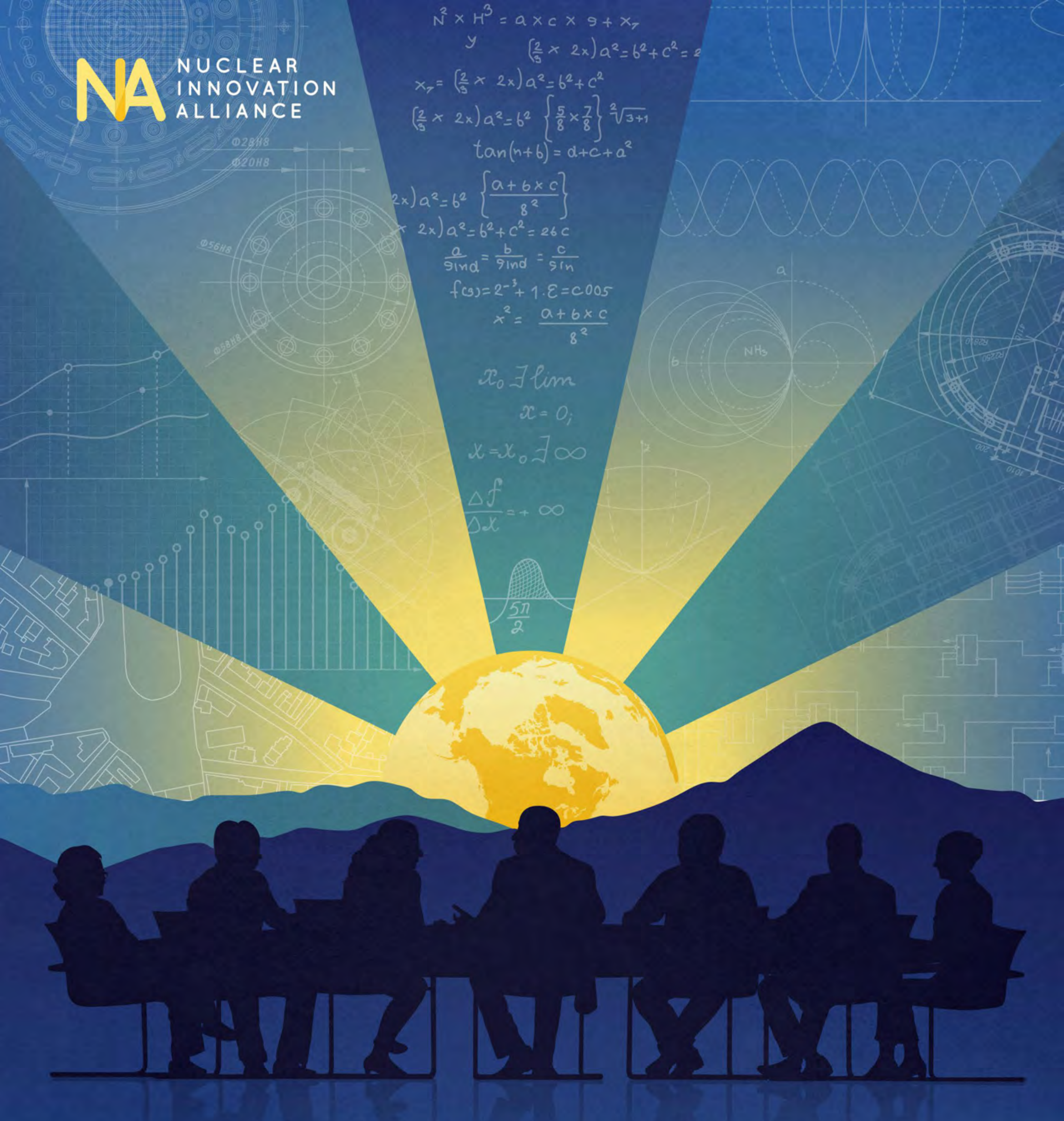
NUCLEAR INNOVATION ALLIANCE



Advanced Nuclear Energy Guide for State Policymakers

December 2023 Update

Advanced Nuclear Energy Guide for State Policymakers

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Disclaimer:
The views expressed herein are solely those of the authors and the Nuclear Innovation Alliance.

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This report is available online at: **nuclearinnovationalliance.org/resources**

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Executive Summary State Policymakers Guide

by Victor Ibarra, Jr

States and local level policymakers are increasingly taking a role in helping deploy advanced nuclear reactor technology as it matures. This Guide serves as an introduction to advanced nuclear energy technologies and policies for these policymakers as well as stakeholders. Nuclear innovators are developing a suite of technologies that represent a fundamental shift from conventional nuclear energy designs. Ranging from microreactors that can provide distributed energy (~less than 10Mwe) to medium-size reactors that can power cities and industry (~300Mwe), advanced nuclear reactors promise clean energy that is reliable, safe, and can contribute to state-level economic development, energy security, and environmental goals. This 2023 update of the Guide incorporates new information since the initial 2021 release.

Conventional Nuclear Energy		Advanced Nuclear Energy
Predominantly Large: More than 1000 MW_e	Reactor Size	Versatile: 1.5 MW_e to 300+ MW_e
Predominantly Advanced Gas Reactors	Reactor Technology	Wide Variety of Reactor Technologies
Primarily Baseload Generation	Generation Type	Flexible and Dispatchable Generation
Designed with Active Safety Systems	Safety Approach	Designed with Inherent Safety Systems

Executive Summary Figure 1: Simple visualization of the differences between conventional and advanced nuclear

The first part of this Brief generally describes advanced reactor technology and its benefits, provides an overview of key enabling federal policies as of October 2023, and reviews state options to incentivize local development of advanced reactors. The second part of the Brief provides case studies with updated information since the last release of emerging state leaders in these technologies, including:

- nuclear projects in Wyoming
- Energy Northwest's plans in Washington State
- the state of play in Virginia and the Virginia Nuclear Energy Consortium
- Texas' leadership in deploying advanced nuclear energy
- the Nuclear Alternative Project in Puerto Rico

The leading actors in these case studies are all entities that may not ordinarily have considered new nuclear energy initially. However, they have all done so because of the role of advanced nuclear technology can play in decarbonizing the electric grid and the economic benefits advanced nuclear energy can bring to local communities. Finally, the last section of this Brief is a compendium of topical briefs that elaborate the characteristics of advanced reactors with respect to safety, economic benefits, waste remediation, the flexibility and dispatchability of advanced nuclear power, and its timing and development. Readers can take advantage of the document's modularity by reading each section in whatever order they would like. We encourage local community leaders and state policymakers to focus on the case studies that exhibit the benefits of advanced nuclear energy in communities across the United States. For those interested in learning more about advanced nuclear energy, the topical briefs serve as introductory resources to the key benefits of advanced nuclear reactors.

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The Case for Advanced Nuclear Energy

by Erik Cothron

Nuclear energy is a clean energy solution for meeting energy security and net-zero emissions goals, and it is saving lives by reducing air pollution. Existing nuclear energy supplies roughly 10% of global electricity and 20% of U.S. electricity. In the United States, the existing nuclear fleet provides roughly the same amount of carbon-free electricity as wind, solar, and hydro power combined. One 2021 study has shown that the reduction of air pollution from generating clean nuclear energy has prevented almost 42 million deaths globally between 2000 and 2020 and projects an additional 46 million lives will be saved by 2040.

The next generation of nuclear reactors are being built now and will begin to be deployed by the end of the decade. Recent government and industry activities are encouraging the development of advanced nuclear reactors. Bipartisan legislation has provided a foundation for federal research, development and demonstration, and has provided funding to ensure many advanced reactors have the fuel they will need. The U.S. Department of Energy's Advanced Reactor Demonstration Program, led by the Office of Clean Energy Demonstrations, is funding public-private partnerships for first-of-a kind demonstrations of advanced nuclear reactors. These advanced nuclear reactors provide several benefits over traditional reactors, and together with renewable energy and other carbon-free energy sources, will allow the United States to reach its energy security and clean energy goals by 2050.

In addition to the benefits traditional nuclear reactors provide, advanced nuclear reactors:

1. Include innovations that can reduce costs, increase fuel efficiency, and improve safety.
2. Create substantial economic benefits, including improved international competitiveness.
3. Help make reaching net-zero emissions a reality by providing firm clean electricity and decarbonizing non-electricity sectors.
4. Mitigate spent fuel concerns.

Reduced Costs, Increased Fuel Efficiency, and Improved Safety:

Nuclear innovators are pursuing multiple strategies to create new designs that make the next generation of reactors even better. Many advanced nuclear reactor designs, including small modular reactors and micro reactors, reduce the size of the reactor, which can lower upfront capital costs, shorten construction timelines, and decrease financing uncertainty. By building plants more quickly, developers can achieve rapid innovation cycles and continuous technological learning to reduce costs. Compared to traditional reactors, advanced nuclear reactors burn more of their fuel, increasing fuel efficiency, decreasing the amount of fuel needed, and ultimately reducing the total cost of fuel needed. Additionally, advanced reactor designs include inherent safety features, making them safer than traditional reactors. Together, these innovations mean that advanced reactors promise to be more economically viable, efficient, and safe.

Economic Benefits and International Competitiveness:

Currently, the U.S. nuclear energy industry supports half a million employees with salaries that are 30% higher than local averages. In addition to higher salaries, nuclear employees have higher rates of uniozation and provide substantial employment opportunities for veterans. Advanced nuclear projects can support regional and state economies through innovation hubs and by attracting human capital. Small microreactors promise to make nuclear energy a distributed energy source for the first time, powering microgrids and remote energy-poor communities that currently rely on diesel fuel for electricity. Advanced nuclear reactors can be located at retiring coal plant sites, making use of transmission and other infrastructure while providing economic benefits to local communities. That is a significant advantage compared to other potential sources of zero-carbon generation, which typically require new sites that may be far from existing transmission, and which do not provide similar levels of economic opportunities. Additionally, U.S. advanced reactor designs can be competitive in global markets, growing U.S. exports while enabling both decarbonization and economic growth for emerging economies.

Reaching Net-Zero Emissions:

Most energy system modeling shows that full decarbonization will require firm zero-carbon electricity generation and decarbonized non-electric energy sectors, in addition to variable renewables. Nuclear energy can do both. Nuclear energy's historical role in providing a firm carbon-free backbone for the electric grid is well understood. Advanced nuclear reactors can also contribute to the broader decarbonization of other sectors. For example, high-temperature and excess heat generated from advanced nuclear reactors have the potential to decarbonize industrial processes, provide district heating to residential and commercial buildings, generate clean hydrogen, and even provide the energy for desalinization plants. Advanced nuclear technology can also enhance electricity market competitiveness through load following and integration with renewables and can generate clean electricity for electric vehicles and heat pumps to decarbonize the transportation, residential, and commercial sectors.

Mitigating Spent Fuel Concerns:

Advanced nuclear reactors can reduce the amount of spent nuclear fuel generated, thereby reducing the amount that requires long-term geological storage. Some advanced reactor designs plan to run on fuel recycled from existing stockpiles. Greater fuel efficiency will reduce the amount of spent nuclear fuel created per unit of nuclear energy produced. Additionally, some advanced reactors may reduce the duration and amount of the radioactivity of spent fuel.

Conclusion:

Advanced nuclear reactors can help meet our energy security and clean energy goals. Many advanced reactor designs have been developed, and several companies are planning to build their design by the end of the decade. These innovative reactor designs include a wide array of benefits that improve upon existing light water reactor technologies. Over the next few decades, advanced nuclear energy can play a vital role in shaping our clean energy landscape, and ensuring we reach net-zero emissions by midcentury.

