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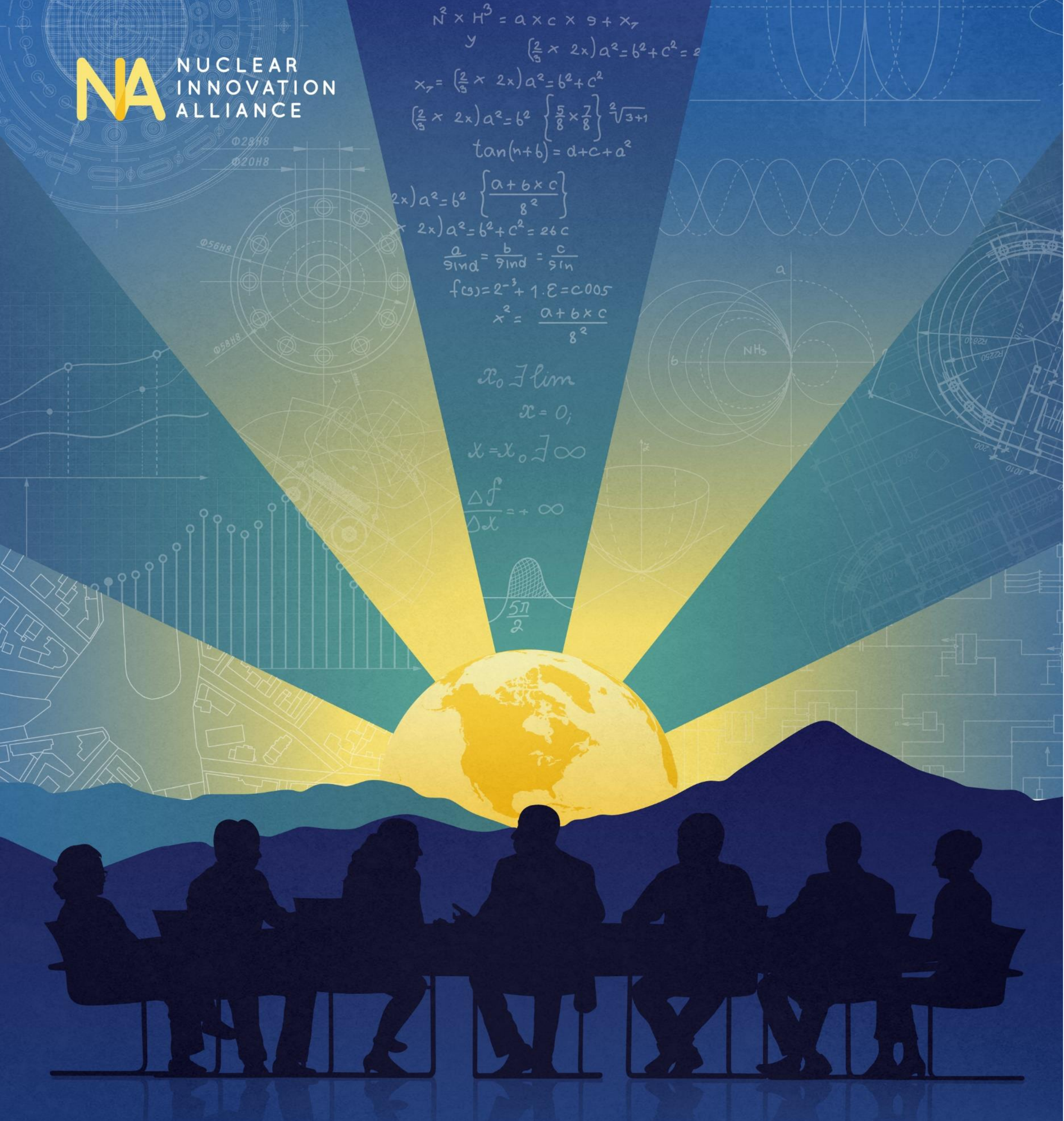

