The Edison Foundation
Institute for
The Energy Transition

Advanced Nuclear – An Overview

Executive Summary

After a decade or more of being relatively flat, electricity demand is now growing at the fastest pace in decades as data centers and increased electrification put pressure on the grid.[1] To meet this increased demand, while keeping electricity reliable and affordable for customers and helping companies meet their long-term clean energy goals, will require doing more with today's grid but also developing and commercializing new technologies that can provide 24/7 clean firm power for the United States. As a result, there is growing interest in advanced clean energy technologies such as advanced nuclear.

Advanced nuclear reactors offer the promise of 24/7 clean reliable power, making it an ideal power source to meet growing demand, particularly from data centers. Advanced nuclear reactors also offer several potential benefits compared to conventional nuclear plants, including greater fuel efficiency, lower waste yields, passive safety measures to reduce the risk of accidents, increased reliability, resistance to proliferation, and flexible designs to reduce construction costs and allow the reactors to be used for more versatile purposes.[2, 3] Despite these promises, advanced nuclear plants—which are currently based on first-of-its-kind reactors—still need to be tested and face challenges such as substantial capital costs.

Nuclear reactors are divided into three different size categories: large reactors (~1 GW), small modular reactors (~50-300 MW), and micro reactors (50 MW or less). Advanced nuclear plants generally refer to small modular and micro reactors. Small modular reactors (SMRs) are named for their size—small because they have an average capacity of 350 MW or less—and modularity, referring to standardized factory production of smaller modular units that can be combined rather than having a unit custom-built on-site.[4] In theory, mass production of SMRs of the same design could further reduce manufacturing costs and construction schedules.[5]

Advanced nuclear technology includes five types of reactor technologies that span two generations: Gen III+ and Gen IV. Gen III+ reactors are the most similar to the conventional reactors that operate today in the United States as they both use water as their coolant and low-enriched uranium (LEU) as fuel.[6] Gen IV reactors use more unique types of fuels—such as high-assay, low-enriched uranium (HALEU)—and coolants, such as gas, metal, or salt.[7] Below is an overview of different types of advanced nuclear reactors, including U.S.-based developers, and the opportunities and challenges advanced nuclear technologies face.

Gen III+ Reactors

Light Water Small Modular Reactors

While many advanced nuclear reactors in development use novel fuels or coolants, small modular reactors can also be built using conventional nuclear technology (i.e, light water reactors, or LWRs).

- **Vendors:** NuScale, Westinghouse, GE Hitachi Nuclear Energy (US-Japan), Holtec International, B&W, Gen4 Energy, Last Energy, Elysium Industries, Energy Impact Center, X-Energy, Ultra Safe Nuclear Corporation (US-France), General Atomics/Framatome (US-France)

Supercritical Water-Cooled Reactor (SWCR)

Supercritical water-cooled reactors are based on existing LWR technologies but use supercritical water—where water has been heated to temperatures greater than 374 ℃ and 221 bars of pressure and has properties of both a liquid and a gas—as coolant. This allows SWCRs to achieve higher plant efficiency than LWRs.[8] However, the additional materials needed to manage the higher temperatures and pressures may also raise construction costs.

- **Vendors:** AECL

Gen IV Reactors

High Temperature Gas Reactor (HTGR)

High Temperature Gas Reactors (HTGRs) use inert gas such as helium for cooling. They operate at much higher temperatures (700 - 1000 C°) than existing reactors.[9] This makes them well-suited for creating heat for industrial processes, such as hydrogen production or petrochemical refining. HTGRs use low-enriched uranium fuel which reduces proliferation risk. The graphite-moderated reactor core can be formed from either hexagon-shaped blocks (prismatic block) or pebbles (pebble-bed).[10] This improves safety, as even the loss of cooling systems would not result in a core meltdown. Many HTGRs are designed as SMRs which allow them to be deployed in remote locations.

- **Vendors:** X-energy, General Atomics, StarCore Nuclear, Framatome

Gas-cooled Fast Reactor (GFR)

Gas-cooled Fast Reactors (GFR) are another type of helium-cooled high-temperature reactor that are well-suited for producing power or industrial heat. However, whereas HTGRs run in the thermal spectrum, GFRs operate in the fast spectrum.[11] The majority of nuclear reactors rely on a moderator to slow down neutrons in the nuclear reaction when using low-enriched uranium to make sure that fission reactions between neutrons happen at a sustaining rate.[12] Fast reactors like GFRs, however, do not use a moderator to slow down neutrons. This requires a higher concentration of uranium or another isotope, such as plutonium, to ensure that fissions occur fast enough to maintain a chain reaction.[13]

GFRs do not need graphite to moderate neutrons and, importantly, can operate with fuel made with plutonium and/or uranium that was separated during reprocessing (recycling) of spent nuclear fuel.[14] Furthermore, like HTGRs, GFRs feature passive safety systems that make them less susceptible to human error or failure.[15]

- **Vendors:** General Atomics

Molten Salt and Liquid Metal Reactors

Molten Salt Reactors (MSRs) and liquid metal reactors – such as Sodium-cooled Fast Reactors (SFRs) or Lead-cooled Fast Reactors (LFRs) – stand out for their heat transfer properties. As reactor coolants, they can remain stable at high temperatures which helps the reactor to get more energy out of nuclear fuel. As a result, these types of plants could operate at lower and safer pressures, which would reduce construction and design costs as they do not require components to withstand extreme pressure. Additionally, these reactors feature passive safety measures that use physics to shut down the reactor in the event of an accident.

