through the design, engineering and regulatory process is a very complex and expensive proposition. It needed a plant owner with an identified location and **an investor willing to wait a significant period of time for a return, and these were not available**" [emphasis added].[17]

NuScale, another U.S. SMR developer, has also consistently been overly optimistic about costs and construction time frames. In 2016, for example, John Hopkins, NuScale's CEO, told the Senate Energy and Natural Resources Committee that the company's SMR project with UAMPS would be commercially operational by 2024. "We expect to deliver our first project of twelve power modules in a 600MWe (gross) plant to UAMPS for an overnight price of approximately $3 billion, with commercial operation commencing in 2024."[18] By the time the project was cancelled in November 2023, full commercial operation had been pushed back to 2030 and the cost had jumped to $9.3 billion.[19]

Despite this real-world experience, Westinghouse, X-Energy and NuScale, among others, continue to claim they will be able to construct their SMRs in 36 to 48 months, perhaps quickly enough to have them online by 2030. GE-Hitachi even claims it ultimately will be able to construct its 300MW facility in as little as 24 months.[20] Admittedly, there is a not-zero chance this is possible, but it flies in the face of nuclear industry experience, both in terms of past SMR development and construction efforts and the larger universe of full-size reactors, all of which have taken significantly longer than projected to begin commercial operation.

[16] Wise International. Nuclear Monitor. March 21, 2017.
[17] American Nuclear Society. mPower Consortium Halts Project. March 16, 2017.
[18] Senate Energy and Natural Resources Committee. John Hopkins testimony. May 17, 2016.
[19] E&E News. NuScale cancels first-of-a-kind nuclear project as costs surge. November 9, 2023.
[20] Hitachi. BWRX-300 Small Modular Reactor. Accessed May 6, 2024.

Figure 4: Nuclear Construction Reality vs. Rhetoric



Source: IAEA Power Reactor Information System, EDF, 2023 World Nuclear Industry Status Report.

Much of the developer optimism regarding rapid completion schedules is tied to the supposed benefits of modular construction—the factory construction of reactor parts that are then shipped to the reactor site and essentially put together like a puzzle. Here, it is worth noting that Vogtle reactors 3 and 4, Georgia Power's just-completed but vastly over-budget and long-delayed project, were built using modular techniques, a feature that Westinghouse touted when marketing its AP1000 reactors, the model built at Vogtle and the one it still touts today.

The same modular construction techniques were also used by Westinghouse at the V.C. Summer project in South Carolina. This project was planned as a two-unit expansion at the existing site, using the same Westinghouse AP1000 design used at Vogtle. The project was cancelled in 2017 after $9 billion had been spent.[21]

[21] The New York Times. U.S. Nuclear Comeback Stalls as Two Reactors Are Abandoned. July 31, 2017.

It is safe to say that modular construction didn't keep costs down or speed construction at either site. Yet SMR advocates, including the U.S. Department of Energy, keep promoting its unproven benefits.[22]

While SMR developers struggle to get just one reactor into commercial operation, the buildout of U.S. renewable resources is rapidly picking up speed. The U.S. Energy Information Administration (EIA) projects that installed solar capacity will jump to 158,000 MW by the end of 2025, a 75% increase from the 90,000 MW installed by the end of 2023.[23]

And this is likely just the beginning. In NextEra Energy's first-quarter earnings call in April, John Ketchum, the company's chairman, CEO and president, stressed the key role renewables will play in meeting the expected strong increase in electricity demand across the U.S. "In fact," Ketchum said, "we believe the U.S. renewables and storage market opportunity has the potential to be three times bigger over the next seven years compared to the last seven, growing from roughly 140 gigawatts of additions to approximately 375 to 450 gigawatts."[24]

The seven-year forecast period is interesting. It is highly unlikely that even one SMR will be commercially operational in the U.S. within seven years.

