

Nuclear Power Partnerships

By John Benson

November 2024

1. Introduction

I have covered several emerging nuclear power technologies in the past. Most recently I combined a trip into my past in the nuclear industry with an emerging manufacturer of liquid metal fast breeder reactors. This post is summarized and linked below.

Nukes Part 8 - Fast Breeders: *Many times, I thought I had left my history in the dust, only to have a new team bring it back to me. In case you are wondering about the title of this paper, these are a type of nuclear fission reactor that were in my deep past. I graduated from college (BSEE) in 1975. My first job out of college was with Rockwell Atomics International. The projects I worked on there all involved a type of reactor called a Liquid Metal Fast Breeder Reactor (LMFBR).*

The “Liquid Metal” was its heat-transfer fluid: either liquid sodium or a sodium-potassium alloy (NaK). “Fast” refers to the neutrons emitted by the nuclear reaction that are “fast” (high-energy), and remain fast until they undergo additional reactions. In a standard water-cooled fission reactor, the neutrons are moderated (have their energy reduced) before reacting with other atoms. Breeder means that the LMFBR breeds its own fuel.

This report is also about Oklo, who wanted to focus on the technology with the most demonstration history, with inherent safety, while having the capability to use waste as fuel. All of these capabilities were demonstrated by LMFBRs well before my history with this technology.

<https://energycentral.com/c/cp/nukes-part-8-fast-breeders>

A LMFBR is a type of fission reactor that is generally called an advanced design. Since the nuclear industry has a long history (the first fission reactors were built during WWII, in the early 1940s), there have been many flavors of advanced reactors. In this post we will look at Kairos Power, who is developing a “Pebble Bed” Reactor using an advanced “Flibe” coolant/heat transfer fluid. This ends up being an ideal design for future Artificial Intelligence (AI) server farms. Thus:

Kairos Power, a US-based nuclear engineering company, recently inked a long-term deal with Google to develop and bring the company’s first SMR online “quickly and safely by 2030,” with continuing rollouts planned through 2035.¹

Note that “SMR” is an abbreviation of another term used for advanced reactors that are “Small, Modular Reactors,” that can be mass-produced and quickly deployed.

Michael Terrell, senior director of energy and climate at Google, lauded the deal as a win for clean energy: “This landmark announcement will accelerate the transition to clean energy as Google and Kairos Power look to add 500 MW of new 24/7 carbon-free power to U.S. electricity grids.”

¹ Tristan Greene, Cointelegraph, “Google’s nuclear power plan could revolutionize cryptocurrency mining,” Oct 15, 2024, <https://cointelegraph.com/news/google-nuclear-power-plan-could-revolutionize-cryptocurrency-mining>

Google's commitment to developing what may ultimately become the first commercial US-based SMR manufacturing partnership represents the opening bell for the nascent commercial nuclear power industry.

While not every company has pockets as deep as Google-parent corporation Alphabet, the cost of entry for on-site nuclear power is likely to drop as the first generation of SMRs are manufactured and improved upon over time.

Generally, artificial intelligence and the cryptocurrency sector use huge amounts of power for the data centers that are driving their growth. Also, their load profile is consistent with 24 x 7 supply profile of nuclear generation. However, this partnership creates several potential problems – read on for more details.