Molten Salt Reactor (MSR) & Fluoride Salt-Cooled High Temperature Reactors (FHRs)

Molten Salt Reactors are reactors that use molten fluoride salts as a coolant or fuel. Salt-cooled MSRs (also known as Fluoride Salt-Cooled High Temperature Reactors (FHRs)) use molten salts to cool the reactor core.[16] This allows large amounts of heat to be absorbed at atmospheric pressure, allowing the reactor to operate at high temperatures.[17] This has the potential to decarbonize industrial processes that require large amounts of heat.

On the other hand, salt-fueled MSRs have the fuel dissolved within the molten salt.[18] Salt-fueled MSRs have a unique safety feature called a 'freeze plug', a solid salt plug that is placed below the reactor core.[19] During an accident where heat might rise within the core, the solid salt plug will begin to melt. This allows for the molten salt fuel to drain into a basin that is designed to prevent the fuel from continuing its fission reactions.[20]

- **MSR Vendors:** Alpha Tech Research Corp, Exodys Energy, Flibe Energy, Kairos Power, TerraPower, Terrestrial Energy USA, ThorCon Power

Lead-cooled Fast Reactor (LFR)

Lead-cooled Fast Reactors use either molten lead or lead-bismuth eutectic alloy as a primary reactor coolant.[21] The use of liquid lead in the reactors allows it to reflect neutrons away from the outside of the reactor back into the core.[22] Furthermore, liquid lead has additional safety features as it also allows for, "low-pressure operations and passive cooling in an accident".[23] LFRs are also able to have a 'closed fuel cycle' that allows them to reuse spent fuel.[24]

- **LFR Vendors:** Hydromine (technology sold to Newcleo), Westinghouse

Sodium-cooled Fast Reactor (SFR)

Sodium-cooled Fast Reactors use liquid sodium as their coolant.[25] SFRs come in two main design variants, loop-type and pool-type.[26] In the pool-type design, the reactor core and primary heat exchanger are immersed in a single pool of liquid metal while, in the loop-type, the primary heat exchanger is stored in a separate vessel. [27] Similar to LFRs, most SFRs would have a 'closed fuel cycle' allowing them to reuse spent fuel.[28]

- **SFR Vendors:** ARC Clean Technology, Columbia Basin Consulting Group, Oklo, GE Hitachi, TerraPower

Microreactors

Microreactors are named for their size and generally produce less than 50 MW of power, with smaller designs having a 1-10 MW capacity range.[29] Microreactors, like SMRs, would be manufactured as modular units in factories to increase, "standardization, learning rate, and cost predictability".[30] This would greatly reduce the time and cost of construction and could potentially lower the cost of building new units.

The size and self-contained nature of microreactors also make them ideal for deployment in remote off-grid locations – such as military bases, mining sites, rural communities, and industrial operations – and for disaster relief.[31]

- **Vendors:** Oklo, X-energy, Westinghouse, Nano Nuclear Energy, Ultra Safe Nuclear Corporation, Radiant, BWXT, Nugen, MicroNuclear

Fusion Reactors

All conventional reactors in operation today, as well as the advanced reactor technologies discussed above, rely on nuclear fission (splitting atoms). Researchers are designing new reactors to harness nuclear fusion (merging atoms) – the same reaction that powers the sun and stars. The fusing of two lighter atoms (usually hydrogen) can theoretically produce unlimited energy. Moreover, it does not produce emissions or nuclear waste.

However, achieving sustained fusion for energy generation is an immense technical and scientific challenge. One approach to achieving nuclear fusion is Magnetic Confinement Fusion (MCF) which uses powerful magnets to heat hydrogen atoms to over 100 million degrees into plasma form and contain the superheated mixture using high-powered magnets (a tokamak device). Another approach is Inertial Confinement Fusion (ICF) which uses lasers or beams to compress fuel pellets for brief fusion bursts. There are also hybrid approaches such as Magneto-Inertial Fusion (MIF) which combines the magnetic holding of MCF and the plasma compressions of ICF.

- **Vendors**: Brillouin Energy, Commonwealth Fusion Systems, General Atomics, Helion Energy, LPP Fusion, Lockheed Martin, MIFTI, NumerEx, TAE Technologies, General Fusion, Oklo

Challenges and Opportunities

Advanced nuclear energy presents a unique opportunity for meeting increased demand, given its ability to produce 24/7 clean, firm power, low lifecycle emissions, land use, lower transmission requirements, safety benefits, versatility and flexibility. However, it also faces challenges such as high upfront costs and risks, long and unpredictable development lifecycles, and community opposition. These opportunities and challenges are summarized below.