Advanced Reactors for State Policymakers, In Brief

October 2021

Advanced Reactors for State Policymakers, in Brief

Unlocking Advanced Nuclear Innovation: The Role of Fee Reform and Public Investment

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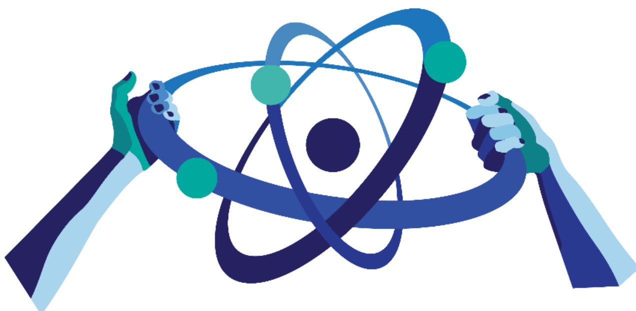

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Disclaimer:

The views expressed herein are those of the author(s) and the Nuclear Innovation Alliance.

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This report is available online at:

https://www.nuclearinnovationalliance.org/advanced-reactors-for-state-policymakers

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Executive Summary

This Brief serves as an introduction to advanced nuclear energy technologies and policies for state-level policymakers and 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 to medium-size reactors that can power cities and industry, advanced nuclear reactors promise clean energy that is reliable, safe, and can contribute to state-level economic, energy, and environmental goals. The first part of this Brief describes advanced reactor technology and its benefits, provides an overview of enabling federal policies, and reviews state options to incentivize local development of advanced reactors. The second part of the Brief provides case studies of emerging state leaders in these technologies:

- The Natrium project in Wyoming;
- Energy Northwest's plans in Washington state;
- Utah Associated Municipal Power Systems' consortium for the first light water small modular reactor, and;
- the Nuclear Alternative Project in Puerto Rico.

These are all entities that may not ordinarily have considered nuclear power initially. However, they have all done so because of the role of advanced nuclear technology 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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Advanced Nuclear Reactors and Associated Policies:

The Case for Advanced Nuclear Energy

- **The next generation of nuclear energy can greatly contribute to state, national, and global carbon reductions in power and other sectors**
- **Advanced nuclear energy protects human health by reducing air pollution while supporting local economic growth with high-paying construction and operations jobs**
- **American companies are leading nuclear technology innovation through research, development, and demonstration projects in partnership with the federal government and local utilities**
- **State and Federal support, regulatory reform, and cost competitiveness are necessary to fully unlock the climate mitigation potential of advanced reactors**
- **As utilities retire fossil fuel-fired plants and replace them with variable renewable resources – such as wind and solar – the electric system must maintain reliability and resilience. Advanced reactors enable this by integrating with renewable resources and maintaining a diversified grid.**

Overview

Advanced nuclear energy is a climate and clean energy solution to meet net-zero emissions goals. Existing nuclear energy supplies 10% of global electricity and 20% of U.S. electricity. In the United States, existing nuclear power plants provide as much carbon-free electricity as wind, solar, and hydro power combined. In addition to providing clean electricity, advanced reactors can also decarbonize non-electric sectors by providing district or industrial heating, producing hydrogen, and desalinating water. Together with renewable energy and other carbon-free energy sources, nuclear power can enable the U.S. to reach 100% clean energy by 2050. Because nuclear power is both highly reliable and carbon-free, studies show that investment in nuclear energy deployment substantially increases the likelihood of achieving mid-century climate goals and reduces the overall cost. Nuclear power also saves lives by reducing air pollution. A 2013 study co-authored by noted climate scientist James Hansen found that nuclear power prevented almost 2 million deaths between 1971 and 2009, and projected nuclear power would save as many as 7 million lives by mid-century.