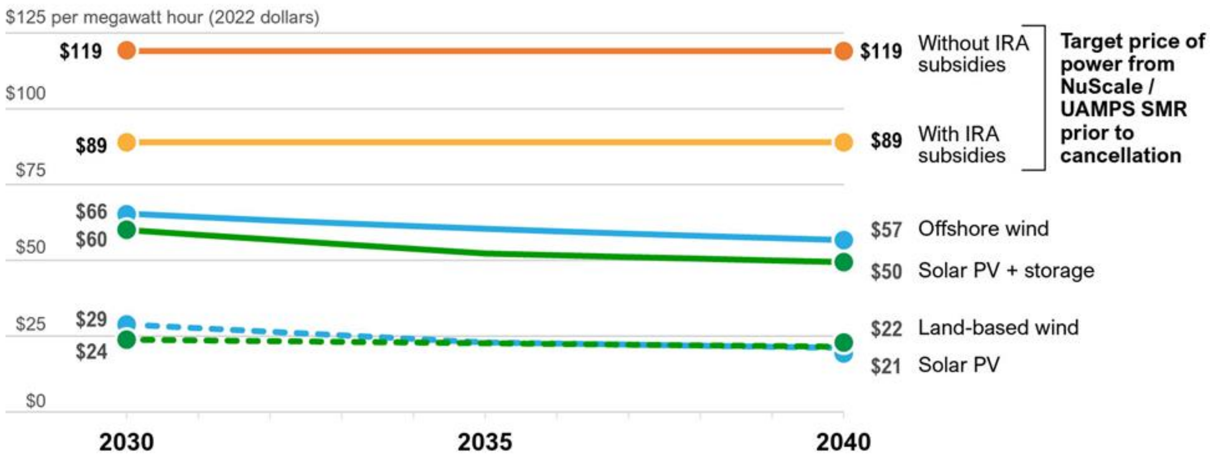
Focusing just on the company's own growth plans, NextEra reported that it expects to build at least 32,000 MW of new renewable capacity, and perhaps as much as 42,000 MW, in the U.S. through 2026—in addition to the ongoing renewable expansion at its utility, Florida Power & Light. There certainly will be no operational SMRs by that date.

NextEra's optimism is not unique. The American Clean Power Association said in May that it expects 260,000 MW of renewable energy generation, mostly solar, to be added to the U.S. grid just through 2028.[25]

It is becoming increasingly clear that the cost of power from SMRs will be far more expensive than that from renewable energy and battery storage. This is illustrated in the figure below, which highlights the substantial gap between the estimated cost of power from the now-cancelled NuScale UAMPS project and projected renewable power costs from the DOE's National Renewable Energy Laboratory.

[22] DOE Office of Nuclear Energy. Benefits of Small Modular Reactors. Accessed May 13, 2024.
[23] Energy Information Administration. Short-Term Energy Outlook Data Browser. Accessed May 7, 2024.
[24] NextEra Energy Q1 Earnings Call Prepared Remarks. April 23, 2024.
[25] S&P. Solar will do 'heavy lifting' during influx of renewables to US grid – analysts. May 10, 2024.

Figure 5: SMR Power Costs Will Be Much Higher Than Renewables, Storage



Source: IEEFA analysis based on data from NuScale, UAMPS and NREL.

Too Risky

Southern Company, Georgia Power's parent, just wrapped up what even its executives acknowledged was an "arduous journey" to complete construction at the two-unit expansion of its Vogtle nuclear plant, with commercial operation at Unit 4 beginning in April (Unit 3 began operations in July 2023). Still, it is safe to say that no utility in the U.S. has a better understanding of the risks of nuclear power than Southern does. And, judging by CEO Chris Womack's comments during the company's first-quarter earnings call, at this time Southern wants no part of any future nuclear construction.

Womack endorsed nuclear power in the abstract, saying "the country is going to need more nuclear. I mean there's clearly no technology better suited to support demands of this increasingly digital economy and society."[26]

But the kicker tells the story. "I'd also say we're going to celebrate what we've done at Vogtle for a very long time before we give any consideration to any more [nuclear]."[27]

Womack is not alone in his risk aversion.