2. Google & Kairos Power

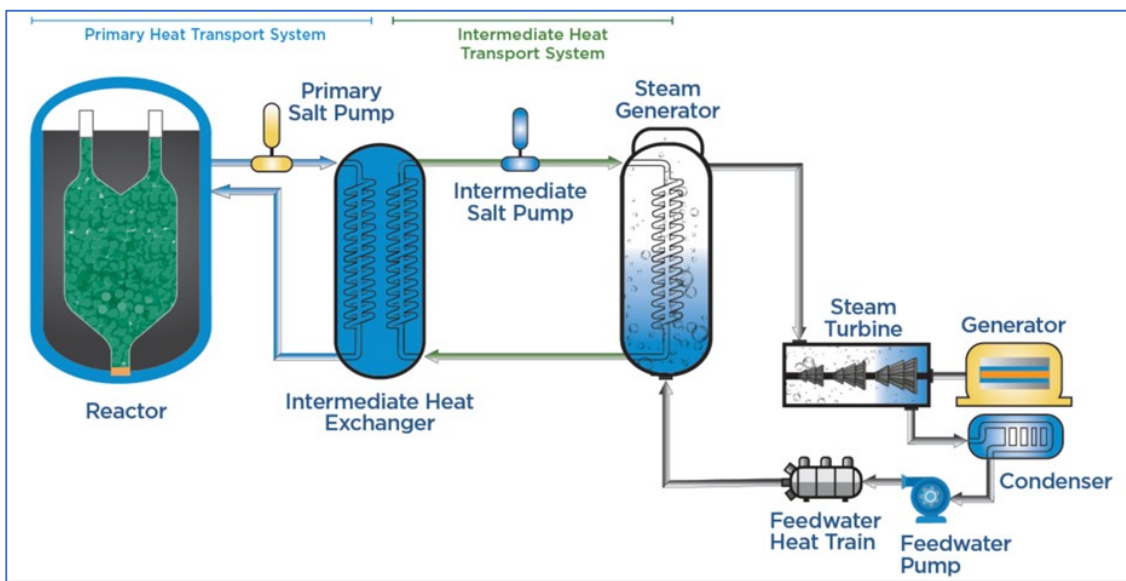
The Kairos Power FHR (KP-FHR) is a novel advanced reactor technology that leverages TRISO fuel in pebble-form combined with a low-pressure fluoride salt coolant. The technology uses an efficient and flexible steam cycle to convert heat from fission into electricity and to complement renewable energy sources.²

Note that “FHR” is (sort of) an abbreviation for “fluoride salt-cooled, high-temperature reactor.”

TRISO stands for TRI-structural ISOtropic particle fuel. Each TRISO particle is made up of a uranium, carbon and oxygen fuel kernel. The kernel is encapsulated by three layers of carbon- and ceramic-based materials that prevent the release of radioactive fission products. The particles are very small (about the size of a poppy seed) and robust.³

They can be fabricated into cylindrical pellets or billiard ball-sized spheres called “pebbles” for use in either high temperature gas or molten salt-cooled reactors.

The figure below is a block diagram of the Kairos FHR.



² <https://kairopower.com/technology/>

³ <https://www.energy.gov/ne/articles/triso-particles-most-robust-nuclear-fuel-earth>

So far Kairos has built a non-nuclear Engineering Test Unit (ETU, see subsection below) and ran it for over 1,000 hours earlier this year. They have also received a construction permit from the Nuclear Regulatory Commission (NRC) to build the Hermes demonstration reactor.

The two tables on the next page describe the demonstration reactor and Kairos currently planned full-scale commercial reactor.

KP-X Commercial Demo Plant (Hermes demonstration reactor)

POWER OUTPUT	50 MWE
DEPLOYMENT CONFIGURATION	SINGLE UNIT
REACTOR OUTLET TEMPERATURE	650°C
REACTOR OPERATING PRESSURE	NEAR ATMOSPHERIC
REACTOR STRUCTURAL MATERIAL	316H STAINLESS STEEL
GRAPHITE GRADE	IBIDEN ET-10
FUEL ENRICHMENT LEVEL	19.75%
REFUELING TYPE	ONLINE
BACK-UP POWER SUPPLY	AUTOMATIC SAFE SHUTDOWN; PASSIVE COOLING UPON LOSS OF POWER

KP-FHR Commercial Plant

POWER OUTPUT	150 MWE (2 X 75 MWE)
DEPLOYMENT CONFIGURATION	DUAL UNIT
REACTOR OUTLET TEMPERATURE	650°C
REACTOR OPERATING PRESSURE	NEAR ATMOSPHERIC
REACTOR STRUCTURAL MATERIAL	316H STAINLESS STEEL
GRAPHITE GRADE	IBIDEN ET-10
FUEL ENRICHMENT LEVEL	19.75%
REFUELING TYPE	ONLINE
BACK-UP POWER SUPPLY	AUTOMATIC SAFE SHUTDOWN; PASSIVE COOLING UPON LOSS OF POWER

2.1. Engineering Test Unit (ETU)

Note that “Flibe,” is a chemically stable combination of lithium fluoride and beryllium fluoride salts, that will be used to cool Hermes’ TRISO-fueled pebble bed design and allow it to operate near atmospheric pressure.⁴