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Advanced Nuclear Energy in State-Level Climate and Energy Policies

by Victor Ibarra, Jr

Summary:
- States are taking an increasing role in deploying advanced nuclear energy technologies
- Advanced reactors will help states and communities achieve their greenhouse gas reduction, economic development, and energy security goals

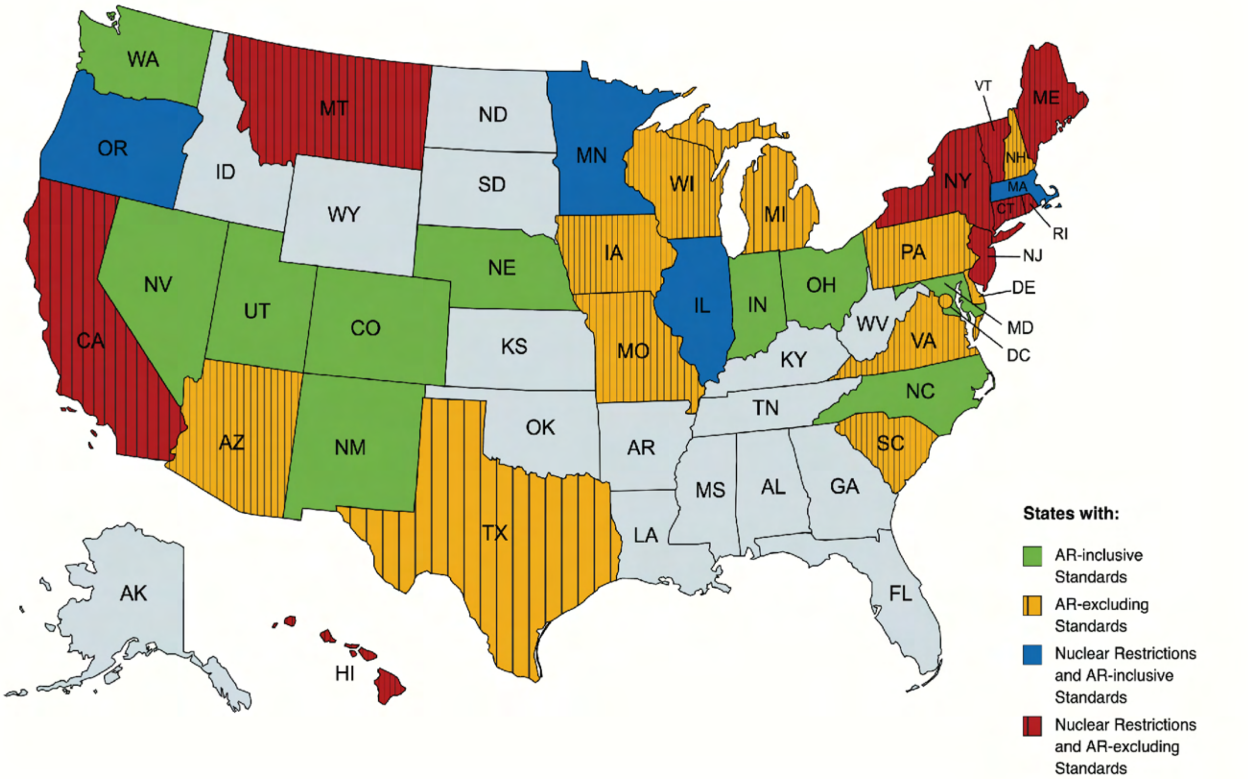

Figure 1: State Energy Standards, Advanced Reactors, and Nuclear Restrictions

Early movers in launching advanced nuclear reactor projects will enjoy large economic and environmental benefits in a time of growing energy demands. Advanced reactors are fundamentally different from conventional nuclear power (see ES Figure 1 in the executive summary of this *Guide*). They are smaller and through modularization will be quicker to build, enabling nuclear energy as an energy option for rural communities, municipal utilities, technology companies, and industrial users. They are scalable, meeting the needs of customers from small universities to traditional large investor-owned utilities. Modular construction, rapid technological learning, and shorter construction times reduce the risks and severity of cost and time overruns. Advanced reactors that operate flexibly provide firm, zero-emission electricity to the grid and can decarbonize non-electrical sectors. Advanced reactors feature improved safety and fuel performance, expanding siting opportunities.

Advanced nuclear is a new industry, poised to achieve substantial and sustained long-term growth. State policymakers, communities, and industries that recognize this potential can become first movers by facilitating early demonstration projects. Early adoption will bring high-paying jobs and supply chain companies, and establish an industry set for rapid growth within that state. State policymakers interested in realizing the potential of nuclear innovation to meet state energy and environmental goals should consider:

- **Recognizing the benefits and opportunities of advanced reactor technologies.** Prerequisite to enacting policies to encourage advanced nuclear energy projects, state policymakers need to understand the opportunities from nuclear innovation and build state- and local-level consensus. Advanced reactors can help states achieve their economic and environmental goals while guaranteeing a high level of safety performance. There are many resources, such as this *Guide*, that policymakers can use to better understand nuclear technologies and to share with colleagues.
- **Including advanced nuclear energy in state decarbonization requirements or Clean Energy Standards (CES).** Many states successfully implemented renewable portfolio standards to establish renewable energy industries in their states. States are now establishing and implementing 100% carbon-free generation requirements or other types of CES. Some of these are technology-inclusive and could incentivize the development of advanced reactors while others focus narrowly on existing nuclear facilities. Including advanced reactors in new or existing state-level decarbonization mandates, carbon-free goals, or CES maximizes a state's chances of achieving decarbonization at the lowest possible cost and with the least impact to reliability.
- **Creating innovation hubs to encourage regional economic development.** Energy innovation is centered on "high technology." Successful deployment of advanced nuclear energy requires state and local government, universities, companies, and communities working together, with the potential for jobs ranging from highly trained engineers to union trades workers. Early movers in pursuing advanced reactor or nuclear manufacturing projects will build innovation hubs centered around the communities where projects are located. As the advanced reactor industry scales over time, these hubs will grow as other states adopt advanced nuclear energy.
- **Removing state restrictions on construction of advanced reactors.** As of October 2023, 12 states still have restrictions on building new nuclear power plants, with many restrictions dating from the 1990s or earlier. These restrictions were primarily based on the economic or environmental characteristics of large conventional reactors. As these states look to achieve energy systems of the future, they should reevaluate the basis, structure, and applicability of these restrictions to advanced reactors.
- **Incorporating advanced reactors into state planning processes, including executive roadmaps and utility Integrated Resource Plans (IRPs).** State governments and regulated utilities are responsible for ensuring reliable, economic electricity supply to serve the public. Coordination between governors, state level regulatory commissions, and utilities can better achieve their energy security and clean energy demands by including advanced reactors in these plans, especially utility IRPs.

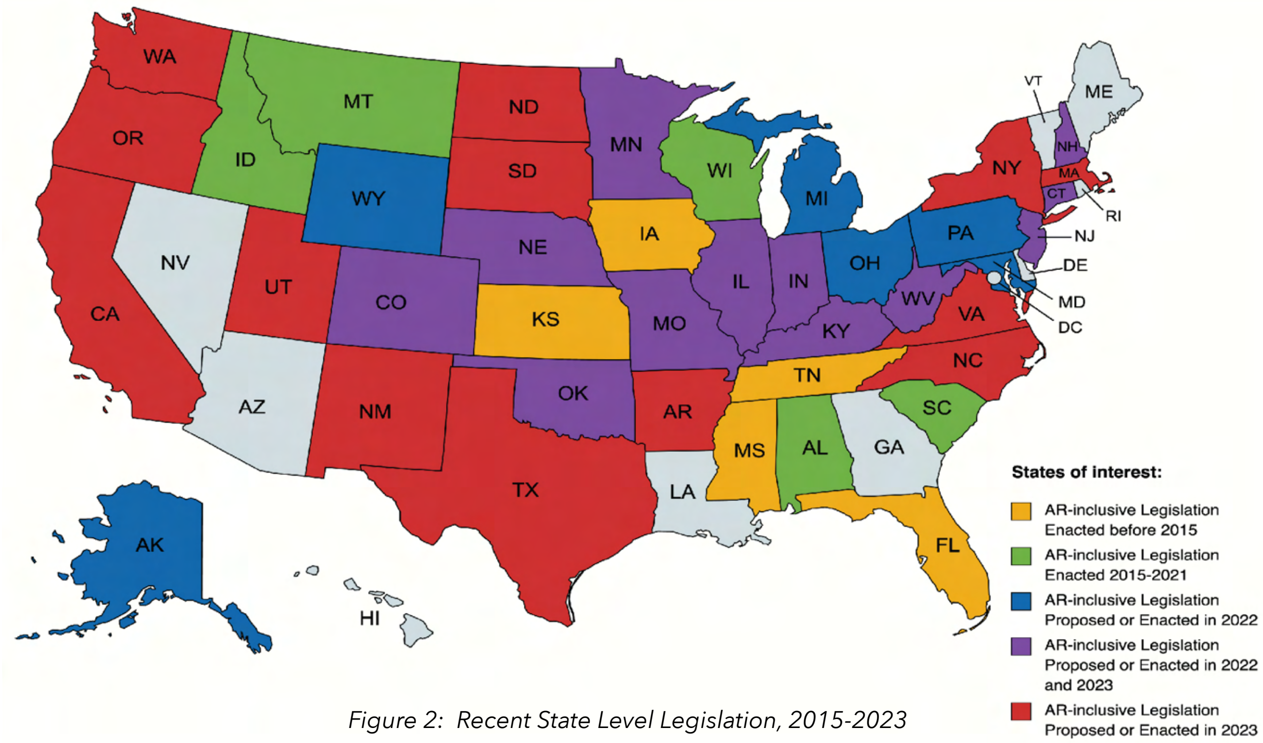

Figure 2: Recent State Level Legislation, 2015-2023

In the past two years, 184 bills were introduced and considered that directly related to the deployment and commercialization of new nuclear reactors or legislation affecting existing nuclear generation; the result was 34 bills enacted in 23 states. As advanced nuclear energy technology continues to mature, more states will continue to place themselves in a position to take advantage of the economic benefits nuclear energy can bring.

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Federal Legislation for Nuclear Innovation

by Victor Ibarra, Jr

Summary:

- There is substantial, bipartisan, and sustained support for advanced reactor technology innovation
- The Nuclear Regulatory Commission (NRC) is embarking on an ambitious regulatory modernization program to facilitate the effective, timely and efficient licensing of advanced reactors
- Federal investments in advanced reactor technology and demonstration projects provide a foundation for U.S. development and commercialization
- Demonstration projects and commercialization will foster economic opportunities for communities

Nuclear Energy Innovation Capabilities Act (NEICA)

Signed into law in late 2018, NEICA established the foundation for accelerated innovation and commercialization of advanced reactors in the United States. NEICA created the National Reactor Innovation Center to bridge the gap between government support and private sector needs, authorized the Versatile Test Reactor as a scientific research testbed to simulate and analyze prototypical conditions, and authorized funding for the demonstration of advanced reactors through cost-shared partnerships with U.S. industry.

The Nuclear Energy Innovation and Modernization Act (NEIMA)

Enacted in early 2019, NEIMA modernizes the U.S. Nuclear Regulatory Commission's (NRC) functions by requiring the commission to develop a "technology-inclusive framework" for advanced reactor licensing in the next four-to-seven years. NEIMA launched a once-in-a- generation opportunity to accelerate the adoption of safe, zero-carbon nuclear power in the United States. Meanwhile, broader regulatory modernization at NRC facilitates timely and efficient deployment of first-of-a-kind advanced reactors at the state and local level.

