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Jed Dorsheimer +1 617 235 7555
jeddorsheimer@williamblair.com

Mark Shooter +1 617 235 7593
mshooter@williamblair.com

"SWU"ning Over Nuclear

Deregulation and Expanding Enrichment Capacity

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Introduction

The world has remembered why it fell in love with commercial nuclear power: It produces the densest power available at scale, with the highest capacity factor and zero carbon emissions—the ideal combination of attributes for electrification. Anthropogenic scale and economic growth have always tracked energy density: coal and the industrial revolution; oil in the roaring 1920s; and most recently natural gas. Nuclear was seen as the clean replacement for hydrocarbons, so what happened? In this paper, we explore our thesis that the conflation with nuclear weapons and the leftover sentiment from the 1960s counterculture movement enabled long-lasting regulatory bloat to suppress the tremendous potential of nuclear energy in the West, which created space for a false narrative around renewables to fill our energy needs.

The fear from the rise of nuclear weapons and incidents at Three Mile Island, Chernobyl, and Fukushima ended any midcentury romance and replaced it with overregulation and "not in my backyard" (NIMBY) fears. An industry that saw over 50 planned and permitted reactors between 1960 and 1979 rapidly shifted to a cancel culture, canceling 67 builds between 1979 and 1988. The fear of nuclear energy is contorted, and NIMBY proponents disregard the fact that the U.S. nuclear power industry has the safest track of any generation source including both solar and wind.

The next challenge is de-risking our nuclear fuel supply chain from Russia, specifically uranium enrichment. U.S. enrichment capacity peaked in 1985 at 27 million separative work units (SWU) per year, but after our love for nuclear power waned, it fell to near zero by 2010, all while Russian enrichment capacity did the exact inverse. Today, the U.S. has only one operating enrichment facility with a capacity of 4.9 million SWU, a third of the 15 million SWU required for the U.S. commercial nuclear fleet. Urenco, a British, Dutch, and German consortium, owns and operates the enrichment capacity in the U.S. There is no American-owned uranium enrichment capacity for commercial use in the U.S. The Russian-Ukraine war has stressed geopolitical relations, and the U.S. has restricted Russian SWU imports, but at the same time issued waivers through 2025 until we can replace that capacity domestically. In 2023, the U.S. still imported 4 million SWU from Russia, 27% of our demand. Our supply-demand model helps contextualize the key challenges in the supply chain, specifically highlighting shortages in the global enrichment supply when excluding Russian, and even Chinese, capacity. We argue that funding of American-owned domestic enrichment capacity is a strategic imperative for U.S. energy independence and national security.

After discussing regulation and nuclear fuel enrichment, we explore three modalities of a nuclear renaissance: 1) uprating and extending the operating life of existing nuclear reactors, 2) restarting decommissioned nuclear reactors, and 3) deploying next-generation small modular reactors (SMRs) and microreactors in the commercial power sector. A modernization of the nuclear energy regulatory regime, coupled with an expansion of the global nuclear fuel enrichment supply through capacity investments, should facilitate a nuclear renaissance by driving reactor uprates and the deployment of SMRs and microreactors.

The report also includes the application of our unique biophysical systems approach to energy investments. We analyze the energy return on investment (EROI), a metric based on the immutable laws of thermodynamics, which demonstrates one of the highest ratios we have seen in the energy sector in over 50 years. This metric, which we outlined in our inaugural report, The Red Pill, connects return on invested capital (ROIC) with EROI, emphasizing their fundamental interdependence. EROI relies on efficient energy utilization, and energy itself is governed by thermodynamic principles. By analyzing the energetics of systems, we can uncover deeper insights into the potential financial returns of energy investments, namely whether a technology has potential for real vs. nominal ROIC. We demonstrate the highest EROI pursuit for our energy grid is uprating and restarting nuclear facilities; however, if regulations are eased and modular reactors scale to run recycled fuel, these too have the potential to provide significant real value creation. To date, this remains mostly theoretical though.

This report serves as part of a compendium with our initiations of BWX Technologies, Centrus Energy, and Oklo.

Four Nuclear Executive Orders

On Friday, May 23, the Trump administration issued four executive orders to promote the nuclear commercial power industry. We view these actions as the most consequential shift in energy policy of our lifetimes. Below we summarize the actions taken in the executive orders.

Reforming the Nuclear Regulatory Commission (NRC)
As we will detail in our report later, the NRC and its overburdensome regulatory regime has been the largest impediment to the nuclear industry. We view this executive order as the most important of the four, enacting a culture shift and changing the goal of the NRC from maximum prohibitive regulation to a balance of safety and economic benefit with the aim to promote nuclear power. The entire supply chain will benefit, especially SMR and microreactor companies.

Key points:

- Reduce NRC review process timeline to maximum 18 months, from often 5 or more years
- Revise scope of National Environmental Policy Act (NEPA) on nuclear reactors
- Replace the overburdensome linear no-threshold (LNT) model
- Establish expedited approval for reactors tested by the Department of Defense (DOD) and Department of Energy (DOE)
- Establish high-volume and standardized applications for SMRs and microreactors

Reinvigorating the Nuclear Industrial Base (Nuclear Fuel Cycle)
This executive order seeks to reduce U.S. dependence on foreign sources by funding a buildout of domestic supply chains to support the current nuclear fleet and an expansion of production by four times by 2050. Emphasized here are uranium enrichment, recycling, uprates, and new reactors, which will benefit companies like Centrus Energy, BWX Technologies, Oklo, and GE Vernova.

Key points—the DOE is instructed to:

- Fund off-take agreements for new domestic nuclear fuel materials
- Deliver report by January 2026 to close the nuclear fuel cycle including recycling
- Prioritize 5 GW in uprating of existing nuclear fleet
- Start construction of 10 new large reactors by 2030

Deploying Advanced Nuclear Reactor Technologies for National Security
In this executive order, AI is defined as a national security objective and the order sets a priority for the DOE and DOD to work with private industry to accelerate deployments of SMRs to power AI. We view Oklo, BWX Technologies, and other companies working on SMRs and microreactors as beneficiaries.

Key points:

- Designate DOE sites appropriate for advanced nuclear reactors in 30 months
- Deploy an advanced nuclear reactor within three years
- Release 20 MT of HALEU for advanced reactor design use

Streamlining Nuclear Reactor Testing at the Department of Energy
This executive order places the design, construction, and operation of reactors under the purview of the DOE. This will shield the approval process from many of the regulatory burdens from the NRC, NEPA, and others, and accelerate the development time frame. We believe this benefits all companies building generation IV reactors, such as Oklo.

Key points:

- Place advanced reactors under DOE regulatory approval
- Eliminate environmental reviews for DOE advanced reactor testing
- Accelerate process to allow first operation within two years of completed application
- Create pilot program by July 4, 2026, to deploy three reactors

Understanding the Regulatory Burden

Nuclear energy will play a role in future electricity generation, but the nuclear regulatory regime is a significant inhibitor. Demand for nuclear energy continues to grow, but regulatory friction is slowing the development of nuclear reactors. For example, the Federal Energy Regulatory Commission (FERC) recently rejected the interconnection agreement between Talen Energy and Amazon under the premise that the energy connection draws from wider grid benefits. The parties are still pursuing the deal regardless of the regulatory setback, which is symbolic of the industry's relentless pursuit of reviving nuclear generation capacity.

We believe that nuclear power is severely constrained by the cost of regulation, herein called regulatory burden, which amounts to a significant percentage of the total cost of nuclear power. Operating a nuclear power plant in the U.S. carries a significant regulatory burden, including licensing, construction oversight, operational compliance, radiation safety, waste management, environmental monitoring, decommissioning, and liability insurance. The U.S. regulatory environment significantly inflates nuclear power costs, akin to forcing auto manufacturers to offer million-mile bumper-to-bumper warranties, theoretically feasible, but economically impractical. We believe the combination of Nuclear Regulatory Commission Chairman David A. Wright and Secretary of Energy Chris Wright sets the stage for the most favorable regulatory overhaul since the creation of the NRC in 1975. Therefore, we believe this could be the catalyst for a nuclear renaissance.

Nuclear Regulatory Commission

Nuclear power plants in the U.S. are overseen by several key regulatory bodies. The primary authority is the NRC, established to license and regulate the civilian use of nuclear energy and radioactive materials to protect public health, safety, and the environment. The NRC sets licensing requirements, oversees operations through inspections and performance assessments, and regulates the handling, storage, and disposal of nuclear fuel and waste.

The NRC was created on January 19, 1975, by the Energy Reorganization Act of 1974, which split the regulatory responsibilities from the Atomic Energy Commission. Before its establishment, over 50 reactors were licensed and in various stages of construction or operation. Since its creation, there have only been two new reactors licensed and built in the U.S., Vogtle Units 3 and 4. This dramatic reduction begs the question: what is the actual motivation of this department? For Vogtle, we estimate the NRC's regulatory oversight has resulted in $7 billion of the $21 billion overrun, and a material component of the seven-year delay, which could make the burden closer to half of the overrun, by our estimates.

One of the problems with new reactors such as Vogtle Units 3 and 4 is that while they are an AP1000 pressurized water reactor (PWR) style reactor, the bespoke attributes make them first of a kind (FOAK) from a licensing perspective. This can significantly increase the NRC regulatory costs. The FOAK design of NuScale's SMR reactor reportedly required 12,000 pages of documentation and cost estimates over $500 million. Third- and fourth-generation reactors, while exposed to initial upfront costs like in the case of NuScale, should be able to replicate the design in Nth-of-a-kind

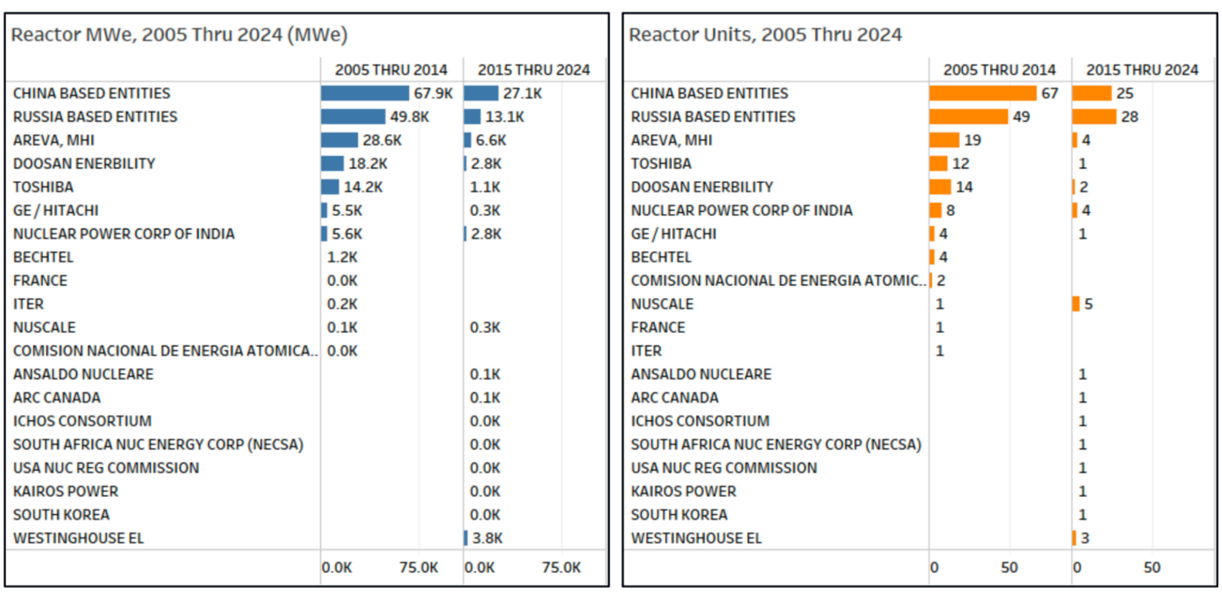
(NOAK) cost structures that are assumed to be much lower. Therefore, the ability to spread these costs across a greater number of reactors has not been possible previously. Think of a traditional reactor as a custom home with unique permitting requirements versus a modular home.

The Vogtle plant has a capacity of 2.2 GW, and a NuScale SMR has a capacity of 77 MW. The Vogtle facility is licensed for 60 years, and assuming a capacity factor of 90%, we calculate the regulatory burden of Vogtle to be an additional $10 per MWh ($7 billion upfront and annual fees of $56 million over the 60 years). While we estimate NuScale has spent over $500 million for a 77 MW facility, the regulatory burden will depend on the number of reactors that these costs can be spread across as a NOAK versus FOAK burden that Voglt carries.

To put this in perspective, the regulatory burden facing the nuclear industry is equivalent to the entire levelized cost of energy (LCOE) of constructing a PV facility (LCOE = $23 per MWh) or roughly half that of a combined cycle gas facility (LCOE = $42 per MWh). Various estimates for the LCOE of conventional nuclear power put the value at roughly $70 per MWh. If easing the regulatory burden can reduce this cost by $20 per MWh, the cost of nuclear declines to $50 per MWh, making it cost competitive with other forms of dispatchable power generation.

LCOE estimates published by scientist Richard Gao and colleagues (Gao et al. 2017) match this analysis, providing a triangulation on the cost of regulation in the U.S. The authors analyzed the cost of nuclear power in China, which has a markedly different regulatory structure. For example, almost all projects built in the last decade have finished construction in less than seven years, and only one experimental project took over a decade. Furthermore, from 2004 to 2024, China and Russia produced 63% of reactor capacity and 65% of the units. The authors calculated the LCOE of nuclear power, including various fuel recycling scenarios, to be between $54 and $56 per MWh; these are the same values we calculate when we net the $20 per MWh regulatory burden from the current $71 per MWh LCOE estimate for conventional nuclear power. These values provide further validation that the $70 per MWh for nuclear is too high of a value, and that the higher costs are not due to differences in capex, rather differences in the regulatory environment.