Opportunities

Advanced nuclear technologies offer several benefits, including additional safety benefits. For example, due to the unique coolants that advanced nuclear reactors use, they can operate at lower pressures.[32] In addition, advanced nuclear reactor designs also offer passive safety features such as the ‘freeze plug’ described above.

Additionally, advanced nuclear reactors offer versatility and flexibility that many conventional reactors do not. This is in part due to their modularity, which allows advanced nuclear power plants to be built at the scale needed to meet demand.[33, 34] Advanced reactors can also vary the amount of power they produce, allowing a greater role in balancing electricity loads.[35]

Finally, advanced nuclear reactors can also provide a way to manage nuclear waste. Spent fuel from nuclear reactors provides a challenge to store safely, as the process is expensive and the waste can last thousands of years.[36] Some advanced nuclear reactor designs, however, consume spent fuel, reducing the long-term challenges of safe storage.

In June 2025, DOE announced the Reactor Pilot Program following President Trump's Executive Order 14301. This program has the goal of "expediting the testing of advanced reactor designs…that are located outside of the national laboratories".[37] The companies selected to receive this assistance are Aalo Atomics Inc., Antares Nuclear Inc., Atomic Alchemy Inc., Deep Fission Inc., Last Energy Inc., Oklo Inc., Natura Resources LLC, Radiant Energy Inc., Terrestrial Energy Inc., and Valar Atomics Inc.[38]

Challenges

Advanced nuclear faces time and cost restraints, much like conventional nuclear. For example, the U.S does not have institutionalized project management knowledge for nuclear construction for future projects.[39] SMRs, whose modularity is a key feature, face challenges due to the different designs that exist and that there are no current or expansive modular assembly capabilities in the U.S.[40]

The U.S. also currently lacks the fuel mining or production capacity to expand nuclear capacity. To reach the estimated 220 GW of new nuclear capacity needed by 2050, U.S. mining/milling capacity will need to increase 25-fold compared to current capacity.[41] This is also true for many other types of nuclear fuel needed, such as UF6 and HALEU.[42, 43]

Finally, some of the coolants that advanced reactors use bring unique challenges. In MSRs, the molten salt used is corrosive and requires testing of new materials to see which ones can withstand the salt.[44] Molten lead on the other hand is opaque, which makes core inspections and monitoring difficult.[45] Technology developers are researching different technologies and materials to address these unique challenges.

EEI Member Advanced Nuclear Projects

1. **EEI Member:** Tennessee Valley Authority (TVA)
    - **Name:** Clinch River Nuclear Site
    - **Technology Company**: GE-Hitachi
    - **Technology**: Boiling Water Reactor (BWRX-300)
    - **Capacity**: 800 MW (multiple SMRs)

    TVA has invested in the standard design of the BWRX-300 as part of a technical collaboration agreement with Ontario Power Generation, Polish company Synthos Green Energy and GE Vernova Hitachi Nuclear Energy. TVA already holds an early site permit for SMRs at the Clinch River site, certifying that the site near Oak Ridge, Tennessee, is suitable for the construction of a nuclear power plant from the point of view of site safety, environmental impact and emergency planning. It has also completed and submitted an Environmental Report for the project to the Nuclear Regulatory Commission and says site preparation for the SMR could begin as soon as 2026.[46]

2. **EEI Member:** Duke Energy
    - **Name:** Belews Creek
    - **Technology**: SMR light water reactor
    - **Capacity**: ~300 MW

    In preapplication activities with plan for an Early Site Permit (ESP) submittal October 2025. Estimate to begin construction ~2030 and to come online Q1 2034. Submitted their ESP in December 2025.
    - Belews Creek Early Site Permit Pre-Application Meeting Slides
    - Submittal of ESP Press Release

3. **EEI Member:** Rocky Mountain Power
    - **Name:** Kemmerer Power Station Unit 1
    - **Technology Company**: Terrapower
    - **Technology**: Sodium-Fast Reactor (Natrium Reactor)
    - **Capacity**: 345 MW (with storage can boost to 500 MW)[47]

    Earlier this year, TerraPower submitted its construction permit application to the U.S. Nuclear Regulatory Commission (NRC) for the Natrium reactor. TerraPower is the first to submit its construction permit application for a commercial advanced reactor to the NRC. Due to its unique design, non-nuclear construction is beginning, while nuclear construction will begin after this application is approved.[48]

4. **EEI Member**: Southern Company
    - **Company**: Terrapower
    - **Technology:** Molten Chloride Fast Reactor (MCFR)

    TerraPower's MCFR design research and development has already expanded into design and testing activities. In January 2016, the U.S. Department of Energy awarded a five-year, $40 million cost-share award for continued research and development into TerraPower's MCFR project. This award served as the inception for a new public-private MCFR project development partnership that includes TerraPower, Southern Company, Oak Ridge National Laboratory, the Electric Power Research Institute and Vanderbilt University.[49]

Endnotes

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