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 bolstering energy independence and reducing reliance on external energy sources. 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 been a reliable source of baseload electricity, but large, centralized reactors face challenges, including lengthy construction timelines, high costs, and complex regulatory requirements. In contrast, SMRs offer a flexible, scalable alternative that can be deployed rapidly and at lower costs.

Key Differences and Benefits:

- Size and Modularity: Conventional reactors are large, centralized facilities generating over 1,000 megawatts electrical (MWe), while SMRs are smaller, modular units that typically produce 50–300 MWe. MMRs are even more compact, with power outputs ranging from 1–20 MWe, suitable for remote and off-grid applications. The modular construction of SMRs enables phased deployment, allowing flexibility in scaling to meet demand incrementally.
- Construction and Deployment: Unlike conventional reactors, which require extensive infrastructure and construction timelines of up to a decade, SMRs are factory-fabricated and transported to sites, significantly reducing deployment time and cost. This modular approach supports faster deployment, allowing SMRs to meet urgent energy needs, especially in high-demand areas like data centers and industrial zones.
- Safety and Risk Management: SMRs incorporate advanced safety features such as passive cooling and underground containment, which reduces accident risk. Their smaller size and modularity simplify maintenance and make SMRs better suited for managing safety compared to large reactors.
- Economic Feasibility: With capital costs far lower than traditional nuclear plants, SMRs are more attractive to investors, utilities, and governments. They’re also viable for smaller grids and remote locations where large reactors would be impractical.

- Flexibility and Grid Integration: SMRs integrate well into decentralized grids, microgrids, and hybrid energy systems combining renewables with nuclear power. Their suitability to rising demand makes SMRs suitable for locations facing growing energy loads.

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 Atomics	Aalo-1	10	STR	Development
Antares Nuclear	R1 Microreactor	0.2	HPM	Development
Arc Clean Technology	ARC-100	100	SFR	Review
BWX Technologies	BANR	50	HTBR	Demonstration
General Atomics	EM^2	265	HTGR	Concept
GE Hitachi Nuclear Energy	BWRX-300	300	BWR	Review
Holtec International	SMR-300	300	PWR	Review
Kairos Power	KP-FHR	75	FHR	Pilot
Last Energy	PWR-20	20	LWR	Development
Natura Resources	MSR-100	100	MSR	Demonstration
NuScale Power	VOYGR	77	LWR	Commercial
Oklo	Aurora Powerhouse	15	HPM	Development
Radiant Nuclear	Kaleidos	1	HTGR	Development
TerraPower	Natrium	345	SFR	Demonstration
Terrestrial Energy	IMSR	195	IMSR	Review
Valar Atomics	Numenor	25	HTGR	Development
Westinghouse Electric Company	eVinci	5	HTHPR	Development
X-Energy	Xe-100	80	HTGR	Pilot

Table Notes and Clarifications:

TerraPower Natrium Reactor:

- TerraPower’s Natrium reactor exceeds the U.S. DOE's current definition of a Small Modular Reactor (≤300 MWe). However, it meets historical definitions set by the International Energy Agency (IEA) as a Small and Medium Reactor (300–700 MWe). It is included here due to its modular design, innovative energy storage integration, and significance in SMR industry developments.

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.

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
  - STR: Sodium Thermal Reactor
  - HPM: Heat-Pipe Microreactor
  - HTBR: High-Temperature Bed Reactor
  - HTGR: High-Temperature Gas Reactor
  - HTHPR: High-Temperature Heat-Pipe Reactor
  - IMSR: Integral Molten Salt Reactor
  - LWR: Light Water Reactor
  - MSR: Molten Salt Reactor
  - PWR: Pressurized Water Reactor
  - SFR: Sodium Fast Reactor

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.
- Demonstration: Limited-capacity operational tests to verify real-world performance and safety, immediately preceding full commercial deployment.
- Commercial: Completion of all regulatory processes and full market readiness.

Global SMR Landscape: Competitive Challenges

Globally, SMRs are advancing rapidly, with China and Russia currently leading in deployment. Russia's first SMR is also the world's first "floating" nuclear power plant, designed as part of a ship that can be transported to regions where energy is needed. China, having recently received International Atomic Energy Agency approval for its SMR project, now has 30 reactors under construction. China is adding nearly 10 reactors annually, putting them on track to surpass U.S. nuclear generating capacity by 2030. In contrast, the U.S. faces significant delays due to lengthy regulatory approval and construction timelines. To remain competitive, the U.S. must address these challenges and accelerate zero carbon energy deployment, like SMRs, especially as global energy priorities continue to shift in response to geopolitical dynamics.

References and Data Sources:

World Nuclear News, 2024; Nuclear Newswire, 2024; World Nuclear Association, 2024

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

The DOE is a key enabler in SMR development through initiatives like the Advanced Reactor Demonstration Program (ARDP), which provides funding and technical support to accelerate commercialization. Additionally, DOE works closely with the Nuclear Regulatory Commission (NRC) to streamline the approval process, ensuring safe and efficient deployment. DOE's ongoing research in improving SMR efficiency, safety, and economic viability positions these reactors as central to the U.S. strategy for a decentralized and resilient energy grid, a goal that not only enhances energy independence but also strengthens the security of critical infrastructure against external threats.

Transforming the Future With New Technology:

To meet the growing power demands of AI, it is likely that tens or even hundreds of gigawatts of power may need to be brought online in the United States by 2030. Corporations with significant AI investments are acquiring existing nuclear facilities and investing in new ones to meet their near-term energy needs. As AI models become more computation-intensive and user bases continue to expand rapidly, the demand for power will increase further. SMRs could become a primary power source for data centers, with several major tech companies already exploring SMR partnerships.

AI Company	**SMR Company**	**Reference**
Amazon	X-Energy	Amazon & X-Energy
Alphabet / Google	Kairos	Alphabet & Kairos
OpenAI	Oklo	OpenAI & Oklo
Oracle	Undisclosed	Oracle & Undisclosed

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. By building SMRs, we can lower energy costs and make desalination more affordable.

Hydrogen Production:
Hydrogen is used for manufacturing chemicals including fertilizers vital to agriculture, treating metals, and as a fuel source, which has the potential to replace gasoline in personal vehicles. These vehicles do not emit carbon dioxide (CO_2) and produce only water as a byproduct of fuel combustion. However, currently "gray" hydrogen is by far the most produced form of hydrogen, and its production utilizes methane and emits significant CO_2. Some facilities involve carbon capture and storage and the resulting "blue" hydrogen has lower associated emissions. But, by using SMRs or other zero carbon energy sources, we can create truly emissions-free hydrogen with a variety of different labels such as "green" or "blue" hydrogen depending on the energy source. Producing hydrogen also currently requires large amounts of freshwater, but when paired with desalination, the water needs for hydrogen production can be solved without tapping into any freshwater stocks and we can create ecosystem-friendly hydrogen.

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 to regions where energy availability and water table contamination have raised concerns.

References and Data Sources:
ForeignPolicy, 2024; Department of Energy, 2019

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 rapid deployment, modularity, and adaptability make 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 independence, reduce carbon emissions, 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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