

Small Modular Reactors: Redefining the Future of Decentralized Energy in the United States

By Dr. Jeff Kleck

Small Modular Reactors (SMRs) and Micro Modular Reactors (MMRs) are emerging as transformative technologies poised to decentralize the energy grid and meet the growing demand for resilient, adaptable, and environmentally responsible power. Beyond their benefits in flexibility and sustainability, SMRs are integral to enhancing U.S. national security by strengthening energy security, diversifying firm domestic generation, and improving the resilience of critical infrastructure. This paper explores the advantages of SMRs over conventional nuclear reactors, the ongoing global race in SMR deployment, and the critical role of the U.S. Department of Energy (DOE) in supporting their development.

The Evolution of Nuclear Power – SMRs vs. Conventional Nuclear Reactors:

Nuclear power has long provided reliable, high-capacity-factor baseload electricity, but conventional gigawatt-scale nuclear plants can require substantial upfront capital, complex construction projects, and lengthy development and regulatory timelines. Small Modular Reactors (SMRs) and Micro Modular Reactors (MMRs) are intended to address some of these challenges through smaller reactor sizes, modular construction, factory fabrication, passive safety features, and the ability to deploy generating capacity incrementally. While many of these advantages have been demonstrated at the design and component level, their ultimate economic and deployment benefits will depend on successful commercialization, standardized production, regulatory efficiency, and deployment at sufficient scale.

Key Differences and Benefits:

- **Size and Modularity:** Conventional nuclear reactors commonly generate approximately 1,000 MWe or more from a single unit, while SMRs generally produce up to 300 MWe per reactor module. MMRs are smaller still, typically producing approximately 1–20 MWe, although definitions vary among organizations and reactor developers. The smaller size of SMRs and MMRs allows generating capacity to be added incrementally and enables nuclear power to serve applications and locations where conventional large reactors may be impractical.
- **Construction and Deployment:** Many SMR designs are intended to shift a greater portion of reactor manufacturing from the construction site to controlled factory environments, where standardized components or complete reactor modules can be produced and transported to their final locations. This approach has the potential to shorten on-site construction schedules, reduce construction risk, and improve manufacturing consistency. However, these benefits will ultimately depend on achieving standardized

designs, repeat manufacturing, efficient supply chains, and streamlined licensing and deployment processes.

- **Safety and Risk Management:** Many SMR and MMR designs incorporate passive or inherent safety features that reduce dependence on active mechanical systems or operator intervention during certain accident conditions. Some designs use underground or partially below-grade structures, while others employ different containment and protection strategies appropriate to their reactor technology. Their smaller reactor cores and lower total inventories of radioactive material can also provide additional options for managing safety, emergency planning, and site configuration. Specific safety characteristics, however, vary significantly among reactor designs.
- **Economic Feasibility:** Because individual SMR and MMR projects are substantially smaller than conventional gigawatt-scale nuclear plants, they can require considerably less total upfront capital for each reactor or deployment phase. Their modularity may also allow capacity to be added progressively as demand increases, potentially reducing financing risk and allowing revenues from initial modules to support later expansion. Factory production and repeated deployment could further reduce costs as manufacturing volume increases. However, lower total project cost does not necessarily mean lower cost per kilowatt or lower levelized cost of electricity, and the long-term economics of many advanced SMR designs have yet to be demonstrated through large-scale commercial deployment.
- **Flexibility and Grid Integration:** SMRs and MMRs can provide firm, dispatchable power in a wider range of locations and grid configurations than conventional large nuclear plants. Their smaller scale makes them particularly suitable for decentralized grids, microgrids, remote communities, military installations, industrial facilities, and data centers. They can also operate alongside renewable generation, energy storage, hydroelectric power, and other technologies as part of hybrid energy systems. In addition to electricity generation, many advanced reactor designs can potentially provide high-temperature process heat for hydrogen production, desalination, manufacturing, and other industrial applications.

