Calamos Sustainable Investing Perspectives

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Nuclear Power: A Changing Frontier in the AI Era

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The AI energy imperative is accelerating nuclear power's moment

The rapid expansion of artificial intelligence infrastructure is creating an unprecedented surge in electricity demand, forcing a fundamental rethink of where reliable, carbon-free baseload power will come from. Data centers, where AI models are hosted, accounted for approximately 1.5% of global electricity use in 2024, equivalent to 415 terawatt-hours.[1] This figure is expected to climb to approximately 3% of global electricity by 2030, growing at roughly 15% per year.[2] AI-focused data center infrastructure is expanding even faster: electricity consumption by AI-optimized servers is projected to grow at 30% per year in the base case, compared to 9% per year for conventional servers.[3]

The technology sector has already drawn a direct line to nuclear. In September 2024, Microsoft and Constellation Energy signed a 20-year power purchase agreement for the restart of the Three Mile Island nuclear plant, citing the need for reliable, carbon-free baseload power for data center operations.[4] Amazon has signed a power purchase agreement for up to 960 MW of nuclear power from the Susquehanna plant to supply its data center operations.[5] The International Energy Agency (IEA) projects that nuclear energy will supply 16% to 18% of data center electricity globally by 2035.[6]

- **Calamos Sustainable Equities Team's proprietary research approach.** Our sustainable research process seeks to reduce risk exposure and find investment opportunities via a three-step sustainable research process that recognizes two main drivers: improving human lives and reducing ecological overshoot.

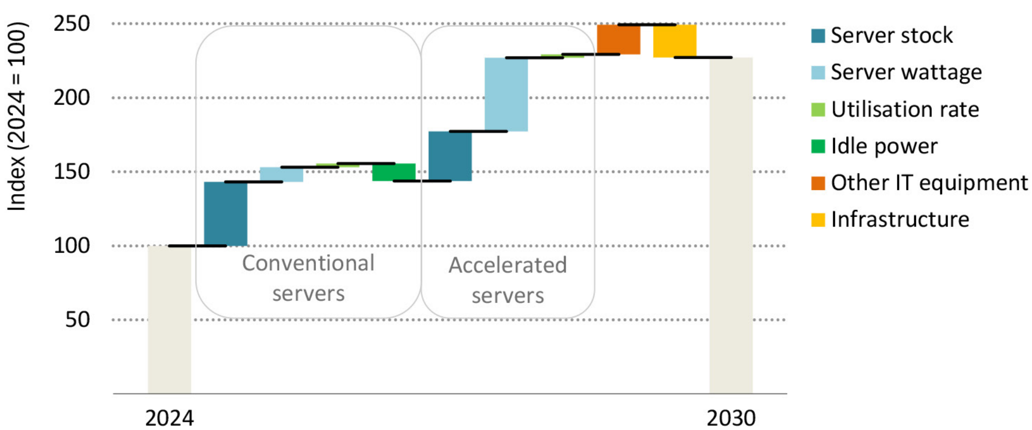
- **Clean energy revolution.** The energy sector is in a period of rapid transition. Global demand is growing, and at the same time, countries worldwide are seeking to address climate crises through reduced reliance on fossil fuels.

- **Nuclear energy: Balancing power and risk.** The increased use of nuclear power could provide a powerful tool in addressing these challenges, provided that the proper guardrails are implemented to address current risks.

- **Identifying and investing in safer and greener nuclear energy innovations.** Although we do not invest in companies exclusively involved in nuclear power generation, we have found opportunities to invest in innovative companies making nuclear power safer and more environmentally friendly. We believe these opportunities will grow over time.

This demand is arriving against a backdrop of rising global energy consumption. Global total energy supply[7] reached a new high of 592 exajoules in 2024, a 2% annual increase, with fossil fuels still accounting for 87% of the energy mix.[8] The challenge of decarbonizing a growing global energy system while simultaneously meeting surging AI-driven electricity demand has made nuclear power's potential contribution more consequential than at any point in the past two decades.

The AI Infrastructure Buildout: A Catalyst for Safer Nuclear Power



Source: IEA (December 2024) – "Energy and AI", International Energy Agency, Paris. Available at iea.org. Figure 2.10 page 63.

Powering the world's growing demand requires multiple energy sources. On a global basis, the largest share of energy supply comes from oil (34%), followed by coal, natural gas, and hydroelectric power.[8] Fossil fuels continue to drive the current energy mix, and global greenhouse gas emissions have grown as a result.

