Hamm Institute for American Energy
OKLAHOMA STATE UNIVERSITY

A NEW AMERICAN NUCLEAR RENAISSANCE

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A New American Nuclear Renaissance: From Promise to Power

The United States invented nuclear energy, both of the civilian and military varieties. Today, America remains the leader in nuclear energy generation, with 882 terawatt-hours (TWh) produced in 2024 (771 TWh in 2023). However, the majority of the fleet is decades old, and this generation is less than one-fifth of the US electricity supply – putting the US outside of the top 15 countries in domestic market share of nuclear energy.[1] The most recent additions – Vogtle Units 3 and 4 in Georgia – went years over schedule and billions over budget, despite utilizing the Westinghouse AP1000, a Generation III+ design that represents a significant evolution from older Generation II light-water reactors through advanced passive safety systems.

The United States has let its nuclear engineering expertise, supply chains, fissile material development, and even its regulatory expertise all atrophy. In the meantime, rivals abroad – both friends like South Korea and foes like China – are making investments in the sector and selling their reactors abroad, yielding both commercial and geopolitical benefits as client states are bound into decades of dependence for maintenance expertise and proprietary refueling, at the expense of America.

Promises of a new "Nuclear Renaissance" in the United States have come and gone several times. Multiple attempts at revival have occurred over the decades. From the futurist fantasies of the Eisenhower era that predicted we would all be driving nuclear-powered cars,[2] to the announcement of Vogtle and the ultimately canceled reactors at the VC Summer plant in South Carolina, to the initial investments in new AP1000 light-water reactors that lost momentum in the wake of the Fukushima tsunami and partial nuclear meltdown, to now, there have been several false starts.

What should make today different? The end of stagnant electricity growth demand that bridged the better part of the last three decades, a renewed focus upon the importance of 24/7 baseload generation as the American economy electrifies and pursues artificial intelligence innovations, private sector investments leading the way, and the awakening to the importance of "energy dominance" for our national security and prosperity have created an environment where it once again seems we may be on the cusp of a new nuclear age in this country.

Green shoots are everywhere, but in order for this time to be different, policymakers will need to grapple with bureaucratic obstacles, permitting requirements tailored to old reactors and business models, and public education about why new designs are safer and the licensing and oversight activities of the Nuclear Regulatory Commission preclude a Fukushima-style event happening in the United States.

This paper will describe recent developments in the nuclear energy space and provide policy recommendations that the federal government and Congress could act upon to ensure that the burgeoning advanced reactor sector can achieve licensure and – when they do – have access to domestically sourced fuel with which to generate electrons.

If this task were easy, it would be done by now. There is no single entity with total oversight of the nuclear energy sector, and there are power centers scattered across executive branch agencies and congressional committees. Overcoming this siloing and bureaucratic inertia will require focus, a whole-of-government approach, and advocacy and public relations work on behalf of the private sector. However, that effort will be worth the reliable baseload generation, price stability, and zero-emissions benefits that nuclear can provide better than any other power source.

How Did We Get Here?

Nuclear energy in today's energy mix depends entirely upon light-water reactors (LWR), the designs of which have been largely consistent since the first civilian nuclear reactor came online nearly 70 years ago. That nuclear fleet has held steady, providing about 20 percent of all electricity and more than half of our carbon-free generation. This is all the more remarkable given the increase in natural gas-fired generation since the fracking revolution kicked into gear roughly 20 years ago, as well as the entry of heavily subsidized intermittent renewable resources.

Our civil nuclear fleet had its starting gun in the form of President Eisenhower's "Atoms for Peace" speech in 1953; Congress passed the Atomic Energy Act of 1954, which amended the framework established when the Atomic Energy Commission was created in 1946, to enable commercial nuclear energy development, which would have rulemaking and enforcement authorities over the nascent nuclear reactor fleet.[3]

Early LWRs were adapted from naval reactor technologies, the first research into which occurred during World War II concurrently (but apart from) the Manhattan Project's development of the first atomic weapons. This meant they often were pressurized and used unusual fuels, including highly enriched uranium, that would not be readily adaptable for broader civilian deployment. The first plant, the Shippingport Atomic Power Station in Pennsylvania, utilized an abandoned powertrain design for an aircraft carrier and required relatively frequent refueling of enriched uranium. After reaching criticality on December 2, 1957, it began supplying electrons to the grid just 16 days later on December 18, 1957 and would remain in operation until 1982.[4] [5]

Pressurized water reactors (PWR) like Shippingport, though later using less exotic, low-enriched fuels, would make up about two-thirds of the US reactor fleet. The remaining third is comprised of boiling water reactors (BWR).[6]

Both types use ordinary, "light" water as the moderator of the nuclear reaction and the mechanism for transferring heat from the core to spin a turbine and ultimately generate electricity. PWR use a contained loop of pressurized water (preventing it from flashing to steam) for this purpose, with heat being transferred to a secondary contained loop that flashes to steam to spin the turbine.[7] By contrast, BWR designs have the water from the core, subject to less pressure, flash to steam and spin the turbine itself, before condensing and returning to the core.[8]

BWR are a simpler design. Like all U.S. light-water reactors (including PWRs), BWRs have a negative void coefficient. This means that if the system has a failure (e.g., circulatory pumps go down), the water flashing to steam creates a void in the reactor, which inherently reduces reactivity, slowing the nuclear reaction.[9] However, a breach of the containment vessel or any of the piping exposes irradiated water to the environment. Notably, the Fukushima Daiichi reactors were decades old GE BWE designs.[10] In general, any type of LWR will require active backup power systems to adequately cool the core and provide safety in the event of an incident. Failure to provide that backup power can lead to a meltdown, as happened when the backup diesel generators at Fukushima were inundated by the tsunami.