However, despite these past and prospective benefits, the United States stopped building plants for decades and has lost the expertise in building nuclear reactors. Industry stagnation has led to the high costs associated with building conventional nuclear technology, with few new nuclear plants built in recent years. With the right policy and financial incentives at both the state and federal level, advanced reactors can catalyze a resurgence of new nuclear power and play a major role in decarbonizing state energy markets.

Among many advantages, advanced reactors feature innovations that reduce costs, improve safety, and mitigate spent fuel concerns. Nuclear innovators are pursuing multiple strategies to create new designs that make the next generation of reactors even better. By reducing the size of reactors, developers can lower absolute upfront capital costs, shorten construction timelines, offer options to smaller communities, and decrease financing uncertainty. With shorter construction timelines, developers can achieve accelerated innovation cycles and continuous technological learning to reduce costs, much like what wind and solar power have achieved. Smaller reactors, less nuclear material, and the use of inherent safety features mean that advanced reactors promise to improve upon the remarkable safety record of conventional reactors. Finally, reactor and fuel cycle innovations can improve fuel efficiency or even recycle used fuel, lowering the spent fuel inventories that require long-term geological storage.

Advanced nuclear technologies can bring substantial economic benefits, including regional income from exports. Currently, the U.S. nuclear power industry supports half a million employees with salaries that are 30% higher than local averages. In addition to higher salaries, nuclear employers provide large employment opportunities for veterans and have higher rates of union labor. First-of-a-kind demonstration projects 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. Internationally, according to the U.S. Department of Commerce, without policy incentives and additional investment, domestic nuclear developers and suppliers will miss out on a $740 billion industry over the next 10 years. U.S.-developed advanced reactor designs can be competitive in global markets, growing U.S. exports and bringing domestic jobs

Government and industry activities are accelerating innovation. Bipartisan legislation has provided a foundation for federal research and development activities, and is catalyzing long-term regulatory modernization. Recently, the U.S. Department of Energy initiated the Advanced Reactor Demonstration Program (ARDP) to fund public-private partnerships for first-of-a-kind commercial demonstrations and other industry activities. Through a 50-50 cost-share, companies like TerraPower and X-energy will receive government funding up to $3.2 billion over seven years to build and operate their innovative advanced reactors by late 2020.

More action is needed to fully unlock the economic and environmental potential of next generation nuclear energy, including continued regulatory modernization, increasing resources for commercialization, and the reduction of barriers to innovation. Along with industry and NGO partners and other stakeholders, groups like the Nuclear Innovation Alliance work to enhance the prospects of advanced reactors substantially contributing to carbon reductions. A comprehensive strategy developed by NIA and the Partnership for Global Security identifies actions the U.S. must take in order to establish advanced reactor leadership, including opportunities for state leadership.

Advanced Reactors in State-level Climate and Energy Policies

Summary:

- Climate and energy policies at the state level can introduce and advance zero-carbon technology efficiently and cost-effectively
- Advanced reactors help states and communities achieve their greenhouse gas reduction goals as well as their economic development targets by providing flexible, reliable, zero-carbon energy

