Nuclear Power: Understanding a changing frontier of opportunity and risk

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Skyrocketing global energy consumption intensifies demand for low-carbon solutions

Demand for energy is growing in many countries as people get richer and populations increase. Globally, primary energy consumption[1] has increased nearly every year for at least half a century. Although energy-efficiency improvements have slowed the rate of change in consumption, energy usage is still trending upward at 1% to 2% per year.[2]

The world's increased use of artificial intelligence (AI) is intensifying the global energy challenge. Data centers, where AI models are hosted, already account for approximately 1% to 1.5% of global electricity use,[3] and this figure is expected to climb to 3% to 4% by the end of the decade.[4]

Powering the world's growing demand requires multiple energy sources. On a global basis, the largest amount of energy comes from oil, followed by coal, gas, and hydroelectric power. Given that fossil fuels drive the current energy mix, global greenhouse emissions have increased approximately 5% since 2020, 9% since 2010, and 32% since 2000, reaching 53.85 billion tons in 2022.[5]

- **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.

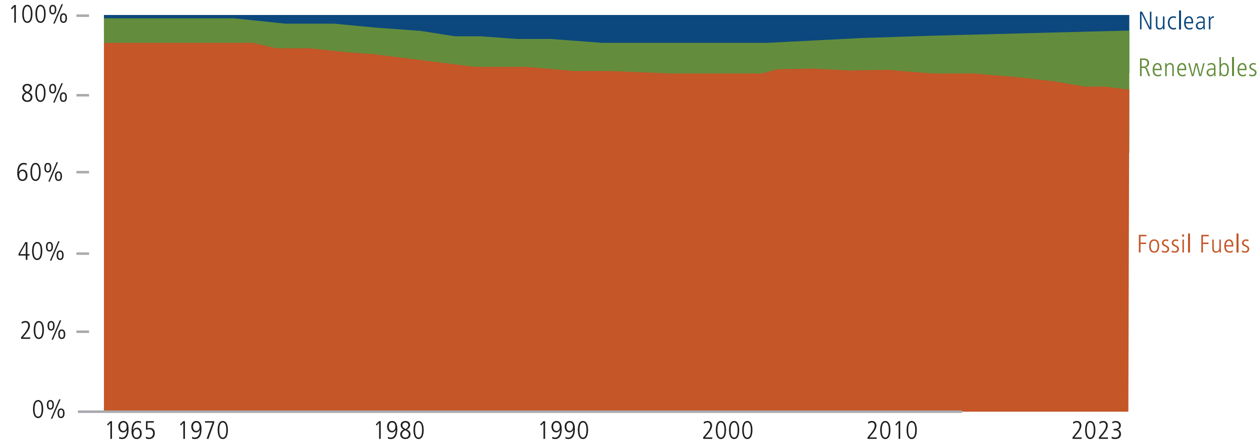
- **Clean energy revolution.** The energy sector is in a period of rapid transition. Global demand is growing, and at the same time, countries worldwide are seeking to address climate crises through reduced reliance on fossil fuels.

- **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.

The share of primary energy from low-carbon sources (defined as the sum of nuclear energy and renewables, which includes hydropower, wind, solar, bioenergy, geothermal, and wave and tidal) has increased, up 4.5% from 2020, 32% from 2010, and 28% from 2000.[6] Despite the decline in fossil fuels and the growth of renewables (ex-nuclear), the decline of available nuclear power has prevented the world from meaningfully addressing our energy and climate conundrum.

The world's primary energy consumption from fossil fuels, nuclear, and renewables