The climate challenge has intensified

Global greenhouse gas emissions reached 57.7 billion tons in 2024, a 2.3% increase from the prior year and the fastest annual growth rate in over a decade. This is up approximately 7% from 2020, 39% from 2010, and 52% from 2000.[9]

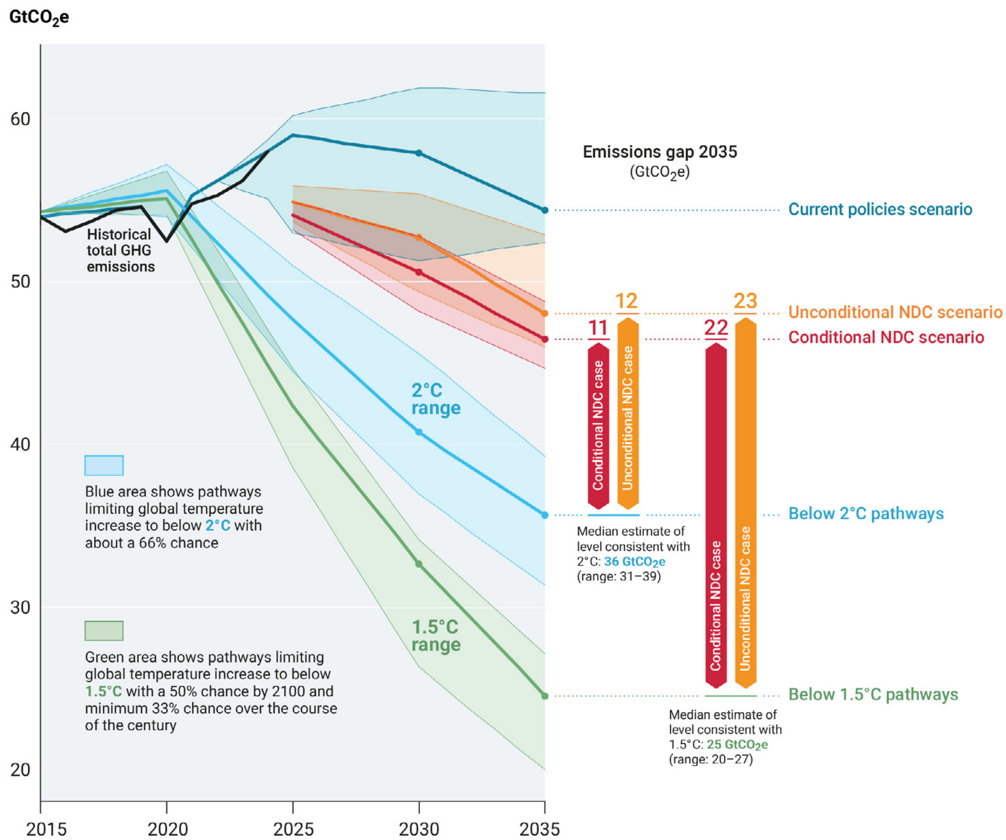
The United Nations Environment Programme (UNEP) estimates that under current government policies, the world is on track for up to 2.8 degrees Celsius of warming over this century.[10] Even if all national climate pledges under the Paris Agreement are fully implemented, projected warming remains at 2.3 to 2.5 degrees Celsius, well above the 1.5-degree threshold targeted by the international community.[10] The gap between current national commitments and a 1.5-degree pathway amounts to approximately 11 to 14 billion tons of CO2-equivalent per year by 2030.[10]

The share of energy supply from low-carbon sources has increased substantially, with renewables growing at more than five times the rate of total energy demand over the past five years.[8] Wind and solar have expanded rapidly, growing 14% in 2024 and now supplying 17% of global electricity generation.[8] Since 2010, the combined deployment of renewables and nuclear power has avoided an estimated 109 gigatons of greenhouse gas emissions, more than twice the total amount emitted globally in 2024.[8]

Despite this progress, the scale of the challenge continues to grow. Addressing it will require contributions from every available low-carbon energy source, including nuclear.