Exhibit 1
Nuclear Industry
Global Installed Nuclear Reactor Capacity (MWe, left) and Number of Units (right)



Source: McCoy Power Reports

China Cost Comparison
China currently has 58 nuclear reactors generating about 54 GW of power, accounting for about 15% of the global nuclear generating capacity. China ranks third in the global distribution of nuclear energy capacity behind the U.S. and France. However, China has 30 reactors under construction and another 36 planned with approvals and funding in place—a stark contrast to zero in the U.S. China contracted Westinghouse to build four AP1000s, which have been completed. Vogtle Units 3 and 4, which are in the U.S., were started a month apart from Sanmen Units 1 and 2 in Zhejiang, China. Vogtle cost $34 billion ($15,000 per kW) and took 15 years to reach operation; the Sanmen power station cost $8 billion ($3,400 per kW) and was completed in 9 years.

Exhibit 2
Nuclear Industry
Operational Comparison: Vogtle vs. Sanmen Nuclear Plants

Metric	Vogtle Units 3 and 4	Sanmen Units 1 and 2
Plant Name	Alvin W. Vogtle Electric Generating Plant	Sanmen Nuclear Power Station
Reactor Design	Westinghouse AP1000 Generation III+	Westinghouse AP1000 Generation III+
Power Output (MW)	2,234	2,386
Total Cost (USD)	$34 billion	$8.08 billion
Cost per kW (USD)	$15,219	$3,384
Construction Start	March 2009 (Unit 3), November 2009 (Unit 4)	April 2009 (Unit 1), December 2009 (Unit 2)
Commercial Operation	July 2023 (Unit 3), April 2024 (Unit 4)	September 2018 (Unit 1), November 2018 (Unit 2)
Construction Time	15 years (2009–2024)	9 years (2009–2018)

Sources: Company reports and William Blair Equity Research

The Vogtle plant cost four times the Sanmen plant and required nearly double the time to build. Although materials and labor cost are far lower in China, this highlights the impact two distinct regulatory regimes can have on building nuclear facilities. China has now developed generation III+ reactors, Hualong One and Two, with reduced costs of $2,000 per kW and a shorter construction time of four years. China's achievements in cost and construction demonstrate what is possible with a streamlined regulatory regime, supportive government, and eagerness to deploy new technology.

How Safe Is Too Safe?
Westinghouse first submitted the design certification for the AP1000 in 2002, and after 15 revisions, it was granted a design certification in 2006; construction did not start on Vogtle Units 3 and 4 until 2009. In June 2009, the NRC introduced an amendment for new nuclear reactors requiring them to be able to withstand impacts from commercial aircraft, a response to the 9/11 attacks. Vogtle Units 3 and 4 were new generation III+ reactors, and although they had already received design certification, they were required to comply with the new aircraft impact assessment requirements. This required a full redesign of shield building and numerous other sections of the plant, three more revisions of the design certification, almost three years of delays, and an estimated $2 billion to $3 billion.

When it comes to radiation, some of us often think of Spiderman or The Simpsons. We have been conditioned by the fear of this material. While we do not dismiss the impact on health, we have never heard of a movie being made about radiation exposure from business travel. Flying at 35,000 feet above the radiation-absorbing atmosphere exposes passengers to 100 times the radiation they would receive on the ground. A frequent flyer (about 100,000 miles annually) will receive 432 times more radiation exposure than a person living within 5 miles of a nuclear power plant. Nonetheless, NIMBY is real and has burdened this power source for decades. This raises the question: are these risks satisfactory or is the NRC asking the nuclear industry to build a car with a 1-million-mile bumper-to-bumper warranty, a technically feasible but practically impossible feat?

Two models are used to govern the operating requirements of radiation exposure: as low as reasonably achievable (ALARA) and linear no-threshold (LNT). While it is reasonable to push for the safest standard possible, both models are applied to nuclear power but nowhere else in the public domain. The specification thus appears to be more onerous than commercial air travel by orders of magnitude or the medical industry based on the number of diagnostic scans (X-rays or MRIs) during our life by 1,500 times. In fact, nowhere in these models does either suggest some exposure to low-level radiation (<100 mGy) can avoid the onset of cancer formation.

Exhibit 3
Nuclear Industry
Radiation Exposure Comparisons

Activity	Radiation Dose
Flight (Boston → San Francisco)	~0.035 mSv per flight
Living near Seabrook Nuclear Plant	≤0.005 mSv per year
Extremity X-ray (e.g., hand)	~0.001 mSv
Dental X-ray	~0.005 to 0.01 mSv
Chest X-ray	~0.1 mSv
Abdominal X-ray	~0.7 mSv
CT scan (Chest)	~6 to 7 mSv
CT scan (Abdomen/Pelvis)	~10 to 12 mSv

Sources: Centers for Disease Control and Prevention, Federal Aviation Administration, Nuclear Regulatory Commission, Environmental Protection Agency, and William Blair Research

Nuclear Is the Grid's Best Option to Meet Demand Inflection

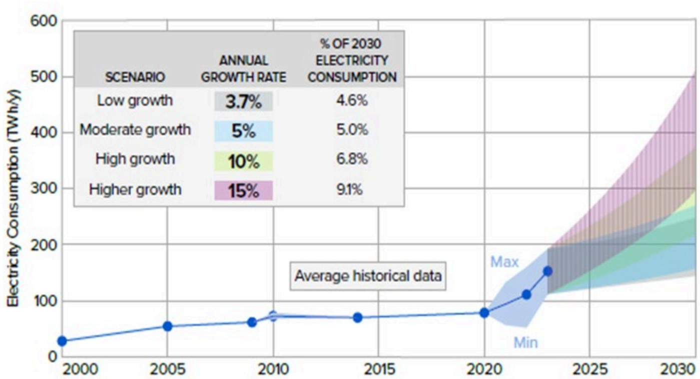
The power grid in the U.S. is strained by rising demand for electricity, the aging infrastructure, and supply bottlenecks, and President Trump's new tariff policy will exacerbate supply pressures and increase power demand through reshoring. In addition, the electrification movement will continue to significantly increase power demand and further strain the U.S. power grid, which has not received adequate investment for the past 40 years. We calculate that the modernization of the U.S. electric grid will require roughly $4 trillion of capital expenditures over the coming decades, or else the U.S. will risk failing to navigate the increase in electricity demand to power datacenters, enable the electrification movement, and accommodate high levels of domestic manufacturing.

Nuclear Enables AI

Artificial intelligence (AI) has become a powerful catalyst of the nuclear renaissance, as datacenter developers scramble to secure reliable baseload power that intermittent sources are not able to provide. As we outlined in our report The Power Behind AI and our more recent collaborative report Navigating the Boom: Confronting Generative AI's Most Pressing Questions, energy, or more specifically electrical power, represents the greatest enabling (or limiting) factor for AI, not the technology itself.

For the first time in over two decades, demand for electricity is projected to increase, driven by the adoption of AI, reshoring manufacturing, and electrification. The share of U.S. electricity production consumed by AI datacenters is expected to increase from 4% to 8% by 2030, according to the Electric Power Research Institute (EPRI). In a fierce competition for access to power, large technology companies have made direct investments into nuclear companies, attempted offtake agreements behind the meter, and even invested to restart decommissioned plants like Three Mile Island.

Exhibit 4
Nuclear Industry
Projected Electricity Consumption for U.S. Datacenters



Source: EPRI Powering Intelligence Report

Exhibit 5
Nuclear Industry
Nuclear Energy Transactions

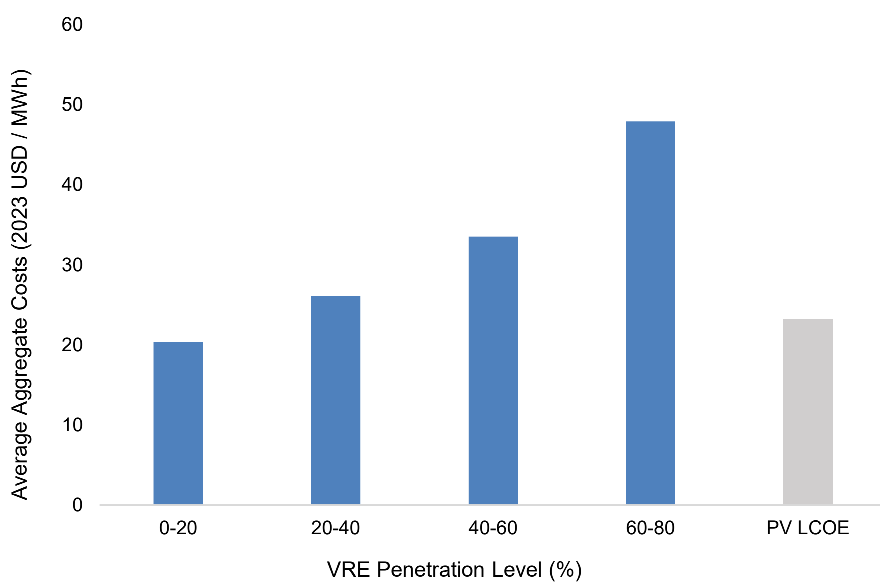
Nuclear Plant Name	Buyer	Seller	Location	Date Announced	Power	Transaction Value	Transaction Description
South Texas Project	Constellation Energy	NRG Energy	Texas	6/1/2023	2,645 MW	$1.75 billion	NRG sold its entire 44% stake in the South Texas Project to Constellation for $1.75 billion, or about $1,503/kW.
Crane Clean Energy Center	Microsoft	Constellation Energy	Pennsylvania	9/20/2024	837 MW	$1.6 billion	Constellation announced the restart of Three Mile Island to serve Microsoft datacenter load, renaming the plant Crane Clean Energy Center. The 20-year PPA is reported to be about $100/MWh.
Susquehanna Nuclear Station	Amazon	Talen Energy	Pennsylvania	3/4/2024	2,494 MW	$650 million	Talen Energy sold the Cumulus datacenter campus connected to the Susquehanna Nuclear Station to Amazon to serve datacenter load.
Various	Google	Kairos Power	Various locations across the U.S.	10/14/2024	500 MW	TBD	Kairos Power and Google have entered a master plant development agreement, paving the way for the deployment of 500 MW of advanced nuclear power projects across the U.S. by 2035.
Various	U.S. Government	Constellation Energy	Mid-Atlantic	1/1/2025	Over 1 million MWh annually	$840 million	Constellation agreed to provide nuclear power to the U.S. government for $840 million over 10 years.

Sources: Company reports and William Blair Equity Research

Renewables Integration Costs Favor Nuclear

The financial picture for nuclear becomes even brighter when considering the increasing costs associated with integrating renewable energy into grid systems. As outlined in our report The Power Behind AI, complications arise when trying to match variable energy with baseload requirements. Our analysis focused on the integration costs associated with managing variable renewable energy in grid systems, which in some cases completely usurp the LCOE of the generating asset (e.g., solar panels and wind turbines). As penetration of variable assets on the grid rises from single digits to above 10%, the integration costs negate any benefit from the lower marginal LCOE costs of renewables. For example, the aggregated costs facing grid systems are at a minimum $20 per MWh ranging up to $45 per MWh to incorporate variable renewable energy (VRE) sources into grid systems. Depending on the current VRE penetration, grid operators can expect cost increases to be as high as new combined cycle gas generation, which has an LCOE of $42 per MWh, according to the U.S. Energy Information Administration (EIA).

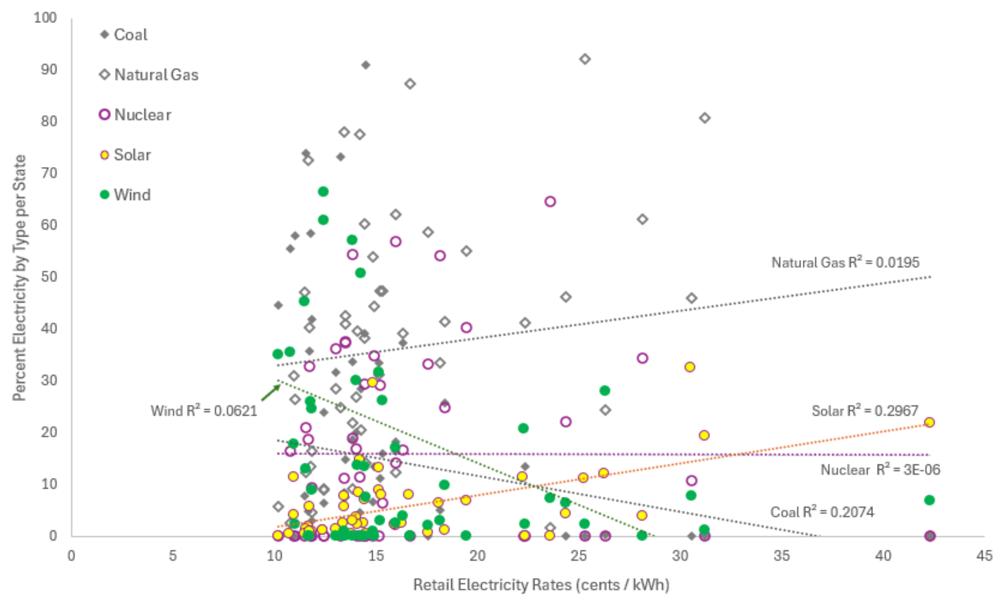
Exhibit 6
Nuclear Industry
Aggregate Costs vs. LCOE for Variable Renewable Energy Penetration



Source: Heptonstall and Gross 2021 and William Blair Equity Research

States with higher shares of baseload generation have lower retail rates as well, reflecting the overall importance of large baseload generators in keeping whole-system costs of the grid system low. We analyzed the electricity rates in all 50 states and regressed them against the percentage of electricity share by type in each state. Coal and solar were the only resources to show any sort of correlation to rates, and they were in the opposite direction. States with a higher share of coal electricity have lower rates, while states with higher solar share have higher rates.