As supply chains developed and nuclear engineering expertise – much of it provided by former military nuclear reactor operators – expanded in the private sector, the nuclear industry experienced rapid growth during the 1960s and into the early 1970s, with utilities ordering nearly 200 reactors between 1965 and 1974 alone.[11] This demand was driven by electricity demand growth of more than five percent per year in the immediate post-War era, as the American middle class grew rapidly and the United States was unchallenged by decimated Europe and Asia as the manufacturing floor of the world.[12] While the 1973 oil embargoes drove demand for domestic energy generation, the creation of the Nuclear Regulatory Commission (NRC) in 1974 was primarily driven by long-standing concerns over the Atomic Energy Commission's conflicting dual roles of both promoting and regulating the nuclear industry to replace the Atomic Energy Commission and regulate the domestic fleet (the Atomic Energy Commission's research and development functions and the Department of Defense's nuclear weapons stockpile were consolidated into the Department of Energy [DOE], which became operational in 1977).[13]

The NRC would license 26 reactors for operation between 1974 and 1978, with many more pending applications, in the five years before disaster struck, several of which remain operational.[14] In 1979, the partial meltdown of an LWR at the Three Mile Island Nuclear Generating Station in Pennsylvania, slammed the brakes on the American nuclear industry. Even though there were no immediate deaths, and government studies found no upticks in negative health externalities like cancers among the surrounding population (though these findings were contested by some epidemiological researchers who reported statistically significant increases in cancer rates downwind of the plant), the incident jarred public perception about the safety of nuclear energy.[15]

This placed pressure on Congress and the NRC to address the perceived safety issues and prevent another Three Mile Island. The NRC implemented extensive new safety and siting requirements, which significantly increased construction costs and licensing timelines, even for plants already under development. Critics will argue that this is when the NRC essentially established a "zero-risk" culture that limited its capacity to approve novel reactor designs, instead sticking with "what they knew" in terms of additional LWR designs.[16]

At the same time, the postwar economic boom had given way to the stagflation of the 1970s.[17] Into the 1980s electricity demand growth slowed sharply.[18] From 1982 to 1985, Saudi Arabia actually cut oil production to support prices; significant production increases did not occur until 1986, when prices subsequently collapsed, reducing the costs of fossil fuel imports into the United States, and therefore the policy drive to source more energy domestically.[19] Interest rates, raised by the Federal Reserve to address the runaway inflation of the 1970s, hurt capital-intensive projects like nuclear power plants disproportionately.[20]

Taken together, these economic trends derailed what had been promising growth forecasts for the nuclear power industry. Utilities canceled 69 verified planned reactors between 1974 and 1984.[21] No new construction permits were issued for reactors after 1978. The last reactor to begin construction before this hiatus was the Tennessee Valley Authority's (TVA) Watts Bar Unit 1, and it was not completed until 1996 – 23 years after breaking ground.[22]

While Vogtle and Summer were expansions of existing nuclear facilities, as new reactor units, Vogtle 3 & 4 and V.C. Summer 2 & 3 were required to obtain Combined Licenses (COLs) from the NRC under the 10 CFR Part 52 regulatory framework, a process that combines construction and operating permits. However, they would run into their own economic headwinds. These two projects were part a renewed "nuclear renaissance" and the start of the 21st Century.[23] As with the policy motivation behind the establishment of the NRC and DOE in the 1970s, energy price shocks motivated this renewed interest in nuclear generation. As oil prices rose over the early 2000s, cresting well above $100 per barrel in 2008,[24] the Bush Administration and Congress looked to alternative sources of domestically produced energy to reduce prices for consumers. In hindsight, the domestic oil and gas sector's adoption of hydraulic fracturing and horizontal technologies, occurring alongside the 2008 financial crisis, undermining economic growth (during which oil prices would decline by nearly $100 per barrel in less than a year [25]), was about to imminently and historically upend global energy markets and make the United States the dominant petrostate, sharply reducing inflation-adjusted oil and gas prices.[26]

But this was not anticipated at the time and the outlook in the Bush Administration's "National Energy Policy" in 2001 was dire.[27] Concerns about climate change were also beginning to steer energy policy considerations within the Democratic Party.[28] The confluence of these political winds yielded the Energy Policy Act of 2005 (EPAct), which was enacted to make investments in a diverse basket of energy technologies.[29] Its successor, the Energy Independence and Security Act of 2007 (EISA) would double down on these policies, as well as creating whole new energy markets, such as for biofuels through the Renewable Fuel Standard.[30] Policymakers were grasping about for energy policies that could alleviate near-term economic stressors, just as the private sector was about to address these commodity prices itself.