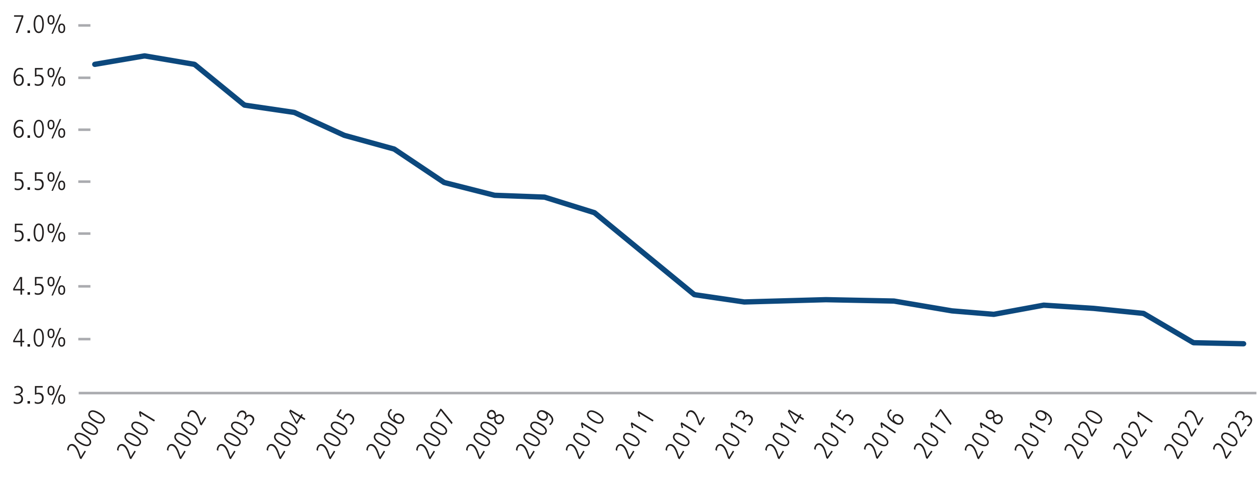
Source: Hannah Ritchie and Pablo Rosado (2020) - "Energy Mix" Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/energy-mix' [Online Resource] Data source: Energy Institute-Statistical Review of World Energy (2024). Primary energy (energy available as resources, such as the fuels burnt in power plants, before it has been transformed) is based on substitution method. The substitution method is used by researchers to correct primary energy consumption for efficiency losses experienced by fossil fuels. It tries to adjust non-fossil energy sources to the inputs that would be needed if it were generated from fossil fuels. Renewables include hydropower, solar, wind, geothermal, wave and tidal, and bioenergy, but not traditional biofuels.

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

Although nuclear power is one of the lowest-carbon-baseload energy sources available, global terawatt-hour usage of nuclear power has decreased by approximately 7% from 2000 to 2023.[7] A large portion of this decline followed the 2011 Fukushima tsunami, which led to the closure of many nuclear reactors in Japan.

Decline in nuclear energy consumption

% of energy consumption by source, world



Source: Energy Institute - Statistical Review of World Energy (2024) – with major processing by Our World in Data. "Biofuels consumption" [dataset]. Energy Institute, "Statistical Review of World Energy" [original data].

More broadly, the decline in nuclear power over the past two decades reflects a combination of factors, including:

1. **Cost**. Aging infrastructure makes nuclear power less profitable. Meanwhile, natural gas prices have declined and total lifetime costs of wind and solar (i.e., total costs from initial investment to decommissioning, including the amount of energy generated) have dropped significantly.[8]

2. **Building new nuclear facilities using conventional technologies is expensive and time-consuming.** Since 2009, the average construction time for reactors worldwide was nearly 10 years, according to estimates from the 2021 World Nuclear Industry Status Report—well above the estimate given by the World Nuclear Association (WNA) industry body of between 5 and 8.5 years.[9] Moreover, the nuclear power industry has failed to manage costs effectively, often because of corruption and inefficiency in large public works projects.

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.[10] Nuclear plants can also become targets for malevolent acts, such as terrorist threats, voluntary airliner crashes, cyberattacks, or acts of war.

4. **Nuclear waste.** Since the start of nuclear electricity production in 1954, approximately 390,000 tons of spent fuel have been generated worldwide.[11] Only one-third of this waste has been reprocessed, while 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. We have included 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 nuclear power.

However, with the growing pressure to meet climate goals, the uptick in energy consumption globally, and new nuclear technological advancements, interest in nuclear energy is growing. Around the world, companies are focused on creating long-term shareholder value by mitigating key risks with "new" nuclear strategies, such as those we outline below.

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

NUCLEAR ENERGY. We do not invest in energy companies involved exclusively in nuclear energy generation. We do not support nuclear power because we consider the cost of new nuclear installations to be high relative to the environmental, health, and safety risks associated with nuclear reactors and waste. A typical reactor will generate 20–30 tons of high-level nuclear waste annually. There is no known way to safely dispose of this waste, which remains dangerously radioactive.

"New" nuclear: Enhancing reactor safety

The case against nuclear energy—particularly avoiding nuclear meltdowns—is rooted in the inherent dangers of the pressurized water reactor design widely used today.

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. Using 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 don't present such explosive risks, water remains the primary coolant in current nuclear power plants, representing a significant operational safety concern for nuclear energy.

However, advancements have been made, even in reactors that utilize water as a coolant. Today, 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-systems improvements. Automation reduces human error, a major cause of serious accidents, while passive safety systems rely on fail-safe mechanisms like gravity.[12]

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

First invented in the early 1960s, molten salt reactors offer a significant improvement over traditional nuclear reactors by replacing water with molten salt as the reactor core coolant. This change eliminates many risks associated with water-cooled reactors, such as core depressurizations, steam flashing, and hydrogen explosions. Molten salt operates at temperatures over 700°C without pressurization, making these reactors safer and more efficient.[13]

Another advantage of molten salt reactors is that they dissolve uranium fuel in the coolant mixture, eliminating fuel rods and the risk of core meltdown. If the coolant pumps stop, the nuclear fission chain reaction stops, and the coolant drains into an emergency reservoir. The design of liquid-fueled molten salt reactors thereby eliminates the risk of the most severe failures that can occur in pressurized water reactors.[14]

"New" nuclear: Innovations in waste reduction

Nuclear waste and storage are focal points of concern, and rightfully so. However, companies are addressing complex challenges through fuel recycling and reprocessing.

