Small Modular Reactors

Factory-built nuclear in search of its first commercial proof

Explainer · June 6, 2026

ABSTRACT

A nuclear reactor that arrives on the back of a truck, assembled from parts stamped out in a factory like aircraft fuselages, is the central promise of the small modular reactor (SMR). Defined as nuclear reactors producing up to about 300 megawatts of electricity (MWe) per unit, roughly one-third the output of a conventional plant, SMRs are pitched as faster to build, cheaper to finance, and safer to run. The mechanism is modularity: standardize the design, fabricate components in series, ship them, and bolt them together on site. Yet as of 2026 the technology is mostly pre-commercial. A handful of units operate in Russia, China, and Japan, the United States has approved exactly one design, and the flagship American project was cancelled in 2023 over cost. The cost-and-scale promise that justifies the whole enterprise remains contingent and, so far, unproven.

Keywords: small modular reactor; nuclear power; modularity; HALEU; passive safety; NuScale; data centers; decarbonization

1. Introduction

In October 2025, Amazon said it would co-develop a nuclear facility in Richland, Washington, using reactors from a startup called X-energy. <cite index="9-1">The plan involved Xe-100 SMRs with an initial deployment of four reactors generating a combined 320 megawatts.</cite> A retailer buying reactors to power its servers is the clearest sign yet of what is pulling nuclear back into the conversation: electricity demand from data centers and artificial intelligence, plus energy security worries and decarbonization targets, all arriving at once. Crucially, the Amazon deal is a framework agreement signaling intent, not a funded, licensed, or committed build. That gap between announcement and concrete steel is the right way to think about this entire field today: enormous interest, real engineering, very little operating proof.

Over the next two to five years, the interesting shift is where the bottleneck sits. For decades, the constraint on nuclear was the gigantic, bespoke, one-off construction project. SMRs propose to move the hard part into a factory, turning reactors from civil-engineering megaprojects into manufactured products. If that works, the leverage point moves from "can we build this" to "can we build a hundred of these," which changes how the industry competes, who finances it, and what counts as a moat. The advantage would accrue to whoever locks in a large, standardized order book first, because the whole cost case depends on repetition. It also reshapes regulation: smaller designs with passive safety features invite arguments for lighter-touch oversight and smaller exclusion zones, which regulators have not yet settled. And fuel becomes strategic, because several advanced designs depend on an enriched uranium that barely exists at commercial scale today. The direction is clear; the timing and the economics are not.

2. The Big Idea and How It Works

Think of the difference between a cathedral and an airliner. A conventional nuclear plant is a cathedral: built once, on site, by thousands of workers, every one slightly different, taking years and rarely repeatable. An SMR aims to be an airliner: designed once, then produced repeatedly on an assembly line, with each unit benefiting from the lessons of the last. In the old world, you got cheaper nuclear power by building one enormous reactor. In the new world, the bet is that you get cheaper power by building many small, identical ones and riding the manufacturing learning curve. The reactor physics is largely familiar. The wager is on the factory.

Start with the definition. <cite index="1-1,1-2">Small modular reactors are typically defined as nuclear reactors with electrical output up to 300 megawatts of electricity (MWe) per unit, about one-third of the capacity of traditional large reactors, which run 1,000 MWe or more.</cite> The "modular" part is the heart of it. <cite index="2-1">SMRs use modular technology with factory fabrication of components to enable shorter construction times and economies of series production</cite>, and capacity can be added incrementally by installing more modules at a site.