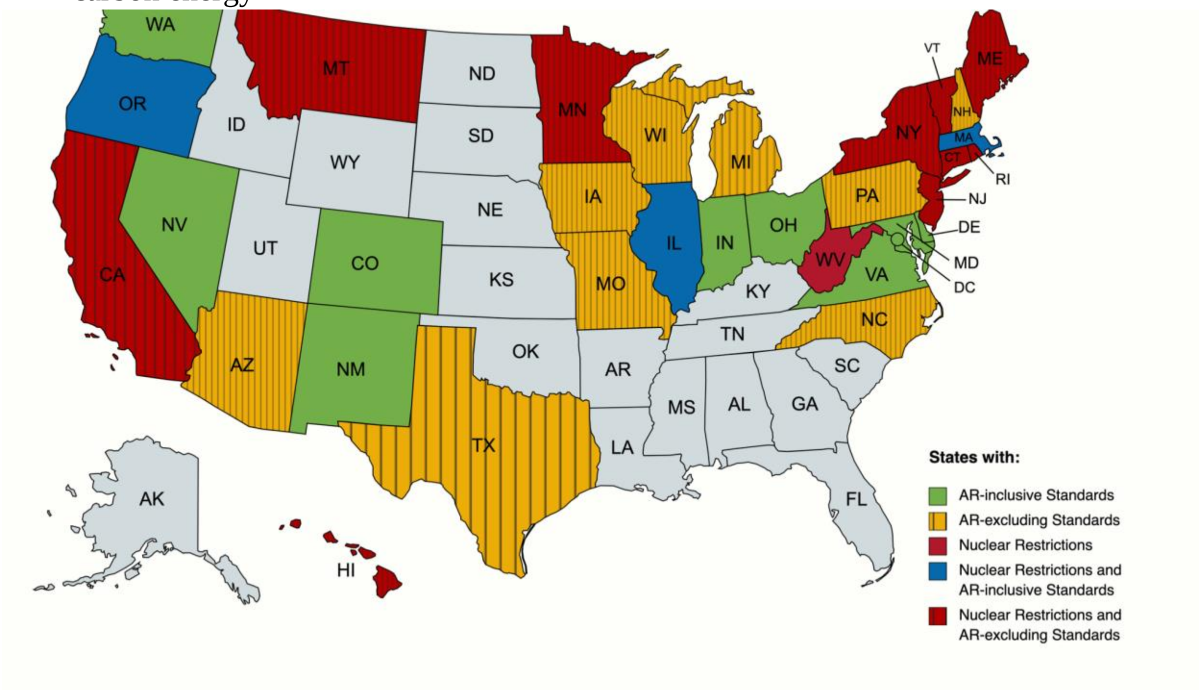

Figure 1: State Energy Standards. Advanced Reactors, and Nuclear restrictions

States are the laboratories of democracy; early movers in launching advanced nuclear reactor projects will enjoy especially large economic and environmental benefits. Advanced reactors are fundamentally different from conventional nuclear power. They are generally smaller and quicker to build, enabling nuclear power as an energy option for rural communities, municipal utilities, and industrial users for the first time. They are scalable, meeting the needs of customers from small universities to 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-power sectors. Advanced reactors feature improved safety and fuel performance, expanding siting opportunities.

This 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. Considering the potential of nuclear innovation to meet state energy and environmental goals, state policymakers wishing to promote advanced reactors should consider:

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- **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 benefits of nuclear innovation and build state-level consensus. Advanced reactors can help states achieve their economic and environmental goals while guaranteeing a high level of safety performance and minimal waste production. There are many resources, such as this Brief, that state policymakers can use to better understand advanced reactor technologies and to share with colleagues.
- **Including advanced reactors in state decarbonization requirements or Clean Energy Standards.** Many states successfully implemented renewable portfolio standards or goals to establish renewable energy industries in their states. Looking forward, states are now implementing 100% carbon-free generation requirements or other types of Clean Energy Standards. Some of these are technology-inclusive and could incentivize 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 Clean Energy Standards 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.** Nuclear innovation is centered on "high technology." Successful deployment of an advanced reactor requires 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 projects will build innovation hubs centered on 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 January 2021, 14 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.** State governments and regulated utilities are responsible for ensuring reliable, economic electricity supply to serve customers. Formal and informal planning processes are central to this mission. State governors, regulatory commissions, and utilities can better achieve these goals by including advanced reactors in these plans, especially utility Integrated Resource Plans.

Enacting other state-level incentives, such as tax credits, as appropriate. When states first looked to adopt wind and solar power, they employed a number of tools to establish first movers in the emerging industries. Many of those tools can also be used for microreactors and small modular reactors. Given the smaller sizes of advanced reactors, states can consider direct procurement of advanced nuclear energy for the first time, helping meet state government clean energy goals. Other potential options include feed-in tariffs, tax incentives, grants, customer surcharge accounts, advanced cost recovery, loan guarantees, and pricing carbon. For more details, please see section 5 of this report from the Maryland Department of Natural Resources.