Fuel recycling and reprocessing. Before exploring the long-term opportunity of fuel recycling and reprocessing, we'll quickly review how nuclear energy has traditionally been produced and how waste has been stored. Natural uranium, primarily consisting of uranium-238 (U-238) with about 0.7% uranium-235 (U-235), is not fissile enough to sustain a nuclear chain reaction. Traditional reactors use enrichment to increase the concentration of U-235, the readily fissionable isotope needed to produce nuclear power. The result of enrichment is two-fold:

1. Low-enriched uranium, which serves as nuclear fuel and depleted uranium. Depleted uranium is typically considered nuclear waste and is stored in cylinders at enrichment facilities.[15]

2. Following the enrichment process, when nuclear fuel can no longer sustain an energy-producing reaction, the spent fuel is removed from the reactor and disposed of in dry casks at reactor sites and deep geological repositories.[16]

Fuel recycling and reprocessing offers an alternative: Approximately 96% of spent fuel, which is comprised of two elements: uranium (U-238) and less than 1% plutonium, can be recovered separately. Recovered uranium can be re-enriched to produce new nuclear fuel, while the recovered fissile plutonium can also be used to create nuclear fuel.[17] The remaining spent fuel (4%), which cannot be reused, is then placed in storage.[18]

While possible, fuel reprocessing and recycling are rarely utilized. For example, the United States primarily stores its nuclear waste, a decision that results in increased costs. The US government has paid reactor owners about $9 billion for storage, and it's estimated that it will cost an additional $30.9 billion until a permanent waste disposal option is completed. The cost of cleaning up nuclear waste in the United States is also significant, with taxpayers paying $6 billion every year.[19]

France is an exception. France has one of the highest shares of nuclear power in its energy production. The country utilizes pressurized water reactors across its power reactor fleet, a fleet that produces nearly 1,150 tons of spent fuel annually. However, unlike most other countries, France closes its national nuclear fuel cycle by sending its spent fuel to a reprocessing plant. In doing so, the French nuclear industry can recover uranium and plutonium from the used fuel for reuse and reduce the volume of high-level waste, thereby lowering its need for natural uranium by 17%.[20]

Breeder reactors. Shifting from pressurized water reactors to breeder reactors is another significant advancement in nuclear technology that can address nuclear waste disposal problems. In traditional reactors, fissile material (for example, uranium-235) is required for fission to occur; while most of the fertile material (uranium-238) is not used and remains in spent fuel unless it is reprocessed.

Breeder reactors are different because they can turn this unused fuel into more usable fuel, thereby generating more nuclear fuel than they consume. For example, in breeder reactors, uranium-238 can be converted into fissile plutonium. Whereas normal reactors only use 1% of uranium-238, breeder reactors use up to 70%, extending the fuel supply and improving the reactor's efficiency.[21]

Moreover, spent fuel from breeder reactors can be reprocessed to extract new usable fuel, which can be used to extend the fuel's lifecycle. This process can be repeated several times, producing 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 traditional reactors.[22]

Alternative fuel sources to uranium. Solving for nuclear waste has also led to technological advancements that yield more energy. Thorium stands out as a promising alternative nuclear fuel because of its abundance and efficient utilization in reactors, which leads to a significant reduction in the production of spent fuel and radioactive waste. In breeder reactors, thorium is more effective than uranium in converting fertile into fissile material.[23] Additionally, because thorium fuel produces more energy yield per ton, it generates less radioactive waste than reactors powered by uranium.[24]

"New" nuclear: Fusion, a potential gamechanger

Although likely much further out on the horizon, nuclear fusion is another promising nuclear innovation. Fusion combines two light atomic nuclei to form a single heavier one, releasing massive amounts of energy. Fusion has the potential to produce four times the energy per kilogram of fuel compared to fission and almost four million times more energy than what is generated by burning oil or coal.[25] Fusion power plants wouldn't emit greenhouse gases or produce dangerous, long-lived radioactive waste.[26] Achieving the necessary conditions for a sustained fusion reaction is a significant challenge, but we are seeing a number of companies work toward the goal.