EPAct established production tax credits (PTCs) and investment tax credits (ITCs) meant to spur domestic, zero-emission power generation, including for nuclear energy. Though best remembered now for the significant expansion of incentives for wind and solar, the nuclear PTC and ITC – along with new federal loan guarantees for nuclear power construction – would breathe new life into the nuclear generation sector. In response to the EPAct policies, expanded upon by EISA, utilities submitted 18 applications for 28 new reactors between 2007 and 2009.[31]

This would represent another abortive“renaissance.” The 2008 financial crisis undermined all sorts of capital-intensive projects, from commercial and residential construction to infrastructure. At the same time, the shale gas revolution and a softened economy yielded lower energy prices. Natural gas would begin to assert itself as a major source of power generation, durably overtaking coal as the primary generation source from 2016.[32] Natural gas units can be scaled quickly and lack the labyrinthine NRC licensing process as well as its requirement that all projects be subject to a full National Environmental Policy Act (NEPA) review, allowing natural gas plants and associated infrastructure to come online in "only" a couple of years barring significant litigation (an ever more frequent occurrence).[33]

As the economic justifications for nuclear investments were waylaid, the Fukushima disaster in 2011 put the final nail in the coffin. Industry observers were aware of this phenomenon in the moment.[34] Of the more than a dozen pending applications, only four reactors would move forward: Vogtle Units 3 and 4 and V.C. Summer Units 2 and 3. They utilized Westinghouse AP1000 designs. Westinghouse was now a subsidiary of the Japanese Toshiba corporation. [35] It is important to note that General Electric (GE) and Westinghouse were historically separate and competing companies; GE had designed and constructed the Boiling Water Reactor (BWR) units at Fukushima Daiichi decades earlier, while Westinghouse specialized in Pressurized Water Reactors (PWRs).

Westinghouse was contracted by Southern Company in Georgia at Vogtle and SCANA in South Carolina at V.C. Summer. Much of the work was then subcontracted. Westinghouse, eager to deliver, essentially promised to pay for any overages or delays from its subcontractors – promises that would go unfulfilled and ultimately result in litigation.[36]

This created a perverse incentive for cost and labor overages, which ultimately stretched into the billions. Paired with the stultified supply chains, nuclear engineering expertise, and regulatory experience of an ageing workforce at the NRC, the projects' cost and timelines ballooned. V.C. Summer was abandoned entirely in 2017 despite sunk costs of nearly $9 billion. Meanwhile, Vogtle was completed at a price tag of more than $30 billion, more than double initial cost estimates.[37] Westinghouse went bankrupt, and the Japanese and US governments had to intervene to ensure that Toshiba survived and its "crown jewel" and strategically significant flash memory business did not fall into Chinese hands (notably, FoxConn had made the highest bid but was rejected).[38] Georgia ratepayers face a total of $7.6 billion higher rate costs to compensate for the construction debacle.

Things were not going well for legacy plants either. Electricity demand was near zero for the first two decades of the 21st Century, and natural gas and heavily subsidized renewable energy prices were undercutting nuclear's cost competitiveness.[39] [40] Significant upfront capital expenditures for nuclear energy are amortized over decades, limiting operators' ability to generate savings.[41] Legacy systems, sometimes analog, reduced the ability to generate savings through innovation or automation and raise long-term maintenance costs as parts and components become scarcer.[42] Without incentives to recognize the baseload generation capacity factor of more than 90 percent, nuclear plants were essentially punished for their stability in terms of reliable generation and price.[43] In spot markets, nuclear plants slipped down dispatch curves.[44] In capacity markets, they were underbid by intermittent renewables that could not guarantee generation during peak demand.[45] The market was failing to sustain the nuclear fleet due to both market factors (natural gas's competitiveness) and market failures and distortions (renewable tax credits).

Between 2013 and 2022, 13 reactors providing 10.2 GW of capacity, were prematurely decommissioned.[46] In that time only one new reactor, Watts Bar Unit 2, entered service – under the aegis of the TVA, which was less susceptible to external market forces as a federal government enterprise.[47] More closures would have occurred but for state governments' subsidizing of the plants to protect their hundreds of employees per facility and to support their contribution as a zero-emission resource to state-level climate goals.[48]

The silver lining to all this is that the reactor fleet that weathered the storm performed superlatively. Enhanced NRC regulatory scrutiny post-Fukushima demonstrated that the US fleet remains the world's safest.[49] The NRC, not subject to the regulatory capture of its Japanese regulatory counterpart,[50] remained a sought-after advisor for Japan and other companies in establishing best regulatory practices. The US remains without a serious safety incident since Three Mile Island.

Nuclear's selling points were on clear display during this time as well. Capacity factors averaged above 90 percent since 2000, besting every other generation source by a wide margin. The 93 operating reactors produced 771,537 gigawatt-hours (GWh) in 2022.[51] Fossil fuel generation of this capacity would have produced 506 million metric tons of carbon dioxide, as well as criteria pollutants that affect human health and the environment.[52]

As electricity demand has broken out of the doldrums of the 2000s and 2010s, forecasts are urgently being revised to account for expanded data center use, the expanded electrification of sectors like transportation and buildings, and the reshoring of energy-intensive manufacturing like electric-arc steel and battery production, the existing fleet has seen several licensure renewals. Some forecasts estimate as much as a 50 percent increase in electricity demand by 2050.[53]

In some cases, plants that had already been extended to the previous regulatory maximum of 60 years are being extended to 80 years of operation.[54] It is likely that we will one day have LWRs that will be operating past the century mark.[55] If that seems unbelievable or unwise, consider that they will have good company from the Eisenhower era in the form of the B-52, currently slated to be in service through the middle of the century.[56] If it ain't broke, don't fix it.