Exhibit 7
Nuclear Industry
Regression of U.S. Electricity Rates vs. the Percentage of Electricity Share by Generation Type



Source: Choose Energy

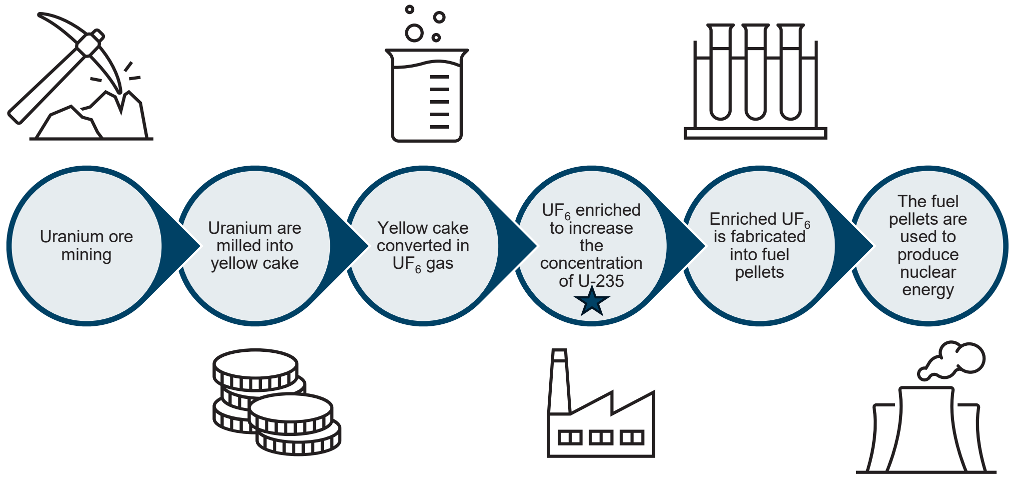
This means that utility-scale solar and wind are likely to reach a natural asymptotic penetration of about 10% of grid generation, and anything beyond this will require a distributed approach including interstate transmission or distributed residential and commercial. Roughly 500 GWh of electricity will need to be fulfilled over the next decade to meet transportation, datacenter, and reshoring of manufacturing; this makes nuclear and natural gas solutions increasingly attractive.

Supply/Demand of Nuclear Fuel Enrichment

Our analysis concludes that if the status quo of geopolitical relations remains, the U.S. will need to replace 4 million Russian SWU, almost 30% of the supply required to operate our commercial nuclear power. Ideally, new enrichment capacity will be domestic and American-owned. Centrus Energy is the most promising option, followed by BWX Technologies, fitting both the domestic and American-owned characteristics. Next are expansions of Urenco and Orano domestically; however, both are owned by foreign allies.

The supply chain for nuclear fuel is dependent on a select few countries that contribute uranium ore and enrichment capabilities. Uranium ore reserves are concentrated in deposits across the world, and about two-thirds of the global production of uranium comes from mines in Australia, Kazakhstan, and Canada. Once the uranium ore is mined and refined, there are only nine countries that can enrich the metal: Russia, the U.K., Germany, Netherlands, the U.S., France, China, Japan, and Brazil. There are slight variations in how much uranium can be enriched based on the level of enrichment, usually centered on 4.0% U-235 by mass, but the supply of enriched uranium is fundamentally limited by the enrichment facilities in these countries. The enrichment process is a critical step in the nuclear fuel cycle that enables nuclear energy generation.

Exhibit 8
Nuclear Industry
Nuclear Fuel Cycle



Sources: Company reports and William Blair Equity Research

Demand

The demand-side model aggregates the existing, active nuclear reactors to estimate the total energy capacity that requires separative work units (SWU) to produce low enriched uranium (LEU) fuel. SWU represents the effort required to separate isotopes of uranium during the enrichment process. Then, the model forecasts the demand for SWU in 2030 and 2035 as a function of the growth of nuclear generating capacity. The model excludes nuclear reactors that do not require enriched uranium, such as Canada Deuterium Uranium (CANDU) reactors, which use natural uranium as fuel and are named for its prominence in Canada. There are 30 operational CANDU reactors in the world, 19 of which are in Canada. The market for CANDU reactors is growing as demand for next-generation technology increases with models that bolster efficiency and lower costs. The supply chain for natural uranium is strong, and we do not expect a shortage, which is the main reason we exclude reactors that do not use enriched uranium from our analysis. The model incorporates the gradual expansion of SMRs in the global nuclear fleet. Many SMR models require high-assay low-enriched uranium (HALEU), which is uranium fuel enriched up to 20%. SWU and uranium enrichment have a positive relationship; enriching uranium at a higher percent requires more SWU, which means HALEU requires more SWU than LEU. As the global nuclear energy generation capacity increases and SMRs begin to commercialize, then HALEU will account for a greater share of the global demand for SWU. We developed three scenarios for the growth of the total global nuclear generation capacity, which are derived from estimates provided by the International Energy Agency (IEA) and the International Atomic Energy Agency (IAEA). The low-growth scenario is based on the IEA's Stated Policies Scenario, the mid-growth scenario is based on the IEA's Announced Pledges Scenario, and the high-growth scenario is based on the IAEA's high case for nuclear generation capacity growth. Each scenario produces a different estimate for future nuclear power demand, which we use to calculate the necessary fuel supply.

The global nuclear energy generating capacity that requires enriched uranium is concentrated in the U.S., Europe, China, Russia, and South Korea. When referring to Europe, we exclude the relevant capacity of Russia because we separately categorize Russian nuclear generating capacity and SWU production. The positive relationship between nuclear energy generation, uranium enrichment, and SWU means the same regions that produce most of the nuclear energy requiring enriched uranium also account for the highest levels of SWU demand.

Europe's current nuclear generating capacity is 121 GW, which accounts for 34% of the global nuclear generating capacity. There are 130 operating nuclear reactors in Europe, and over half of Europe's nuclear generating capacity comes from France, which generates about 70% of its electricity from nuclear energy. The nuclear generating capacity in Europe demands 11 million SWU per year to produce the required enriched uranium to fuel its reactors. In 2035, we forecast Europe to have a nuclear generating capacity of 163 GW and a SWU requirement of 15 million. The growth of nuclear generation in Europe will be driven by 1) geopolitical initiatives to reduce reliance on Russian energy sources and 2) the pursuit of net-zero emissions by 2050.

The U.S. currently accounts for 28% of the global nuclear generating capacity with an aggregated nuclear capacity of 97 GW. There are 94 operating reactors in the U.S. across 28 states, and Illinois has the most of any state with 11. The U.S. nuclear fleet demands 12 million SWU per year to produce the enriched uranium required to fuel its reactors. In 2035, we forecast the U.S. to have a nuclear generating capacity of 128 GW and demand 16 million SWU. The growth of nuclear generation in the U.S. will be driven by 1) the rising electricity demand from electrification and the expansion of data center demand, 2) the pursuit of net-zero emissions by 2050, and 3) the favorable economics of uprating existing reactors coupled with deploying SMRs.

China's current nuclear generating capacity is 54 GW, which accounts for 15% of the global nuclear generating capacity. China has experienced a rapid expansion of its nuclear capacity over the last decade, adding 34 GW. There are 58 operating nuclear reactors in China and an additional 30 reactors are under construction. The nuclear generating capacity in China demands 8 million SWU per year to produce the required enriched uranium to fuel its reactors. In 2035, we forecast China to have a nuclear generating capacity of 75 GW and a SWU requirement of 12 million. The growth of nuclear generation in China will be driven by 1) cost efficiencies related to the construction of nuclear reactors and 2) the application of advanced technologies such as thorium reactors, high-temperature gas-cooled reactors, and various SMRs.

Russia's current nuclear generating capacity is 25 GW, which accounts for 7% of the global nuclear generating capacity. Although Russia does not have nuclear energy capacity on the same scale as the U.S., France, and China, Rosatom, the state-owned nuclear developer, is actively involved in expanding nuclear production across Europe. There are 36 operating nuclear reactors in Russia including FOAK SMRs and microreactors. The nuclear generating capacity in Russia demands 3 million SWU per year to produce the required enriched uranium to fuel its reactors. In 2035, we forecast Russia to have a nuclear generating capacity of 33 GW and a SWU requirement of 5 million. The growth of nuclear generation in Russia will be driven by 1) the preservation of energy security and 2) the expansion of Russia's influence on the global nuclear industry.

South Korea has 26 operating nuclear reactors, and its current nuclear generating capacity is 24 GW, which accounts for 7% of the global nuclear generating capacity. The nuclear generating capacity in South Korea demands 3 million SWU per year to produce the required enriched uranium to fuel its reactors. In 2035, we forecast South Korea to have a nuclear generating capacity of 31 GW and a SWU requirement of 4 million. The growth of nuclear generation in South Korea will be driven by 1) the increase in electricity demand from AI and semiconductors and 2) the deployment of SMRs.

Exhibit 9
Nuclear Industry
Major Global Nuclear Demand Markets

Nuclear Generating Capacity (MW)

Region	2025	2030	2035	Percent of Global Nuclear Generating Capacity - 2025
Europe	120,511	138,272	162,575	34%
U.S.	96,952	111,241	127,635	28%
China	53,816	61,747	75,082	15%
Russia	25,422	29,169	33,468	7%
S. Korea	23,874	27,393	31,430	7%

SWU Demand (SWU/yr)

Region	2025	2030	2035	Percent of Global SWU Demand - 2025
U.S.	12,077,565	13,857,549	15,899,867	30%
Europe	11,202,455	12,853,466	15,210,660	28%
China	8,272,477	9,491,669	11,541,362	21%
Russia	3,433,491	3,939,517	4,520,120	9%
S. Korea	2,652,621	3,043,563	3,492,122	7%

Sources: Company reports and William Blair Equity Research

Supply

There are four major suppliers of enriched uranium in the world, which operate in Russia, Europe, China, and the U.S. Each company is wholly or partly state-owned.

- Rosatom is owned by the Russian government and operates through its subsidiary TENEX, which is one of the world's leading suppliers of uranium enrichment services.
- Urenco is a consortium of companies controlled by the British and Dutch government and by two German utilities. Urenco has installed capacity at its European and U.S. enrichment facilities.
- China Nuclear Energy Industry Corp. (CNEIC) is owned and operated by the Chinese government. CNEIC is dedicated to supplying domestic enrichment requirements in China.
- Orano operates under the majority ownership of the French government. The company's Georges Besse II plant is the largest enrichment facility in Europe. Orano is in the process of establishing uranium enrichment capacity in the U.S.

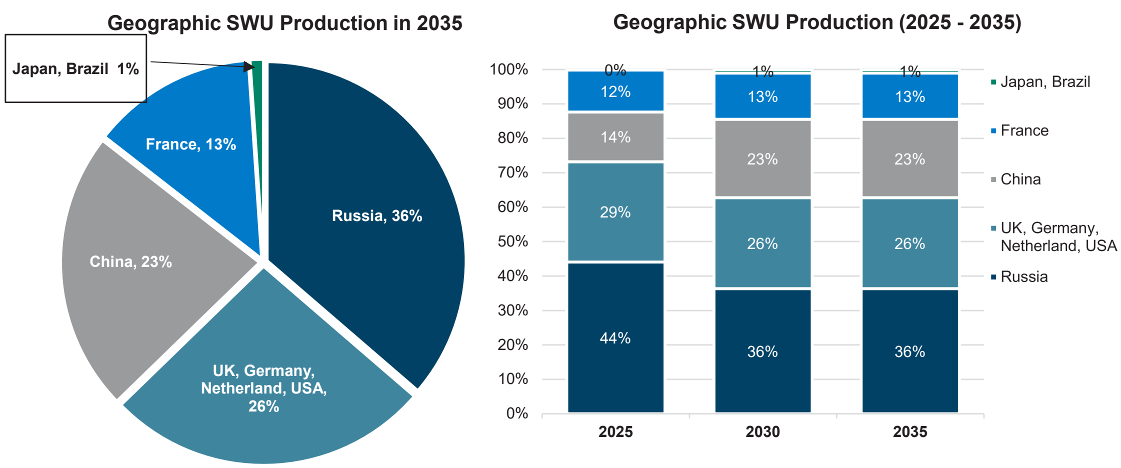
Current SWU production is sufficient to meet the demand for enriched uranium fuel, but Russia and China account for the majority of global SWU production, and current geopolitical tensions coupled with trade restrictions jeopardize access to Russian and Chinese SWU. If the supply from China and Russia is removed, then there will be large supply deficits relative to demand.

Exhibit 10
Nuclear Industry
Global Nuclear Enrichment Suppliers

Company	Jurisdiction	2025 SWU Production Capacity (million SWU/yr)	2030 SWU Production Capacity (million SWU/yr)
Rosatom	Russia	27.1	27.1
Urenco	U.K., Germany, Netherlands, U.S.	17.9	19.7
CNEIC	China	8.9	17
Orano	France	7.5	10
Other	Japan, Brazil	0.1	0.8
Total		**61.5**	**74.6**

Sources: Company reports and William Blair Equity Research

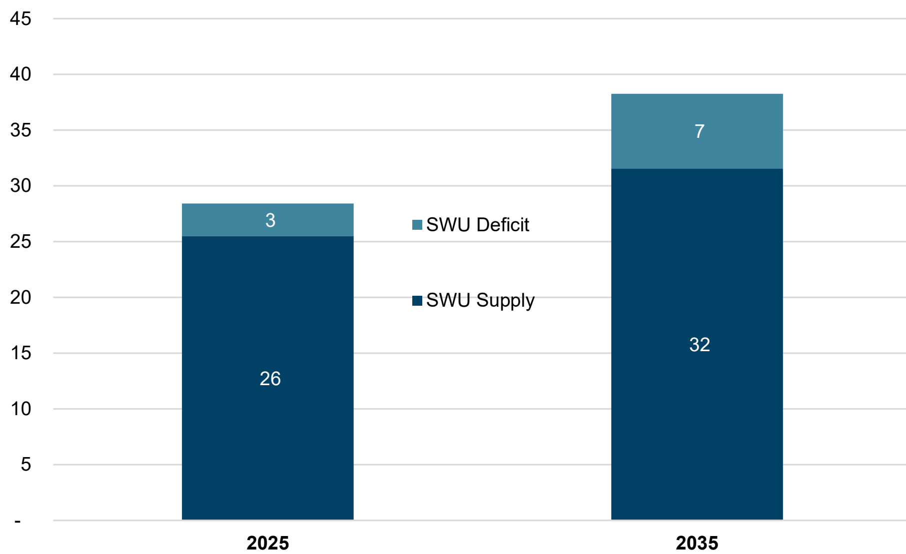
Exhibit 11
Nuclear Industry
Geographic Breakdown of SWU Production in 2035



Sources: Company reports and William Blair Equity Research

When excluding Chinese and Russian SWU supply, the current deficit is 2.9 million SWU per year, which is 12% of the total supply. The deficit could grow to 18% by 2035 if the current geopolitical dynamic persists, and nuclear energy demand continues to increase. The increasing demand for SWU, paired with uncertain trade restrictions, will put upward pressure on its price.