The Engineering Test Unit (ETU) has officially become the largest Flibe system in the world. In October, the team at KP Southwest, Kairos Power’s testing and manufacturing facility in Albuquerque, NM, began the careful process of loading 14 tons of molten fluoride salt coolant into ETU, initiating the largest Flibe transfer since the Molten Salt Reactor Experiment in 1969.²

⁴ <https://www.energy.gov/ne/articles/kairos-power-breaks-ground-molten-salt-production-facility>

The ETU represents a major step in our rapid iterative approach to technology development and reflects our culture of learning by building. Scaled at the same size as the Hermes demonstration reactor with nearly identical operating parameters, ETU is a non-nuclear prototype of Kairos Power's fluoride salt-cooled high-temperature reactor (KP-FHR) that demonstrates the integration of principal systems, structures, and components. Lessons learned from ETU will be integrated into Hermes and future iterations on the path to commercializing KP-FHR technology.

2.2. Fuel Pebbles

Kairos Power's reactor uses fully ceramic fuel, which maintains structural integrity even at extremely high temperatures. This fuel will be undamaged to well above the melting temperatures of conventional metallic reactor fuels. Proven methods for fabricating and testing these fuels have been demonstrated at U.S. National Laboratories. By using pebble-type fuel, Kairos Power reactors can refuel on line, enabling exceptional reliability and availability.

2.3. Flibe Coolant

Kairos Power's reactor uses molten fluoride salt coolant. Molten fluoride salts have outstanding capability to transfer heat at high temperature, excellent chemical stability, and the ability to retain radioactive fission products that might be released from fuel. Extensive experience and design information exists from the early U.S. reactor development program that studied and tested liquid-fueled molten salt reactors. These studies confirmed the compatibility of these salts with Kairos Power's high-temperature structural materials, enabling commercially attractive reliability and service life.

2.4. Passive Safety

Passive safety means that Kairos Power reactors do not require electricity to remove heat from the core after shutting down. Kairos Power reactors have uniquely large safety margins based on the selected combination of fuel and coolant, which allows emergency cooling to be driven by fundamental physics (heat-driven circulation) rather than engineered systems. In Kairos Power's reactor, there is no need to provide for make-up coolant (since the coolant cannot boil away), and the fuel tolerance for extremely high temperatures allows orders of magnitude more cooling capability under accident scenarios compared to water-cooled reactors. High-temperature fuel and coolant dramatically simplifies emergency cooling under all conceivable accidents.

2.5. Low Pressure Reactor

The intrinsic low pressure in Kairos Power reactors enhances safety and eliminates the need for bulky and expensive high-pressure containment structures. Kairos Power technology leverages key U.S. federal investments in design, structural materials, and components for low-pressure pool-type reactors, including critical updates to the ASME Boiler and Pressure Vessel Code for design at our service conditions.

2.6. Google Agreement

Since pioneering the first corporate purchase agreements for renewable electricity over a decade ago, Google has played a pivotal role in accelerating clean energy solutions, including the next generation of advanced clean technologies. Today, we're building on these efforts by signing the world's first corporate agreement to purchase nuclear energy from multiple small modular reactors (SMRs) to be developed by Kairos Power. The initial phase of work is intended to bring Kairos Power's first SMR online quickly and safely by 2030, followed by additional reactor deployments through 2035. Overall, this deal will enable up to 500 MW of new 24/7 carbon-free power to U.S. electricity grids and help more communities benefit from clean and affordable nuclear power.⁵

This agreement is important for two reasons:

The grid needs new electricity sources to support AI technologies that are powering major scientific advances, improving services for businesses and customers, and driving national competitiveness and economic growth. This agreement helps accelerate a new technology to meet energy needs cleanly and reliably, and unlock the full potential of AI for everyone.

Nuclear solutions offer a clean, round-the-clock power source that can help us reliably meet electricity demands with carbon-free energy every hour of every day. Advancing these power sources in close partnership with supportive local communities will rapidly drive the decarbonization of electricity grids around the world.

Why we're supporting new advanced nuclear energy

This agreement is part of our efforts to develop and commercialize a broad portfolio of advanced clean electricity technologies to power our global data centers and offices. This approach will complement our use of variable renewables, like solar and wind, and help us reach our ambitious 24/7 carbon-free energy and net-zero goals.

The next generation of advanced nuclear reactors offers a new pathway to accelerate nuclear deployment thanks to their simplified design and robust, inherent safety. The smaller size and modular design can reduce construction timelines, allow deployment in more places, and make the final project delivery more predictable.