A Widening Gap

Global GHG emissions under different scenarios and the emissions gap in 2030 and 2035



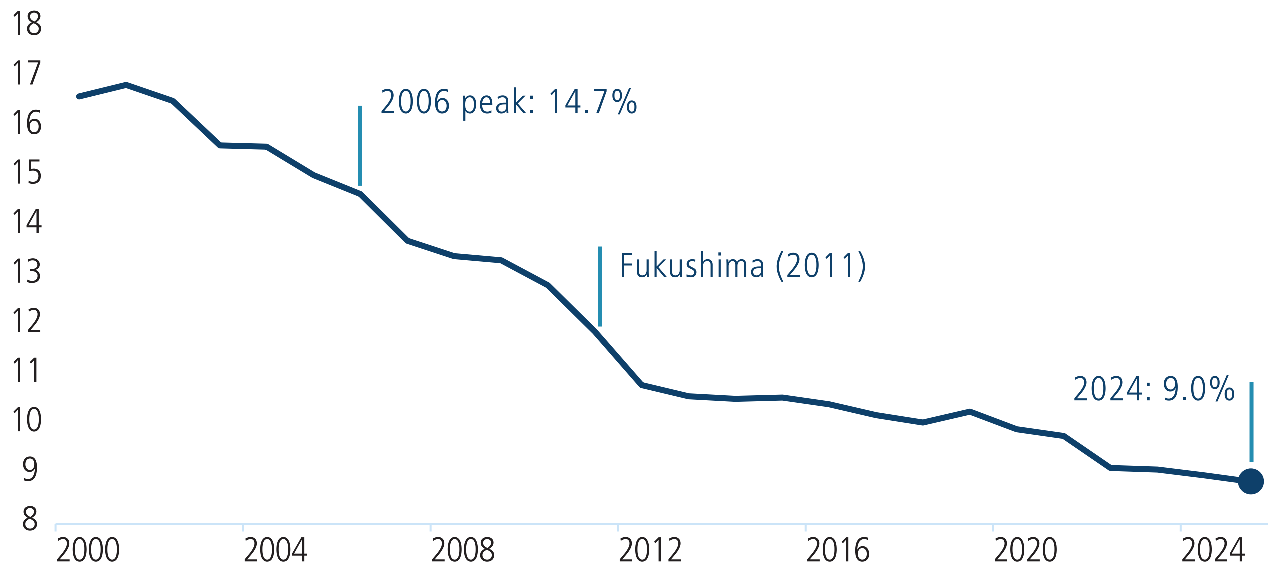
Source: United Nations Environment Programme (2025) – "Emissions Gap Report 2025: Off target", UNEP, Nairobi. Available at unep.org.

Why nuclear power, a low-carbon solution, is on the decline

Although nuclear power is one of the lowest-carbon baseload energy sources available, its share of global electricity generation has declined substantially over the past three decades, falling from a peak of 17.5% in 1996 to approximately 9% in 2024, the lowest level in four decades and approximately 45% below that 1996 peak.[11]

In 2024, global nuclear generation reached 2,677 terawatt-hours, a new record and a modest recovery from the post-Fukushima lows of the mid-2010s.[11] However, this recovery largely reflects France and Japan returning aging plants to service after extended maintenance outages, and continued expansion by China's state-owned operators. Outside China, nuclear generation in 2024 remained approximately 14% below its 2006 peak.[11] The record reflects the performance of existing conventional fleets, not new construction.

Nuclear Energy Share of Global Electricity Generation



Nuclear energy share of global electricity generation (%). Source: Energy Institute (2025), Statistical Review of World Energy 2025, Energy Institute, London. Available online at: https://www.energyinst.org/statistical-review/home.

Note: Outside China, 2024 generation remained approximately 14% below the 2006 peak.

The decline of conventional nuclear power reflects a combination of factors:

1. **Cost.** Aging infrastructure makes conventional nuclear power less profitable. Meanwhile, the total lifetime costs of wind and solar, covering construction, operation, and decommissioning, have dropped significantly, increasing competitive pressure on baseload generation, including nuclear.[12]

2. **Building new nuclear facilities using conventional technologies is expensive and time-consuming.** As of mid-2025, at least 26 of the 63 reactors under construction worldwide were behind schedule, with 14 reporting increased delays.[11] In 2024, only 7 of the 14 reactors originally scheduled for startup actually connected to the grid. The nuclear industry has also demonstrated a pattern of cost escalation in large projects, often driven by engineering complexity, regulatory requirements, and project management challenges.

3. **Safety and security concerns.** From the outset, there has been a strong awareness of the potential hazard of releasing radioactive materials. The disasters at Three Mile Island, Chernobyl, and Fukushima Daiichi stand as grave testaments to the potential health, environmental, and economic dangers of nuclear energy.[13] Nuclear plants can also become targets for malevolent acts, including terrorist threats, cyberattacks, or acts of war.