Key Players in the Development of SMRs and MMRs:

The following table lists key players actively developing Small Modular Reactors (SMRs) and Micro Modular Reactors (MMRs) for the U.S. market, each contributing unique advancements to the field of nuclear energy:

Company	Model	Power (MWe)	Type	Status
Aalo Atomix	Aalo-1	10	STR	Demonstration
Alpha Tech Research	ARC Generator	12	MSR	Development
Antares Nuclear	R1 Microreactor	0.2-0.3	HPM	Demonstration
Apollo Atomix	A-10	10	PWR	Development
Arc Clean Technology	ARC-100	100	SFR	Development
BWX Technologies	BANR	20	HTGR	Development
Deep Fission	DFBR-1	15	PWR	Development
Deployable Energy	Unity Nuclear Battery	1	GCR	Demonstration
Flibe Energy	LFTR	100-250	MSR	Development
General Atomix	EM ²	265	GFR	Concept
GE Hitachi Nuclear Energy	BWRX-300	300	BWR	Review
Hadron Energy	Halo MMR	10	LWR	Development
HolosGen	Holos Quad	13	HTGR	Development
Holtec International	SMR-300	300	PWR	Review
Kairos Power	KP-FHR	75	FHR	Construction
Last Energy	PWR-20	20	PWR	Development
NANO Nuclear Energy	KRONOS	15	HTGR	Development
Natura Resources	MSR-100	100	MSR	Development
NuCube Energy	NuSun-1	1.3	HPM	Development
NuScale Power	NPM	77	PWR	Approved
Oklo	Aurora Powerhouse	15-75	SFR	Demonstration
Radiant Nuclear	Kaleidos	1	HTGR	Pilot
TerraPower	Sodium	345	SFR	Construction
Terrestrial Energy	IMSR	195	MSR	Development
Valar Atomix	Numenor	25	HTGR	Demonstration
Westinghouse Electric Company	eVinci	5	HPM	Demonstration
X-Energy	Xe-100	80	HTGR	Review

Table Notes and Clarifications:

TerraPower Natrium Reactor:

- TerraPower's Natrium reactor exceeds the current definition of a Small Modular Reactor (≤ 300 MWe). However, it falls within the International Atomic Energy Agency's historical classification of a medium-sized reactor (300–700 MWe). It is included here because of its modular design, integrated energy-storage system, and significance to advanced reactor deployment in the United States.

Terrestrial Energy:

- Terrestrial Energy completed a Phase 2 pre-licensing Vendor Design Review of its IMSR technology with the Canadian Nuclear Safety Commission and is currently engaged in pre-application activities with the U.S. Nuclear Regulatory Commission. The company is also advancing U.S. deployment activities at the Texas A&M-RELLIS campus and through U.S. Department of Energy programs. Its commercial IMSR Plant consists of two approximately 195-MWe reactor units producing a combined 390 MWe.

Power Ratings:

- Power ratings listed are for a single reactor module/unit. Some manufacturers plan facilities that integrate multiple reactor modules, yielding higher aggregate generating capacities per site.

Multi Reactor Models:

- Aalo, Kairos Power, and NuScale use scalable multi-reactor configurations. Aalo's standard Pod comprises five 10-MWe reactors totaling 50 MWe, with larger multi-unit stations planned. Kairos offers a two-reactor 150-MWe minimum configuration and a six-reactor 450-MWe standard configuration, with larger configurations possible. NuScale offers four-, six-, and twelve-module plants totaling 308, 462, and 924 MWe, respectively.

Acronyms and Definitions:

- Company: Developer or manufacturer of the reactor.
- Model: Specific name or designation of the reactor technology.
- Power (MWe): Nameplate electrical capacity (megawatts electric).
- Type Definitions:
 - BWR: Boiling Water Reactor
 - FHR: Fluoride High-Temperature Reactor
 - GCR: Gas-Cooled Reactor
 - GFR: Gas-Cooled Fast Reactor
 - HPM: Heat-Pipe Microreactor
 - HTGR: High-Temperature Gas Reactor
 - LWR: Light Water Reactor
 - MSR: Molten Salt Reactor
 - PWR: Pressurized Water Reactor
 - STR: Sodium-Cooled Thermal Reactor
 - SFR: Sodium-Cooled Fast Reactor

Status:

- Status reflects the most advanced publicly documented U.S. activity associated with the listed reactor technology. Demonstration and Construction status may reflect testing or construction of a representative research, test, prototype, or demonstration reactor; however, Review and Approved status refer to regulatory milestones applicable to the listed commercial power reactor or its commercial deployment.