"New" nuclear: "Small" solutions could lead to large cost and efficiency improvements

Traditional nuclear reactors are costly to run and relatively inefficient. We're watching with interest as new innovations are developed, such as small modular reactors (SMRs). SMRs have the potential to change the risk/reward of nuclear power from economic, environmental, human development, and investment standpoints. SMRs are advanced reactors that can produce a significant amount of low-carbon electricity and are considered to have enhanced safety features due to their smaller size and innovative design.

SMALL	MODULAR	REACTORS
SMRs are physically smaller than traditional nuclear reactors, typically having a power capacity of up to 300 MW(e) per unit.[27] This is about one-third of the generating capacity of conventional nuclear power reactors.	SMRs are designed to be factory-assembled and transported as a unit to the installation site.[28] This modular approach allows systems and components to be standardized and mass-produced, which can reduce costs and construction times.	Like all nuclear reactors, SMRs harness nuclear fission to generate heat, which is then used to produce energy.[29]

The assembly-line manufacturing of SMRs could offer a potential solution to the cost and schedule overruns in traditional nuclear power plant construction projects. This approach, similar to the mass production of automobiles and aircraft, is not without risks but could offer the nuclear power industry the same economies of scale, reducing costs and improving efficiency. Although the data is patchy about the amount of waste produced, SMRs also have the advantage of containing all the nuclear waste within the reactor itself, reducing the cost of decommissioning.[30]

SMRs, particularly microreactors, offer a versatile solution for energy generation in areas with inadequate transmission infrastructure. They can be integrated into existing grids or operate independently, providing low-carbon power to both industries and local populations. Microreactors, a specialized type of SMR, have a capacity of up to 10 MW(e) and a smaller footprint, making them ideal for areas without access to clean energy. They also have the potential to act as emergency power sources or replace diesel generators in remote locations, offering a more sustainable and reliable alternative.[31]

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

Traditional nuclear technologies continue to assume significant financial, safety, and environmental risks. However, exciting technologies offer the potential to mitigate these risks and make nuclear power a more viable and palatable alternative to fossil fuels.

Accordingly, at this time, we believe it is appropriate to keep our risk-based exclusionary screen in place. Our screen states that we will generally avoid energy companies earning more than 5% of revenues from traditional nuclear energy generation. While the Calamos Sustainable Equities Team is optimistic that new innovations will address the existing environmental and safety concerns, to date, we have not identified any generation companies that meet both our financial and non-financial requirements. That said, we have found investment opportunities in diversified companies that we believe will assist in bringing safe and secure nuclear power to the table. Below, we highlight three.

» **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. This technology provides zero-emission power to industrial facilities and large data centers.[32] Through this partnership, these companies are also leveraging Digital Twin software that creates virtual models to design, test and develop prior to construction, which results in a reduction of project time to market and cost as well as more efficient operations. This collaboration offers solutions to the major energy challenges faced by many heavy industries operating a wide range of industrial processes. In April 2023, the Canadian Nuclear Safety Commission concluded that there were no fundamental barriers to licensing the IMSR plant for commercial use.[33]

» **Dassault Systemes SE** is currently making significant strides in the nuclear energy sector. Dassault focuses on developing advanced nuclear reactors, particularly SMRs, to help meet climate targets. Looking ahead, Dassault Systemes SE plans to continue exploring nuclear energy. The company is considering the possibilities of nuclear fusion, aiming to harness the sun's power and develop energy infrastructure capable of delivering electricity to the grid.[34]

» **Hitachi** is involved in the nuclear energy sector through various divisions and projects. Hitachi has partnered with General Electric to form one of the world's most comprehensive nuclear power plant and services operations. Regarding molten-salt reactors, Hitachi-GE Nuclear Energy is developing four new reactor designs, one of which is the PRISM, an innovative, small modular sodium-cooled fast reactor.[35] As for breeder reactors, Hitachi-GE Nuclear Energy is developing the Resource-Renewable Boiling Water Reactor (RBWR), a light-water-cooled fast reactor.[36] GE-Hitachi has also created an advanced nuclear reactor called the Power Reactor Inherently Safe Module (PRISM), a sodium-cooled reactor that can burn recycled used nuclear fuel and depleted uranium.[37] Additionally, Hitachi has been part of the nuclear fusion field from the earliest stages of fusion research, designing and manufacturing experimental equipment in Japan. This includes the coils and vacuum vessels used in the main reactor bodies, neutral beam injectors, controllers, and power supply systems.[38]

The Calamos Sustainable Equities Team is committed to continuing our analysis of the promising innovations in the nuclear power ecosystem. We, as a team, understand how the energy mix contributes to the gravity of the climate crisis. We urge regulators, countries, public and private investments as well as investors to push the envelope across all low-carbon energy sources, including nuclear.

[1] Primary energy consumption refers to the total energy demand of a country, encompassing energy used within the energy sector itself, losses during transformation, distribution losses, and final consumption by end users.

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