4. **Nuclear waste.** Since the start of nuclear electricity production in 1954, approximately 430,000 tons of spent fuel had accumulated worldwide by the end of 2022.[14] Only one-third of this waste has been reprocessed; the rest remains in storage.

"New" nuclear: Addressing risks with innovation

The Calamos Sustainable Equities Team has long recognized the economic, environmental, and safety risks of nuclear energy described above. We have maintained nuclear energy as one of our risk-based exclusionary screens as we seek to avoid companies directly involved in the operation and/or generation of conventional nuclear power.

With growing pressure to meet climate goals, the continued rise in global energy consumption, and meaningful technological advancements in reactor design, interest in a new generation of nuclear energy is growing. Unlike conventional pressurized water reactor technology, these new approaches target the root causes of nuclear power's four core challenges: reactor safety, nuclear waste, construction cost and time, and fuel cycle limitations. Around the world, companies are focused on creating long-term shareholder value by mitigating these risks with fundamentally different designs. The sections below examine each area of innovation in turn.

"New" nuclear: Enhancing reactor safety

The safety risks of conventional nuclear power are rooted in the pressurized water reactor design. Any meaningful improvement in nuclear safety therefore begins with addressing the physics of that design.

These reactors harness the heat from nuclear fission reactions to produce electricity. The water-filled core absorbs this heat, which must be continuously circulated to prevent overheating. Control rods can stop the fission reaction, but decay heat persists, necessitating constant cooling. If circulation pumps fail, as they did in the Fukushima Daiichi disaster, the remaining decay heat can cause a meltdown with catastrophic consequences. Water as a coolant poses additional risks; under extreme conditions, it can separate into hydrogen and oxygen, creating an explosive mixture. This was a contributing factor in both the Fukushima and Chernobyl disasters. Despite the availability of alternative coolants that do not present such explosive risks, water remains the primary coolant in current nuclear power plants, representing a significant operational safety concern.

Advancements have been made even in reactors that utilize water as a coolant. Generation III+ reactors represent the latest innovations in pressurized water reactor technology. These reactors are safer than their predecessors because of significant automation and passive safety system improvements. Automation reduces human error, a major cause of serious accidents, while passive safety systems rely on fail-safe mechanisms such as gravity.[15]

One of the greatest safety risks of conventional nuclear power plants results from using pressurized water as the coolant in the reactor core. Alternatives such as molten salt reactors utilize coolants that do not require pressurization and therefore cannot cause hydrogen explosions.

Calamos Sustainable Equities Team Risk-Based Exclusion Statement on Nuclear Energy

NUCLEAR ENERGY

We do not invest in energy companies involved exclusively in conventional nuclear energy generation. We do not support conventional nuclear power because we consider the cost of building new reactors and power plants to be high relative to the environmental, health, and safety risks associated with nuclear reactors and waste. From a financial risk perspective, conventional nuclear technologies maintain high capital costs, waste-disposal liabilities, accident risk, and significant regulatory delays.

NUCLEAR WASTE CONTEXT

A typical conventional reactor generates 20 to 30 tons of high-level nuclear waste annually. Despite recent progress, including the world's first permanent deep geological repository now under construction in Finland, the safe, permanent disposal of this waste remains an unresolved global challenge. The United States alone has paid **$11.1 billion** in damages to utilities for interim storage costs, with total projected future liability now estimated at **$37.6–44.5 billion.**[14]

First demonstrated at Oak Ridge National Laboratory in the 1960s, molten salt reactors offer a significant improvement over traditional designs by replacing water with molten salt as the reactor core coolant. This change eliminates many risks associated with water-cooled reactors, including core depressurizations, steam flashing, and hydrogen explosions. Molten salt operates at temperatures over 700 degrees Celsius without pressurization, making these reactors both safer and more thermally efficient.[15]

Molten salt reactors also dissolve uranium fuel directly in the coolant mixture, eliminating fuel rods and the risk of core meltdown. If the coolant pumps stop, the fission chain reaction stops, and the coolant drains into an emergency reservoir. This passive shutdown mechanism eliminates the most severe failure modes associated with pressurized water reactors.[15]