The Next Generation

The awakening to the need for reliable and price-stable energy as electricity demand expands, an interest in American energy independence and dominance, and the awareness that – despite some environmental stakeholders' opposition – nuclear energy is essential to any remotely feasible net-zero emissions energy mix,[57] is facilitating another look at nuclear energy. In particular, the tech sector is looking for energy sources that can provide the 99-percent uptime they need for cloud and artificial intelligence (AI) systems for their customers while also meeting corporate climate goals.[58] This has led to a Silicon Valley and venture-capital centered incubation of nuclear energy startups.[59]

Their technologies vary, from traditional LWR designs to more exotic technologies. However, the common thread through all of these "advanced reactor" designs is their focus on scalability and driving down cost through economies of scale. These factors are what define the new "small modular reactor" (SMR) paradigm.[60]

Nuclear energy's primary market challenge remains cost. Giant LWRs require significant upfront investment, and much of the infrastructure is bespoke to the site. LWRs are typically hundreds of megawatts as scaling up in generation capacity adds only incidental costs beyond the initial plant. LWRs also have specific site requirements that must consider access to water needed for cooling, transmission infrastructure, and a security envelope that includes factors both manmade (e.g., terrorist attack) and natural (e.g., seismicity).[61]

SMRs are meant to address these challenges. Rather than targeting a large plant in the 1 GW range or more, these will be smaller, scaled-down units generating 50-300 MW per unit. Smaller units can have most of the core components (such as the reactor, containment vessel, pumps, etc.) fabricated in factories and then shipped whole or in fewer parts to the construction site.[62]

The theory here is that economies of scale can be achieved both in terms of manufacturing and the ability to increase generation through the addition of more prefabricated units as necessary, reducing upfront and total capital costs. With fewer site-specific elements, construction timelines, and regulatory reviews should be shortened. SMR designs incorporate passive safety features to make them safer in the event of power disruptions, making them both safer and obviating the need for overly expansive regulatory requirements on siting. Finally, SMRs can be more easily ramped up or down depending on demand than larger units, though their primary function is likely to remain consistent baseload generation, whether to provide power to the grid or serve customers "behind the meter"for data centers, mining, desalination, or other purposes.[63]

This new paradigm expands the viability of power purchasing agreements (PPAs) as a means for SMR developers to get into the market; previously, nuclear generation was the domain solely of large investor-owned utilities or federal power agencies like TVA that could stomach the capital costs, provide transmission assets, and share the expenses across regulated ratepayers.[64] The new SMR nuclear merchants are likely to be more nimble and diverse.

Several types of SMR reactors are competing to be the first to deploy and win the economic arguments. They fall into a few categories.

Smaller, modern adaptations of legacy LWR technologies include:

- NuScale Power has developed a 77 MW PWR reactor design that is intended to be an SMR.[65] NuScale is the first to receive an NRC design certification in August 2020, putting it at the head of its class of competitors. However, licensure necessary for construction requires a demonstration project. NuScale had planned to construct this demonstration project at the Idaho National Laboratory (INL), however this project was canceled in November 2023 due to financial challenges. Despite this setback, NuScale is examining future deployment opportunities.[66]
- GE Hitachi has a 300 MW BWR design, the BWRX-300.[67] Everything old being new again, GE Vernova – the spinoff of General Electric's former turbine business – is getting back into the LWR space, in partnership with another Japanese conglomerate. The design is undergoing NRC review for American deployment.[68] GE Hitachi is seeking to break ahead

of competitors through commercial deployment in Canada, having been selected for an Ontario Power Generation project.[69] How that will fare given the current state of trade and geopolitical relationships between the US and Canada (and the US and Japan, for that matter) will be something to watch. It is highly likely that the components and fuel fabrication supply chains will require crossing the northern border several times, potentially incurring tariffs each step of the way unless a free trade agreement between the US and Canada is renewed.
- Holtec SMR-160 is a 160 MW PWR design with an emphasis on redundant passive safety systems.[70] Holtec has completed the first phase of review by the Canadian Nuclear Safety Commission.[71] However, its review by the NRC has been suspended as of December 2023.[72]

More exotic are molten salt reactors (MSRs). MSRs replace water with a type of molten salt as the fission moderator.[73] In some designs, the salt flows like water between fuel rods or even pebbles; in others, the nuclear fuel itself is dissolved into the molten salt. The benefit of this design is greater efficiency, less solid waste, and inherent passive safety – if the power is disrupted, the salt hardens around and isolates the core, limiting radioactive exposure. With no water flashing to steam or potential hydrogen off-gassing, these designs are deemed safer from a variety of operational hazards.

MSR competitors of interest include:

- Kairos Power's Fluoride Salt-Cooled High-Temperature reactor (KP-FHR) uses tri-structural isotopic (TRISO) fuels. TRISO fuels are small"kernels" of uranium-based fuels. The TRISO particles are embedded within spherical graphite fuel pebbles, similar to golf balls. These pebbles are then placed in the reactor core, where they are cooled by the circulating molten fluoride salt (Flibe). The graphite pebbles provide a second layer of containment and serve as a moderator to sustain the nuclear reaction. Kairos has received a DOE award through the Advanced Reactor Demonstration Program (ARDP) and is working to construct a demonstration unit at the Oak Ridge National Laboratory.[74]
- TerraPower has both Natrium sodium-cooled fast reactor (SCFR) and molten chloride fast reactor (MCFR) MSR designs. Backed by Bill Gates, Terra Power's MCFR has also received a DOE ARDP award for a demonstration project. In June 2024, TerraPower began construction of a demonstration of its Natrium SCFR design in Wyoming. As a fast reactor, Natrium can consume transuranic nuclear wastes via actinide burning – essentially transmuting harmful, long-lived radioactive isotopes into shorter-lived, less radioactive byproducts by means of forcing their fission through more energetic, "fast neutron" exposure.[75]

- There has been discussion about thorium salt reactors (TSR), which would have a lower cost to operate due to thorium's greater availability compared to uranium. Thorium has no use in strategic nuclear weapons, also alleviating concerns about proliferation. However, thorium fuel designs are nascent compared to other MSR technologies using more traditional fissile materials like uranium. China is ahead of the United States in the development of this technology.[76]