In a 2022 conference presentation, NextEra's Ketchum voiced significant skepticism regarding SMRs.

[26] Southern Company Q1 earnings call transcript. May 2, 2024.
[27] *Ibid*.

"… I'm very skeptical with regard to SMRs," Ketchum said. "They are going to be very expensive and then you're going to be taking a bet on the technology. Right now, I look at SMRs as an opportunity to lose money in smaller batches."[28]

> **Right now, I look at SMRs as an opportunity to lose money in smaller batches.**
>
> John Ketchum
> Chairman, CEO and President of NextEra Energy

Instead, Ketchum reiterated that NextEra will continue with its rapid buildout of wind, solar and battery storage. In the company's first-quarter 2024 quarterly earnings call, NextEra projected that its Florida Power & Light (FPL) subsidiary will add 21,000 MW of solar capacity and 4,000 MW of battery storage capacity in its service territory in the next 10 years, pushing solar's share of its generation from 6% to 38%.

"FPL's annual Ten-Year Site Plan continues to indicate that solar and storage are the most cost-effective answer for customers to add reliable grid capacity over the next decade," Kirk Crews, the company's newly appointed chief risk officer, told analysts. Even though FPL operates the two-unit, 1,747MW Turkey Point nuclear plant and has an existing site license from NRC to build two additional reactors at the site, there was no mention of new nuclear.

That risk aversion is even shared by Constellation, the U.S.'s largest nuclear power company. In its first-quarter earnings call this month, company executives talked extensively about their nuclear operations and plans for growth, particularly to serve the strong forecasted growth in electricity demand from data centers and the burgeoning artificial intelligence (AI) industry. But Joseph Dominguez, the company's president and CEO, made it clear that the financial risks for any new builds would be borne by customers, not the company.

The current thinking, Dominguez explained, is to negotiate power purchase agreements (PPAs) to supply companies looking for carbon-free power with electricity from Constellation's existing nuclear facilities, and then in the future to consider the construction of one or more SMRs to provide new capacity. "…[T]he customer, through increases in the PPA, would begin to fund site development work construction," Dominguez said, "ultimately scaling up to the point where the PPA absorbs the full cost of an operating new unit."[29]

The structure may work for Constellation, but given the cost increases and construction delays that have plagued the SMR sector already, this will push enormous financial and time risks onto customers, potentially undercutting their interest and ability in pursuing such projects.

[28] S&P Global. NextEra CEO sees US climate law catalyzing decades of clean energy growth. Oct. 3, 2022.
[29] Constellation Q1 earnings call transcript. May 9, 2024.

Aware of these risk-related problems, the Department of Energy has floated several ideas to get the government involved in the buildout of the SMR sector. These include providing “cost overrun insurance,” other undefined financial assistance, becoming an owner or serving as a buyer for the power.[30] None of these options would reduce the development risk—they would simply transfer those risks and the associated costs to U.S. taxpayers.

Other Cost and Risk Considerations

A 2023 study for the U.S. Air Force underscored the concerns raised by Ketchum, highlighting the virtually complete lack of publicly available data about construction costs and future performance. It also raised other concerns that have not yet been considered in the discussions about building SMRs: “Since SMR technology is still developing and is not deployed in the U.S., information is scarce concerning the various costs for [operations & maintenance], decommissioning and end-of-life dissolution, property restoration and site clean-up and waste management.”[1]

In other words, it is not just the construction costs that matter. All other potential costs need to be factored into the decision-making process before moving forward with plans for an unproven SMR.

[1] Pacific Northwest National Laboratory. Emerging Technologies Review: Small Modular Reactors. April 2023.

[30] U.S. Department of Energy. Pathways to Commercial Liftoff: Advanced Nuclear. March 2023, p. 4.