The Energy Act of 2020

In addition to other programs, this law authorizes the Advanced Reactor Demonstration Program (ARDP), which funds multiple companies to work with the U.S. Department of Energy (DOE) to demonstrate their advanced reactor technology.

Figure 1: Enabling Nuclear Energy Legislation Enacted 2018-2020

Nuclear power is one of the United States' largest sources of carbon-free, reliable electricity. Once internationally pre-eminent, the United States is falling behind in building new reactors globally, and federal lawmakers understand the importance of revitalizing and modernizing the nation's nuclear industry. As a result, there is substantial bipartisan and sustained support for advanced reactor innovation in Congress and across administrations. Three major pieces of legislation highlight continuing actions to promote advanced reactors (see Figure 1).

Since then, three additional pieces of legislation have passed that will enable communities across the United States to deploy advanced nuclear energy (see Figure 2).

Infrastructure Investment and Jobs Act (IIJA)

Signed into law in late 2021, IIJA authorized and appropriated funding for the DOE's ARDP.

- The bill authorized the full amount ($3.2 billion) to support the ARDP Demonstration projects.
- It also appropriated $2.4 billion to fund the ARDP Risk Reduction and Advanced Reactor Concepts (ARC-20) projects.
- It also established the "Office of Clean Energy Demonstrations" within DOE to conduct project management and oversight of the ARDP demonstrations and other covered clean energy demonstration projects.

Creating Helpful Incentives to Produce Semiconductors and Science Act (CHIPS+)

Enacted in late 2022, the "CHIPS+ Act" invested in the next generation of nuclear technologies and professionals by funding critical DOE RD&D programs and university research programs.

- The bill authorized $390 million to establish as many as four new research reactors.
- The bill also authorized $800 million for the DOE to establish the Fission for the Future program, which will allow eligible entities to support RD&D activities for advanced nuclear reactors, including projects near retired coal plants.

Inflation Reduction Act of 2022 (IRA)

- The largest investment in clean energy to date, the IRA included crucial provisions to deploy nuclear energy.
- The IRA included technology-neutral tax credits for which advanced nuclear is eligible.
- The IRA invested $700 million to jumpstart a domestic HALEU program.

Figure 2: Enabling Nuclear Energy Legislation Enacted 2021-2022

Both the Trump and Biden administrations provided significant investment in the development of advanced nuclear energy. NEICA, NEIMA, The Energy Act of 2020, IIJA, CHIPS+, and IRA demonstrate bipartisan commitment to advanced nuclear energy playing an important role in the future. These laws provide a basis for nuclear innovation, and Congress is working on additional bipartisan legislation to address fuel availability, accelerate commercialization of microreactors, and more. With the federal government and private sector investing billions of dollars, each advanced reactor project will create high-paying manufacturing, construction, and operations jobs. This investment will fund activities at the state and community level, meaning federal support is poised to drive economic growth in first mover states.

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Case Study: Repowering Wyoming Communities

by Victor Ibarra, Jr.

In 2020, nuclear energy **generated more electricity** in the United States than coal for the first time ever, primarily due to coal plant retirements. While falling coal generation reduces greenhouse gas emissions, it can greatly hurt local communities and risks leaving them behind during the energy transition. In states like Wyoming, where 4 coal plants providing 5,500 megawatts of power are expected to retire in the next 15 years, local communities now face economic hardship. Advanced nuclear energy can help solve this problem by reusing retired brownfield coal power plant sites for nuclear energy, preserving local jobs and spurring local economic growth.

In June 2021, Wyoming emerged as a national leader in nuclear innovation by proposing a project to do exactly that. TerraPower, Wyoming Governor Mark Gordon, and electric utility PacificCorp (Rocky Mountain Power) announced that they will be demonstrating the Natrium project, a sodium cooled fast reactor with a molten salt energy storage system, at a retiring coal plant site in Wyoming. Supported by fully authorized federal funding through a public-private partnership, the project is a first-of-a-kind opportunity to demonstrate advanced nuclear energy. It also serves as an opportunity to facilitate the first ever coal-to-nuclear transition which would prove the viability of such projects, revitalize the local community, and show that repurposing certain key pieces infrastructure like transmission lines can be a massive benefit to a new nuclear project. In November 2021, **TerraPower announced Kemmer-er, Wyoming** as the preferred site for the Natrium reactor and in August 2023, purchased land in Kemmerer. Since then, TerraPower has been busy finalizing contracts with suppliers for the project and performing site characterization. the state has done a lot more to attract nuclear innovation within their borders, including enacting key legislation, but their work goes back before the TerraPower announcement.

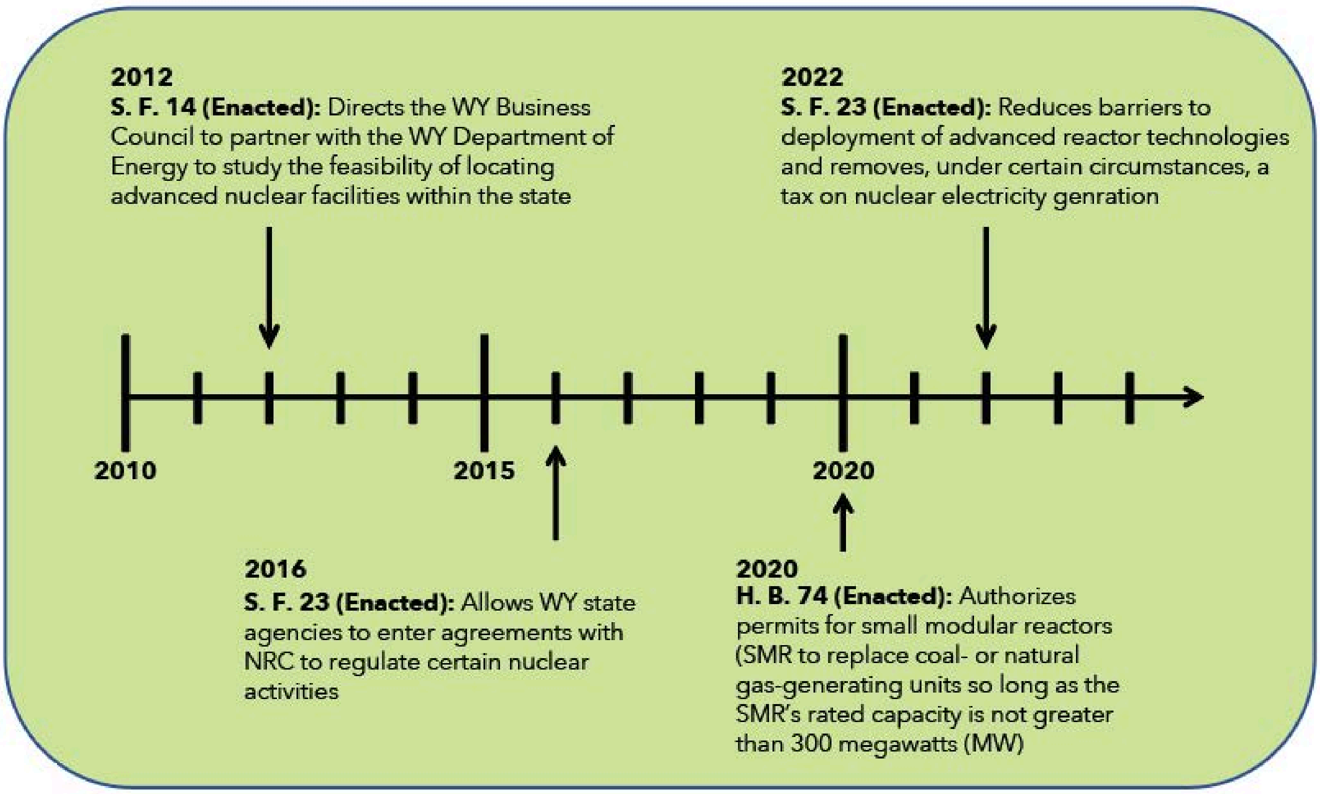


Figure 1: Key Legislation Enacted Leading to Wyoming's Position as a Nuclear Leader

This legislation not only reflects a commitment to diversifying Wyoming's energy portfolio but also demonstrates the state's forward-thinking approach to addressing future energy challenges through advanced nuclear energy. By promoting the development of nuclear energy, Wyoming aims to secure a more sustainable and resilient energy future while fostering economic growth and job opportunities in the state. It's a pivotal step in the broader transition towards a greener and more robust energy sector, with potential implications for the entire nation's energy landscape, and others have taken notice.

Beyond the TerraPower project, the Wyoming Energy Authority has announced a two-phase, two-year contract with BWXT, a company working to deploy their BWXT Advanced Nuclear Reactor (BANR), a TRISO-fueled microreactor. Under phase one of the contract, BWXT will work with Wyoming industries to define the requirements basis for nuclear applications of heat and power needs of the trona mining operations within the state. BWXT will also perform engineering work to further the design of its integrated "BANR" microreactor system that can help meet Wyoming's future power needs. This work will also include identifying areas where Wyoming's existing supply chain can demonstrate capabilities for reactor component manufacturing and support reactor deployment. In late September 2023, Tata Chemicals **signed an agreement** with BWXT to explore the viability (through support from the Wyoming Energy Authority) of using microreactors to decarbonize their industrial processes in Wyoming.

Case Study: Washington State's Commitment to Nuclear Energy

by Victor Ibarra, Jr

Washington State's commitment to cutting greenhouse gas emissions was cemented when Governor Jay Inslee signed into law the **Clean Energy Transformation Act** in 2019. The law, which applies to all electric utilities serving retail customers, sets specific milestones to reach 100% clean electricity by 2045 using renewable or low-GHG emitting generating sources. Consequently, this rulemaking left utilities with two key questions:

1. ***What are optimal electricity portfolios to achieve deep decarbonization in the Pacific Northwest?***
2. ***How does the availability of different zero-emitting generation technologies, like advanced nuclear energy, affect the cost of achieving deep decarbonization?***

A **2020 study** conducted by E3 concluded that utilities could achieve substantial electricity sector emission reductions at competitive costs, provided firm generating capacity is available. Using data from advanced reactor company and the National Renewable Energy Laboratory, the study found the use of advanced nuclear energy could competitively help Washington State achieve a zero-emissions energy portfolio.

To meet its future energy needs, Energy Northwest, a public power joint operating agency that provides at-cost power to public utilities across the northwest U.S., began exploring options to develop advanced reactor projects. Considering Energy Northwest's experience with nuclear energy as the operator for the Columbia Generating Station, Washington and Energy Northwest are in an excellent position to launch a new generation of nuclear reactors.

This was the rationale behind an April 2021 announcement between X-energy (DOE ARDP Demonstration Award Winner), the Grant County Public Utility District (Grant PUD), and Energy Northwest to evaluate, develop, and build four Xe-100 high temperature gas reactors at the Columbia Generating Station, adding a station with 320 megawatts of zero-emission electricity to Grant PUD's and Energy Northwest's portfolio. Under the original agreement between X-energy and DOE, DOE would invest a total of $1.2 billion over seven years for X-energy, Energy Northwest, and Grant PUD to demonstrate X-energy's design, including building a fuel fabrication facility.

Since then, things have changed but Energy Northwest and X-energy remain committed to deploying an advanced nuclear reactor in Washington state. In June 2023, following a joint March 2023 announcement between X-energy and Dow to move X-energy's ARDP award from Energy Northwest to Dow, Energy Northwest confirmed their continued relationship with X-energy by signing a "Joint Development Agreement (JDA)" for up to 12 Xe-100 advanced small modular reactors in central Washington. Under the JDA, X-energy and Energy Northwest will define the scope, location, and schedule under which the commercial development of the project will move forward. The companies will also work together to determine the best approaches to licensing and regulatory matters, as well as the project delivery model. The project will be able to benefit from lessons learned from the Dow project.