Molten salt reactors: Mitigating the risks of nuclear power plants

	PRESSURIZED WATER REACTOR	MOLTEN SALT REACTOR
Operating pressure	155 bar	1 bar (atmospheric)
Coolant temperature	~325°C	700°C+
Hydrogen explosion risk	Yes	No
Passive shutdown	No — active cooling required after shutdown	Yes — coolant drains to emergency reservoir
Core meltdown risk	Present	Eliminated by design
Waste per reactor/year	20 to 30 tons high-level waste	Significantly reduced; varies by design

Source: World Nuclear Association (2024) – "Safety of Nuclear Power Reactors", published online at world-nuclear.org, and OECD Nuclear Energy Agency (2025) – "Extended Storage and Transportation of Spent Fuel and Radioactive Waste from Current and Future Reactor Technologies: Summary of the Workshop", OECD/NEA, Paris. Available at oecd-nea.org. p. 1.

"New" nuclear: Innovations in waste reduction

Reactor safety and nuclear waste are closely connected problems; both stem from the same fuel cycle that drives conventional fission. New approaches address waste not only through better storage, but by fundamentally changing how fuel is used and what remains after the reaction.

Fuel recycling and reprocessing

Natural uranium consists primarily of uranium-238 (U-238), with approximately 0.7% uranium-235 (U-235). Because U-235 is the fissile isotope needed to sustain a nuclear chain reaction, traditional reactors use an enrichment process to increase its concentration. The enrichment process produces two outputs:

1. **Low-enriched uranium,** which serves as reactor fuel, and depleted uranium, which is typically considered nuclear waste and stored in cylinders at enrichment facilities.

2. **Spent fuel,** which is removed from the reactor when it can no longer sustain an energy-producing reaction and disposed of in dry casks at reactor sites or in deep geological repositories.[16]

Fuel recycling and reprocessing offer an alternative pathway. Approximately 96% of spent fuel, comprised of uranium-238 and less than 1% plutonium, can be recovered and reused. Recovered uranium can be re-enriched to produce new reactor fuel, and recovered fissile plutonium can also be used as fuel.[17] The remaining 4% that cannot be reused is placed in storage.[18]

While technically feasible, nuclear fuel reprocessing remains limited in practice and is not currently deployed commercially in the United States, where policy instead emphasizes direct disposal and interim on-site storage of spent fuel. Most U.S. nuclear waste is therefore stored at reactor sites in wet pools or dry cask systems, as no permanent repository has yet been established.[19] The federal government, which was obligated to take possession of this spent fuel under the Nuclear Waste Policy Act, has already paid more than $11.1 billion in damages to utilities for failure to do so, with total projected future liability now estimated at $37 billion to $44.5 billion.[20] Annual damage payments to utilities currently run as high as $800 million per year, with no permanent disposal solution in sight. [20]

France is a notable exception. With one of the highest shares of nuclear power in its energy mix, France sends its spent fuel to a reprocessing plant, recovering uranium and plutonium for reuse and reducing the volume of high-level waste. This approach lowers France's requirement for natural uranium by approximately 17%.[21]

Breeder reactors

In traditional reactors, fissile material such as uranium-235 is required for fission to occur. Most of the fertile material, uranium-238, is not consumed and remains in spent fuel unless it is reprocessed.

Breeder reactors are designed to convert this unused fertile material into additional usable fuel, generating more nuclear fuel than they consume. In a breeder reactor, uranium-238 is converted into fissile plutonium. Whereas conventional reactors use approximately 1% of uranium-238, breeder reactors can utilize up to 70%, extending the fuel supply and improving overall efficiency.[22]

Spent fuel from breeder reactors can also be reprocessed to extract new usable fuel. This cycle can be repeated multiple times, producing substantially more energy from the original fuel. As a result, the portion of fuel that ends up as waste is reduced by up to 80% compared to conventional reactors.[23]

Alternative fuel sources: Thorium

Thorium is a promising alternative to uranium because of its greater natural abundance and more efficient utilization in reactor designs, which leads to a significant reduction in spent fuel and radioactive waste. In breeder reactors, thorium is more effective than uranium at converting fertile material into fissile material.[24] Because thorium fuel produces more energy per ton, it generates less radioactive waste than uranium-fueled reactors.[25]

"New" nuclear: Fusion

The innovations described above reduce the risks of fission. Fusion takes a different path entirely; it replaces the fission reaction with a process that produces no long-lived radioactive waste and carries none of the meltdown or proliferation risks associated with conventional nuclear technology.