Federal Nuclear Innovation Activities

Summary

- There is substantial, bipartisan, and sustained support for advanced reactor technology innovation at the federal level
- The Nuclear Regulatory Commission is embarking on ambitious regulatory modernization to facilitate 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 state and local communities

Overview

Nuclear power is the United States' largest source 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:

- **The 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 to speed up 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 level.
- **The Energy Act of 2020.** In addition to other programs, this law authorizes the Advanced Reactor Demonstration Program, which funds ten companies to work with the U.S. Department of Energy to demonstrate their advanced reactor technology.

These bills provide a basis for nuclear innovation, and Congress is working on additional bipartisan legislation to address fuel availability, accelerate commercialization of microreactors, establish tax credits equivalent to other zero carbon technologies, 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.

Case Studies:

Repowering Wyoming Communities with an Advanced Reactor

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 Pacific Corp announced that they will be demonstrating the Natrium project, a sodium cooled fast reactor with a moltage salt system, at a retiring coal plant site in Wyoming. Supported by federal funding in 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 analyze how feasible it is to repurpose existing coal plant infrastructure with nuclear systems. Analysis shows that many of the functions needed for a new nuclear plant can be matched by systems in a coal plant. This includes the fossil-powered turbines used to produce the electricity, the transmission lines used to distribute electricity to homes nearby, and even comparable roles and jobs to operate the power plant.

Wyoming's willingness to host Terrapower's demonstration project also reflects local community interest in advanced nuclear energy. The candidate host communities welcome the project. The nuclear plant would have a positive impact by keeping local energy jobs by retaining previous coal plant workers and bringing in new jobs, stimulating their communities' economies. Bruce Roumell, mayor of Glenrock, a potential site where the project may be built, was "glad to see they're looking to do something to keep our economy going, instead of just shutting the plants down and letting them mothball."[1] Community colleges are on board too. Carter-King and Rock Springs Mayor Tim Kaumo said local community colleges would be able to retrain coal workers to make the transition to advanced nuclear power easier for locals.

Transitioning to a carbon-free future is necessary to mitigate climate change, but it should not occur at the expense of local communities. Projects like Natrium in Wyoming demonstrate that energy innovation can support communities during the transition.

[1] See: https://trib.com/business/energy/wyoming-towns-eager-to-host-next-generation-nuclear-reactor/article_f73e3b4d-032f-5727-87a7-88bb3e23d890.html

Utah Associated Municipal Power Systems

The Utah Associated Municipal Power Systems (UAMPS) is planning to build the Carbon Free Power Project (CFPP) using the small modular reactor designed by NuScale Power. Set for completion by the end of this decade, this project will serve as a catalyst for advanced reactor deployment and will provide key insight into the economic viability and public demand for deep decarbonization through advanced nuclear energy.

UAMPS is a public power consortium of community-owned power systems throughout the western United States. UAMPS member utilities are located in Utah, California, Idaho, Nevada, New Mexico, and Wyoming. Many of them rely heavily on aging coal facilities and are looking at options to develop or buy clean energy to meet their future energy needs.

In 2015, UAMPS introduced the CFPP, an initiative to reduce carbon emissions in their portfolio by phasing out aging fossil fuel capacity and replacing it with nuclear power. The CFPP features a small modular reactor (SMR) at the Idaho National Laboratory (INL) site near Idaho Falls, Idaho. The NuScale SMR design, a series of 77-megawatt light-water nuclear power modules grouped in 4-pack, 6-pack, 8-pack, or 12-pack module configurations, was selected for the project.