Case Study: Texas's Role in Pioneering Nuclear Innovation

by Victor Ibarra, Jr

The state of Texas has a rich history in nuclear energy production but as energy demands continue to escalate, the Texas Public Utility Commission (PUC) and policymakers face an increasing urgency to find a solution to the strain on its electrical grid. To put it simply, the demand for reliable, flexible, and scalable energy solutions has never been higher but nuclear energy, with its proven track record in Texas and potential as a unique energy solution, emerges as a strategic avenue to meet these growing needs.

Figure 1: Rendering of Abiliene Christian University's Molten Salt Reactor Project and Dow Chemical's and X-energy's Advanced Reactor Demonstration Program Project; Source: ACU and Dow

In August 2023, Texas Governor Greg Abbott directed the Texas PUC to establish the **Texas Advanced Nuclear Energy Working Group**. The Working Group, comprised of experts and leaders in the policy, environmental safety, grid operation, and investment arenas, is evaluating how advanced nuclear reactors can provide safe, reliable, and affordable energy for Texas, including how to make the state a national leader in the deployment of nuclear power to take advantage of the economic benefits nuclear energy projects provide to states and local communities. The Working Group comes at a time where Texas is already demonstrating its leadership in nuclear innovation as two non-traditional players, Abilene Christian University (ACU) and Dow are expecting to deploy new reactors within the decade.

Through **ACU's** Nuclear Energy eXperimental Testing Laboratory (NEXT Lab) and a partnership between three major universities (Georgia Tech, UT-Austin, and Texas A&M), ACU is expected to design, license, and construct a molten salt research on or near their campus by 2026. The proposed research reactor would be an up to 1 megawatt-thermal, graphite moderated, fluoride salt flowing fluid (fuel dissolved in the salt). The project is a trailblazer as it marked the first advanced reactor university test reactor project to submit their Construction Permit (CP) application in late 2022. The application was accepted for review by the Nuclear Regulatory Commission (NRC) and will have a final safety and environmental determination made by the agency in 2024.

The flagship nuclear project in Texas will be the commercial scale public-private demonstration between the federal government and **X-energy at Dow's Seadrift facility**. The project, expected to be in operation by the end of the decade, represents a growing private-sector partnerships between industrial companies and nuclear technology companies to find low-carbon and reliable energy decarbonization solution using high-temperature gas-cooled reactors. A CP application is expected to be submitted to the NRC by 2024. Texas's trajectory as a leader in nuclear energy innovation is underpinned by its storied history in nuclear power, robust university systems, and groundbreaking projects spearheaded by institu-tions like ACU and partnerships like Dow Chemical/X-energy. The combination of research, education, and industry engagement creates a dynamic ecosystem that is poised to shape the future of nuclear energy not only for Texas but for the world.

Case Study: Virginia's Advanced Nuclear Energy Future

by Victor Ibarra, Jr

In October 2022, the Governor of Virginia released a **new energy plan** with a proposal for $10 million in funding for innovative energy technologies including hydrogen, carbon capture, battery storage, and advanced nuclear energy. Out of this $10 million, $5 million would fund the establishment of a Nuclear Innovation Hub in Southwest Virginia. According to this plan, the Nuclear Innovation Hub would lever-age the existing "nuclear ecosystem" in Virginia and catalyze advanced nuclear innovation across the United States by deploying new nuclear technologies. The Nuclear Innovation Hub would focus on:Unit-ed States by deploying the following technologies. The Governor's Nuclear Innovation Hub in South-west Virginia would focus on:

- Deploying the first commercial small modular reactor (SMR) in the US,
- Funding for nuclear workforce development,
- Developing Spent Fuel recycling technology, and
- Deploying nuclear-hydrogen energy projects across the state, leveraging the existing and future nuclear reactors throughout Virginia

Each project would be a first of its kind and would provide economic and social benefits to communities across Virginia. The Governor's Plan builds off years of momentum in the Virginia Legislature. In the years since 2013, the Virginia Legislature **has enacted multiple bills** that have spurred clean energy technology development, including Advanced Nuclear Reactor Technologies (ANRT).

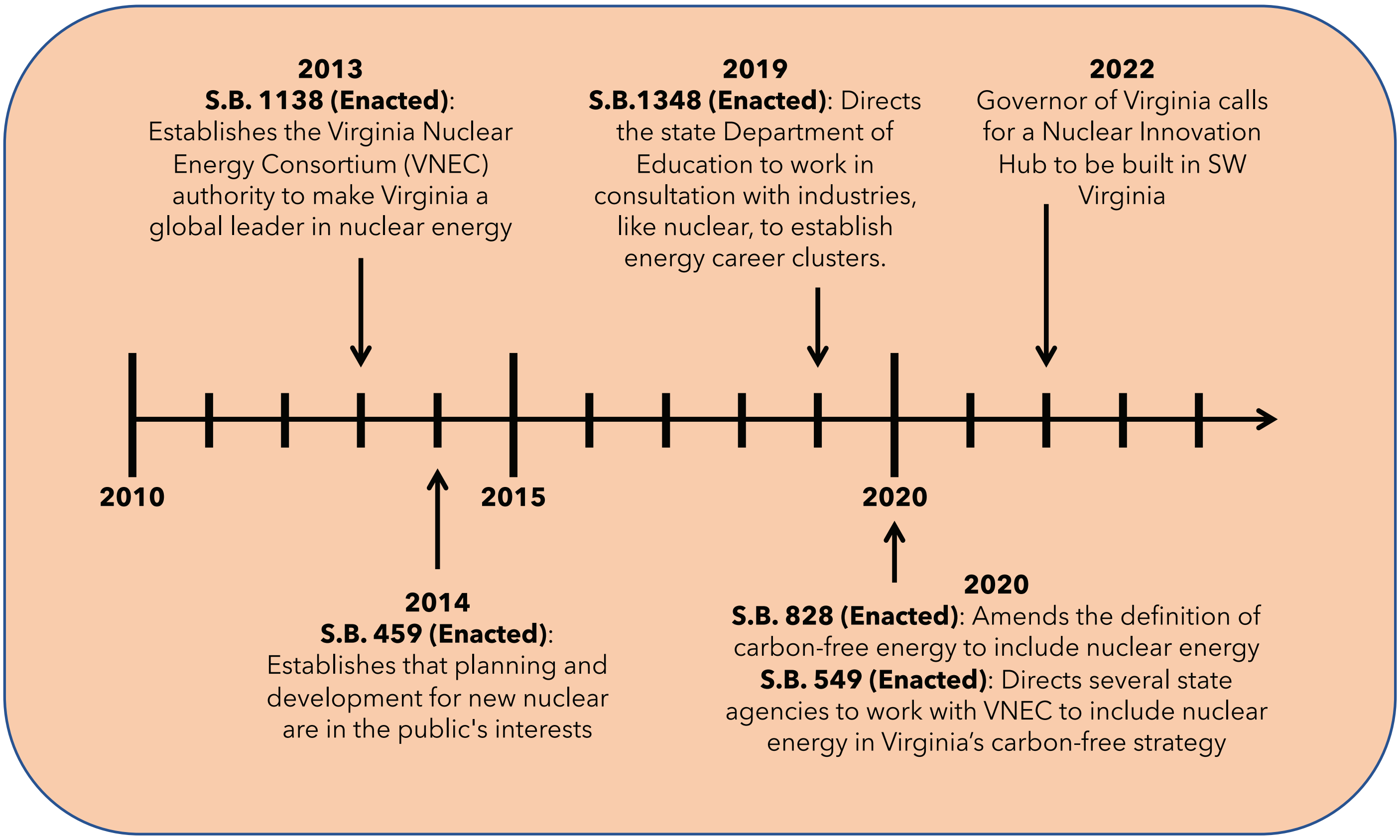


Figure 1: Key Legislation Enacted Leading Up to Nuclear Innovation Hub Annoucement

A key driver of Virginia's potential nuclear energy future is the **Virginia Nuclear Energy Consortium** (VNEC). The consortium consists of universities, utilities, and reactor technology companies ranging from developers to nuclear fuel companies. Their mission is to sustain and enhance the Commonwealth of Virginia as a national and global leader by serving as an interdisciplinary business development, research, training, and information resource on nuclear energy issues.

Universities

- Virginia Tech
- Virginia Commonwealth
- Liberty
- University of Virginia
- James Madison University
- George Mason University
- Old Dominion University

Reactor Technology Companies

- Framatome (reactor and fuel developer)
- GE-Hitachi (reactor and fuel developer)
- Lightbridge (fuel developer)
- Newport News Shipbuilding

Utilities

- Dominion Energy (nuclear power plant operator)
- Appalachian Power Company

Figure 2: Virginia Nuclear Energy Consortium (VNEC) Members

As a result of S.B 529 (2020), VNEC developed and submitted the **"Virginia is Nuclear" Strategic Plan** in early 2021 to advance Virginia's nuclear energy industry. Through VNEC and their work, Virginia is well poised to bring a Nuclear Innovation Hub into reality. With an existing nuclear workforce, a variety of companies involved in nuclear innovation and operation, and a university system that can support the next generation of engineers, experts, and technologists, Virginia is among few states with the level of infrastructure required to develop a Nuclear Innovation Hub.

Early adoption of the Nuclear Innovation Hub plan would provide Virginians **more high paying jobs** and centralized supply chains that can serve as footholds for a rapidly growing and dynamic industry. The deployment of advanced nuclear can also help achieve Virginia's long-term energy goals by serving as a reliable, flexible, low-carbon emission energy source that can be used to generate electricity as well as decarbonize other sectors with hydrogen production or process heat. Virginia can also lead the nuclear waste conversation by developing spent fuel recycling technology in the state.

The Governor's proposal is one example momentum across the United States for nuclear innovation and the deployment of advanced nuclear projects. From Alaska to Virginia, states have begun to take notice of the advantages of advanced nuclear energy and have taken the first steps to deploy these technolo-gies by introducing and enacting nuclear-inclusive legislation. Before the Nuclear Innovation Hub is official, it must be approved by the Virginia General Assembly. Under Virginia's biennial budget sched-ule, Virginia's budget bill is adopted in even-numbered years and amended in odd-numbered years. The budget would need to be amended in 2023 to include the Nuclear Innovation Hub proposal or the next biennial budget in 2024 could include the hub.

Case Study: Nuclear Power for Puerto Rico

by Erik Cothron

In September of 2017, Hurricane Irma and Hurricane Maria hit the island of Puerto Rico within a span of two weeks, bringing widespread and catastrophic damage including a 100% power failure across the island. The hurricanes left residents with no drinkable water and killed thousands of people, creating the deadliest U.S. disaster in over 100 years. The disaster left some residents of Puerto Rico without access to clean drinking water or electricity for months–and even years–and the impacts of the hurricanes are still seen today. Due to its size and location, Puerto Rico will continue to be particularly susceptible to the effects of climate change as warmer sea temperatures and higher sea levels are expected to intensify hurricane strength and impact.

Recognizing the vulnerability of the aging Puerto Rican energy grid that relies heavily on energy imports, a group of Puerto Rican professionals began working together after the hurricanes to bring nuclear energy to Puerto Rico, founding the **Nuclear Alternative Project (NAP)**. In May of 2020, the NAP collaborated with nuclear energy leaders like the Pacific Northwest National Laboratory and Pillsbury to conduct the **"Preliminary Feasibility Study for Small Modular Reactors and Microreactors for Puerto Rico"** and found many socio-economic motivations to pursue advanced nuclear technology. Since then, NAP has been an active voice for bringing advanced nuclear energy to Puerto Rico. They have conducted dozens of webinars, participated in public debates, and appeared on several podcasts to help spread awareness and educate the public about the benefits of advanced nuclear energy. Going forward, NAP plans to continue their advanced nuclear educational campaign and also publish an advanced nuclear site suitability study, as well as a preliminary economic study.