A Bad Fit

Another tenet for SMR developers is that their reactors will be complementary resources for renewable-dominated electric grids.

In 2020, for example, Jay Wileman, president and CEO of GE Hitachi Nuclear, told a panel hosted by the World Nuclear Association that SMRs can be more than just baseload generation.

"However, as we start to see the increase in penetration of renewables, you will need to acknowledge the ability for nuclear not to just be baseload, but to load-follow: something that is not typically thought of with a nuclear reactor. I think that, looking forward, small modular reactors are excellently fit for that purpose, and the ability to follow the output of renewables and load-follow on the grid," he said.[31]

Similarly, TerraPower says its planned Natrium SMR, a 345MW reactor with accompanying storage, will be able "to operate as a baseload power source or as a flexible, load-following system to support grids with variable-output renewables."[32]

Finally, NuScale consistently touts the flexibility of its planned SMR, which it says can help integrate renewables into the grid.[33]

But here too, the reality and the rhetoric don't mesh.

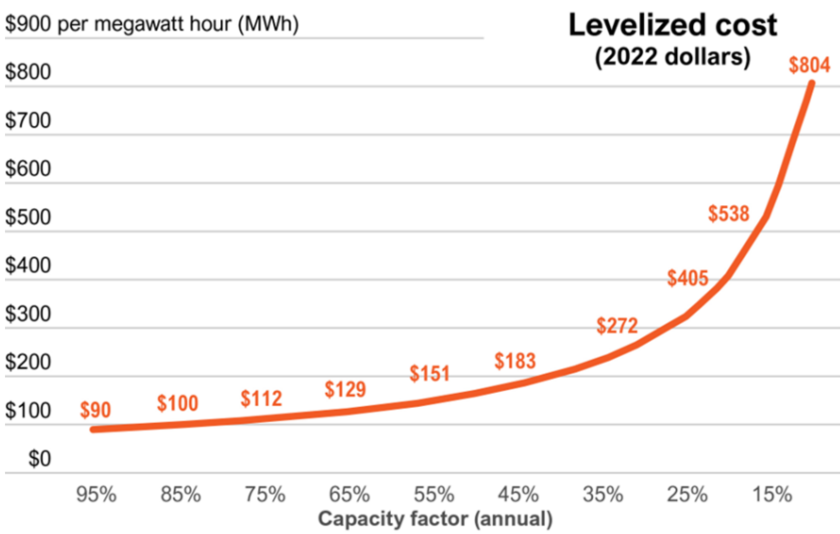
NuScale has based its reactor cost estimates on the assumption that its SMR will operate with a capacity factor of 95%. If built, that is possible, although probably optimistic, since the average for the operating reactors in the U.S. has never been that high. Duke Energy, for example, one of the largest nuclear plant operators in the U.S., says its fleet average has hit 95% during a couple of years, but not consistently.[34] Still, the key point is that if NuScale did consistently post a 95% capacity factor it would be impossible by definition for it also to be a flexible, load-following resource. Both things cannot be true.

The reality is that developers bringing multibillion-dollar SMRs onto the electric grid would have every incentive to run them as much as possible to recover their costs through electricity sales. Instead of working with renewables, they would effectively be blocking renewables from the grid.

The graphic below illustrates the problem for SMR developers. The less they run, the more their per megawatt-hour costs rise and the harder it will be for them to compete in the market. Having invested billions, it is unlikely developers will willingly cycle their plants to accommodate renewables.

[31] World Nuclear News. Cost-competitive SMRs will find place in electricity ecosystem. September 16, 2020.
[32] Natrium Power website. Accessed May 7, 2024.
[33] NuScale Power 2023 Earnings Release. March 14, 2024.
[34] Duke Energy. Nuclear Generation - On track to a cleaner energy future. October 18, 2022.

Figure 6: SMR Power Costs Rise as Capacity Factor Falls



Source: IEEFA analysis using data in the November 2020 Development Cost Reimbursement Agreement between UAMPS and NuScale.