A smaller cousin sits below them. Microreactors are a subset of SMRs, though the authoritative definitions differ: the International Atomic Energy Agency (IAEA), the United Nations nuclear watchdog, cites up to roughly 10 MWe, while the U.S. Department of Energy uses a 1–20 megawatt thermal band, a different unit that measures heat rather than the electricity produced. The distinction matters because vendors and agencies sometimes mix the two, making capacity comparisons tricky. <cite index="3-1">Microreactors can operate grid-connected, off-grid, or as part of microgrids.</cite>

On the technology, most near-term designs play it safe. <cite index="4-1,4-2">Many near-term SMRs are water-cooled reactors based on proven pressurized-water or boiling-water reactor technology, essentially down-scaled versions of existing designs, while other SMR designs use non-light-water coolants such as gas, liquid metal, or molten salt.</cite> Several advanced designs need high-assay low-enriched uranium (HALEU), fuel enriched to between 5% and just under 20% uranium-235, more potent than the roughly 5% used in today's reactors. Finally, the safety pitch: <cite index="5-1">many SMR designs incorporate passive safety features relying on natural circulation, gravity, and physics rather than active systems, to shut down safely without human or power-dependent intervention</cite>, and some can be buried underground.

3. Implications and Tensions

For companies and power buyers, the appeal is matching supply to demand without betting the balance sheet on a single decade-long megaproject. A data center operator, an industrial site, or a remote community could in principle add a module or two sized to its load. That is the logic behind the Amazon and X-energy arrangement: power generated next to the thing that needs it, on a timeline closer to a product order than a public-works program.

For work and roles, the center of gravity moves toward manufacturing, supply chains, and licensing rather than enormous on-site labor forces. The skill that matters becomes producing identical units reliably and getting a standardized design through regulators once rather than fighting each project separately.

The concrete, near-term reality is more modest than the marketing, and it cuts both ways. The genuine milestones are real: <cite index="6-1">as of May 2026, operational SMRs are located in Russia, since 2020, China, since 2021, and Japan, where a test reactor was brought online in 2024.</cite> On the regulatory front, <cite index="7-1">in August 2022 the U.S. Nuclear Regulatory Commission approved the design for the nation's first SMR, a 50-megawatt advanced light-water reactor developed by NuScale Power</cite>; the company later won approval for an uprated 77 MWe module in 2025. Set against those milestones is the counterweight: the U.S. flagship deployment was cancelled in late 2023 over cost. The medium-term, directional bet is that a sufficiently large order book lets later units fall in price. Whether that happens is the open question of the field.

Small scale fights itself. A smaller reactor loses the efficiencies that made big plants economic, and the first units pay a steep premium. <cite index="8-1">The IEA estimates first-of-a-kind SMR overnight costs in the EU at around $10,000 per kW, compared to $6,600 per kW for traditional nuclear.</cite> The hope is that mass production claws this back; the proof does not yet exist.

The cautionary tale. The U.S. flagship NuScale Carbon Free Power Project, run with a Utah municipal utility group, was cancelled in late 2023 amid cost escalation. It is the single most concrete data point against the cheap-and-fast promise, because it is the case where the economics met reality and lost.

Fuel and waste. HALEU enrichment capacity is widely flagged as a possible bottleneck for advanced designs, with no settled answer on whether supply scales in time. And SMRs inherit nuclear's unresolved waste problem, including the absence of a U.S. spent-fuel repository, possibly with more numerous and varied fuel forms to manage.

4. Hooks, Takeaways, and For the Nerds

A handful of lines that travel well in conversation:

- "The reactor isn't the hard part anymore. The factory and the order book are. Nobody has proven you can mass-produce these cheaply yet."
- "Amazon's nuclear deal is real interest, but it's a framework agreement, not a funded build. Watch what actually gets licensed."
- "The first-of-a-kind units cost more per kilowatt than big conventional reactors. The whole case rests on the second hundred being cheaper."
- "There are operating SMRs, but they're in Russia, China, and Japan, and they don't look much like the Western light-water designs in the pipeline."
- "The most honest data point we have is the NuScale project that got cancelled in 2023 over cost."

If you remember three things. SMRs are factory-built reactors under about 300 MWe, betting that repetition, not size, makes nuclear cheap. The bet is unproven; Demand from data centers and decarbonization is driving real interest, but most announcements, including Amazon's, are intent rather than committed builds; Watch whether those power-purchase commitments turn into licensed, funded construction, and whether HALEU fuel supply scales. That is the moment the thesis moves from modeling to evidence.