Approximately 98% of the electricity generated in Puerto Rico comes from fossil fuel imports (primarily oil) and the island has a poor record of power operations reliability with an outage rate 12 times higher than the United States. This combination of dependence on fossil fuel imports and poor reliability puts the Puerto Rican economy under extreme stress, especially when global oil prices spike. The aftermath of natural disasters has also led Puerto Rico's residents to seek firm energy sources that are resilient under extreme weather conditions.

According to the study, the Puerto Rico Electric Power Authority (PREPA), the commonwealth's governing body responsible for delivering energy, expects the retirement of a total of 3,600 megawatts of electric generation over the next 10 years–74% of PREPA's total electric portfolio. Advanced nuclear reactors can offset the required retirement of PREPA's aging power plants with an expeditious installation of new capacity to ensure a reliable energy grid. The study also found that electricity from microreactors or SMRs can be cost competitive when compared to imported diesel and natural gas. Thus, Puerto Rico can benefit economically and gain energy security by adopting nuclear energy resources.

Bringing nuclear energy to Puerto Rico would not only benefit the island's residents, but could also serve as a model for other U.S. states and territories, including those with military bases. The U.S. has four additional territories outside of Puerto Rico–the U.S. Virgin Islands, Northern Mariana Islands, Guam, and American Samoa–all of which consume petroleum products to produce electricity at relatively high costs. These remote communities can reduce their dependence on expensive petroleum products while also reducing pollution and greenhouse gas emissions from fossil fuels use by investing in advanced nuclear technology. Similarly, the military is considering the use of microreactors at military bases in the U.S. to increase base resilience and energy security. As the U.S. Department of Defense explores advanced nuclear energy technologies, states and territories are well positioned to support these mission-critical energy projects.

Advanced Reactor Deployment Timelines

by Dr. Patrick White and Victor Ibarra, Jr

Multiple advanced reactor developers have announced domestic demonstration projects in the 2020s (Figure 1). While these projects will not be completed until later in the decade, reactor developers are already engaging with the Nuclear Regulatory Commission (NRC) to obtain the required regulatory approvals (Figure 2). These nuclear reactors will provide the licensing, construction, and operational basis for rapid commercial expansion of advanced nuclear energy in the late 2020s and early 2030s.

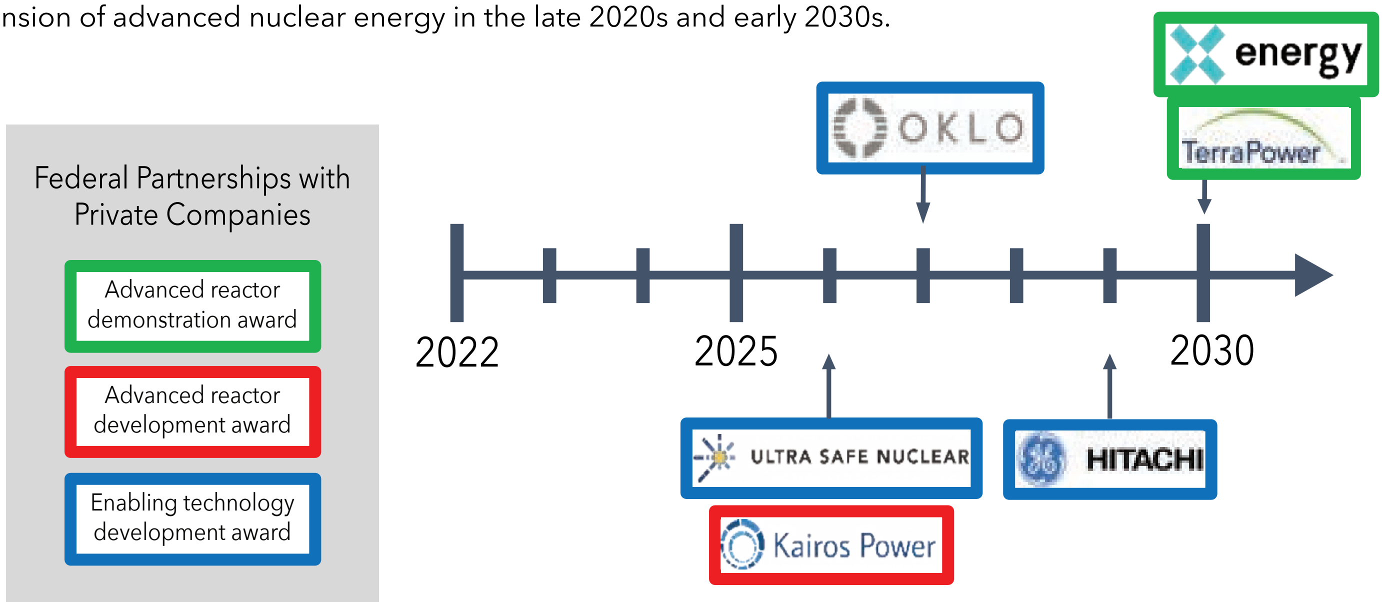


Figure 1: Announced Deployment Timeline for Selected Advanced Reactor Projects Supported by Federal Partnerships in the United States

The DOE's flagship nuclear projects include the two major Advanced Reactor Demonstration Project (ARDP) winners, X-energy and TerraPower. X-energy will build four Xe-100 reactors at Dow's Seadrift Site in Texas and TerraPower will build their Natrium reactor at a retiring coal facility in Kemmerer, Wyoming. Other projects supported by the DOE are planned for construction at the Idaho National Laboratory include demonstration microreactors for Oklo and BWXT (Project Pele). Kairos Power and Ultra Safe Nuclear Corporation (USNC) have both announced plans for construction and operation of test reactors in preparation for a commercial power reactor. The first Kairos reactor will be sited near the East Tennessee Technology Park and the first USNC reactor will be sited at the University of Illinois at Urbana Champaign. GE-Hitachi announced commercial partnerships with the Tennessee Valley Authority and Ontario Power Generation to deploy the BWRX-300 reactor technology at the Clinch River Site in Tennessee and the Darlington site in Canada.

Site-Specific Applications

- Kairos Power: Hermes CP/OL *(submitted)*
- ACU: NEXT MSR CP *(submitted)*
- GEH: BWRX-300 CP - Clinch River
- X-Energy: Xe-100 CP - Seadrift
- Westinghouse: eVinci CP - Penn State
- TerraPower: Natrium CP - Kemmerer
- Kairos Power: KP-FHR - TDD
- Oklo: NCSFR-1 COL
- Oklo: NCSFR-2 COL

Pre-Application Interactions

- General Atomics: EM2
- Terrestrial Energy: IMSR
- FLiBe: LFTR
- ARC: ARC-100
- BWXT: BANR

Design-Specific Applications

- NuScale: NuScale US460 *(submitted)*

Figure 2: Expected Advanced Reactor Engagement with NRC in FY24; Source: **NRC NUREG 1100, Volume 39**
Note: CP=Construction Permit; OL= Operating License; COL=Combined Construction and Operating License

Technology, business, and regulatory lessons learned from first-of-a-kind (FOAK) projects will facilitate lower costs and shorter construction timelines for subsequent nth-of-a-kind (NOAK) reactors due to wide-scale deployment and technological learning. Utilities and other customers that gain early experience with FOAK or early NOAK projects will be in competitive positions to become technology leaders.

NUCLEAR INNOVATION ALLIANCE

Economics of Advanced Nuclear Energy

by Victor Ibarra, Jr.

Summary

- Advanced reactors are designed to be economically competitive and reduce investor risks associated with construction.
- Nuclear reactors can economically provide energy over very long lifetimes, making them sound long-term investments.
- Levelized cost of energy (LCOE) estimates, while a convenient metric, exclude system costs such as new transmission and storage. When all costs are included, nuclear energy is competitive with variable renewable generation, and may be essential in many regions.
- Most analyses of decarbonization pathways confirm that including firm energy sources such as nuclear energy, in addition to variable renewable energy, decreases the overall cost of decarbonization.
- Host communities find commercial nuclear plants attractive because they provide well-paying union jobs, bring investment, support the local tax base, and stimulate local economies.
- Recent interest demonstrates that advanced nuclear energy is particularly attractive as a replacement for retiring coal plants. They can be built on existing sites using existing transmission, making development and interconnection far simpler than for new, greenfield power generation.

Advanced reactor designs were developed with a specific focus on cost-competitiveness and reducing construction complexity and risk compared to conventional nuclear plants. Advanced reactor designs feature smaller physical footprints than conventional plants and emphasize the use of manufactured components to reduce the amount of on-site construction. Advanced reactors are designed for modular construction with reduced capital investment, and less construction complexity. This enables faster construction and scalable, incremental power additions to meet energy demand as needed. Advanced reactors can be designed to limit water requirements and potentially reduce the need for large scale off-site emergency evacuation require-ments, **opening up deployment options**, such as repowering retired coal facilities or providing heat and power to industrial sites. Further, smaller designs like microreactors can unlock new uses and enable decarbonization of high-cost, carbon-intensive remote grids.

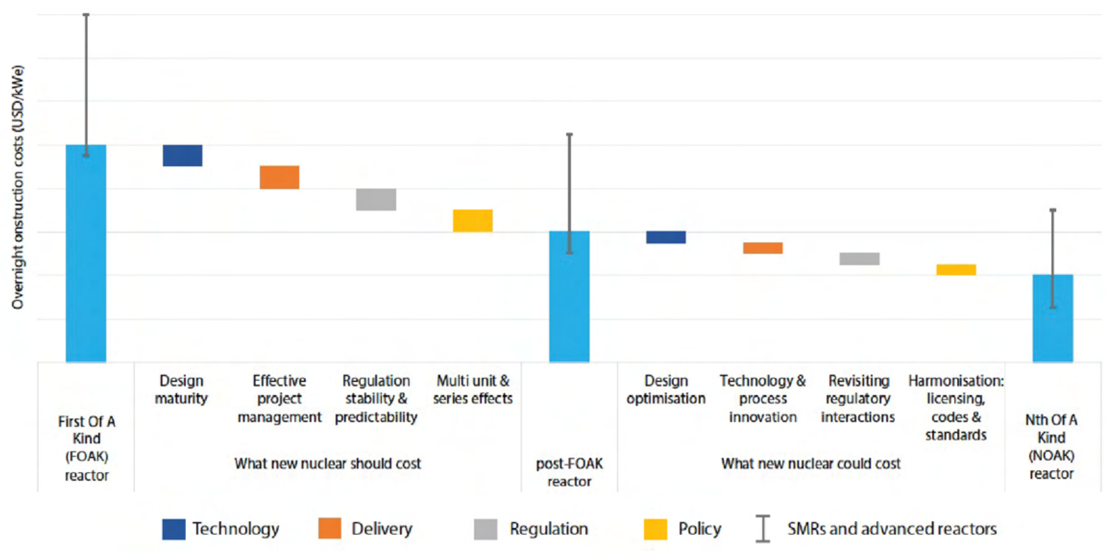


Figure 1: Simplified visualization on how advanced reactors can reduce construction costs Source: NEA

Nuclear power plants have the longest lifetime operation among energy sources. Nuclear power plants are typically designed to operate upwards of 60 years. The Nuclear Regulatory Commission (NRC), the independent federal agency with authority to license the operation of commercial nuclear power plants in the United States, issues initial operating licenses for commercial power reactors to operate up to 40 years. These licenses can be extended for an additional 20 years at a time after an initial license, and many nuclear power plant operators are expected to seek a second, and potentially even a third, license extension. Out of 93 operating commercial nuclear reactors in the United States, 79 have been granted their first license renewal, and 6 have been granted their second license renewal. Most advanced nuclear reactors are also expected to operate between 60-80 years or more. In comparison, wind and solar energy sources are anticipated to operate on average between 30 and 40 years.