Outside of these categories, there are other entrants into the SMR competition with other designs beyond the LWR and MSR categories. High-profile examples include:

- Oklo's 1.5 MW Aurora Powerhouse design.[77] The Aurora uses high-assay, low-enriched uranium (HALEU fuel), which can be domestically sourced from the down blending of legacy enriched uranium and surplus defense materials.[78] The company is investing in fuel fabrication and is also examining the use of transuranic wastes and even plutonium as potential fuel sources, given that its fast-reactor design can reduce these waste volumes and their radioactivity. Oklo was an early mover among non-LWR SMR companies, having submitted the first non-LWR advanced reactor design ever to the NRC in 2020. However, the application was denied without prejudice in 2022.[79] Oklo has stated its intentions to reapply. As a microreactor design, the Powerhouse requires only three acres of space and can be scaled accordingly and needs no access to water. The company is pursuing a demonstration project at INL[80] and a Department of Defense (DOD) deployment at Eielson Air Force Base in Alaska.[81]
- X-energy's Xe-100 design used a "pebble bed" of uranium and graphite fuel, with helium as a coolant in a high-temperature gas-cooled reactor (HTGR) design.[82] X-energy has also received a DOE ARDP award[83] and is pursuing a four-module demonstration project at the Manhattan Project-era Hanford site in Washington state in coordination with Energy Northwest.[84] X-energy uses a TRISO HALEU fuel. This more energetic fuel allows for longer run times.[85] X-energy and Oklo, both using HALEU fuel in radically different designs, demonstrates broader demand for the fuel type, which is currently not fabricated at scale in the United States and is largely reserved for Defense applications, such as naval reactors and reactors to create tritium for nuclear weapons.[86] [87] [88]
- BWXT's Advanced Nuclear Reactor (BANR) is a 50-MW-HTGR design that is designed to be small enough to be transported by rail or truck. [89] Another recipient of an ADRP award, BWXT has been working with the DOE and DOD on its design since 2021, and is also pursuing a demonstration project in Wyoming.[90] As with Oklo's Eielson deployment, its generation capacity will not be wholly electric, but steam heat cogeneration may be the primary function to serve DOD installations and deployments abroad, particularly in the Arctic.

Current Barriers to Advanced Reactor Deployment

There are many competitors in this burgeoning SMR sector, more than are listed above. Some will succeed, while some will fail. But if the market will be the decider, then the regulatory and licensing process cannot be so broken as to essentially decide the fates of less-capitalized competitors through delay and attrition. Unfortunately, in the current policy paradigm, that is almost certain to happen.

As with the industry it regulates, the NRC has a rapidly graying workforce.[91] Most NRC employees have never worked on even traditional LWR design and construction licenses (the former applies to a type of reactor, such as an AP1000 and is only needed once barring significant modification of the design later; the latter is necessary for every deployment of said design and includes site-specific elements and a NEPA review). Its culture is now extremely risk averse, and in some guidance documents, is zero-risk – an impossibility in any field of human endeavor.[92]

The NRC's existing regulations are specific to LWR designs and do not adapt to the improved safety and smaller scale of SMRs with passive safety features – Kairos' Hermes 2 was the first non-LWR reactor design approved since the 1960s.[93] In the jargon of the NRC, it began its Part 53 rulemaking meant to address advanced non-LWR designs back in 2020. The initial draft was proposed by NRC staff on March 1, 2023. It is not expected to be finalized until 2027 at the earliest.[94]

Without Part 53 in place, there is an immense degree of regulatory uncertainty for SMR applications that will be held against regulatory and safety requirements that may have made sense for huge 1 GW or more LWRs but do not make sense for their specific technologies. The NRC is slowly awakening to this issue, offering regulatory guidance in 2024.[95] [96] The goalposts of such reviews are likely to be moved over and over, absent clarity more durable than internal agency documents. With PPAs signed to go active this decade,[97] Part 53 finalization and NRC licensure of design and construction certifications threatens to delay or derail several of these companies' commitments and financial viability, never mind delaying nuclear energy's contributions to the grid and the power-hungry artificial intelligence race.[98]

NRC review is also costly and time-consuming at the best of times. The NRC is funded through licensing activities with reactor designers and utilities, though its budget is still subject to oversight by congressional appropriators.[99] The NRC design certification process costs and timelines vary significantly by reactor type. For larger reactor designs like the AP1000, costs can range from $50 to $100 million and take four to five years or more. However, simpler designs like NuScale's SMR achieved approval in approximately 3.5 years with lower costs.[100] That is for the design alone, not the construction licensing that can require similar investments and also ensnares other agencies such as the Environmental Protection Agency and the Fish and Wildlife Service as partner agencies under NEPA review process. Due to federal insurance backstops under the Price-Anderson Act, all nuclear energy projects are deemed "major federal actions" triggering mandatory NEPA review, even if the project takes no federal money and does not otherwise implicate NEPA review (e.g., by being on federal lands or between state borders).[101]

Let us say you are the CEO of a nuclear startup that somehow makes it through this NRC process. We hope you were also investing in your fuel supplies contemporaneously. In this, not only is there a significant upfront capital investment, but companies are entirely dependent on federal control over fissile materials.[102]

Given the health, environmental, and proliferation risks of this material, federal oversight makes sense. However, the United States has never envisioned what a thriving private nuclear sector with diverse designs demanding diverse fuels would look like. During the Cold War, the United States sunk more than $5 trillion dollars[103] and an estimated seven percent of domestic electricity[104] into the production of highly enriched uranium and plutonium – more than enough to generate weapons that can destroy the world many times over.