For the nerds. The economic argument lives entirely in the learning rate. <cite index="8-1">Against the IEA's roughly $10,000 per kW first-of-a-kind figure versus $6,600 for conventional nuclear</cite>, modeling from the National Academy of Engineering and the Nuclear Innovation Alliance suggests that at 10–20% learning rates, SMRs could reach cost parity after roughly a dozen units, given a real order book. No Western SMR has operated at commercial scale, so those learning curves are assumptions, not data.

Mechanically, many light-water SMRs rely on an integral primary system: the core, steam generators, and pressurizer all sit inside a single vessel, which minimizes the large-diameter piping that creates potential loss-of-coolant paths. Combined with natural circulation that reduces reliance on pumps, this is what underpins the passive-safety pitch.

Two debates are worth tracking. First, passive safety: developers argue it justifies shrinking the emergency planning zone toward the site boundary rather than the conventional 10-mile radius, while critics including the Union of Concerned Scientists worry about securing many dispersed sites and novel fuels. Performance under multi-module accidents is mostly modeled, not demonstrated. Second, the operating precedents are genuinely odd reference points: Russia's unit is a floating Arctic barge, and China's is a gas-cooled pebble-bed design, neither a clean template for the light-water pipeline.

WHERE SOURCES DISAGREE

Will modular series production ever overcome the diseconomies of small scale?
One reading, drawing on IEA and National Academy of Engineering FOAK figures plus the cancelled NuScale flagship, holds that early units cost more per kilowatt than large reactors and that the cheap-SMR case is unproven. Another reading, from NAE and Nuclear Innovation Alliance modeling, finds that with 10–20% learning rates SMRs can reach cost parity "after a dozen or so units" given a sufficient order book
Unresolved: no Western SMR has operated at commercial scale, so learning-curve assumptions cannot be confirmed or refuted by operating data

NuScale per-module output figure.
One set of sources reports 50 MWe (the 2022 NRC-certified design); others cite ~77 MWe (the 2025 uprated approval) or 250 MWt (a thermal rating)
Unresolved: as a single number because the figures legitimately describe different design stages and different units (thermal vs. electrical) rather than contradicting each other

Are Russia's and China's operating units meaningful precedents?
One reading treats them as idiosyncratic — Russia's Akademik Lomonosov a floating Arctic barge, China's HTR-PM a gas-cooled pebble-bed reactor unlike Western light-water designs. Another, from IAEA and OECD-NEA tracking, treats them as the first operational SMRs and central deployment case studies, with HTR-PM positioned as the reference for follow-on commercial units
Unresolved: both characterizations are accurate: the plants are genuine first-of-kind deployments yet technologically distinct from the U.S./European light-water pipeline

HALEU fuel supply adequacy.
Multiple sources flag HALEU enrichment capacity as a potential bottleneck for the many advanced designs that depend on 5–20% enriched fuel. No source in the evidence describes a resolved supply-scaling answer
Unresolved: the materials describe the risk without documenting whether enrichment capacity will scale in time

Smaller emergency planning zones versus dispersed-site security.
Developers argue enhanced passive safety justifies shrinking emergency planning zones toward the site boundary, versus the conventional 10-mile radius. Critics, including the Union of Concerned Scientists, raise concerns about the security of more numerous, dispersed sites and novel fuels
Unresolved: passive-safety performance under multi-module accidents and external hazards is largely modeled, not operationally demonstrated

SMR waste management.
One reading holds that SMRs will face the same
Unresolved: structural problems as conventional nuclear, including the absence of a U.S. spent-fuel repository, potentially compounded by more numerous and diverse fuel forms. The countervailing view is largely silent in the evidence. Unresolved because the materials flag the problem but contain no analysis of whether SMR waste streams ease or worsen the existing repository gap