When all costs are included, nuclear energy is competitive with variable renewable generation, and may be essential in many regions. LCOE estimates are often cited to compare the economics of power generation options. However, the LCOE calculation has many limitations and should be used in combination with other metrics and factors to give a more comprehensive view of the economic and environmental impact of specific generating technologies over their lifetime.

Including nuclear power gives the world the best chance to tackle climate change and energy security. Princ-eton University's Net Zero America study analyzed the ability and affordability of five distinct technological pathways, all using technologies known today, to decarbonize the U.S. economy. Out of the five pathways, all but one used nuclear energy and the pathway that used the largest amount of nuclear energy **was also the most affordable.** While it is impossible to predict the exact energy mix necessary to fully decarbonize the world's economy by 2050, nuclear energy will likely play a significant part.

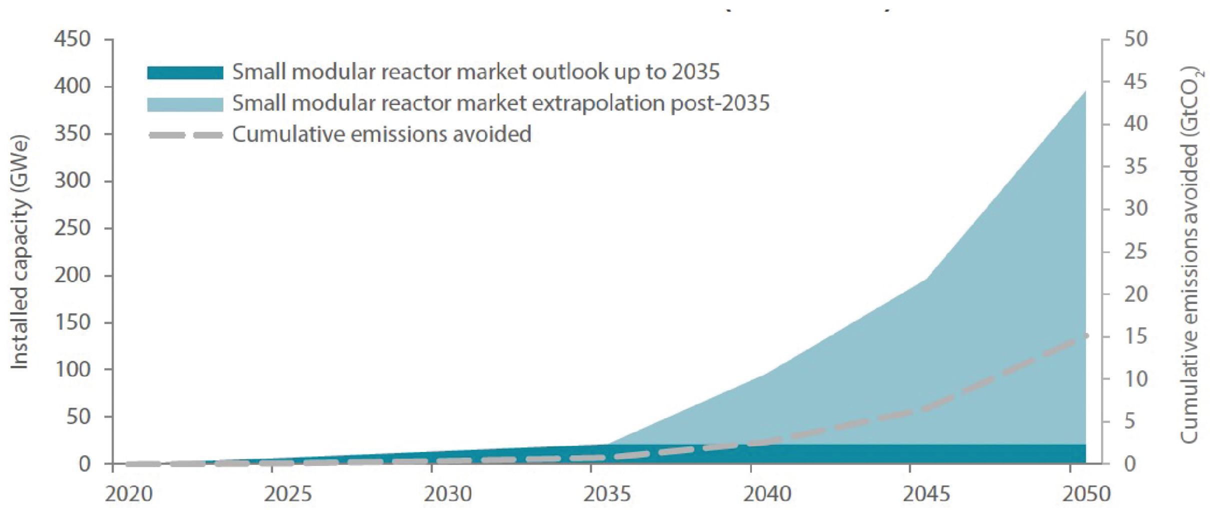


Figure 2: The potential of advanced nuclear to help reduce global GHGs. Source: NEA

Building new nuclear plants will allow communities to retain well-paying union jobs and a significant tax base in the clean energy transition. Beyond competitively priced power, nuclear energy brings significant economic benefits to individuals, local communities, and states. Each year, a typical commercial U.S. reactor generates tens of millions of dollars in state and local tax revenue, stimulating local economies through local infrastructure buildout and maintenance. Construction of new nuclear power plants also benefits local and regional suppliers of design, engineering, procurement, construction and consulting services. These are well-paying jobs with high union rates that will allow communities the opportunity to retain workforces as carbon-emitting sources around the country retire.

Advanced nuclear energy can also repower retiring fossil fuel sources. A September 2022 U.S. Department of Energy report on coal-to-nuclear feasibility found that advanced nuclear energy could play a major role in communities with retiring coal facilities. The DOE found that 80% of retired and operating coal power plant sites could host an advanced nuclear reactor, paving the way for over 250 GWe of coal-to-nuclear replacement projects across the United States. A 924 MWe coal-to-nuclear conversion could increase regional economic activity by $275 million and add 650 new, high-paying, permanent jobs to the region, many of which are traditional coal jobs that could transition to roles at an advanced reactor.

Advanced reactors have the potential to supply low-cost, zero-carbon energy for industrial and other energy needs. Many advanced reactor designs will be able to operate at and produce high-temperature heat that can be used for industry, hydrogen production, desalination, and similar applications. This is why certain companies, like Dow Chemical, are exploring using high-temperature gas reactor technology to decarbonize some of their industrial processes. Similarly, the University of Illinois-Urbana Champaign is also planning to take advantage of process heat from a USNC microreactor to provide clean heat and power to its university campus.

Flexibility of Advanced Nuclear Energy

by Victor Ibarra, Jr.

Summary

- Future electricity grids will need to incorporate high levels of variable renewable energy and manage concerns about grid reliability and resilience in the face of extreme and changing weather.
- Advanced reactors are well suited to provide firm, flexible and resilient electricity supply in future energy grids.
- Advanced reactors can supply energy for industrial requirements and enable co-production of hydrogen and desalination, helping to decarbonize other energy-intensive economic sectors and mitigate the impacts of climate change.

Electricity markets require closely matching electricity supply to demand on an instantaneous basis. Power system operators "dispatch" or adjust the production of power from electric generating units so that total generation matches demand as it varies throughout the day, season, and year. As the share of variable renew-able energy continues to grow, the rest of the electric grid must feature increased flexibility to economically balance energy requirements while maintaining reliability. As economies grapple with how to balance variable renewables, advanced reactor developers can provide the zero-carbon on-demand power needed when renewable generation is unavailable, and work in tandem with renewable energy and energy storage to decar-bonize energy systems.

Flexibility and compatibility with renewable energy have been part of advanced reactor designs from the start. Advanced reactor designs will be able to change their power level rapidly to complement variable levels of wind and solar generation. Some designs will even be able to ramp up or down from **40% to full power** in 12 minutes to match fluctuating supply or demand. In addition, most designs consist of multiple units that can be managed separately to meet fluctuations. In fact, it's a common misperception that nuclear reactors aren't compatible with renewables. Existing reactors were originally licensed to be able to also modify their output to match changing energy demand (called load following to help maintain the stability of the electric grid) but have not typically done so in the United States because in the past, it has been more economically efficient for them to operate continuously at full power (i.e., as a "baseload" electricity resource). Reactors in France, flexibly dispatch nuclear units to balance the grid. Advanced reactor designs will be able to change their power level rapidly to complement variable levels of wind and solar generation. Some designs will even be able to ramp down to and up from 40% in 12 minutes. France, flexibly dispatch to balance the grid.

In addition to their ability to vary their output, some advanced reactor designs incorporate energy storage capability, to save power when there is a lot of renewable energy available, and provide it later, when it's needed. TerraPower's Natrium reactor can increase its output by about 45% for 5.5 hours using thermal stor-age. Holtec's SMR-160 also can be paired with an energy storage system.

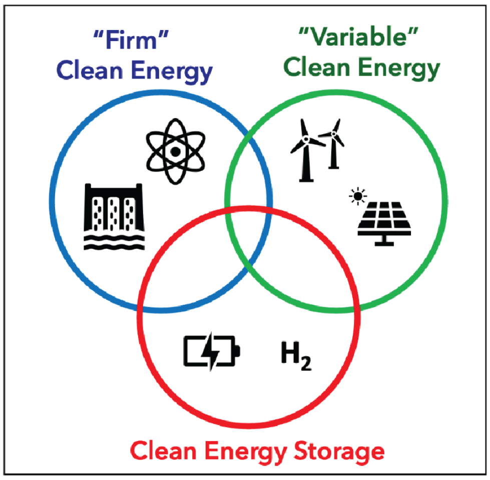


Figure 1: Simplified visualization of how grid flexibility can be achieved using clean energy sources

Figure 2: Range of applications that advanced nuclear can decarbonize. Source: Modified from X-energy presentation

Advanced reactor technologies are also capable of supplying high-temperature output for industrial requirements, and of powering hydrogen production and decarbonizations. The ability to provide energy for industrial production will be critical to achieving decarbonization objectives. Futhermore, it may be feasible to use some of these additional energy requirements to balance the production of electricity for the grid, providing an additional source of flexbility for power generation.

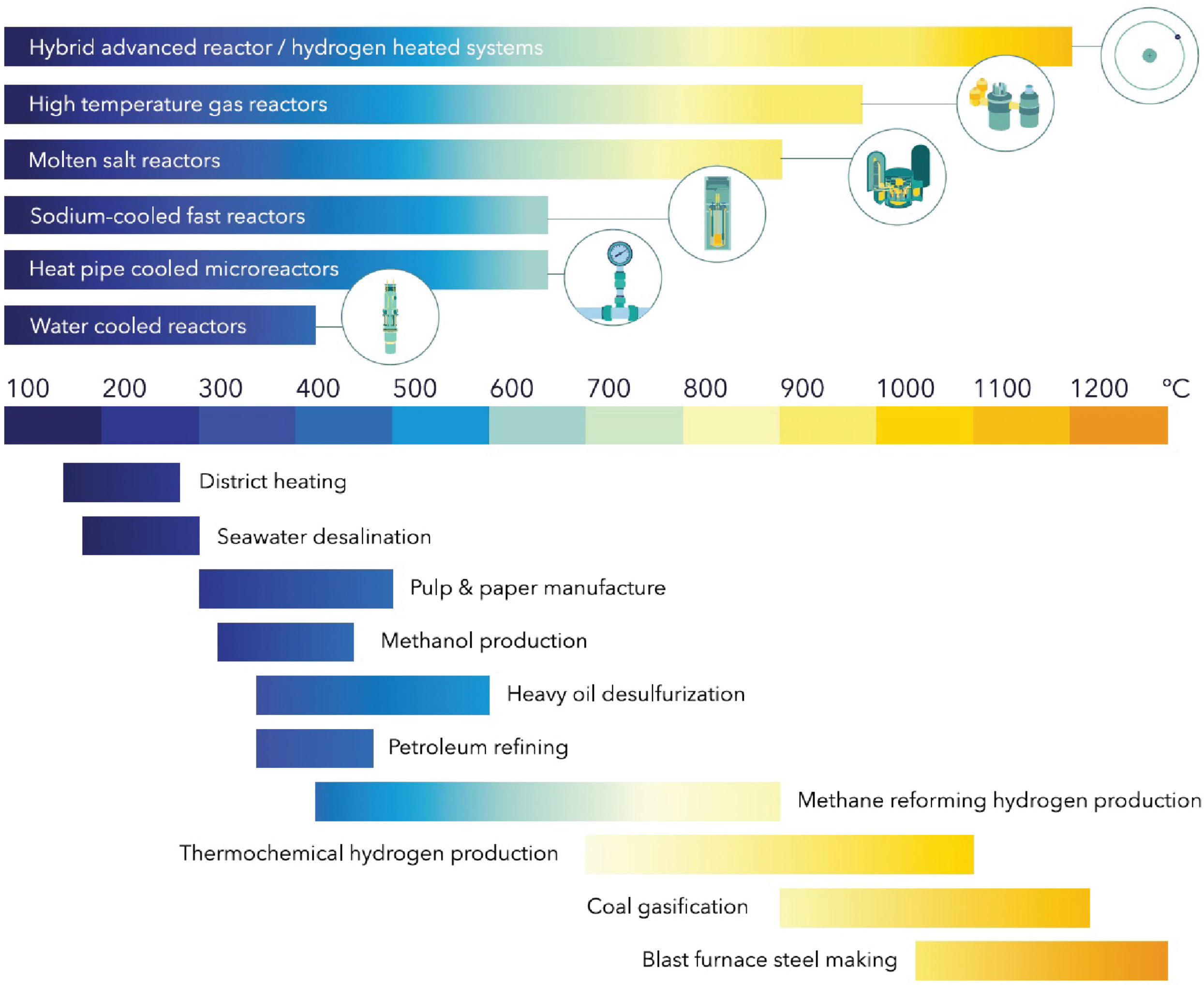


Figure 3: Temperature ranges for several industrial processes and reactors operating ranges. Source: NIA