Status Stages:

- Concept: Initial development phase; involves conceptual studies and preliminary engineering assessments.
- Development: Detailed engineering, prototyping, laboratory testing, and early-stage validations.
- Pilot: Real-world deployment for collecting operational data, assessing reliability, and preparing for regulatory submission.
- Review (Regulatory Review): Formal evaluation by regulatory bodies for safety, compliance, and environmental standards prior to commercial licensing.
- Approved (Design): Regulatory review of the reactor design has been completed and the design has received formal approval from the relevant regulatory authority; site-specific licensing and construction may still be required before deployment.
- Construction: Regulatory approvals necessary to begin construction have been obtained and physical construction of the reactor or nuclear facility is underway.
- Demonstration: Operation or testing of a prototype, test reactor, or representative reactor system to validate reactor physics, safety, components, and performance prior to commercial deployment.
- Commercial: Completion of all regulatory processes and full market readiness.

References and Data Sources:

International Atomic Energy Agency, Small Modular Reactors Catalogue, 2024; Canadian Nuclear Safety Commission, Phase 2 Pre-Licensing Vendor Design Review — Terrestrial Energy Inc., 2023; U.S. Nuclear Regulatory Commission, Integral Molten Salt Reactor (IMSR) — Terrestrial Energy USA Inc., 2026.

Global SMR Landscape: Competitive Challenges:

Globally, SMRs are advancing rapidly, with China and Russia currently leading in deployment. Russia operates the Akademik Lomonosov, the world's first purpose-built floating nuclear power plant, which entered commercial operation in May 2020 and incorporates two 35 MWe KLT-40S SMR units. China is rapidly expanding its nuclear fleet. As of May 2026, China operated 60 nuclear reactors totaling 58.7 GW and had 36 additional reactors under construction representing approximately 38.9 GW of capacity. China is also developing the ACP100, or Linglong One, its first commercial demonstration SMR. The ACP100 previously underwent an International Atomic Energy Agency (IAEA) Generic Reactor Safety Review; however, such reviews are not design certifications or reactor licenses, which remain the responsibility of national regulatory authorities. In contrast, the U.S. continues to face comparatively lengthy regulatory approval and construction timelines. To remain competitive, the U.S. must continue improving the efficiency of nuclear licensing, construction, and deployment while maintaining appropriate safety standards, particularly as electricity demand grows from data centers, artificial intelligence, manufacturing, and other energy-intensive industries.

References and Data Sources:

International Atomic Energy Agency, Advanced Reactor Information System (ARIS), 2026; U.S. Energy Information Administration, 2026; International Atomic Energy Agency, Small Modular Reactors Catalogue, 2024; International Atomic Energy Agency, Generic Reactor Safety, 2026.

The Role of the U.S. Department of Energy (DOE):

The U.S. Department of Energy (DOE) plays a central role in accelerating advanced reactor development and commercialization. Through the Advanced Reactor Demonstration Program (ARDP), DOE supports the first commercial-scale deployments of TerraPower's Sodium reactor and X-energy's Xe-100. More recently, DOE established the Reactor Pilot Program to accelerate the testing of privately developed advanced reactors under DOE authorization. Three Reactor Pilot Program participants—Antares Nuclear, Valar Atomix, and Aalo Atomix—achieved zero-power fueled criticality by July 4, 2026. Separately, Deployable Energy's Unity reactor achieved criticality on June 30, 2026 under DOE's Nuclear Energy Launch Pad initiative, bringing the total number of DOE-authorized advanced reactor criticality demonstrations to four by July 4, 2026. DOE has also opened the Demonstration of Microreactor Experiments (DOME) test bed at Idaho National Laboratory and created the Fuel Line Pilot Program to accelerate development of domestic advanced nuclear fuel production. Together with ongoing NRC licensing modernization and federal efforts to expand domestic uranium enrichment and HALEU availability, these programs are intended to reduce technical, regulatory, fuel-supply, and deployment barriers facing the next generation of U.S. nuclear reactors.

References and Data Sources:

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Launch Pad, 2026; U.S. Department of Energy, DOME Microreactor Test Bed, 2026; U.S. Department of Energy, Fuel Line Pilot Program, 2026.