Investing in advanced nuclear technology can also provide direct economic benefits to communities across the U.S. Nuclear power has the highest economic impact of any power generation source, according to the U.S. Department of Energy (DOE), and creates high-paying, long-term jobs. The agency estimates reaching 200 GW of advanced nuclear capacity in the U.S. by 2050 will require an additional 375,000 workers...

Our work to scale advanced technologies to benefit everyone

By procuring electricity from multiple reactors — what experts call an “orderbook” of reactors — we will help accelerate the repeated reactor deployments that are needed to lower costs and bring Kairos Power's technology to market more quickly. This is an important part of our approach to scale the benefits of advanced technologies to more people and communities, and builds on our previous efforts.

⁵ <https://blog.google/outreach-initiatives/sustainability/google-kairos-power-nuclear-energy-agreement/>

Last November, we completed a first-of-its-kind enhanced geothermal project with developer Fervo Energy. And earlier this year, we partnered with utilities across the U.S. to create a new clean transition rate that helped expand this commercial pilot to 25x the amount of enhanced geothermal capacity.

We'll continue working to accelerate a diverse portfolio of advanced clean electricity technologies and bring new 24/7 clean, affordable energy onto every grid where we operate.

3. Amazon Web Services

When Amazon Web Services paid US \$650 million in March to add an existing data center to its armada, the tech giant thought it was buying its own private link to a steady supply of nuclear energy to power it, too. The Susquehanna Steam Electric Station, outside of Berwick, Penn., which generates 2.5 gigawatts of nuclear power, sits adjacent to the data center and has been directly powering it since the center opened in 2023.⁶

But shortly after striking the deal, Amazon sought to buy an additional 180 megawatts—a more than 50 percent increase—from the nuclear plant. Susquehanna agreed. But local utilities objected, and the deal has become bogged down in a regulatory battle that will likely set a precedent for data centers, cryptocurrency mining operations, and other computing facilities with voracious appetites for carbon-free electricity.

Putting a data center right next to a power plant so that it can draw electricity from it directly, rather than from the grid, is becoming more common as data centers seek out cheap, steady, and often carbon-free power. Proposals for co-locating data centers with nuclear plants have popped up in New Jersey, Ohio, and Texas. In Europe, Sweden is considering using small modular reactors to power future data centers.

However, co-location raises questions about equity and energy security, because directly connected data centers can avoid paying fees that would otherwise help maintain grids. It also hogs hundreds of megawatts that could be going elsewhere.

"They're effectively going behind the meter and taking that capacity off of the grid that would otherwise serve all customers," says Tony Clark, a former commissioner at the Federal Energy Regulatory Commission (FERC), who has testified to a U.S. House subcommittee on the subject.

The dustup over Amazon's Susquehanna deal started in June, after Amazon Web Services filed a notice to change its interconnection service agreement (ISA) in order to buy the additional power from Susquehanna's parent company, Talen Energy. Amazon wanted to increase the amount of behind-the-meter power it buys from 300 MW to 480 MW. Shortly after Amazon requested the change, utility giants American Electric Power (AEP) and Exelon filed a protest against the agreement and asked FERC to hold a hearing on the matter.

⁶ Andrew Moseman, IEEE Spectrum, "Utilities Question Amazon Nuclear Deal," Oct, 2024, <https://spectrum.ieee.org/amazon-data-center-nuclear-power>

*Their complaint: The deal between Amazon and the nuclear plant would hurt all the customers who buy power from AEP or Exelon utilities by removing generation from the general supply and forcing utility customers to pay for Amazon's share of grid maintenance, among other things. The protest document argues that the arrangement would shift up to \$140 million in extra costs onto the people of New Jersey, Pennsylvania, and other states served by PJM, a regional transmission organization that oversees the grid in those areas. Susquehanna responded by effectively saying that its deal with Amazon is none of AEP and Exelon's business. (AEP, Exelon, Talen/Susquehanna, and Amazon declined to comment for this article). **Author's comment:** per the above, Amazon only needs to pay grid costs if they use the grid. Here they don't.*

Amazon is betting big on nuclear power to drive a massive data-center expansion that includes more than \$52 billion across just three U.S. states.⁷

Amazon and Dominion Energy, the \$48 billion (market cap) energy behemoth, announced Wednesday that they've entered into an agreement to explore the development of small modular reactors (SMRs), a type of advanced nuclear reactor less than 10% the size of a traditional nuclear plant, in Virginia. Amazon simultaneously announced an agreement to fund the development and deployment of small modular reactors in Washington state with the public power agency Energy Northwest.