NUCLEAR INNOVATION ALLIANCE

Spent Nuclear Fuel Management

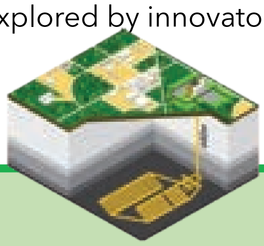
by Erik Cothron

The U.S. nuclear power industry has safely and effectively managed spent nuclear fuel (SNF) for decades. This specific form of nuclear waste is tracked with great precision and stored to keep it isolated from the environment. SNF is currently stored at facilities on nuclear power plant sites, but several well-understood approaches could be used for long-term storage, and innovators are exploring new ones. Given the relatively small quantity of SNF compared to the energy generated, it is feasible to greatly expand nuclear energy production and still safely and effectively manage this spent fuel. **To summarize:**

- **Safety:** Commercial SNF has been stored safely in the United States for decades. **No member of the public** has ever been harmed by the commercially generated spent nuclear fuel that is stored in 35 states.
- **Amount:** The total amount of SNF produced in the United States is very small in comparison to wastes from any other part of the energy sector and relative to the amount of energy it produces. In over 65 years of operation, the entire U.S. nuclear industry has produced around 90,000 metric tons of SNF, enough to cover one football field to a depth of about 10 yards. In contrast, coal power plants produce over **100 million metric tons** of coal ash every year. For context, the amount of SNF generat-ed from an individual's lifetime electricity consumption of nuclear generated electricity would only fill a soda can.
- **Management:** SNF is currently stored safely at reactor sites across the United States in dry casks or in wet storage, and it is precisely tracked and managed. Therefore, the nuclear energy industry is the only industry that is completely responsible for monitoring and managing every aspect of its waste and ensuring it does not negatively affect the public.

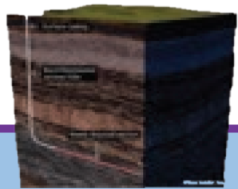
There are several approaches to disposing SNF:

While the current SNF management system in the United States is safe and effective, it is meant to only be a near-term and mid-term solution. Under the original Nuclear Waste Policy Act (NWPA), the U.S. Department of Energy (DOE) is responsible for taking waste from commercial reactor sites and putting it into long-term storage. However, DOE has yet to fulfill this responsibility. SNF will eventually need to be placed in a permanent storage facility. The good news is that solutions are available, and more are being explored by innovators, to help safely and permanently dispose of SNF. They include:



Geological Repositories

A geological repository is an underground facility designed for safe permanent disposal of SNF. Geological repositories are being implemented in several countries, including **Finland and Sweden** through successful consent-based siting implementation



Deep Boreholes

Deep borehole technology would use advanced drilling techniques to safety store SNF deep underground in multiple boreholes. These boreholes could be easier to site and can be placed much deeper underground than mined repositories. Private companies like Deep Isolation, which recently received funding from ARPA-E, are already exploring this innovative solution.

Recycling

DOE is investing heavily into two SNF recycling programs to reduce the total amount needed to be stored and to provide fuel for advanced reactors. These include Optimizing Nuclear Waste and Advanced Reactor Disposal Systems (ONWARDS) and Converting SNF Radioisotopes Into Energy (CURIE). Projects within CURIE were recently **awarded $38 million in funding**.

Interim Storage: While not a permanent solution, DOE is considering establishing one or more interim storage facilities. DOE is in the process of developing a **consent-based siting process** that will be used when selecting an interim storage site and has recently established a consent-based siting consortia with $26M in funding to universities, nonprofits, and private-sector entities.

SNF from Advanced Reactors:

Advanced reactors offer opportunities to change the conversation about SNF. Numerous advanced reactor designs, such as Oklo's Aurora Powerhouse reactor, plan to run on fuel recycled from existing SNF stockpiles. Additionally, advanced reactor designs generally offer greater efficiency and better utilization of nuclear fuel, reducing the rate at which SNF is generated per unit of nuclear energy produced.

Recent studies from **Argonne National Laboratory** and the **National Academies** found that the amount of SNF produced by small modular reactors (SMRs) and microreactors will be comparable to that produced by conventional nuclear reactors. The table below shows the volume and mass of SNF produced from several SMRs analyzed in the Argonne National Laboratory study, compared to a refer-ence conventional pressurized water reactor (PWR). The amount of SNF from each SMR varies based on its unique design, but in general, they are roughly comparable to or significantly less than the reference PWR.

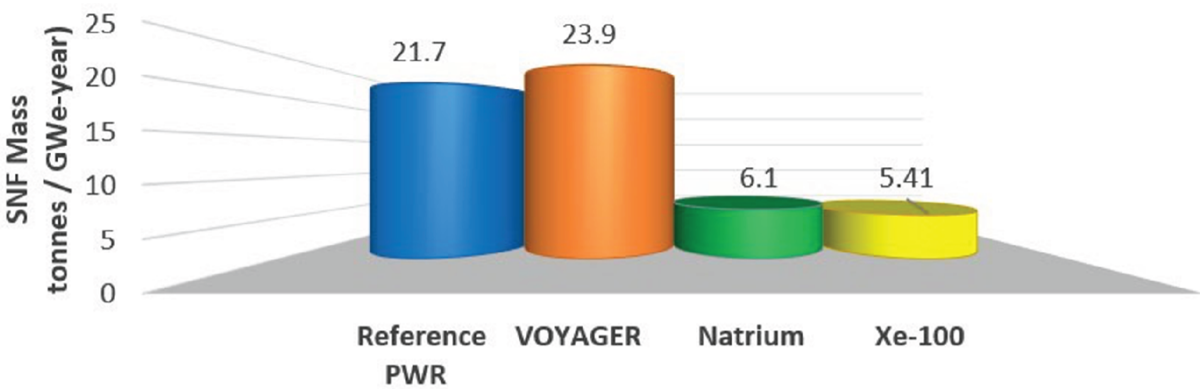


Table 1: Comparison of SMR SNF to a reference PWR

Additionally, some advanced reactors may also have the potential to reduce the lifetime of their SNF. Certain advanced reactor designs and fuel cycles can turn highly radioactive elements in SNF with extremely long half-lives into elements with much shorter half-lives. As a result, these designs could produce SNF that is radioactive for shorter time periods, which would significantly simplify the design and siting requirements for SNF disposal facilities.

Conclusion:

Existing SNF is the byproduct of generating nearly one fifth of the United States' electricity and nearly half of its clean energy, and the quantity of SNF is very small in the context of the energy produced. SNF is currently safely stored at existing nuclear power plant sites across the United States. Recent studies have shown that SNF from advanced nuclear reactors will be comparable to that generat-ed by the existing nuclear fleet. Therefore, our current waste management system should be well equipped to handle SNF from advanced nuclear reactors as they are deployed towards the end of this decade, and beyond.

Although the United States' current solution to handling SNF is safe and effective, it is meant to only be a short to mid-term solution. While the United States has yet to implement a long-term solution to storing SNF, there are existing and potential new approaches to long-term disposal, some of which are being implemented in other countries.

Safety of Advanced Nuclear Energy

by Victor Ibarra, Jr

Summary:

- Advanced reactors build on the nuclear industry's modern record of safety with features that further reduce accident risks.
- Globally, commercial nuclear energy is overseen by independent nuclear regulators and the U.S. Nuclear Regulatory Commission (NRC) is considered a gold standard in excellence of nuclear regulation and safety
- To achieve widespread deployment, advanced reactors will have to demonstrate to independent safety regulators that they can provide adequate protection.

Overview:

Advanced nuclear reactors build upon the experience and lessons learned from the existing fleet of nuclear reactors and incorporate additional innovations creating even safer products. Over the course of more than 15,000 reactor-years of operation globally, humanity has gained millions of person-years of experience with nuclear power plants. While there are public concerns about the safe operation of nuclear energy, nuclear energy remains one of the safest forms of energy production available globally.

Based on operational experience and lessons, advanced reactors feature innovations that further reduce the risks and consequences of accidents. These can include:

- Additional inherent and passive safety designs
- Reduced inventory of radioactive material
- Coolants or working fluids with improved thermochemical properties
- New and more robust forms of fuel, such as Tri-structural Isotropic, particles, molten salts, and metals
- Operating at reduced or atmospheric pressure
- Underground plant structures to limit operational and security risks

The U.S. Nuclear Regulatory Commission (NRC) provides strong independent regulatory oversight of operating and proposed nuclear power plants. Over the course of its existence, the NRC has protected the public interest and ensured that no member of the public has been harmed by the radiation from the operation of U.S. nuclear power plants. Today, the NRC is considering and evaluating the merits of numerous different advanced reactor designs as well as different approaches for their deployment. Over the previous several years, the NRC has educated its staff and developed a roadmap to prepare for the licensing and review of advanced reactor designs, drawing upon new and innovative methods of review. These efforts, as well as the strong independent track record of the NRC, will allow the safety cases for numerous advanced reactor concepts to be thoroughly and appropriately vetted, and are already doing so. Kairos Power, for example, received a safety determination for their molten salt, pebble bed reactor Hermes Test Reactor from NRC staff in record time. Additionally, the NRC completed a rulemaking introducing a methodology for reducing the Emergency Planning Zone requirements for advanced reactors, signaling to the public the expected safety of these new designs.

Figure 1: Example of TRISO fuel developed by advanced nuclear reactor companies USNC and X-energy

NUCLEAR INNOVATION ALLIANCE

Opportunities for a Coal-to-Nuclear Transition

by Victor Ibarra, Jr

Many communities across the U.S. rely heavily on aging coal facilities for electricity generation and as major sources of economic activity. Over the past 20 years, hundreds of coal facilities have shut down totaling around 100 gigawatts (GWs) of lost electric generation, leaving these coal communities susceptible to economic decline during the energy transition to zero-carbon emitting sources. These communities are looking for solutions that provide high-quality jobs and a reliable tax base as the nation seeks new sources of clean, reliable electricity.