Now, many of these weapons systems are due for maintenance. Missiles need replacement.[105] Fissile pits of the weapons themselves need refabrication.[106] Improved targeting and multiple independently-targetable reentry vehicles (MIRVs) on each missile have obviated the need for the sheer number of weapons in the US strategic stockpile.[107] The costs of rejuvenating the US strategic forces under the direction of the National Nuclear Security Administration (NNSA) within the DOE will cost hundreds of billions of dollars,[108] but is necessary as China builds out its nuclear arsenal and Russia prioritizes a similar rejuvenation campaign. [109]

This process will also generate waste and surplus fissile material. Already, the DOE is undertaking "plutonium disposition" projects.[110] Essentially, DOE is downblending surplus plutonium at the Savannah River site in South Carolina to make it less radioactive, then shipping it to be buried in the deserts of New Mexico.[111]

The military is reticent to downblend weapons-grade uranium (90-percent enrichment level) to the level of HALEU (five to 20-percent enrichment level) for use in advanced reactors, though there has been renewed interest in this conversion.[112] This is higher than the approximately three to five-percent level of enrichment in LWR low-enriched uranium (LEU) fuel. The US mines uranium ore in small quantities in Wyoming but is dependent upon imports from Canada and, previously, Russia. Generally, there is minimal enrichment and fabrication capacity within the federal government and its nuclear contractors. Outside of the public sector, this capacity is nonexistent.[113]

To put it mildly, it will be difficult to power the reactors of tomorrow without fuel. Even if the material is available, the NRC must qualify fuel designs for safety and reliability. This process can take decades and hundreds of millions of dollars, and again, the NRC lacks familiarity with novel fuel designs and higher enrichment levels and will err on the side of lower risk profiles.[114]

Without signals to the private sector that the federal government is addressing these challenges, the financial runways for these new civilian nuclear players may be short. Even setting aside licensure and fueling issues, nuclear physics is hard. Sophisticated factories making materials with advanced metallurgies and strict design tolerances on par with spacecraft will be expensive. First-of-a-kind costs for these designs may deter additional rounds of investment, and the domestic supply chain to serve these factories will have to be developed from scratch.[115]

Electric markets do not adequately compensate for the unique reliability, resilience, and zero-carbon benefits of nuclear power. Subsidized renewables and other market distortions will need to be corrected by federal policy. If electric markets or severe economic downturns occur, investors will not stay with novel nuclear designs over the long haul. We have seen this before due to broader economic conditions, especially compounded by black swan events like Three Mile Island and Fukushima that simultaneously undermine investor confidence.

Moreover, those investors need to be willing to wait a long time for their return on investment. The high capital costs and long development timelines make nuclear power a multi-decade investment play of the sort best undertaken by utilities with reliable cash flows. And even then, as we have seen, projects can struggle. New, smaller players in the field will not have as much ability to amortize their costs and will be more susceptible to the precociousness of the stock market. Federal loan guarantees may be essential until the new entrants achieve scale.[116]

Federal Policy Recommendations

So, a lot has to go right for the nuclear renaissance to succeed this time. Policymakers will need to be educated on the strategic, economic, and geopolitical benefits of robust American nuclear technology leadership. Maintaining a dynamic civilian reactor fleet ensures the US retains the expertise and supply lines to also serve its military. Reliable energy at stable prices, all without emissions, is essential to supporting a creaking grid during a time of declared national energy emergency – especially for modern 24/7 factories and the needs of data centers and AI clusters. Exports of American nuclear reactor designs will bind partner countries into a multi-decadal economic and security relationship.[117] The alternative is to cede that territory to rival powers, some of them hostile.

Needed reforms generally fall into two buckets based on which the successors to the Atomic Energy Commission retain the relevant authority.

- Nuclear Regulatory Commission authorities need reform to ensure timely certifications of reactor designs, construction licenses, and fuel qualifications. The Department of Energy – essential a nuclear weapons apparatus with a small National Lab system attached – needs to avail the sector of funding (whether direct awards or through loan guarantees) and create a program that can allow surplus weapons materials to be safely transmitted to the private sector.
- The oversight of the Nuclear Regulatory Commission falls to the House Energy and Commerce Committee (E&C) and the Senate Environment and Public Works Committee (EPW). The Department of Energy's programs are overseen by E&C, but also the Senate Energy and Natural Resources Committee (ENR). NEPA reform is the purview of House Natural Resources (HNR). The DOE research activities are under the House Science Committee. With regard to treaty obligations concerning nuclear nonproliferation, the House Foreign Affairs Committee (HFAC) and Senate Foreign Relations Committee (SFRC) have their say. Of course, our strategic forces and the NNSA are within the jurisdiction of the House and Senate Armed Services Committees (HASC, SASC). And finally, the House and Senate Appropriations Committees will have their say, scattered between their Defense and Energy & Water Subcommittees.
- Within the White House, the National Economic Council (NEC), the Office of Science and Technology Policy (OSTP), the National Security Council (NSC), the National Energy Dominance Council (NEDC), and the Office of Management and Budget (OMB) all have their own equities.

That is a lot of divergent stakeholders to have to wrangle. Education of these policymakers is essential, as is the (preferably bipartisan) direction of the White House and congressional leadership to focus on the broader nuclear policy agenda. The clearest starting point to hone this attention on Capitol Hill – particularly in an era of unified, one-party government as currently exists – would be policy directives out of the West Wing.