Shortly after the CFPP was introduced in 2015, the U.S. Department of Energy (DOE) awarded NuScale $16.6 million in cost-shared funding for the preparation of a combined license application with UAMPS. In 2016, DOE issued a site use permit to UAMPS which allowed UAMPS to identify and select its preferred site at the INL. The final site was selected in 2019 after careful study, environmental review, and cost analysis. In October 2020, DOE approved a $1.355 billion multi-year cost-share award to UAMPS to fund construction of the CFPP.

The CFPP is structured to support community collaboration, with UAMPS participating members able to vote to stay in or exit the project any time there is a budget amendment or cost update. After several of these votes since 2015, the project continues to have sufficient buy-in to distribute and de-risk the cost of siting and constructing this first-of-a-kind reactor concept. This is indication that many public power utilities recognize the economic and environmental value of incorporating advanced nuclear energy into their electric generation mix.

During the 2020s, the CFPP is expected to bring significant economic benefits to the region. The project will create an estimated 1,600 jobs in the Idaho Falls area over the construction period. Through indirect and induced economic effects, the plant will also bring an additional 667 jobs to the region over its estimated lifetime. It is estimated that labor income in the region will increase by nearly $48 million and regional economic output will increase by $81 million, adding nearly $3 million to local and state tax revenues. The economic potential of the CFPP has led to overwhelming support from state policymakers in Idaho. In 2018, the Idaho legislature passed bills that would provide tax incentives for the deployment of advanced nuclear reactors in the state, further signaling the state's commitment to the project and potentially other advanced nuclear reactor projects.

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Washington State's First of a Kind Initiative

The state of Washington's commitment to cutting greenhouse gas emissions was cemented when Governor Jay Inslee signed the Clean Energy Transformation Act in 2019. The law applies to all electric utilities serving retail customers and sets specific milestones to reach a 100% clean electric supply by 2045 using renewable or non-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 very deep electric emission reductions at manageable costs, provided firm generating capacity is available. Using data from NuScale Power and the National Renewable Energy Laboratory, the study found the use of advanced reactor technologies could competitively help achieve a zero-emissions energy portfolio.

To meet its future energy needs, Energy Northwest, which provides at-cost power to public utilities across the northwest, began exploring options to develop advanced reactor projects. Considering Energy Northwest's experience with nuclear power, it is in an excellent position to launch a new generation of nuclear energy.

In late 2020, the U.S. Department of Energy (DOE) made two awards to X-Energy and TerraPower under the Advanced Reactor Demonstration Program to build two advanced nuclear reactors that will be operational within seven years. Under the agreement, DOE will invest a total of $3.2 billion over seven years for TerraPower and X-energy to demonstrate their advanced reactor designs. TerraPower's Natrium technology, a sodium-cooled fast reactor coupled with a molten salt energy storage system will demonstrate nuclear load-following capabilities (See Wyoming Case Study). X-energy's Xe-100 advanced reactor, a high temperature gas-cooled reactor, will demonstrate Tri-structural Isotropic fuel technology and jump-start fuel cycle investments. Under the ARDP agreement, Energy Northwest will serve as a utility partner for both of these projects and will also provide licensing assistance for both designs. Energy Northwest will also provide operating experience to the TerraPower-GE Hitachi team.

In April 2021, X-energy, the Grant County Public Utility District (Grant PUD), and Energy Northwest announced their partnership to evaluate, develop, and build four Xe-100 reactors, at the Columbia Generating Station in Washington state, adding an additional generation station with 320 megawatts of zero-emission electricity to Grant PUD's and Energy Northwest's portfolio. The announcement signals one of the first modern commercial advanced reactor designs that will be built in the United States and is described as a "game-changer" by Congressman Dan Newhouse (R-WA). This TRi Energy Partnership, as it's referred to, signals the success of cost-sharing and public-private partnerships programs, like the ARDP, in developing advanced reactor technology.

Nuclear Power for Puerto Rico

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." They found many socio-economic motivations to pursue advanced nuclear technology. 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 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 Department of Defense explores advanced nuclear energy technologies, states and territories are well positioned to support these mission-critical energy projects.