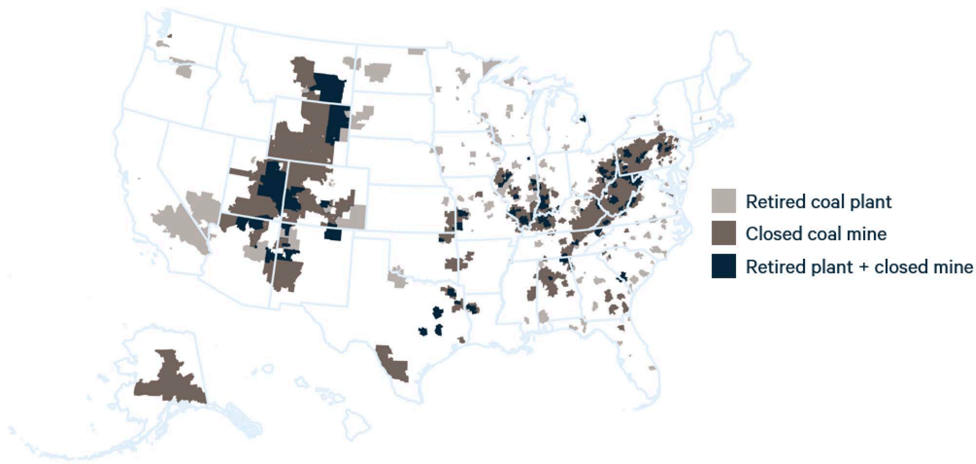


Figure 1: Retired coal facilities in the United States will affect communities nationwide. Source: RFF

A September 2022 U.S. Department of Energy report on coal-to-nuclear feasibility found that advanced nuclear energy could play a major role in communities with retiring coal facilities:

Advanced Nuclear Energy Can Repower the Grid

The DOE found that 80% of retired and operating coal power plant sites could host an advanced nuclear reactor, paving the way for 263.3 GWe of coal-to-nuclear replacement projects across the United States. Advanced nuclear is a zero-carbon, "always available" energy source that helps meet communities' energy needs and complements renewable energy

Advanced Nuclear Energy Can Repower Communities

A 924 MWe coal-to-nuclear conversion could increase regional economic activity by $275 million and add 650 new, high paying, permanent jobs to the region, many of which are traditional coal jobs that could transition to roles at an advanced reactor.

In August 2022, President Biden signed the Inflation Reduction Act of 2022 (IRA) providing an opportunity for coal communities to invest in advanced nuclear energy. Included in the advanced nuclear energy tax provisions in IRA were additional boosters for each type of tax credit if a clean energy project is located within an "energy community". Retired coal sites, as defined by IRA, are considered "energy communities" and are eligible for boosted tax credits for clean energy projects. Fully decarbonizing the U.S. power grid and producing zero-carbon fuels will require hundreds of GWs of new zero-carbon, "always available" energy. Repowering coal plants with advanced nuclear energy helps to achieve decarbonization while taking advantage of a local workforce with experience running energy facilities. For more information on coal-to-nuclear transitions, see NIA's report: **"Resources for Coal Repowering with Nuclear Energy".**

NUCLEAR INNOVATION ALLIANCE

Advanced Nuclear Energy Tax Provisions in the Inflation Reduction Act of 2022

by Victor Ibarra, Jr

On August 16, 2022, President Biden signed the Inflation Reduction Act (IRA), creating two new technology neutral tax credits for zero-emitting, clean energy projects: **a Clean Electricity Production Tax Credit (PTC) and a Clean Electricity Investment Tax Credit (ITC)**. The technology tax credits are intended to accelerate deployment of clean energy technologies, including advanced nuclear reactors. A project developer could elect either tax credit, but not both. Below is a summary of the two new tax credits that advanced nuclear energy projects can choose from:

Tax Provision	Value without satisfying wages and apprenticeship requirement	Value with satisfying wages and apprenticeship requirement	Additional booster(s)
Clean Electricity Production Credit (PTC)	0.5 cent/kWh*	2.5 cents/kWh*	10% domestic content bonus
			10% booster if project located within an energy community
Clean Electricity Investment Credit (ITC)	6% of initial capital cost	30% of initial capital cost	10 percentage point domestic content bonus
			10 percentage points if project is placed within an energy community

*The Clean Electricity Production Credit is adjusted for inflation every year and the values in this table are given in 2021 dollars

As shown above, the IRA encourages clean energy project developers to invest in workers and communities by boosting the tax credits for projects that pay prevailing wages, provide for apprenticeships, and/or are sited in energy communities (draft or final guidance for these provisions can be on the **Treasury's website**). Municipal power companies or tax-exempt cooperatives are eligible for "direct pay", which means they can receive a payment from the government in lieu of a tax credit. For private entities, the tax credits are transferable to any other taxpayer. To be eligible for either credit, projects must be placed in service after December 31st, 2024. This is an important improvement relative to the House-passed Build Back Better bill that tied eligibility to commencing construction after December 2026. The PTC would be available for electricity produced during a facility's first 10 years of operation. The credits begin to phase out for new facilities that commence construction after 2032, or when power sector greenhouse gas emissions decline by 75% relative to 2022 levels, whichever is later. Each credit would phase out over a three-year period - 75% of the initial value after 2032, 50% of the initial value after 2033, and then 0% after 2034.

Another important incentive in the IRA is a "Clean Hydrogen" Production Tax Credit. Hydrogen produced from nuclear power plants will be eligible for the tax credit. The Hydrogen PTC base value is $0.60/kg, rising to $3.00/kg of clean hydrogen produced for projects that pay prevailing wages, provide for apprenticeships, and/or are sited in energy communities.

For more information on the impact of the new Inflation Reduction Act clean electricity tax credits on new nuclear energy projects, please see NIA's newest report, **"Implications of Inflation Reduction Act Tax Credits for Advanced Nuclear Energy".**

HALEU Provisions in the Inflation Reduction Act of 2022

by Victor Ibarra, Jr

On August 16, 2022, President Biden signed the Inflation Reduction Act, providing $700M to support High Assay, Low Enriched Uranium (HALEU) fuel availability for advanced nuclear reactors. The purpose of the funding is to catalyze commercial supply chains for HALEU fuels and enable the operation of next generation reactors expected in the mid-2020s.

One challenge facing the deployment of advanced nuclear energy is that some reactor technologies require nuclear fuels with higher uranium enrichment levels. Most operating commercial nuclear reactors use uranium fuels enriched with the uranium isotope U-235. Reactors in the United States currently use fuels enriched to 3-5% U-235. Many advanced reactors will also use 3-5% enriched uranium for fuel, but some designs will require fuel enrichments of up to 20% U-235. There is currently no commercial infrastructure in the United States to produce these higher uranium enrichments for HALEU fuels for advanced reactors.

Creating a commercially viable HALEU fuel cycle is critical to the successful deployment of many advanced reactor technologies. The only current commercial supplier of HALEU globally is TENEX, a Russian state-owned company. Developing domestic supply chains for HALEU is important for both enabling deployment of advanced nuclear energy as a climate solution and providing energy security for the United States and its allies.

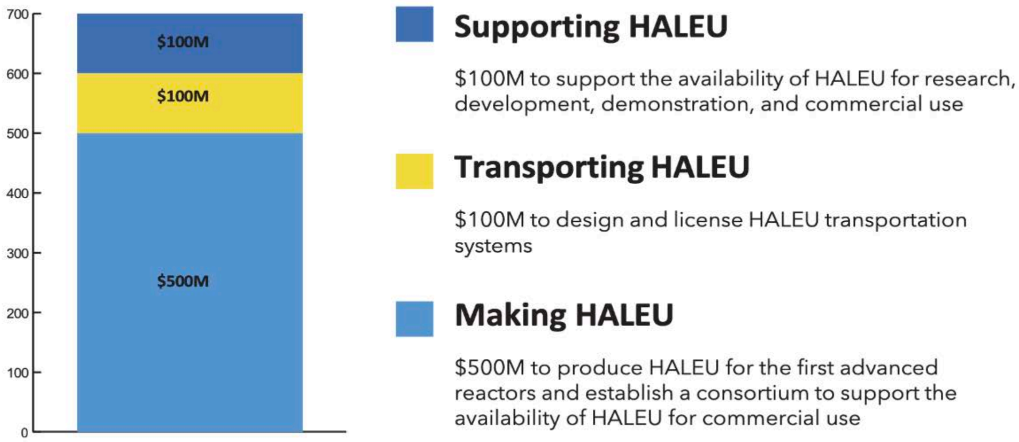


Figure 1: HALEU Provisions in the IRA

The $700M designated for HALEU availability is a major investment in new HALEU infrastructure critical for advanced nuclear energy. Continued congressional support is vital to catalyzing a sustainable commercial HALEU market and meeting the mid-term and long-term supply needs of advanced reactors. A reliable commercial fuel cycle for advanced nuclear reactors is necessary for the successful deployment of advanced reactors, increasing the likelihood and lowering the costs of achieving the world's climate goals.

For more information on how policymakers can support near-, mid-, and long-term solutions for HALEU availability, read the report, **"Catalyzing a Domestic Commercial Market for High-Assay, Low-Enriched Uranium (HALEU)",** published by the NIA in April 2022, which describes the challenges and opportunities associated with development of a domestic commercial HALEU market and identifies potential policy options that can be used to catalyze market development. Also, read the NIA 2-pager **"Additional Flexible Funding is Needed to Break Dependence on Russian Nuclear Fuel"**, published by NIA in June 2023, which highlights the need for an additional one-time appropriation of $2.1 to $3.5 billion to catalyze new domestic LEU and HALEU production and break our dependence on Russian nuclear fuels.

The Role of Nuclear Energy in a Hydrogen Future

by Victor Ibarra, Jr

Hydrogen promises to be a versatile tool that can help us achieve a zero-carbon future and is at the center of energy discussions across many economic sectors. It already plays an important role in our economy, but over 95% is produced by steam-methane reforming, which emits greenhouse gases (GHGs).

	Transportation Applications	Chemicals and Industrial Applications	Stationary and Power Generation Applications	Integrated/Hybrid Energy Systems
Existing Growing Demands	• Material-Handling Equipment • Buses • Light-Duty Vehicles	• Oil Refining • Ammonia • Methanol	• Distrubuted Generation: Primary and Backup Power	• Renewable Grid Integration (with storage and other ancillary services)
Emerging Future Demands	• Medium-and Heavy-Duty Vehicles • Rail • Maritime • Aviation • Contruction Equipment	• Steel and Cement Manufacturing • Industrial Heat • Bio/Synthetic Fuels	• Reversible Fuel Cells • Hydrogen Combustion • Long-Duration Energy Storage	• Nuclear/Hydrogen Hybrids • Gas/Coal/Hydrogen Hybrids with CCUS • Hydrogen Blending

Figure 1: Existing & Emerging Demands for Hydrogen, Source: U.S. Department of Energy Hydrogen Plan (2020) Note: CCUS refers to Carbon Capture, Utilization, and Storage

Hydrogen consumption is **expected to grow** from 90 Mt in 2020, to over 500 Mt by 2050 worldwide. While other non-carbon emitting sources can produce hydrogen through water electrolysis, hydrogen can also be produced by conventional and advanced nuclear reactors using low and high-temperature electrolysis (LTE and HTSE) methods. Due to **nuclear energy's unique characteristics**, like its high-operating capacity factor and low land requirement, nuclear energy can produce hydrogen more efficiently and at a rate that can help meet the global demand of the future. There are several DOE sponsored projects under construction or operation to show the advantage of producing hydrogen from nuclear energy in different ways. DOE's nuclear-hydrogen demonstration projects include:

- **Constellation will host a 1 MWe LTE demo at Nine Mile Point (NY) in 2023**
- **Energy Harbor will host a 1-2 MWe LTE demo at Davis Besse (OH) in 2023**
- **Xcel Energy will host a <1MWe HTSE demo at Prairie Island (MN) by 2024**

Other recent Federal Investment in developing nuclear-hydrogen projects include provisions in the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA):

IIJA: $8 billion for hydrogen hubs, including a dedicated nuclear-hydrogen demo hub

IRA: A ten-year Hydrogen PTC, with direct pay for the first five years

To achieve decarbonization across all economies, we will have to use every tool at our disposal, including hydrogen produced from conventional and advanced nuclear reactors.