Exhibit 12
Nuclear Industry
SWU Supply & Demand – Excluding China and Russia (Base Case)



Sources: Company reports and William Blair Equity Research

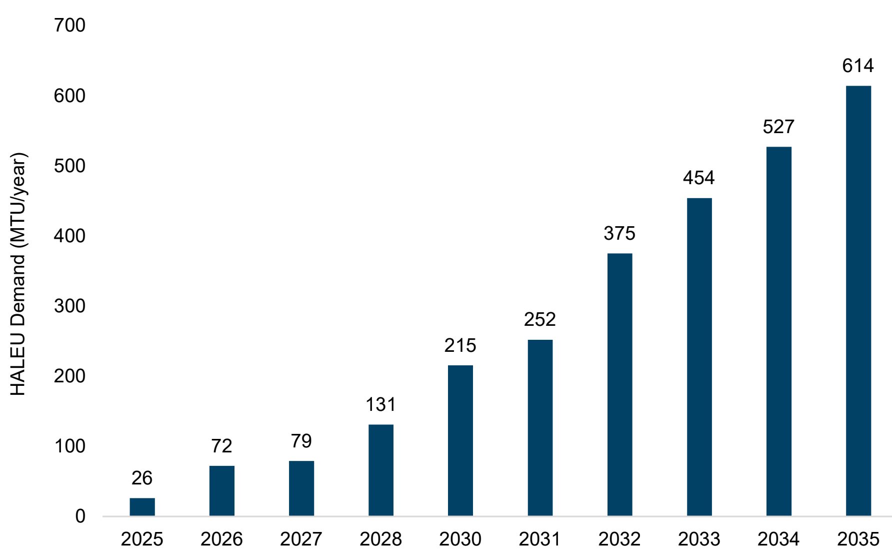
The global nuclear fuel cycle is currently dependent on Russian SWU supply, and China is expected to expand its SWU capacity from 2025 to 2035, making it a major supplier in the market. Russia accounts for about 44% of the global SWU supply, which is anticipated to shrink to 37% by 2035 as China increases its share of the supply market from 14% in 2025 to 23% in 2035. There will be a global surplus of SWU if the development of projected SWU capacity is realized; however, geopolitical tensions are expected to limit the available supply of SWU. Rostam and its operating subsidiary TENEX are subject to quotas under the Russian Suspension Agreement (RSA), which governs imports of Russian uranium products into the U.S. The current structure of the RSA allows U.S. companies to distribute Russian enriched uranium to its customers, but the U.S. enacted the Important Ban Act in 2024, which blocks imports of uranium products from Russian producers as of August 2024. The DOE can issue waivers to circumvent the trade restrictions, allowing imports of uranium products to fulfill existing deliveries to various U.S. companies and the foreign customers of U.S. companies. For example, Centrus Energy has received waivers from the DOE permitting it to deliver Russian uranium products to its customers with committed orders through 2025. The DOE has not provided clarity on the status of waivers beyond 2025. The Russian government has instituted its own trade restrictions under the Russian Decree, which prevents TENEX from exporting uranium products to the U.S. through December 2025. TENEX has received unique export licenses from the Russian government to complete its orders in 2024 and 2025, and it has expressed a desire to receive additional export licenses for its future deliveries; however, the approval of additional licenses is not guaranteed. The supply contracts that U.S. and foreign companies have with TENEX could be affected by the war in Ukraine, which is escalating geopolitical tensions. If the geopolitical relationship between Russia and the U.S. worsens and the trade war between the U.S. and China persists, the U.S. will be forced to expand its domestic enrichment capacity.

Status of the HALEU Market

The market for HALEU is nascent, but demand is expected to increase dramatically over the next decade as advanced nuclear reactors are deployed on a global scale. Russia and China are currently the only countries with commercial HALEU supply chains; however, national security concerns will prevent the U.S. from relying on Russian and Chinese HALEU to power its fleet of advanced reactors. The U.S. currently produces limited amounts of HALEU at the Idaho National Laboratory for national security purposes, but it is making significant investments to support the development of HALEU, which will preserve its energy independence from Russia and China. The DOE is attempting to catalyze the commercial application of HALEU through the Energy Act of 2020, which established the HALEU Availability Program. This program will allocate HALEU produced from DOE-owned assets to U.S. nuclear reactor developers to spur future HALEU production capabilities. The DOE made the first round of conditional HALEU supply commitments to five U.S. nuclear reactor developers in April 2025: TRISO-X, TerraPower, Kairos Power, Radiant Industries, and Westinghouse Electric Company. The companies could receive the HALEU as early as fall 2025. The DOE expects to have provided a total of 21 metric tons of HALEU to advanced reactor developers by June 2026. The DOE is also partnering with private companies to establish a robust HALEU supply chain. Centrus Energy and Orano are committed to enhancing their enrichment capabilities to serve the needs of the U.S. government and commercial advanced reactors. Centrus has an NRC license to produce HALEU for commercial reactors and national security needs. The company has already delivered about 545 kilograms of HALEU to the DOE. Orano plans to scale up its enrichment capabilities to supply enrichment greater than 6% by 2030.

The goals of enrichment suppliers are promising, but the main challenge of establishing a commercial-scale HALEU supply chain is the required investment. The Nuclear Energy Institute estimates the HALEU enrichment and deconversion capacity necessitates more than $500 million of upfront capital. The problem is that investment will not flow without sustained advanced reactor customers, but those customers need HALEU to prove their concept, which underscores the importance of the DOE's continued subsidization of the HALEU supply chain. Companies like Centrus and Orano are vital to the future of the domestic HALEU supply chain, and both are favorably positioned if the projected demand for HALEU is realized.

Exhibit 13
Nuclear Industry
HALEU Demand Forecast



Source: Centrus Energy, Nuclear Energy Institute, and William Blair Equity Research

SWU Pricing
The SWU spot price will continue to rise amid escalating geopolitical tensions with Russia and the transition to a new American foreign policy that will prioritize protectionist initiatives. In January 2022, the SWU spot price was about $55, which increased 127% to $125 in December 2022. As of December 2024, the SWU spot price was $190, representing a 23% constant annual growth rate from December 2022. In the short run, SWU prices are expected to gradually increase because of supply shortages that may be eased by trade waivers. Established uranium enrichment suppliers will capitalize on the supply bottleneck, and the evolution of HALEU fuel could catalyze significant growth for those suppliers considering that each company will charge a premium for higher levels of enrichment. While there will be market winners in the short run, the U.S. and Europe must bolster their enrichment capabilities in the long run to ensure sufficient supply and end their reliance on Russian enrichment capacity.

Exhibit 14
Nuclear Industry
Historical SWU Spot and Long-Term Pricing

Source: ASPI

Uprating and Restarting

The two “fast” paths to adding nuclear power are uprating the current fleet and restarting decommissioned plants. GE Vernova has stated it sees over 5% power increase potential from uprating reactors and facilities under its maintenance contracts. The DOE also supports the restart effort; in 2024, the DOE provided a $1.52 billion loan to Holtec International to restart the Palisades Nuclear Facility in Michigan, which shut down operations in 2022. NextEra Energy is exploring the possibility of restarting a closed nuclear power station, and it hopes to revitalize the Duane Arnold Energy Center in Iowa, which has 615 MW of capacity.

Uprating
Uprating existing nuclear plants can increase power output by up to 20%. Roughly 2 GW of existing or planned uprates are underway in U.S. nuclear plants, adding power to the grid without the need for new facilities. Over 8 GWe of uprates have been approved by the NRC. The most

promising opportunities for these uprates are related to older nuclear plants, where initial designs allow room for operational tweaks like turbine and cooling system upgrades. Following a "best-first" approach, these projects have prioritized plants with the most straightforward modifications and highest efficiency gains, meaning that future uprates may yield diminishing returns as the most suitable plants reach peak output. Vistra, a Texas utility that owns four nuclear plants, recently indicated that it was in discussions with several hyperscale datacenter operators to increase the output of its nuclear power projects through nuclear plant uprate projects.

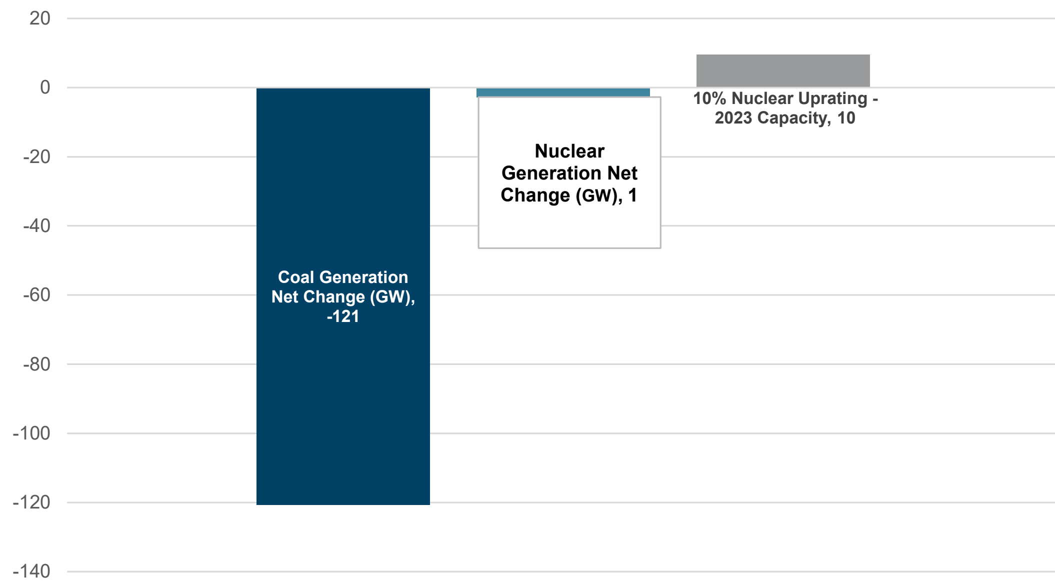
Exhibit 15
Nuclear Industry
Largest NRC Uprate Approvals Since 2010 (by percentage uprate)

Plant Name	Uprate %	Power Capacity Added (MWt)	Date Approved
Point Beach 1	17	260	5/3/2011
Point Beach 2	17	260	5/3/2011
Nine Mile Point 2	15	521	12/22/2011
Turkey Point 3	15	344	6/15/2012
Turkey Point 4	15	344	6/15/2012
Browns Ferry 1	14.3	494	8/14/2017
Browns Ferry 2	14.3	494	8/14/2017
Browns Ferry 3	14.3	494	8/14/2017
Grand Gulf 1	13.1	510	7/18/2012
Monticello	12.9	229	12/9/2013
Peach Bottom 2	12.4	437	8/25/2014
Peach Bottom 3	12.4	437	8/25/2014
St. Lucie 1	11.9	320	7/9/2012
St. Lucie 2	11.9	320	9/24/2012

Source: Nuclear Regulatory Commission

New fuel technology will also result in uprating of existing facilities. New helical fuel rod designs that can shed heat more efficiently, increasing the efficiency of a PWR reactor by 10%. Coal and nuclear provide the largest baseload generation in the country, and generation from both sources has declined over the past five years. Uprating nuclear facilities by fuel switching completely offsets the recent declines in nuclear output and begins to offset the declines in the coal industry.

Exhibit 16
Nuclear Industry
Net Change in Electricity Generation for Coal and Nuclear Sources (2014-2023)



Source: Energy Information Administration

Restarting

The nuclear industry is dominated by pressurized water reactors (PWRs), which account for 306 of the 415 operational reactors (74%). Boiling water reactors (BWRs) make up about 10% of existing reactors. Notable examples of these types under consideration for recommissioning in the U.S. include:

- Three Mile Island Unit 1 (PWR)
- Palisades Nuclear Generating Station (PWR)
- Duane Arnold Energy Center (BWR)

These reactors are part of a broader push to revitalize retired facilities and capitalize on their proven technologies. With 78% of global nuclear power capacity generated by PWRs and 12% by BWRs, restarting these facilities aligns with the dominant reactor types already in operation. Still, little is known about the costs associated with restarting a nuclear reactor since it has never been done before.

Exhibit 17
Nuclear Industry
Operational Nuclear Reactors in the World

Reactor Type (abbr.)	Reactor Type	Net Electrical Capacity (MWe)	Share of Electricity Capacity (%)	Number of Reactors	Share of All Reactors (%)
PWR	Pressurized Light-Water Moderated and Cooled Reactor	293,147	78%	306	74%
BWR	Boiling Light-Water Cooled and Moderated Reactor	43,071	12%	41	10%
PHWR	Pressurized Heavy-Water Moderated and Cooled Reactor	24,794	7%	47	11%
LWGR	Light-Water Cooled, Graphite Moderated Reactor	6,508	2%	10	2%
GCR	Gas Cooled, Graphite Moderated Reactor	4,685	1%	8	2%
FBR	Fast Breeder Reactor	1,380	0%	2	0%
HTGR	High Temperature Gas Cooled Reactor	150	0%	1	0%
Total		**373,735**		**415**	

Source: International Atomic Energy Agency

Restarting a nuclear facility is not a trivial matter. Even though the PWR model is common, each one was developed and built in a bespoke way for its geography and expected usage, which means each facility is unique and the reopening process will be different for every reactor.