Nuclear fusion combines two light atomic nuclei to form a single heavier nucleus, releasing large amounts of energy in the process. Fusion has the potential to produce four times the energy per kilogram of fuel compared to fission, and approximately four million times more energy than burning oil or coal.[26]

Fusion produces no long-lived radioactive waste, no greenhouse gas emissions, and no weapons-grade material. The primary byproduct is helium. The fuel source, hydrogen isotopes derived from seawater, is effectively unlimited in supply. A fusion reactor cannot melt down; if plasma conditions are not maintained, the reaction simply stops.

Achieving the conditions necessary for a sustained fusion reaction has been a significant scientific and engineering challenge. In December 2022, the US National Ignition Facility (NIF) demonstrated fusion ignition for the first time, producing more energy output than the laser energy input. This milestone was repeated in 2023.[27]

Private investment in fusion has grown substantially since that milestone. The sector has attracted significant private capital in recent years, with cumulative global investment now exceeding $9 billion, reflecting growing investor confidence in the commercial potential of fusion energy.[28] Commonwealth Fusion Systems, TAE Technologies, Helion Energy, and others have moved from research stages into engineering development. In 2023, Microsoft signed the world's first commercial fusion power purchase agreement with Helion Energy, targeting electricity delivery by 2028.[29]

Commercial fusion power plants remain a decade or more from deployment. However, the supply chain supporting fusion development, including advanced superconducting magnets, plasma diagnostics, high-temperature materials, and precision control systems, offers investable opportunities that are relevant today, ahead of commercial plant construction.

Higher risk — Moderate risk — Lower risk

	CONVENTIONAL FISSION	ADVANCED FISSION / SMR	FUSION
Waste profile	Long-lived high-level waste; 20-30 tons per reactor per year	Significantly reduced; varies by design	Short-lived; helium only
Meltdown risk	Present; requires active cooling	Reduced via passive safety systems	None; reaction stops if conditions not met
Proliferation risk	Present; enriched uranium and plutonium byproducts	Reduced; depends on fuel cycle design	Minimal; no weapons-grade material produced
Fuel availability	Uranium supply finite; mining required	Uranium or thorium; thorium more abundant	Hydrogen isotopes; effectively unlimited from seawater
Commercial timeline	Deployed today (aging fleet)	SMRs: first license 2025;deployment 2030+	Hydrogen isotopes; effectively unlimited from seawater

Source: Original Calamos analysis. Fusion data: IAEA (2023); Kuranz (December 2022), PBS.org.

"New" nuclear: Small modular reactors

While molten salt reactors, breeder reactors, and fusion address the safety and waste dimensions of the nuclear challenge, small modular reactors (SMRs) target a different constraint: the prohibitive cost and lengthy construction timelines associated with conventional large-scale nuclear plants.

SMRs are designed around an assembly-line manufacturing model, with components fabricated in factories and assembled on site. This approach has the potential to reduce the cost overruns and project delays that have long characterized conventional nuclear construction. If successfully executed, the factory-build model could enable economies of scale similar to those achieved in industries such as gas turbines or aircraft engines, reducing per-unit costs over successive builds.[30]

SMRs also offer operational flexibility that conventional reactors cannot match. Microreactors, a specialized subset of SMRs with capacities of up to 10 MW(e), can operate independently of transmission grids, providing low-carbon power to remote industrial sites, communities without grid access, and locations currently reliant on diesel generation.[31]

Despite these advantages, progress in Western markets lagged early expectations. For more than a decade, SMR development was characterized by announcements rather than deployment. NuScale Power, the most prominent US developer, spent approximately $2 billion before cancelling its only commercial project in 2023 due to cost escalation. Similarly, Argentina's CAREM-25 project was abandoned in December 2024 after it was deemed economically uncompetitive.[32]

The first concrete milestone came in April 2025, when Canada's Nuclear Safety Commission granted Ontario Power Generation a license to construct a GE Vernova Hitachi BWRX-300 at the Darlington site, the first SMR construction license issued in a G7 country. Four units are planned, totaling 1,200 MW, with a combined capital cost of approximately C$20.9 billion. The first unit is estimated at C$7.7 billion, reflecting typical first-of-a-kind economics, while subsequent units are expected to benefit from cost reductions as the factory model matures. Grid connection is targeted by end of 2030, and the project has drawn international attention from utilities evaluating similar deployments.[32]

The BWRX-300 is also advancing in other key markets. In the United Kingdom, it completed Step 1 of the Generic Design Assessment in December 2024, while in the United States, the Tennessee Valley Authority submitted a construction permit application for its Clinch River site in May 2025.[32]

Our focus: Niches of sustainable opportunity in the nuclear power ecosystem

Conventional nuclear technologies continue to carry significant financial, safety, and environmental risks, which is why we believe our risk-based exclusionary screen aligns with prudent investing. However, a growing range of innovations offers the potential to reduce these risks and make nuclear power a more viable contributor to a low-carbon energy system. Here is where we find attractive investment niches.