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Topical Briefs:

Economics of Advanced Nuclear Energy

Summary

- Nuclear energy is an economically viable energy source essential to deep decarbonization.
- Advanced nuclear reactor designs promise to lower capital costs and reduce investor risks associated with construction.
- Once built, nuclear reactors are low cost to operate and maintain.
- Commercial nuclear plants provide high-paying union jobs, bring investment, support the local taxbase, and stimulate local economies.

Overview

Nuclear energy continues to be an economically competitive energy source that can help meet deep decarbonization goals. Once built, nuclear reactors have nearly constant operating and fuel costs, can support local economies, and produce carbon-free reliable electricity at stable prices. Nuclear reactors, however, are conventionally considered construction mega-projects that are prone to cost and time overruns due to their size and complexity. Construction cost overrun risks have stymied growth in conventional nuclear energy development despite increasing demands for clean energy.

In response to these economic pressures, developers are pursuing advanced reactor (AR) designs that minimize construction costs and maximize cost competitiveness. AR designs feature smaller physical footprints, reduced capital investment, and less construction complexity. This enables faster construction, which can provide scalable, incremental power additions to meet energy demand as needed. ARs may also be designed with limited water requirements and elimination of the need for off-site emergency evacuation requirements, opening up deployment at sites not possible for larger, conventional nuclear reactors. Further, smaller designs like microreactors can unlock new customer types and enable decarbonization of high-cost, carbon-intensive remote grids. These factors together reduce overall capital costs and investor risk, making advanced reactors attractive assets for utilities and companies seeking low-cost clean energy.

Beyond competitively priced power, nuclear energy brings significant economic benefits to states and local communities. Nuclear jobs have the highest median hourly wages of the ten energy industries and a high rate of hiring military veterans. Compared to median energy wages that hover around $25 an hour, nuclear power can boast a median $39.19 hourly wage and a high rate of unionization, providing additional benefits to workers. 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 development and maintenance. Construction of new nuclear power plants also benefits local and regional suppliers of design, engineering, procurement, construction and consulting services to billion dollar nuclear projects.

Finally, advanced reactors have the new potential to supply low-cost energy for markets outside of just electricity production. Researchers are currently examining the feasibility of using advanced nuclear reactors for multiple purposes. Advanced reactors can play a significant role and are already expected to produce hydrogen, clean water, and chemicals, and to be used in other industrial applications requiring high-temperature heat and steam. These systems can also couple nuclear reactors with renewable energy—a combination that will further increase economic competitiveness, job creation and grid reliability.

For more information, please visit: https://nuclearinnovationalliance.org/economics

Flexibility of Advanced Nuclear Reactors

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 weather.
- Advanced reactors are well suited to provide flexible and resilient electricity supply in these future grids using a variety of strategies.
- Some of these flexible strategies, such as hydrogen production or desalination, can help decarbonize other energy-intensive economic sectors.

Overview

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 variation in demand throughout the day. As the share of variable renewable energy sources continues to grow, the rest of the electric grid must feature increased flexibility to economically balance load while maintaining reliability. As states grapple with how to balance variable renewables, advanced reactor developers can offer multiple solutions to provide increased flexibility to electricity markets.

A common misconception about conventional nuclear reactors is that they are not designed to load-follow. Existing reactors, like Westinghouse's Pressurized Water Reactor (PWR) designs, can perform both frequency control and load following but do not do so in the United States because it is more profitable to operate continuously at full power (i.e., as a baseload electricity resource). Reactors in other countries, like France, flexibly dispatch nuclear units to balance the grid. In the French electricity transmission network, nuclear power plants operating in the load-following mode can change power output from 100 to 30% in half an hour, and also support unplanned load-following techniques in the case of an emergency.