President Trump previously issued an Executive Order concerning SMRs in his first term.[118] It is overdue for an update. Clear directives to agencies to streamline processes, stand up programs to facilitate transfer – potentially via auction, to generate revenue for taxpayers – and the reprocessing of fissile materials by the private sector, and support for resource, development, and deployment of SMRs on federal facilities would be a great start. This signaling alone could facilitate market support for nuclear energy developers.

Such an Executive Order and subsequent Presidential Budget Requests should also call on Congress to make statutory reforms needed. These changes are not only needed but will be the most consequential, durable changes to our stilted way of deploying nuclear energy.

Priority matters to address include:

Atomic Energy Act reforms. The Atomic Energy Act of 1954 remains the basic framework for nuclear regulation in the United States. Its most impactful provisions with regard to the civil nuclear fleet are the regulatory processes authorized in Sections 103 (commercial licenses) and 104 (research and development licenses). This seems a simple delineation: demonstrations of technology move through a laxer 104 process; fully operational commercial units operating in our communities should be held to a tighter design and construction licensure proceeding.

However, currently, projects undergoing a Section 104 approval cannot sell any electrons to the grid. This means a demonstration project at INL or on a military base must dump its heat and electricity for little meaningful utility. Reforming Section 104 to allow even limited electricity sales would provide a market signal to investors and provide reportable revenue for nuclear reactor developers while they await full licensure. By limiting this allowance to units operating on DOE or DOD facilities, assurances can be provided that such limited sales are not a loophole for demonstration reactors to enter into commercial service.

Section 104 should also be expanded to include specific support from the NRC to assist novel reactor demonstration projects through the process. Safety standards should be tailored to the actual risks and scales of modern SMRs with advanced passive safety systems, not shoehorning or extrapolating risks from irrelevant, larger, legacy LWR designs. Specificity on the types of demonstration testing provisions to be required so that it does not appear that NRC regulators are “building the plane as they fly it” would facilitate greater clarity and collaboration between applicants and Commission staff.

Similarly, Section 103 governing commercial reactors should be updated to incorporate appropriate, risk-informed, and technology-inclusive principles tailored to new SMR designs. The inherent risk profiles of the different technologies should inform their licensure processes. Risk assessments should scale with the power level, and risk of deployments, including how these may change if modular designs are scaled into larger generation projects in the future with additional reactors. A project with one SMR licensed today should know what requirements or regulatory prohibitions may limit future expansion for additional power generation.

Section 103 should also be modified to account for non-electric applications of nuclear generation, particularly heat for industrial applications or the production of hydrogen (so-called "pink hydrogen"). Even mobile reactor applications like BWXT's should be envisaged in the statute.

Change NRC's way of doing business

The recently enacted Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy (ADVANCE) Act included several reforms to NRC's operational model.[119] Unfortunately, then Chairman Chris Hanson publicly interpreted ADVANCE as an endorsement of the NRC's existing zero-risk, remote-work operational model.[120] This makes clear successor legislation is necessary. Concurrent with the aforementioned Section 103 and 104 reforms, and "ADVANCE 2.0" should:

- Reform the NRC's budget structure to reduce the burden on advanced nuclear reactor design applicants. As discussed earlier, the NRC's budget is a 90-percent fee-recovery model. Additional appropriations targeted to funding and expediting advanced reactor reviews would reduce costs for early movers and signal to the market at least some defraying of the upfront costs of the regulatory process, encouraging investment. ADVANCE included "x-prizes" for early movers in reactor design and fuel certifications, but this fee reform would encourage far more entrants into the space.
- ADVANCE allowed some flexibility from the federal scale to draw in private sector-level talent to the NRC. This should be expanded with additional flexibility and the direction to NRC to allow cooperative partnership agreements to dedicate staff to specific developers' applications for an additional fee. The NRC should also be directed to accept qualified academic fellows, private sector regulatory professionals, and staff exchanges with qualified DOE National Laboratory and DOD staff.
- The NRC should be required to establish or utilize categorical exclusions (CEs) and programmatic environmental impact statements (EIS) to streamline environmental reviews and provide certainty for NEPA reviews. Reforms should be made so that not all nuclear projects – particularly those not receiving direct federal funds in grants or loans – are not "major federal actions" for the purpose of NEPA. CEs and programmatic EIS can be linked to the general risk profiles of new SMR designs.
- The licensing under Section 103 and 104 should be clearly tiered and allowed to occur simultaneously, with feedback and application modifications immediately transferable between the two siloes. Fuel design and fabrication qualification should be allowed to occur contemporaneously and be expedited when linked to a viable design application. A tiered approach would also allow incremental regulatory investment, alleviating immediate financial burdens on applicants while they ensure their designs will ultimately be viable.