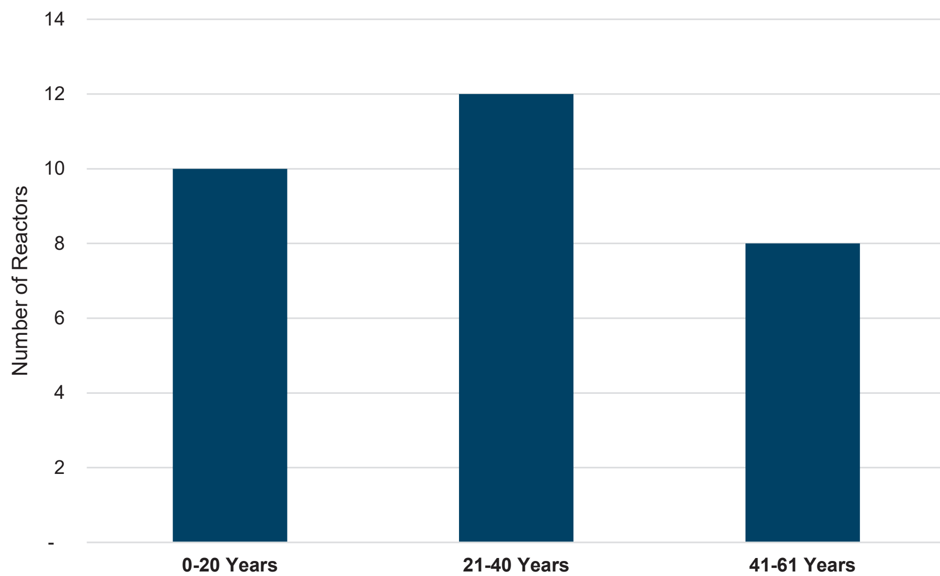
The closing process for nuclear facilities has a few steps that are universally applied to facilities in the U.S., and similar analogs for those in nuclear facilities in the global community. Understanding this process can provide insight into which facilities have potential for reopening and which will likely remain closed forever.

Understanding Decommissioned Reactors

According to NRC rules, once a "cessation of operations" letter is accepted, a nuclear facility is officially closed. Recommissioning the facility after this point, according to the guidelines, would require a relicensing process that is the same as it would be for a new reactor. The problem is that many of the facilities that are prime candidates for recommissioning were built decades ago with materials and processes that do not meet today's standards, despite being safe at the time of decommissioning. As a result, the NRC is developing guidance documents on how to recommission a closed facility so that complete rebuilds will not be required.

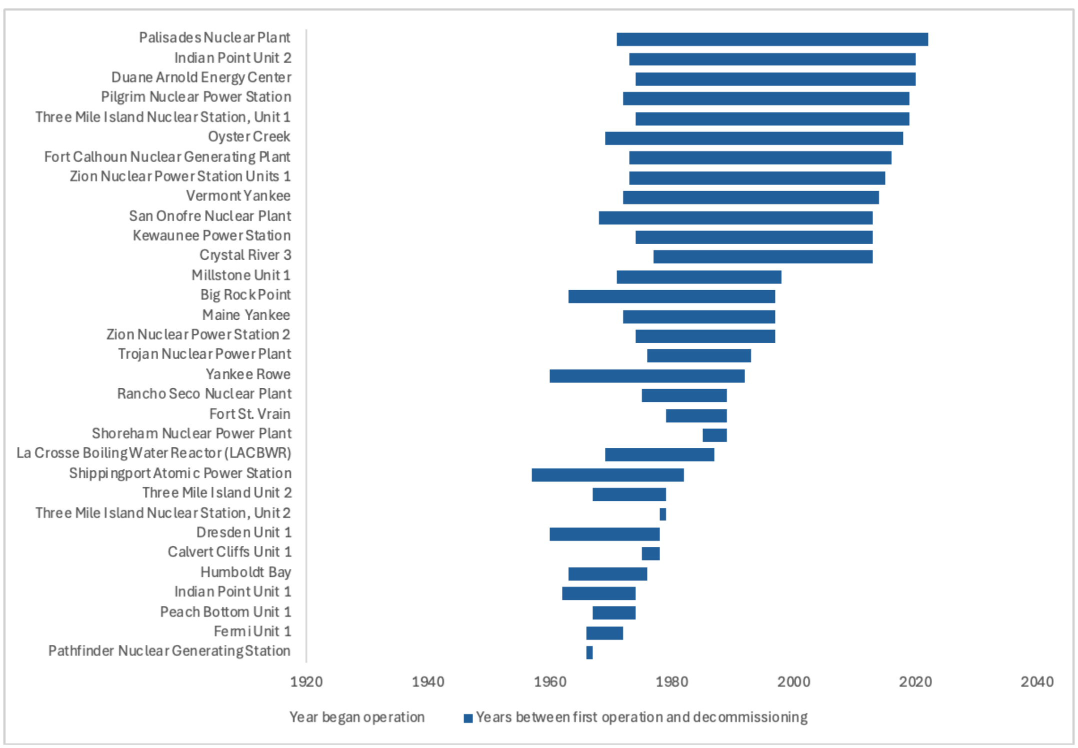
Not all nuclear plants built in the 1960s to the 1980s are still operating. Over 25 nuclear power plants and early demonstration plants are in various stages of decommissioning. The operating life of these plants varied from 0 to 51 years, with a third lasting 0 to 20 years, and eight reactors lasting greater than 40 years. Many of the reactors that are in line for recommissioning are also those that have had longer operating lifetimes.

Exhibit 18
Nuclear Industry
Lifetimes of Decommissioned Nuclear Plants



Sources: McCoy Power Reports and William Blair Equity Research

Exhibit 19
Nuclear Industry
Timeline of Decommissioned Nuclear Power Plants



Source: Nuclear Regulatory Commission, McCoy Power Reports

Facilities Next for Restarts

Beginning in 2024, nuclear operators began to consider restarting decommissioned plants. NextEra CEO John Ketchum told investors in a Q&A session during the company's second-quarter earnings call that it was considering the option of restarting the Duane Arnold nuclear plant in Iowa. Constellation Energy followed with an announcement in September 2024 that it would restore Three Mile Island in Pennsylvania to service and enter a 20-year power purchase agreement with Microsoft. In October 2024, Holtec International began the regulatory process of restarting electricity production at the 800 MW Palisades Power Plant in Michigan, and the company plans to restart the facility in August 2025.

We compiled data from McCoy Power to identify which other recently decommissioned nuclear facilities could be recommissioned. Two main factors determine the feasibility of restarting a nuclear plant. The first is whether the plant is in DECON or SAFSTOR status of decommissioning, and the second is the time since the plant has ceased operations (see appendix B for an explanation of DECON and SAFSTOR). Plants in SAFSTOR status may have more vital plant systems intact, and plants that were decommissioned more recently will simply be in better condition than ones that were decommissioned long ago. Other factors such as local opposition to restart may further influence the feasibility of the plant restarting but are not analyzed here. For example, the Indian Point Energy Center in Buchanan, New York, was shut down in 2021 due to concerns about its proximity to population centers in the New York City metropolitan area, despite a sound operational record. Similar arguments could exist today if the plant were considered for recommissioning.

Of all the shuttered facilities in the U.S., only 12 were decommissioned since 2013. Out of the 12 facilities, three are being considered for restarts (Palisades, TMI1, and Duane Arnold), which are the most recently decommissioned reactors and the only ones in SAFSTOR status. The remaining nine reactors are in various stages of decontamination. Exhibit 21 provides the probable outcomes for these nine remaining reactors. Our analysis indicates that the Indian Point Energy Center and the Pilgrim Nuclear Power Station would be the next facilities in line for a restart. Other recently closed facilities are too far gone for a restart but could be host sites for SMRs in the future.

Exhibit 20
Nuclear Industry
Decommissioned Nuclear Facilities – Targets for Reopening or New SMRs

Facility Name and Reactor Type	Details	Status	Potential for Restart
Three Mile Island Unit 1 (PWR)	- Constellation planning a restart - Deal struck with Microsoft to sell power behind the meter, currently in legal disputes with FERC	SAFSTOR	Restart possible with reconstruction of reactor vessel
Palisades Nuclear Generating Station (PWR)	- Holtec International filed with the NRC to begin the process of restarting electricity production	SAFSTOR	Restart possible with reconstruction of reactor vessel
Duane Arnold Energy Center (BWR)	- NextEra energy is planning a restart	SAFSTOR	Restart possible with reconstruction of reactor vessel
Indian Point Energy Center (PWR)	- Decommissioned in 2020 and 2021 - Owned by Holtec International - Dismantling of reactor vessel underway on both units two and three would need to be reconstructed - Senate Bill S9898, 2023-2024 Legislative Session introduced to establish a commission on reopening Indian Point (currently in committee)	DECON	Restart possible with reconstruction of reactor vessel
Pilgrim Nuclear Power Station (BWR)	- Decommissioned in 2019 - Owned by Holtec International - Internal portions of the reactor have been dismantled and are being staged on site for shipping to Texas and buried for long-term storage - The demolition of remainder of reactor delayed for a second time in 2023 due to uncertainty about the release of 900,000 gallons of radioactive and contaminated water which are being stored in the reactor	DECON	Restart possible with reconstruction of reactor vessel
San Onofre Nuclear Generating Station (SONGS) 2 and 3 (PWR)	- Decommissioned in 2013 - Approximately 50% of the buildings have been demolished as of 2013 (Reporting by Greenberg 2024) - Mentioned as a “long shot” for recommissioning (Reporting by Martucci 2024)	DECON	Restart unlikely but possible with reconstruction of reactor vessels and support buildings
Oyster Creek (BWR)	- Decommissioned in 2018 - Reactor dismantled to the point that unable to make a “Palisades-like restart” unfeasible (Reporting by Greenberg 2024) - But the site is being considered for installation of small modular nuclear reactors, SMR-300 (Reporting by Conklin 2024)	DECON	Potential site for SMR
Fort Calhoun Nuclear Generating Plant (PWR)	- Smallest rated capacity of any US nuclear plant, 484 MW - Reactor vessel removal and segmentation completed 2023 - Undergoing dismantling, containment building demolition scheduled for 2025 - Unable to be restarted	DECON	Potential site for SMR
Crystal River 3 (PWR)	- Decommissioned in 2013 - Completed removal and segmentation of internal components in December 2023 - Advanced DECON stages makes restart extremely low probability	DECON	Potential site for SMR
Kewanee Power Station (PWR)	- Decommissioned in 2013 - Advanced demolition and dismantling completed	DECON	Potential site for SMR
Vermont Yankee (BWR)	- Decommissioned in 2014 - Only one of the original buildings remains intact, the rest have been demolished - Unable to be restarted	DECON	Restart impossible, no talk of SMR

Sources: Company reports and William Blair Equity Research, Nuclear Regulatory Commission, McCoy Power Reports

Recently Decommissioned Nuclear Reactors Outside of the United States

European and Asian countries have seen numerous decommissioned nuclear facilities over the past two decades, with 24 plants in the EU, Japan, and South Korea closing in the past five years. In the EU, national energy policies driven by sustainability goals, energy transition strategies, and public concerns over nuclear safety have significantly influenced the increase in nuclear plant decommissioning.

Exhibit 21
Nuclear Industry
Nuclear Plants Shutdown Since 2019 in Europe, Japan, and South Korea

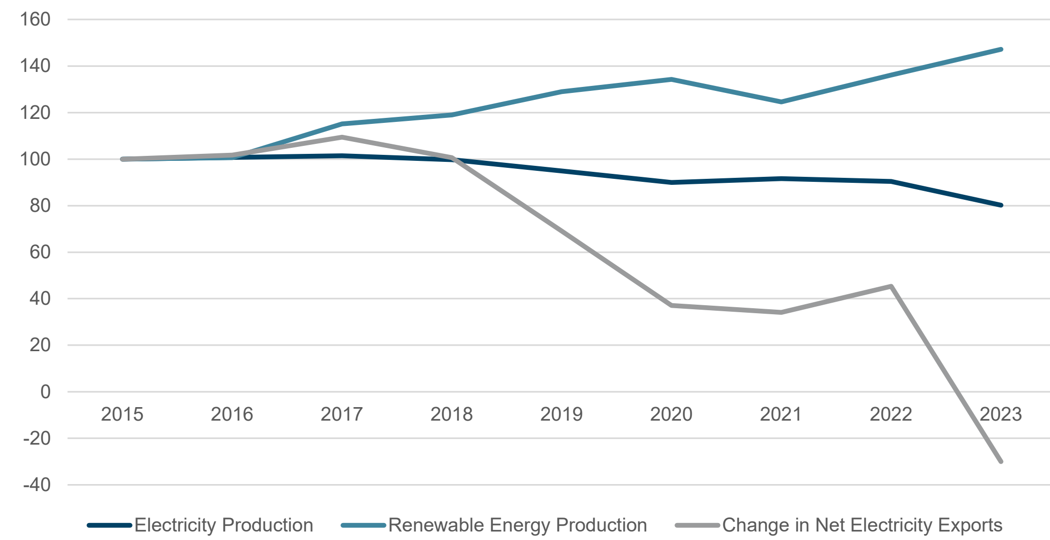
Country	Name	Type	Capacity Net (MW)	Start Year	Duration (Years)	Shut-down year	Reactor Code
GERMANY	ISAR-2	PWR	1410	1988	35	2023	DE -31
GERMANY	EMSLAND	PWR	1335	1988	35	2023	DE -33
GERMANY	NECKARWESTHEIM-2	PWR	1310	1989	34	2023	DE -44
BELGIUM	TIHANGE-2	PWR	1008	1983	40	2023	BE -6
BELGIUM	DOEL-3	PWR	1006	1982	40	2022	BE -5
UK	HINKLEY POINT B-1	GCR	485	1978	44	2022	GB -16A
UK	HINKLEY POINT B-2	GCR	480	1976	46	2022	GB -16B
UK	HUNTERSTON B-2	GCR	495	1977	45	2022	GB -17B
GERMANY	GROHNDE	PWR	1360	1985	37	2021	DE -27
GERMANY	GUNDREMMINGEN-C	BWR	1288	1985	37	2021	DE -28
GERMANY	BROKDORF	PWR	1410	1986	35	2021	DE -32
UK	HUNTERSTON B-1	GCR	490	1976	46	2021	GB -17A
UK	DUNGENESS B-1	GCR	545	1985	36	2021	GB -18A
UK	DUNGENESS B-2	GCR	545	1989	32	2021	GB -18B
SWEDEN	RINGHALS-1	BWR	881	1976	45	2020	SE -4
FRANCE	FESSENHEIM-2	PWR	880	1978	42	2020	FR -12
FRANCE	FESSENHEIM-1	PWR	880	1978	42	2020	FR -11
GERMANY	PHILIPPSBURG-2	PWR	1402	1985	35	2019	DE -24
KOREA, REP.	WOLSONG-1	PHWR	661	1983	37	2019	KR -3
SWEDEN	RINGHALS-2	PWR	852	1975	45	2019	SE -5
SWITZERLAND	MUEHLEBERG	BWR	373	1972	47	2019	CH -2
JAPAN	FUKUSHIMA-DAINI-1	BWR	1067	1982	38	2019	JP -25
JAPAN	FUKUSHIMA-DAINI-2	BWR	1067	1984	36	2019	JP -26
JAPAN	GENKAI-2	PWR	529	1981	38	2019	JP -27

Source: International Atomic Energy Agency

Germany's Energiewende policy mandates a complete phaseout of nuclear power, leading to the rapid decommissioning of reactors like Gundremmingen-B and Philippsburg-2. Similarly, France, with the largest fleet of nuclear reactors in Europe, has committed to reducing nuclear energy's share in its electricity mix under its "Loi relative à l'Énergie et au Climat," driving the closure of older plants such as Fessenheim-1 and -2. The European Green Deal and national commitments to achieving net-zero emissions have further pressured nations to prioritize renewable energy sources, leading to the gradual retirement of nuclear facilities. Countries in Eastern Europe, such as Bulgaria and Slovakia, are also decommissioning Soviet-era reactors as part of EU accession agreements and compliance with modern safety standards. These policies collectively highlight a shift away from nuclear power in favor of alternative renewable energy solutions, accelerating the pace of nuclear decommissioning across the EU.