Our exclusionary screen states that we will generally avoid energy companies earning more than 5% of revenues from conventional nuclear energy generation. While the Calamos Sustainable Equities Team is optimistic that new innovations will address existing environmental and safety concerns, to date, we have not identified any generation companies that meet both our financial and non-financial criteria. Several pure-play nuclear developers have attracted significant investor interest, but as pre-revenue or early-revenue businesses without commercial operating track records, they do not meet our quality criteria, which require well-capitalized companies with demonstrated returns on invested capital and consistent cash generation above the cost of capital.

We have, however, found investment opportunities in diversified companies that we believe are advancing safe and innovative nuclear technologies. We highlight three below.

Schneider Electric has partnered with Terrestrial Energy, a developer of Generation IV advanced nuclear power plants, to deploy Terrestrial Energy's Integral Molten Salt Reactor (IMSR) technology. The IMSR uses molten salt rather than pressurized water as its coolant, which removes the hydrogen explosion risk inherent in conventional reactors. The technology is designed to provide zero-emission baseload power to industrial facilities and large data centers, a market that has grown considerably since the original publication of this paper.[33]

Through this partnership, Schneider Electric and Terrestrial Energy are also leveraging digital twin software to create virtual models of the reactor for design, testing, and development prior to physical construction. This reduces project development time and cost and improves operational efficiency. In April 2023, the Canadian Nuclear Safety Commission concluded that there were no fundamental barriers to licensing the IMSR plant for commercial use.[34]

Siemens AG's Siemens Digital Industries Software unit develops Simcenter STAR-CCM+, which is used in the design and virtual testing of advanced nuclear reactor concepts. X-energy applies it to its pebble bed reactor, modeling how heat moves through the reactor core in a level of detail that older design tools cannot match. Siemens also uses the software on liquid-metal-cooled Generation IV designs, including TerraPower's, where its simulations have closely tracked the results of physical experiments.[35]

Siemens Digital Industries Software contends that a comprehensive digital twin can cut the design cycle for new reactor technology in half and substantially reduce the cost of testing required to support licensing.[35] The broader Xcelerator portfolio supports the full nuclear asset lifecycle, from conceptual engineering through operations and decommissioning, providing product lifecycle management, simulation, and data management tools that connect design, regulatory, and operational information. Without high-fidelity digital twin technology, Siemens argues, many next-generation reactor designs will not make it through the licensing and commissioning phase, given the regulatory requirement to demonstrate safety performance without the ability to test a full-scale reactor to destruction.

GE Vernova is a global energy technology company spun off from General Electric in April 2024, encompassing GE's power generation, wind, and electrification businesses. Through its nuclear division, GE Vernova has partnered with Hitachi to form GE Vernova Hitachi Nuclear Energy, one of the world's most capable advanced nuclear development and services operations. The joint venture is at the forefront of two of the most significant advanced reactor programs underway globally.

Its BWRX-300 small modular reactor is a 300 MW water-cooled, natural circulation design incorporating passive safety systems that cool the reactor without active pumping. The BWRX-300 became the first SMR to receive a construction license in a G7 country when Canada's Nuclear Safety Commission approved the Darlington New Nuclear Project in April 2025.[36]

GE Vernova Hitachi is also a key technical partner in TerraPower's Natrium project in Kemmerer, Wyoming. The Natrium reactor is a 345 MW design cooled by liquid sodium rather than water, again using natural circulation rather than active pumping. Unlike conventional reactors, it runs on recycled nuclear fuel and depleted uranium, substantially reducing both the volume and the longevity of the waste it produces. In June 2024, TerraPower broke ground on a facility to handle the reactor's sodium coolant at the Kemmerer site, with commercial operation now projected for 2031.[36] In June 2025, Nvidia participated in a $650 million TerraPower funding round, reflecting growing interest from the technology sector in advanced nuclear development.[32]

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