Transforming the Future With New Technology:

U.S. electricity demand from data centers is growing rapidly, driven in significant part by artificial intelligence and high-performance computing. Lawrence Berkeley National Laboratory's 2026 analysis estimates that data centers could account for approximately 11.8% of total U.S. electricity consumption by 2030, with modeled scenarios ranging from 9.5% to 15.3%. In response, major technology companies are investing in new generation, entering long-term power agreements, supporting existing nuclear generation, and financing advanced nuclear technologies. SMRs and other advanced reactors are increasingly being considered for data centers because they could provide firm, high-capacity-factor power in locations with rapidly growing electricity demand.

Technology Company	SMR Company	Reference
Amazon	X-Energy	Amazon & X-Energy, 2024
Alphabet / Google	Kairos	Alphabet & Kairos, 2024
Oracle	Undisclosed	Oracle & Undisclosed, 2024
Meta	TerraPower; Oklo	Meta & TerraPower, 2026 ; Meta & Oklo, 2026

References and Data Sources:

Lawrence Berkeley National Laboratory, United States Data Center Energy Usage Report: 2025 Update, 2026; Amazon & X-Energy, 2024; Alphabet / Google & Kairos, 2024; Oracle & Undisclosed, 2024; Meta & TerraPower, 2026; Meta & Oklo, 2026.

Desalination:

Fresh water is the most foundational resource on the planet. In addition to the water needs of the environment, the growing human population requires an increasing amount of water to enable our survival and industries. At present, desalinated water is more expensive than freshwater, with 25-40% of the associated cost being energy consumption. SMRs could provide reliable electricity and process heat for desalination, potentially improving the economics and resilience of water production where energy availability or cost is a limiting factor.

References and Data Sources:

U.S. Department of Energy, Powering the Blue Economy: Desalination, 2019.

Hydrogen Production:

Hydrogen is used in the manufacture of chemicals, including fertilizers vital to agriculture, in metals processing, and as an energy carrier and transportation fuel. Hydrogen fuel-cell vehicles generate electricity through an electrochemical reaction between hydrogen and oxygen, producing water and heat rather than carbon dioxide at the point of use. Today, most hydrogen is produced from natural gas and is commonly referred to as “gray” hydrogen, a process that results in significant carbon dioxide emissions. When natural-gas-based hydrogen production is combined with carbon capture and storage, the resulting hydrogen is commonly referred to as “blue” hydrogen. Hydrogen produced through electrolysis powered by nuclear energy is sometimes termed “pink hydrogen” and can have very low lifecycle carbon emissions. Nuclear reactors can also provide high-temperature process heat that may further improve the efficiency of hydrogen production. Because hydrogen production can require significant quantities of water, pairing nuclear-powered hydrogen production with desalination could provide both the energy and water needed for large-scale production without placing additional demands on limited freshwater supplies.

References and Data Sources:

U.S. Department of Energy, Fuel Cell Basics, 2026; U.S. Department of Energy Alternative Fuels Data Center, Fuel Cell Electric Vehicles, 2026; U.S. Department of Energy, H2IQ Hour: Learn to use the GREET Model for Emissions Life Cycle Analysis, 2021; U.S. Department of Energy, Innovative Clean Energy: Nuclear Loan Guarantee Solicitation, 2022; U.S. Department of Energy, Hydrogen Production: Electrolysis, 2026.

Rare Earth Materials:

Rare earth materials are essential to the global economy. Mining and processing rare earth elements require substantial water and energy. SMRs could supply both energy and desalinated water to make rare earth extraction and processing more feasible in regions where energy availability and water table contamination have raised concerns.

References and Data Sources:

U.S. Department of Energy, DOE Invests \$10 Million to Increase Domestic Supplies of Water and Critical Minerals, 2023.

Conclusion:

As the U.S. transitions toward a sustainable and resilient energy future, SMRs offer a viable pathway to achieving a decentralized and secure power grid. Their potential for modular and incremental deployment, combined with their adaptability, makes SMRs suited to meet diverse energy needs, supporting essential infrastructure while also ensuring the security of critical installations. By advancing SMR technology, the U.S. can strengthen energy security, reduce carbon emissions, improve grid resilience, and support economic and strategic goals.

For more information on Small Modular Reactor technology and its role in decentralizing the U.S. power grid, please contact Dr. Jeff Kleck at Jeff@OpenPowerEnergy.Net.

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