This trend is struggling to meet two opposing goals: 1) reducing nuclear power production and 2) reducing emissions. This has left Germany's industrial productivity more reliant on the surrounding EU countries. Our analysis shows that German industrial production is highly correlated with electricity consumption. Over the past 10 years, renewable energy's share of the German grid system has been growing, but the overall grid system's output declined and became significantly more reliant on energy imports. In 2015, Germany exported 68 TWh of electricity and imported only 17 TWh. In 2023 those numbers have almost completely reversed, exporting 39 TWh of electricity and importing 54 TWh.

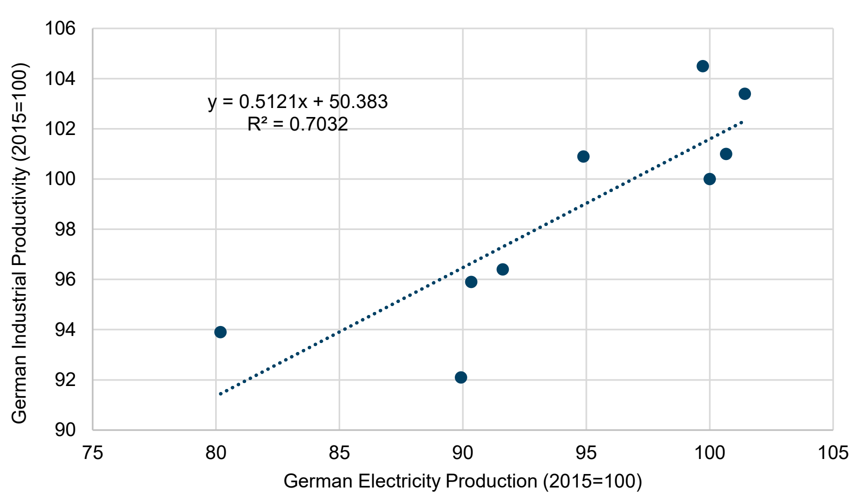
Exhibit 22
Nuclear Industry
German Electricity Production, Net Exports of Electricity and Renewable Energy Share of Electricity Production (2015 = 100)



Source: Destatis, AG-Energiebilanzen, Bundesnetzagentur

Nuclear energy solves many problems for Germany, so it would be foolish to not reverse course and start recommissioning reactors. Germany, Belgium, and Japan appear to have the best opportunities to restart decommissioned plants. Germany has seven closed nuclear plants that have not undergone significant decommissioning activity and where technical barriers to restart are relatively low. Two Belgian plants, Tihange-2 and Doel-3, are on track to restart in 2026 after previously being slated for permanent shutdown. Germany's recent shutdowns represent 9,515 MW of power capacity, which equates to 15% of annual electricity production.

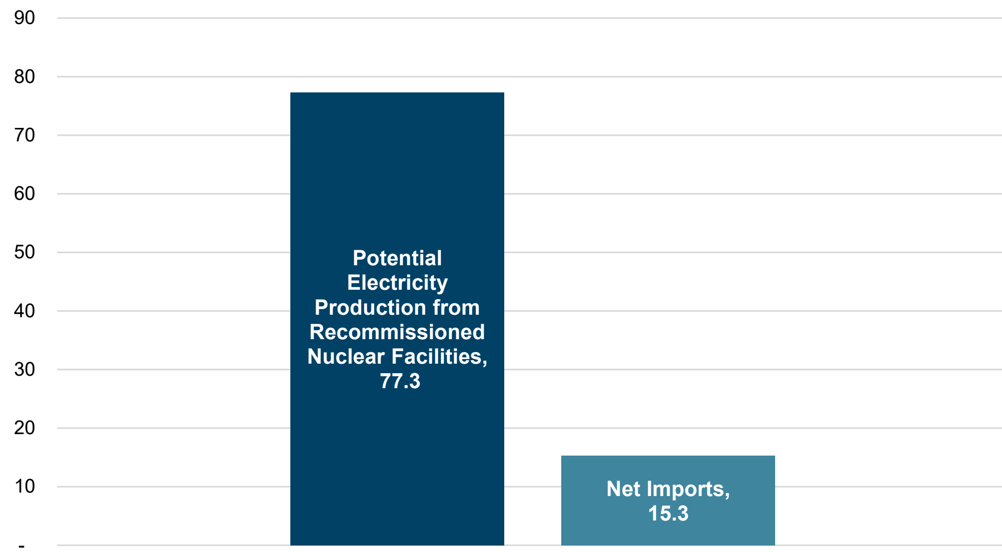
Exhibit 23
Nuclear Industry
German Industrial Productivity as a Function of Electricity Production



Source: Destatis, AG Energiebilanzen

Importantly, recommissioning the most recent closures in Germany would make it a net exporter of electricity again.

Exhibit 24
Nuclear Industry
Potential Electricity Production from Recommissioned Nuclear Facilities Compared to the Net Imports of Electricity in Germany (2023)



Source: International Atomic Energy Agency, Bundesnetzagentur

Japan is looking toward nuclear restarts to fulfill demand from datacenters and chip makers. Hokkaido Electric Power wants to restart the Tomari-3 reactor to satisfy a surge in demand from local datacenters and provide long-term stable production of electricity. Part of these plans include the construction of a 19-meter seawall. In addition, South Korea has extended the life of several nuclear reactors that had been slated for decommissioning in 2025.

Other recently decommissioned plants, such as Ringhals 1 and 2 in Sweden, are unlikely to be restarted as the decommissioning process has advanced too far. Instead, Sweden is pursuing new nuclear reactors as part of its national energy strategy, but these will take years to come online. Hinkley Point 1 and 2 in the U.K. are being decommissioned and not in discussion for restart, and Hinkley Point 3 has been delayed and its projected cost is currently 2 times more than its original budget.

Process of Decommissioning

Decommissioning a nuclear power plant is a complex, multi-stage process focused on safe dismantling, waste management, and site clearance for future use. The decommissioning process for nuclear power plants, following NRC guidelines, involves several stages and is typically carried out using a combination of two primary strategies: DECON and SAFSTOR. In DECON, decommissioning starts immediately after shutdown, with dismantling and decontamination proceeding right away. SAFSTOR allows the plant to remain secured and monitored for up to 60 years, letting radiation levels decay naturally before dismantling. Most U.S. plants employ a mix of these strategies, progressing through NRC-aligned stages. Over 60% of decommissioned plants in the U.S. have elected DECON and the remainder have opted for SAFSTOR.

The general stages of decommissioning according to the NRC are:

1. ***Planning and preparation:*** A detailed decommissioning plan is developed, covering cost estimates, safety protocols, and timelines, to ensure regulatory compliance.

2. ***Post-shutdown transition:*** The plant is secured by transferring spent fuel to pools or dry cask storage, shutting down systems, and implementing security and radiation controls.

3. ***Decontamination (DECON):*** Radiation levels are reduced by cleaning and dismantling contaminated components. Some plants enter a period of SAFSTOR, where the plant is kept intact and monitored while some radioactive elements decay, prior to DECON.

4. ***Dismantling and demolition:*** Structures and components, including large radioactive items like the reactor vessel, are dismantled, with materials sorted for recycling or disposal.

5. ***Waste management and disposal:*** Radioactive waste is packaged and transported per regulations, with high-level waste stored onsite until a permanent solution is available.

6. ***Final site survey and license termination:*** A radiological survey confirms the site's safety for release, and documentation is submitted to the NRC to officially terminate the license.

Once decommissioned, nuclear facilities in the U.S. are categorized as either SAFSTOR or DECON. Decommissioned nuclear plants outside the U.S. follow similar decommissioning strategies but are labeled as undergoing immediate dismantling (equivalent to DECON) or delayed dismantling (equivalent to SAFSTOR). A third option, entombment (ENTOMB) is used when other decommissioning strategies cannot be used and entails encasing the structures, systems, and their components in a long-lived structure like concrete until the radioactivity is reduced to acceptable levels.

Since the decommissioned plants in SAFSTOR status still have most of their buildings and equipment intact, the few sites currently in SAFSTOR offer the best chance for recommissioning in comparison to the majority of decommissioned reactors, which are in various stages of DECON. To be clear, all nuclear facilities in permanent shutdown have their nuclear fuel removed and placed into storage. The fuel removal stage is central to nuclear decommissioning but significantly impacts containment units and other plant systems. These impacts—ranging from structural breaches to contamination and irreversible equipment damage—effectively preclude restarting the reactor, as repairing the compromised containment and cooling systems can be economically and technically impractical.

The Case for SMRs

Nuclear reactors can be categorized into three group: 1) legacy reactors, 2) generation III+ SMRs, and 3) generation IV reactors. Each design is tailored to address different energy needs, regulatory environments, and technical challenges.

Legacy nuclear reactors provide the most energy capacity, ranging from 300 MW to 1,700 MW per unit. These reactors typically use LEU fuel and light-water cooling technology. Most of the world's existing nuclear power plants are legacy reactors, which were deployed in the late 1960s. These reactors were designed for commercial electricity production, focusing on improving the reliability, power output, and economic competitiveness of nuclear energy. They include well-known reactor types like PWRs and BWRs, which make up most of the nuclear reactors in operation today. The reactors have safety systems but require active controls and human intervention to respond to emergencies. Some legacy reactors use natural uranium as fuel paired with heavy-water cooling technology, such as CANDU. The CANDU reactor design is more cost-efficient than light-water reactors because it does not depend on the uranium enrichment supply chain, and Canadian developers are modernizing the reactor design to provide enhanced safety and shorter construction schedules.

Generation III+ SMRs represent a grouping of two types of reactors: 1) generation III+ reactors and 2) SMRs. Generation III+ reactors, such as the AP1000, incorporate passive safety systems that allow for automatic shutdown and heat removal without operator intervention. These designs are intended to lengthen the lifespan of nuclear plants beyond that of earlier generations, with up to 60-year operation periods that can be extended. The European pressurized reactor (EPR) is a generation III+ design that significantly improves upon older PWR designs. The EPR incorporates several passive safety systems and redundant layers of protection designed to meet enhanced safety standards and reduce the risk of severe accidents. The EPR operates at higher thermal efficiency than earlier PWRs because of an optimized coolant system and improved thermal conditions. The EPR can produce about 1,600 MW of electricity, making it one of the highest-capacity reactors in use. Current EPRs are in operation or under construction in countries like Finland, France, China, and the U.K. SMRs represent the second component of this reactor category and have between 20 MW and 300 MW of energy capacity. The majority of SMRs use LEU fuel coupled with light-water cooling technology. SMRs are designed to be smaller and more modular than traditional reactors, allowing for factory-style construction and easier scalability to meet varying energy demands. The most popular use-case for SMRs is colocated power generation for datacenters and other industrial companies with large power demand. SMRs can provide behind-the-meter baseload power generation that is reliable, which is essential to customers that require continuous power. Blue-chip companies like Amazon, Google, and Meta are partnering with SMR developers to establish a viable market, and the DOE reissued the $900 million generation III+ SMR program to support the development and deployment of SMRs. The SMR industry must simultaneously promote the benefits of commercialized advanced nuclear technology and navigate the regulatory landscape, which is inherently slowing the growth of commercialized SMR technology.

Generation IV reactors represent the future of nuclear power and focus on sustainability, efficiency, and reduced nuclear waste. These are SMRs that use advanced technologies that will disrupt the legacy nuclear reactor design by providing modularity and scalability with enhanced safety. The generation IV reactors provide an energy capacity ranging from 20 MW to 300 MW and can be fueled by LEU or HALEU depending on the technology. Notable generation IV reactors under development include the molten salt reactor, fast neutron reactor, high-temperature gas-cooled reactor, and sodium-cooled fast reactor.

- ***Molten salt reactors (MSRs)*** use liquid fluoride or chloride salts as both fuel and coolant. They operate at lower pressures and higher temperatures, which enhances their safety. MSRs can effectively burn nuclear waste, reducing the amount of long-lived radioactive materials.

- ***Fast neutron reactors (FNRs)*** use fast neutrons to produce fissile material, which can efficiently burn nuclear waste and effectively use uranium resources.

- ***High-temperature gas-cooled reactors (HTGRs)*** operate at extremely high temperatures, which make them ideal for diverse applications such as hydrogen production and waste heat utilization. The reactor's fuel pebbles can be engineered to burn or recycle nuclear waste.

- ***Sodium-cooled fast reactors (SFRs)*** use liquid sodium as coolant and have the capability to recycle spent nuclear fuel. This process reduces waste and extends the lifespan of uranium resources.