Amazon signed a separate agreement with X-energy, a developer of SMRs, that is building one as part of the partnership with Energy Northwest. The startup is currently building its first advanced reactor with chemical giant Dow in Seadrift, Texas. As part of its agreement with X-energy, Amazon is anchoring a \$500 million investment in the startup, which was founded by billionaire serial entrepreneur Kam Ghaffarian in 2009, through its Climate Pledge Fund.

Through this deal, Amazon and X-energy plan to bring more than 5 gigawatts of new power projects online across the United States by 2039 — enough to power more than one mid-sized city — in an effort to meet the ballooning power needs of artificial intelligence.

Back to reference 6.

Many disputes will likely follow as more data centers try to co-locate with carbon-free energy sources. Kevin Schneider, a power-system expert at Pacific Northwest National Laboratory, says it's only natural that data center operators want the consistency of nuclear power. "If you look at the base load nature of nuclear, you basically run it up to a power level and leave it there," he says. That operating style is well aligned with the needs of a server farm.

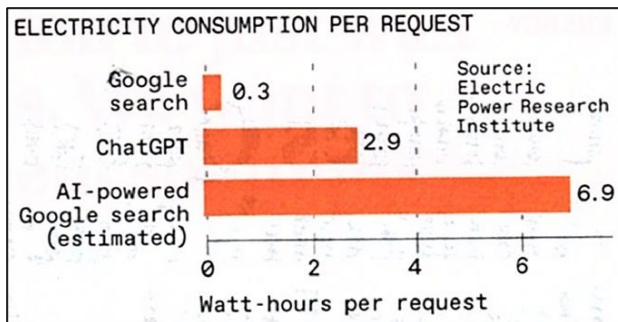
*Yet such arrangements could have major consequences for other energy customers, argues Clark, who is now a senior advisor at the law firm Wilkinson Barker Knauer. For one, directing all the energy from a nuclear plant to a data center is, fundamentally, no different than retiring that plant and taking it offline. "It's just a huge chunk of capacity leaving the system," he says, resulting in higher prices and less energy supply for everyone else. **Author's comment:** We live in a capitalistic economy. High-bidders can purchase any commodity.*

⁷ Forbes Current Climate Newsletter, Oct 21, 2024.

Another issue is the "behind-the-meter" aspect of these kinds of deals. A data center could just connect to the grid and draw from the same supply as everyone else, Clark says. But by connecting directly to the power plant, the center's owner avoids paying the fees that are used to maintain the grid and grow its infrastructure. Those costs could then get passed on to businesses and residents who have to buy power from the grid. **Author's comment:** Ditto my comment on the top of the prior page.

Even the "carbon-free" public relations talking points that come with co-location may be suspect in some cases. In Washington state, where Schneider works, new data centers are being planted next to the region's abundant hydropower stations, and they're using so much of that energy that parts of the state are considering adding more fossil fuel capacity to make ends meet. This results in a "zero-emissions shell game," Clark wrote in a white paper on the subject.

These early cases are likely only the beginning. A report released in May by the Electric Power Research Institute predicts energy demand from data centers will double from 2023 levels by 2030, a leap driven by the fact that AI queries need about 10 times as much energy as traditional Internet searches (see figure below). The International Energy Agency says that doubling from 2024 levels may happen as soon as 2026. Data centers, AI, and the cryptocurrency sector consumed an estimated 460 terawatt-hours in 2022, and could consume more than 1,000 TWh in 2026, the agency predicts.



The potential for unsustainable growth in electricity needs has put grid operators on alert, and in some cases, they've been sounding the alarm. Eirgrid, a state-owned transmission operator in Ireland, warned in August of a "mass exodus" of data centers in Ireland if it can't connect new sources of energy.

There's only so much existing nuclear power to go around, and there are enormous logistical and regulatory roadblocks to building more. Some data center operators and tech giants are looking for creative solutions, including small modular reactors (SMRs) -- advanced nuclear reactors with smaller operating capacities than conventional reactors.