Transform military surplus from liability to asset

The United States possesses more than 60 metric tons of surplus weapons-grade plutonium. What to do with this material has bedeviled policymakers for decades. Contaminated treatment sites and canceled projects like the Mixed Oxide (MOX) Fuel Fabrication Facility at Savannah River, as well as simply protecting and managing the inventory of a highly radioactive material prone to spontaneous combustion in ambient air, have cost taxpayers untold billions of dollars. The trend is for this to continue, with the dilution and disposal of this plutonium through the Waste Isolation Pilot Plant (WIPP) taking – at best – 30 years and $18 billion to ultimately get rid of something the taxpayer funded the creation of, with no economic benefit.[121]

Congress should end all this by:

- Legislatively terminating the Plutonium Disposition Program. Surplus plutonium should be preserved until a program for its safe transmission to private sector stakeholders is devised. In the meantime, a Strategic Plutonium Reserve would be a more secure and cost-effective means of inventorying this material than diluting it, shipping it, and burying it in the desert.
- Directing the DOE to create an auction system for plutonium resources. Partnering with the NRC, viable applicants for reactor designs and fuel certification should be able to bid on plutonium materials for eventual use as fuel.
    - Concurrently, the DOE should lease legacy nuclear weapons facilities and potential fuel fabrication sites to make new fuel assemblies for SMRs. Many of these buildings are contaminated and underused, posing a cleanup liability for the federal government. The terms of leases should include sole use for approved fuel processing and fabrication purposes, and requirements that leaseholders – renewable terms measured in decades – decontaminate or fully decommission the facilities, saving federal taxpayers the expense.

Plutonium is not the only military surplus fissile material of interest to the private sector. Highly enriched uranium can be down-blended HALEU. Both the defense sector and the private sector will also need access to new uranium and HALEU supply lines.

Congress can facilitate this by:

- Establishing a robust and closed-loop nuclear fuel cycle. The DOD and DOE should establish public-private partnerships with companies to expand domestic centrifuge enrichment as well as deconversion capabilities, including at existing federal facilities.
    - Prizes or funding programs for novel enrichment or fuel processing technologies could spur innovation while serving national security imperatives.
- Providing tax incentives akin to PTCs and ITCs for nuclear fuel production.
- Requiring the DOD and DOE to engage in long-term contracts for HALEU production and fuel fabrication for federal use, while also allowing for some commercial-grade production, to demonstrate consistent market viability.
    - Other exotic nuclear fuels would benefit from this approach, such as TRISO, metallic fuels, and molten salts. Demonstration of a viable thorium salt medium would also potentially kickstart a whole new fuel source.
- Funding advanced recycling technologies to utilize transuranic wastes as fuel while reducing the total volume of waste materials and their radiotoxicity. Federally funded pyroprocessing and advanced separation techniques, electrochemical processing for metallic fuels, and final end-of-life waste treatment and disposal would signal long-term viability of the SMR sector.[122]

Facilitating the market

Finally, Congress could provide market signals and financial incentives to investors and to end distortions in the electric spot and capacity markets.

- At the risk of drawing in even more congressional Committees, the House Ways and Means and Senate Finance Committees should replace electric generation PTCs (Section 45)[123] and ITCs (Section 48),[124] including for nuclear, in favor of a tax credit that rewards generation assets based on capacity factors. This would do more to support grid reliability and end market distortion than efforts to make technology-specific, countervailing incentives in an attempt to balance existing incentives against new ones.
- The DOE Loan Programs Office (LPO)[125] could provide technological and financial risk insurance to SMR developers, including those in the NRC process, to even modestly offset the risk to investor returns and subcontractors caused by delays from the federal review processes. A small federal surety would have an outsized influence in market signaling, making additional private sector dollars available to support developers. This would be less costly and less risky than actual federal loan guarantees, the current primary mission of the LPO.
- Reforms to programs like the EPA's Superfund[126] and Brownfields[127] initiatives to prioritize new SMR projects would expedite deployments. Sites like retired coal plants

and other industrial facilities would generally have transmission assets and river or rail access that can facilitate site development while bringing durable employment and tax revenues into communities that need it most.

- Direction to the Export-Import Bank[128] to prioritize and expand financing to US nuclear reactor and fuel exporters, and reducing the burdens for this trade, with 123 Agreement trade partners not subject to US sanctions.[129] In concert, the Department of Commerce and US Trade Representative should waive tariffs related to nuclear energy supply chains. This can be a sector where low tariffs paired with financial guarantees from Ex-Im will reduce US trade deficits with billion-dollar commercial exchanges.

Conclusion

The history of failed "nuclear renaissances" and the complexity of the underlying policy environment – never mind the actual engineering and operation of nuclear facilities themselves – suggests that the challenges and costs associated with nuclear energy are simply too much for society to bear. Many pundits, critical of nuclear energy, say it should be abandoned for their favored generation source of choice – primarily on the basis of cost.

However, if the US is to be energy independent and maintain leadership at the cutting edge of innovation, it must lead in the nuclear space. Nuclear energy is unique in its sheer capacity to convert small amounts of fuel into immense amounts of energy[130] and to do so at a constant rate.[131] This reliable baseload generation, with zero emissions of carbon dioxide or criteria pollutants, in the SMR era also requires minimal land use and no use of freshwater resources. It is a technology perfectly matched to modern data and manufacturing sector needs. And, it goes without saying, maintaining robust nuclear engineering expertise and supply chains will remain essential to national security, from strategic weapons to naval craft to powering remote military installations.

As with many things, the challenges are financial. Distilled down, the concern about regulatory timelines, fuel availability, and the rest can be defined in dollars and market sentiment. This is all the more reason that Washington must signal it is serious about addressing these issues to bend the nuclear cost curve downwards. Without direction from federal policymakers, the market will not be able to overcome the headwinds and pricing distortions created by federal policies themselves.

The sooner reforms are implemented, and the private sector can invest and deploy in SMRs, the better. This can be done without downside risks to public health and safety. Indeed, one could say that failure to do so – given the downside externalities of other energy sources –is more harmful to the general welfare and our environment. Too many other sectors are relying upon reliable baseload generation and they are growing too quickly for America to fail here.

This time, we need the nuclear renaissance to hold. And that means all of official Washington needs to get to work.

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