These reactors are intended to be safer, more efficient, and capable of using a closed fuel cycle to minimize nuclear waste. They also operate at higher temperatures, which allows for better electricity generation efficiency and the potential for hydrogen production through thermochemical processes. Generation IV reactors often make use of alternative coolants like helium or molten salt, as opposed to water, enabling higher operational temperatures and better thermal efficiency. These advancements allow the reactors to be used for industrial processes beyond electricity generation, such as producing hydrogen or desalinating water, broadening the applications of nuclear technology beyond power generation alone. Currently there are three generation IV reactors being built. Construction began on the HTGR in China at the Shidao Bay Nuclear facility in 2012 and commercial operation began in 2023. The other two generation IV reactors are in the U.S. The Hermes low-power demonstration reactor is located at the Oak Ridge facility in Tennessee, which is a fluoride sodium-cooled high-temperature reactor. Construction began on this facility in July 2024, with an operational date of 2027. TerraPower began construction of its Natrium reactor in Kemmerer, Wyoming, in June 2024 with a targeted operational date of 2030.

Investors should expect that there will be winners and losers in the SMR landscape. Below is a breakdown of the key SMR companies and technologies.

Exhibit 25
Nuclear Industry
Various Types of Small Modular Reactors and Microreactors

Company	Reactor Type	Coolant/Fuel Type	Reactor Capacity (MW)	Key Features
NuScale Power	Water-Cooled Reactors	Water/Uranium Dioxide (UO_2)	77	Modular PWR that is scalable with passive safety
GE Hitachi	Water-Cooled Reactors	Water/Uranium Dioxide (UO_2)	300	Simplified BWR design with 60% cost reduction
TerraPower	Sodium-Cooled Fast Reactors	Liquid Sodium/Metallic	345	Combines sodium cooling with molten salt energy storage
ARC Clean Technology	Sodium-Cooled Fast Reactors	Liquid Sodium/Metallic	100	Compact sodium-cooled reactor design
X-energy	High-Temperature Gas-Cooled Reactors	Helium/TRISO (UO_2/UCO in ceramic)	80	Pebble-bed reactor using TRISO fuel. Produces electricity and industrial heat.
Chinese Government	High-Temperature Gas-Cooled Reactors	Helium/TRISO (UO_2/UCO in ceramic)	100	First grid-connected HTGR using helium coolant
Kairos Power	Molten Salt Reactors	Liquid Salt/Uranium or Thorium	75	Fluoride-salt-cooled reactor for deployment by 2030
Terrestrial Energy	Molten Salt Reactors	Liquid Salt/Uranium or Thorium	195	Offers flexibility for industrial heat and power generation
Oklo	Liquid-Metal Cooled Fast Reactor	HALEU	15 - 75	Compact, self-sustaining fast reactor using recycled nuclear waste
BWXT	Microreactor	TRISO	1 - 5	Mobile and resilient power for mission-critical government needs
Westinghouse Electric Company	Microreactor	TRISO	5 - 15	Passive cooling system and solid-state core, which reduces the need for extensive infrastructure and water use

Sources: Company reports and William Blair Equity Research

The energy cost of fuel production represents roughly half of the life-cycle energy inputs for conventional PWRs and BWRs, and SMRs use a variety of different fissile material. The most conventional of the SMRs are the light-water reactors, which use traditional uranium dioxide. These reactors are similar to conventional PWRs or BWRs, but are somewhat smaller and modular, making them an SMR. Fast breeder reactors (FBRs) such as SFRs tend to use a mixed oxide (MOX) fuel, which is a composite of plutonium and uranium. HTGRs, such as the Xe-100 from X-energy, uses TRISO fuel, which is a ceramic-coated uranium fuel.

Exhibit 26
Nuclear Industry
Various SMR Fuel Types

Fuel Type	Reactor Types	Source Material
Uranium Dioxide (UO_2)	Light-water reactors (PWRs, BWRs)	Natural uranium, enriched to 3-5% U-235
Mixed Oxide (MOX)	Modified LWRs, some fast breeder reactors (FBRs)	Plutonium dioxide (PuO_2) blended with UO_2
Uranium Carbide (UC), Uranium Nitride (UN)	Fast neutron reactors (FNRs), advanced reactors	Enriched uranium processed into carbide or nitride compounds
TRISO Fuel	High-temperature gas-cooled reactors (HTGRs)	Uranium dioxide (UO_2) or uranium oxycarbide (UCO), coated with carbon and ceramic layers
Metallic Fuels	FBRs, research reactors	Enriched uranium alloyed with zirconium
Thorium-Based Fuels	Heavy-water reactors (HWRs), advanced reactors	Thorium-232, converted to Uranium-233

Sources: Company reports and William Blair Equity Research

SMRs offer colocation as a solution for hard-to-decarbonize sectors. SMRs represent a significant innovation in nuclear technology, promising flexible, scalable, and safer nuclear power solutions. The energy capacity of SMRs range from 5 MW to 400 MW, compared with the typical 1,000 MW capacity of large-scale reactors. The business model for SMRs is that they can be produced in a factory and assembled onsite, significantly reducing the cost and time required for construction compared to traditional nuclear plants. However, SMR technologies are nascent, and commercial success is yet to be proved. The 2022 Inflation Reduction Act allows new nuclear facilities to qualify for a 30% investment tax credit, improving the financial landscape for deploying SMRs and other advanced nuclear technologies.

Costs of SMRs will remain unreasonably high unless the regulatory burden changes. The current cost estimates of SMRs across technologies are still highly variable. The data reported in Energy magazine (Steigerwald et al., 2023) shows a range of values for the LCOE of SMR technologies from a low of $116 per MWh for a helium-cooled fast-neutron reactor to a high of $5,222 per MWh for an SFR. Other research (Asuega et al., 2023) lists the LCOE for four different SMR technologies as ranging from $80 to $89 per MWh. Since none of these technologies are proven at commercial scale, the LCOE estimates provided can only be considered provisional. In conversations with nuclear experts, we also learned that the technologies closest to the existing conventional fleet would be the most likely to see commercial success, which are the BWR and PWR designs.

Exhibit 27
Nuclear Industry
LCOE Estimates for SMR Technologies

Reactor Model	Reactor Type	LCOE (2020 USD/MWh)
BWRX-300	BWR	$230
UK SMR	PWR	$222
SMR-160	PWR	$273
SMART	PWR	$329
NuScale	PWR	$414
RITM 200M	PWR	$506
ACPR 50S	PWR	$619
KLT-40S	PWR	$672
CAREM	PWR	$732
EM2	Helium-Cooled Fast Neutron	$116
HTR-PM	Gas-Cooled Pebble-Bed Reactor	$136
PBMR-400	Gas-Cooled (Helium) Pebble-Bed Reactor	$139
ARC-100	Sodium-Cooled Fast Reactor	$1,217
CEFR	Sodium-Cooled Fast Reactor	$3,484
4s	Sodium-Cooled Fast Reactor	$5,222

Source: Steigerwald et al. 2023

Exhibit 28
Nuclear Industry
LCOE Estimates for Three Different Types of SMRs

Reactor Type	Companies	LCOE ($/MWh)
Light-Water SMR	NuScale VOYGR; GE Hitachi BWRX-300	$89.6
Gas-Cooled SMR	X-energy (XE-100); China HTR-PM	$81.5
Molten-Salt SMR	Kairos Power (KP-FHR)	$80.7

Source: Data from Asuega et al. (2023)

LCOE estimates give us one metric to analyze across technologies, but it is also important to understand the limitations of LCOE. LCOE ignores grid balancing concerns, among other things. As stated by the National Renewable Energy Laboratory, "LCOE does not capture the economic value of a particular generation type to the system and therefore may not serve as an appropriate basis for comparing technologies. An area of potential growth for SMRs is in colocation and decarbonizing the so-called "hard to decarbonize" industrial sector. "

Industry requires electricity, and large amounts of it, continuously and reliably. Variable renewable generation from wind and solar is a poor fit for this sector, which currently uses colocated natural gas co-generation or diesel generators to provide continuous onsite power. SMRs and microreactors can provide continuous, onsite power in large quantities and are thus a natural solution.

The total addressable market (TAM) is significant. To get an idea of the potential market, we calculated the industrial electricity consumption in the U.S., Europe, and Asia. The power required by industry around the globe creates a market for almost 100,000 microreactors or roughly 20,000 SMRs, assuming a microreactor size of 10 MW and an SMR size of 50 MW.

Exhibit 29
Nuclear Industry
TAM for Microreactors and SMRs

Region	Industrial Electricity Consumption (TWh/yr)	Power Capacity (GW)	TAM Microreactors (Assumed 10 MW)	TAM SMRs (Assumed 50 MW)
United States	1,008	115	11,499	2,300
Europe	876	100	9,991	1,998
Asia	6,559	748	74,832	14,966
Total	8,443	963	96,323	19,265

Sources: Energy Information Administration, EC Europa, International Energy Agency

Energy Return on Investment of Recommissioning Nuclear Facilities

Energy return on investment (EROI) is a metric of energy profitability and serves as a proxy for return on invested capital. Originally introduced in our report The Red Pill, EROI is a litmus test to assess the potential for ROIC from an energy system by analyzing the underlying thermodynamics of a technology. With respect to nuclear restarts, EROI will tell us how the net electricity generated from a recommissioned nuclear facility compares with the amount of energy required to restart and operate the facility for the next 20 or 40 years. Obviously, if a facility requires more energy to restart—that is, energy to make concrete, steel, nuclear fuel, and other components of a nuclear facility—than it produces in electricity, then the facility is a net energy sink on society.

The equation for EROI is as follows:

$$EROI = \frac{EnergyOutput_{PE-EQ}}{EnergyInput_{PE-EQ}}$$

Where energy output (EO) is the total amount of energy produced by the technology over its lifetime, energy input (EI) is the total amount of energy required to build, operate, and decommission the nuclear facility over its lifetime. EO is thought of as the biophysical equivalent to net operating profit after tax (NOPAT), while EI is analogous to the invested capital.

Our results indicate that recommissioning a nuclear facility results in significant energy profits, signaling the potential for significant ROIC. For every unit of energy invested in recommissioning a nuclear facility, society will receive between 49 and 73 units of energy in return. We calculated the EROI for a recommissioned PWR and BWR using the following scenarios: 1) a low-cost scenario where recommissioning requires $2 billion in investment and 2) a high-cost scenario where it costs $4 billion. We also calculated the EROI assuming a 20- and 40-year facility life. Despite doubling the investment in the high-cost scenario to $4 billion, the energy returns remain very high, mostly because the majority of the lifecycle costs are associated with fuel inputs and not facility construction.

Exhibit 30
Nuclear Industry
Energy Return on Investment (EROI) Values for Recommissioned PWR and BWR Reactors

	PWR		BWR	
Energy Input Category	**20-Year**	**40-Year**	**20-Year**	**40-Year**
Recommissioning Energy Input (Low-Cost Scenario)	6,730	6,730	6,730	6,730
Recommissioning Energy Input (High-Cost Scenario)	13,460	13,460	13,460	13,460
Lifecycle Energy Input (Excluding Recommissioning/Construction	17,496	34,992	19,365	38,730
Total Energy Input (Low Cost)	24,226	41,722	26,095	45,460
Total Energy Input (High Cost)	30,956	48,452	32,825	52,190
Total Energy Output	1,521,819	3,043,638	1,521,819	3,043,638
EROI Low Cost	**63**	**73**	**58**	**67**
EROI High Cost	**49**	**63**	**46**	**58**

Sources: Future Earth Analytics, company reports, and William Blair Equity Research

The most energy-intensive stage of the conventional nuclear lifecycle is the production of fuel. BWRs use a simpler fuel cycle, which represents 49% of the lifecycle energy inputs. PWRs have a more complicated fuel cycle, which leads to an increased lifecycle energy input of 54%. BWRs require more energy in total to construct and operate over their life, which leads to slightly lower EROI numbers.

Exhibit 31
Nuclear Industry
Energy Costs by Category as a Portion of Total Lifecycle Energy Inputs

	Percent of Total Energy Cost	
Energy Input Category	**BWR**	**PWR**
Construction of Nuclear Power Plant	35%	33%
Treatment of Spent Nuclear Fuel	10%	10%
Uranium Fuel Element Production (3.8% Enriched)	49%	NA
Nuclear Fuel Element	NA	54%
Total	94%	97%

Source: Future Earth Analytics

Methods to Calculate EROI for Recommissioned Nuclear Facilities

Estimates of the costs, financial or energetic, of restarting a nuclear facility are fuzzy at best because it has never been done before. The best we can do is provide an estimate, accounting for cost overruns. For now, the best estimates we have for the financial cost of recommissioning come from companies paying for the recommissioning. Holtec International plans to invest $500 million alongside a loan guarantee from the Department of Energy totaling $1.52 billion, for a combined investment of $2 billion. Constellation Energy estimates that reopening Three Mile Island Unit 1 will cost $1.6 billion.

From this data, we can estimate that it will cost roughly $2 billion to reopen a decommissioned facility. It is also worth noting that each of the restarts applies to one reactor at these facilities. Given the cost overrun history of this industry, perhaps a better investment target is between $2 billion and $4 billion.

The data in EcoInvent, a life cycle analysis database, for facility construction represents the energy inputs to build a new PWR or BWR. The data for new technologies or new processes like recommissioning nuclear facilities are nonexistent. In these situations, it is common to use proxy data to estimate energy inputs. One common way to do this is to use data to calculate the energy intensity of an economic sector, in units of megajoules of energy inputs per dollar of economic output. The energy intensity value is then multiplied by the dollar investment value to yield a proxy measure of the energy input required for that investment amount.