The Boeing Problem

One key issue that has received too little attention in the discussion of SMR commercialization is the potential for systemic flaws in reactors with the same standardized design.

This has been referred to as the "Boeing Problem" by Arjun Makhijani of the Institute for Energy and Environmental Research because of problems that affected the company's fleet of 787 Dreamliners.[35] But it could also apply to Boeing's more recent experience with a poorly designed feature in its 737 MAX aircraft that led to two critical crashes, and several years of the 737 MAX air fleet needing to be grounded until the problem was identified and fully corrected. Similarly, an unexpected and unidentified design flaw discovered in a key component of a highly standardized SMR could lead to extended and expensive outages, repairs and design changes. But taking an airplane back to Boeing for those repairs and design changes is relatively easy. Taking an SMR back to the factory would be extremely difficult, if not impossible.

The potential risk that a problem identified in one SMR will affect the costs, and maybe the operation, of other SMRs with the exact or similar standardized design, is not merely hypothetical. The same problems have cropped up at many existing reactors around the world due to materials choices and design decisions made by the industry before these plants were even being built.

For example, according to the World Nuclear Association, operators have been forced to replace steam generators at more than 110 pressurized water reactors (PWRs)—more than half of which

[35] Light Water Designs of Small Modular Reactors: Facts and Analysis. Revised September 2013.

have been in the U.S.—since 1980.[36] These replacements were the result of the denting and wall thinning of large numbers of steam generator tubes that had been made from a material called heat-treated Alloy 600. Five additional U.S. PWRs were shut down early due to steam generator tube cracking.

Similarly, a decision on the material to be used in key safety-related piping in boiling water reactors (BWRs) led to significant pipe cracking from intergranular stress corrosion cracking (IGSCC). As a result, nine U.S. BWRs completely replaced their full recirculation system piping with pipes made from lower carbon steel. Another three BWRs replaced the heavily cracked sections of their recirculation system piping.[37] Detailed inspections of key piping systems and changes to the water chemistry used in the plants were made at essentially all BWRs in the U.S.

The efforts required to fix these systemic problems were both time-consuming and expensive.

We're not arguing that new SMRs will have these same issues. We expect that the design and material decisions made for SMRs will reflect remedial measures taken at existing reactors. Our concern is broader in that a problem at one SMR might have serious repercussions at many other SMRs with the same standardized design.

[36] World Nuclear Associate website. Accessed May 13, 2024.
[37] U.S. Nuclear Regulatory Commission. Pipe Cracking in U.S. BWRs: A Regulatory History.

Conclusion

The pro-SMR rhetoric in the U.S. is loud and persistent. But it does not mesh with reality.

IEEFA released its first analysis of the SMR sector more than two years ago, concluding that the much-hyped resource would be too slow, too expensive and too risky to help in the transition away from fossil fuels. We stand by that conclusion.

Experience with the few existing SMRs that have been built or are under construction shows a repetition of the nuclear industry's longstanding history: The facilities have been both significantly over budget and have taken much longer to complete than forecast.

New data from proposed SMR projects in the U.S. also shows a worrying upward trend in cost estimates, undercutting the repeated rhetoric that the plants can be built economically without the dizzying construction price increases that pushed Vogtle's total costs to more than $36 billion—more than two and a half times the original estimate—and resulted in the cancellation of the V.C. Summer project.

Perhaps most concerning is the risk factor, especially when compared to the known costs and construction timelines for readily available wind, solar and battery storage resources. On this issue, the new estimate for renewable capacity additions recently offered by NextEra's Ketchum is worth repeating: At least 375,000 MW of new renewable energy generating capacity is likely to be added to the U.S. grid in the next seven years. By contrast, IEEFA believes it is highly unlikely any SMRs will be brought online in that same time frame.

The comparison couldn't be clearer. Regulators, utilities, investors and government officials should acknowledge this and embrace the available reality: Renewables are the near-term solution.

About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

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