"To me, it does seem like a space where, if big tech has a voracious electric power needs and they really want that 24/7, carbon-free power, nuclear does seem to be the answer," Clark says. "They also have the balance sheets to be able to do some of the risk mitigation that might make it attractive to get an SMR up and running."

4. Recent Nuclear Power Plant Restarts

The U.S. has never restarted a decommissioned nuclear reactor, but today Holtec International closed a \$1.5 billion loan from the U.S. Department of Energy's Loan Programs Office to do just that: The money will help finance the reopening of the 805-megawatt Palisades Nuclear Generating Station in Covert Township, Michigan.⁸

⁸ Eric Wesoff, Canary Media via Yahoo News, "The hottest trend in nuclear power: Reopening shuttered plants," <https://news.yahoo.com/news/hottest-trend-nuclear-power-reopening-205100352.html>

It's the latest development in the effort to turn mothballed nuclear reactors back online in the U.S., where electricity demand is rising for the first time in decades. In late September, Microsoft announced a multibillion-dollar deal to turn back on Three Mile Island Unit 1 in Pennsylvania, as the tech giant seeks around-the-clock carbon-free power for its AI-fueled data center buildout.

The Palisades project is also the first to close a loan under the Energy Infrastructure Reinvestment (EIR) program of the Inflation Reduction Act, which finances projects that repower or retool idled energy infrastructure. As of today, the Loan Programs Office has \$64.89 billion in applications for advanced nuclear projects under consideration or in process; most are seeking a form of EIR funding.

Located on Lake Michigan, the Palisades plant was shuttered by utility Entergy in May 2022 because of financial issues after 50 years of operation. It was the eighth-oldest nuclear plant in the nation at the time of its closing — Palisades produced its first electricity on New Year's Eve in 1971.

In June 2022, Holtec became its new owner and removed the nuclear fuel with plans to complete the decommissioning process by 2041. But just weeks later, Holtec halted the process and applied for federal funding to turn the plant back on. The company is now aiming to restart the plant by the end of 2025 — also known as next year — with plans to provide baseload power until 2051.

Informed insiders suggest that it will take years to recommission the plant, something that has happened only a few times worldwide.

The funds from the new loan will be used to perform the inspections, testing, and restoration work necessary to restart the plant, while Holtec simultaneously pursues a reauthorization of the Palisades operating license with the Nuclear Regulatory Commission (NRC).

Calling it “a climate comeback story,” White House national climate adviser Ali Zaidi told reporters at a Friday press briefing that the Palisades restart is being done in partnership with union labor, “so we're not just putting steel in the ground, but steel in the spine of the American middle class ... And it's translating into jobs and economic growth on the ground.”

Restarting Palisades is expected to create or keep up to 600 jobs, many of them union positions, in what is considered a disadvantaged community, where residents have higher energy burdens than those in 97 percent of communities in America, according to the DOE.

Along with the DOE funding, Palisades will also receive a boost from the U.S. Department of Agriculture's Empowering Rural America program. Last month the Inflation Reduction Act program awarded two rural electric cooperatives in the region with over \$1.3 billion in grants to purchase nuclear power from Palisades.

The USDA will provide more than \$650 million to the Wolverine Power Cooperative to finance the purchase of approximately 435 megawatts of wholesale energy from the Palisades plant for its members across rural Michigan. And Hoosier Energy is being granted more than \$675 million to help purchase approximately 370 megawatts of energy from the restarted Palisades plant, along with 250 megawatts of solar power for its members in Illinois and Indiana.

The USDA grants will create demand for the restarted reactor's power — and defray the costs of nuclear power from Palisades by one-quarter for co-op members.

In addition to the Loan Programs Office funds and the USDA grant, if Holtec successfully repowers Palisades, it will be able to tap federal incentives such as a \$15 per megawatt-hour production tax credit meant to keep the existing nuclear fleet competitive, as well as an investment tax credit intended to accelerate new plant construction. Michigan Gov. Gretchen Whitmer (D) backs the plan and directed \$150 million to the reopening effort in the state's budget.

Final author's comment: Although the rapid growth of data center power requirements described above will create much chaos, it will also drive rapid growth in the nuclear industry. This will be in (1) restarting shuttered existing reactors, (2) redirecting power from existing reactors, thus increasing their viability, and (3) many new small modular reactors (SMRs). Hopefully the last will ultimately drive down the prices of SMRs and make them more powerful tools to mitigate climate change.