The input-output tables from the Bureau of Economic Analysis (BEA) provide GDP output at the economic sector level, and the EIA provides energy inputs by sector. Dividing the energy inputs by the economic output yields the energy intensity value. For example, the BEA lists the GDP of the industrial sector as $5.28 trillion in 2023, and the EIA's Monthly Energy Review states that total energy consumption in the industrial sector was 31,132 * 109 BTU, or 32.8 * 109 megajoules (MJ). Dividing the two gives us 6.21 MJ per dollar of industrial sector GDP, while that same statistic for the service sector is 0.52 MJ per dollar, indicating the much smaller energy footprint of services compared to industry. Using these values, we can convert the amount of investment required per sector to restart a nuclear facility into energy inputs to calculate the EROI. EI for "construction of a nuclear facility" is thus calculated as follows:

$$NuclearFacilityConstructionEnergyInput_{PE-EQ} = \sum_{i=1}^{2}\left(\frac{EnergyConsumption_i}{GDP_i}\right)(Investment_i)$$

Where i is the economic sector and energy consumption is the amount of energy consumed by that sector in the year according to the EIA in megajoules, GDP is the economic output of that sector over the year in dollars, and the investment is the amount of investment in that sector required to restart the nuclear facility in dollars.

The reported data for Three Mile Island and Palisades indicates that restarting an 800 MW PWR nuclear facility will cost between $2 billion and $4 billion. Based on conversations with nuclear industry experts, they assumed that roughly half of the recommissioning cost would be spent on capital equipment and the other half will be services related to workforce training. By using the BEA values for energy intensity in industry as a proxy for the capital equipment and construction and the service sector as a proxy for workforce training, we estimate that the total energy input associated with recommissioning an 800 MW PWR to be 6.7 billion MJ, or 6.7 terajoules (TJ).

Assuming the energy inputs for the fuel cycle and decommissioning of the facility will remain similar to other PWRs and BWRs, we then use the EcoInvent database to estimate the remaining energy inputs to attain the energy input required to recommission and operate a nuclear facility over an assumed 20- and 40-year life.

EO was calculated by converting the net electrical output from the recommissioned facility into primary energy equivalents. Electrical output was first calculated for an 800 MW facility, assuming a 92.7% capacity factor for both the 20- and 40-year scenario. The net electrical output was converted to primary energy equivalents by multiplying by the heat rate for the Midwest Reliability Organization (MRO) in the U.S., which is 11.7 MJ of primary energy per kWh produced. The net electricity is converted back to primary energy units so that it can be compared to the primary energy required as energy inputs to construct, operate, and decommission the facility. In practice, one can think of it this way: if the electricity from the nuclear facility were replaced in the MRO grid system with a mix of the existing grid, how much primary energy would be required from the environment to produce that electricity? The answer to that question for the MRO is that 11.7 MJ are required per kWh of electricity produced in the MRO, according to the EcoInvent database.

Conclusion

After a long time apart, the world is falling in love again with commercial nuclear power. To enable the nuclear renaissance, two critical bottlenecks must be solved: deregulation and nuclear fuel enrichment capacity. We calculate over $2,000 per kWh of additional regulatory burden is foisted upon nuclear facilities, which is as expensive as a heavy-duty natural gas turbine in extra cost. China is a useful example of what is possible. The country has 30 reactors under construction and another 36 planned with approvals and funding in place, a stark contrast to the U.S.'s zero, and is building at one-fourth the cost. Without deregulation, the nuclear renaissance is a nonstarter. Next, we need to rebuild our domestic and American-owned nuclear enrichment capacity. Currently, almost 30% of our nuclear fuel supply is imported from Russia, creating a national security and energy independence vulnerability. If we solve these two roadblocks, we can usher in the next era of nuclear, first starting by uprating our current fleet, then restarting recently decommissioned facilities, and lastly building new SMRs sited at current facilities and co-located at demand.

The prices of the common stock of other public companies mentioned in this report follow:

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Alphabet, Inc. (Outperform)	$168.47
BWX Technologies, Inc. (Outperform)	$119.49
Centrus Energy Corp. (Outperform)	$113.29
Lightbridge Corporation	$15.20
Meta Platforms, Inc. (Outperform)	$627.06
Oklo Inc. (Outperform)	$48.87

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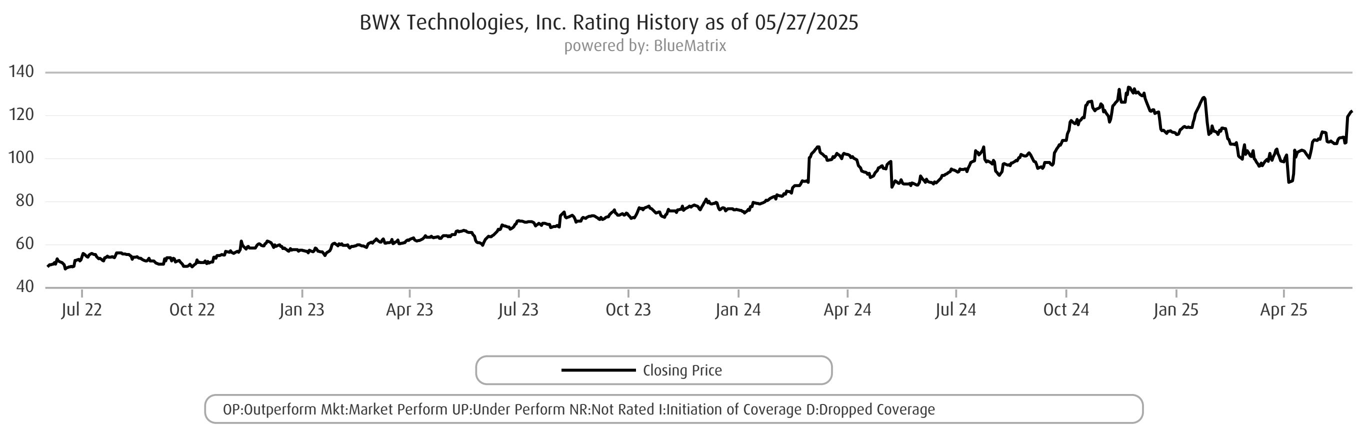

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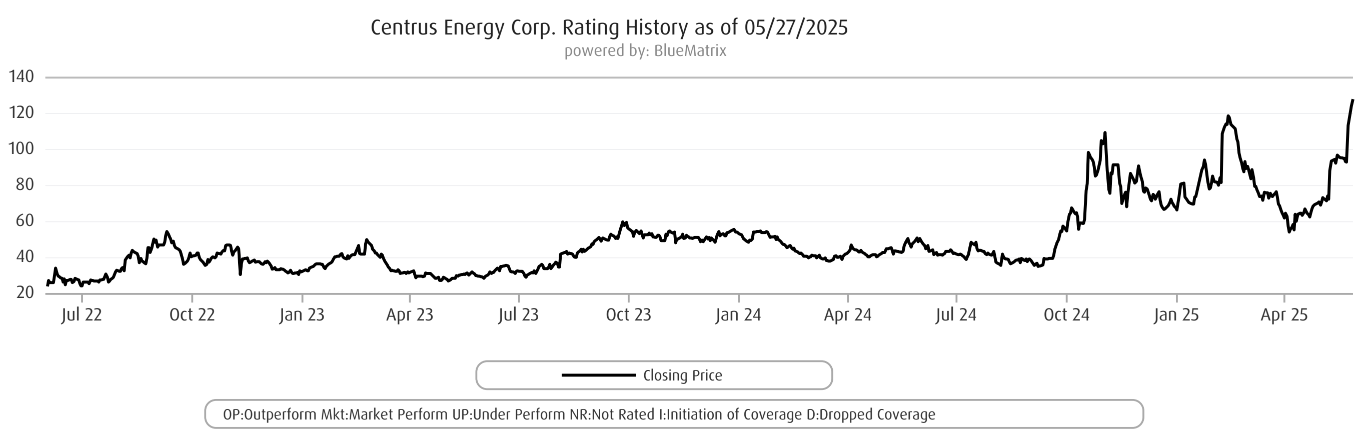

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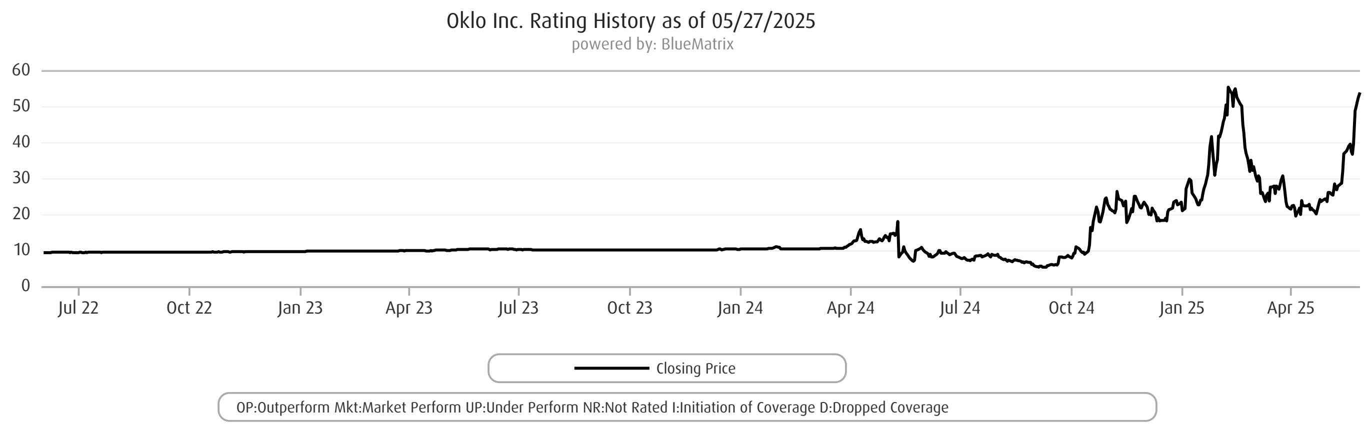

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William Blair

Equity Research Directory

John Kreger, Partner Director of Research +1 312 364 8612
Kyle Harris, CFA, Partner Operations Manager +1 312 364 8230

Scott Hansen, Partner Associate Director of Research +1 212 245 6526

CONSUMER

Sharon Zackfia, CFA, Partner +1 312 364 5386
Group Head–Consumer
Lifestyle and Leisure Brands, Restaurants, Automotive/E-commerce

Jon Andersen, CFA, Partner +1 312 364 8697
Consumer Products

Phillip Blee, CPA +1 312 801 7874
Home and Outdoor, Automotive Parts and Services, Discount and Convenience

Dylan Carden +1 312 801 7857
E-commerce, Specialty Retail

ECONOMICS

Richard de Chazal, CFA +44 20 7868 4489

ENERGY AND POWER TECHNOLOGIES

Jed Dorsheimer +1 617 235 7555
Group Head–Energy and Sustainability
Generation, Efficiency, Storage

Tim Mulrooney, Partner +1 312 364 8123
Sustainability Services

FINANCIAL SERVICES AND TECHNOLOGY

Adam Klauber, CFA, Partner +1 312 364 8232
Group Head–Financial Services and Technology
Financial Analytic Service Providers, Insurance Brokers, Property & Casualty Insurance

Andrew W. Jeffrey, CFA +1 415 796 6896
Fintech

Cristopher Kennedy, CFA +1 312 364 8596
Fintech, Specialty Finance

Jeff Schmitt +1 312 364 8106
Wealthtech, Wealth Management, Capital Markets Technology

GLOBAL SERVICES

Tim Mulrooney, Partner +1 312 364 8123
Group Head–Global Services
Commercial and Residential Services

Andrew Nicholas, CPA +1 312 364 8689
Consulting, HR Technology, Information Services

Trevor Romeo, CFA +1 312 801 7854
Staffing, Waste and Recycling

HEALTHCARE

Biotechnology

Matt Phipps, Ph.D., Partner +1 312 364 8602
Group Head–Biotechnology

Sami Corwin, Ph.D. +1 312 801 7783

Lachlan Hanbury-Brown +1 312 364 8125

Andy T. Hsieh, Ph.D., Partner +1 312 364 5051

Myles R. Minter, Ph.D., Partner +1 617 235 7534

Healthcare Technology and Services

Ryan S. Daniels, CFA, Partner +1 312 364 8418
Group Head–Healthcare Technology and Services
Healthcare Technology, Healthcare Services

Margaret Kaczor Andrew, CFA, Partner +1 312 364 8608
Medical Technology

Brandon Vazquez, CFA +1 212 237 2776
Dental, Animal Health, Medical Technology

Life Sciences

Matt Larew, Partner +1 312 801 7795
Life Science Tools, Bioprocessing, Healthcare Delivery

Andrew F. Brackmann, CFA +1 312 364 8776
Diagnostics

Max Smock, CFA +1 312 364 8336
Pharmaceutical Outsourcing and Services

INDUSTRIALS

Brian Drab, CFA, Partner +1 312 364 8280
Co-Group Head–Industrials
Advanced Manufacturing, Industrial Technology

Ryan Merkel, CFA , Partner +1 312 364 8603
Co-Group Head–Industrials
Building Products, Specialty Distribution

Louie DiPalma, CFA +1 312 364 5437
Aerospace and Defense, Smart Cities

Ross Sparenblek +1 312 364 8361
Diversified Industrials, Robotics, and Automation

TECHNOLOGY, MEDIA, AND COMMUNICATIONS

Jason Ader, CFA, Partner +1 617 235 7519
Co-Group Head–Technology, Media, and Communications
Infrastructure Software

Arjun Bhatia, Partner +1 312 364 5696
Co-Group Head–Technology, Media, and Communications
Software

Dylan Becker, CFA +1 312 364 8938
Software

Louie DiPalma, CFA +1 312 364 5437
Government Technology

Jonathan Ho, Partner +1 312 364 8276
Cybersecurity, Security Technology

Sebastien Naji +1 212 245 6508
Infrastructure Software, Semiconductor and Infrastructure Systems

Maggie Nolan, CPA, Partner +1 312 364 5090
IT Services

Jake Roberge +1 312 364 8056
Software

Ralph Schackart III, CFA, Partner +1 312 364 8753
Internet and Digital Media

Stephen Sheldon, CFA, CPA, Partner +1 312 364 5167
Vertical Technology – Real Estate, Education, Restaurant/Hospitality

EDITORIAL AND SUPERVISORY ANALYSTS

Steve Goldsmith, Head Editor and SA +1 312 364 8540
Katie Anderson, Editor and SA +44 20 7868 4451
Audrey Majors, Editor and SA +1 312 364 8992
Beth Pekol Porto, Editor and SA +1 312 364 8924
Lisa Zurcher, Editor and SA +44 20 7868 4549