Advanced reactor designers are pursuing multiple strategies to expand these technical capabilities and incorporate operational flexibility into their designs:

- TerraPower's Natrium reactor is a sodium-cooled fast reactor paired with a molten salt energy storage system that will allow the power plant to produce an average of 345 megawatts and ramp up to a maximum of 500 megawatts for 5.5 hours to balance the grid
- Some designs, like NuScale's Power Module, consist of multiple units that can be managed separately or rapidly vary reactor power to meet fluctuating supply or demand
- Other advanced reactors, such as X-energy's Xe-100 reactor, are designed to integrate process heat, hydrogen production, desalination, or other types of coproducts to enable flexible dispatch of energy and electricity

Beyond flexible dispatch, advanced reactors can also enhance grid reliability and resilience. Black-start capabilities enable restart of the grid in the event of a significant blackout. Many advanced reactors do not require large amounts of water for cooling and are thus more resilient to drought and heat waves. Finally, advanced reactors have high fuel efficiency and long refueling timelines, limiting the impact of fuel supply disruptions on their operations. Advanced reactors with continuous on-line fueling and on-site fuel storage can deliver capacity factors near 100%, further improving on nuclear power's status as America's most reliable energy source.

Timing of Advanced Nuclear Reactor Commercialization

Summary

- Multiple advanced reactor developers are planning demonstration projects in the 2020s and are looking for commercial customers and host states now.
- Reactors built in the mid-2020s provide the basis for rapid commercial expansion in the late 2020s and early 2030s.
- Utilities and states that are early adopters of advanced reactors will accrue significant, growing economic benefits as the sector expands.

Overview

Globally, dozens of advanced reactors are in late stages of development. Domestically, several designs are entering licensing to construct and operate commercially:

- Oklo's Aurora powerhouse microreactor, to be sited at Idaho National Laboratory.
- NuScale's SMR, slated to supply Utah Associated Municipal Power Systems.
- X-energy's Xe-100, likely to be sited in Richland, Washington for Energy Northwest and Grant PUD.
- TerraPower's Natrium design, which would replace a retiring coal plant in Wyoming.

Additionally, several companies are planning pilot, test, or research reactors (in Illinois and Tennessee) and the federal government is investigating procurement of microreactors.

There are emerging opportunities for states to become early leaders in advanced nuclear energy. Companies are now identifying utility and other customers for first-of-a-kind (FOAK) projects, and supportive state policy environments are a critical factor in siting decisions. The exact deployment timelines for advanced reactors will depend on licensing schedules and the size of reactor designs, but the first microreactor projects are expected to begin operations in the mid-2020s, with larger projects coming online beginning in the late 2020s.

Successful operation of early pilot and demonstration projects will provide utilities and states with new commercial options for the deployment of advanced reactors. While these projects will not be completed until later in the decade, these early movers and other reactor developers will be looking for customers over the next several years. The long lead times associated with reactor licensing and construction mean that commercial decisions that occur before 2025 will be critical to the successful deployment and commercial operation of advanced reactors in the late 2020s and early 2030s. These timelines are consistent with state and national clean energy goals, not only for the power sector but also for non-power sectors such as hydrogen production and industrial heating.

Lessons learned from 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. At the state level, early projects create innovation hubs, combining skilled workers, local universities, company experience, and state policy, that lead to state leadership in advanced reactors and substantial economic benefits.

Safety of Advanced Nuclear Energy

Summary

- Advanced reactors build on the nuclear industry's modern record of safety with features that further reduce accident risks, including inherent safety and reduced use of materials.
- Nuclear energy is overseen by independent nuclear regulators. The U.S. Nuclear Regulatory Commission 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 safety of nuclear energy, nuclear energy remains one of the safest forms of energy production available globally. One study estimated global nuclear energy production has historically prevented at least 1.75 million deaths related to air pollution and could prevent an additional 7 million more.

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

- Inherent cooling technologies
- 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. The widespread deployment of advanced reactors will only occur for designs that receive regulatory approval. The safety-focused licensing process will ensure that nuclear power of the future is as safe as possible, enabling wide use to mitigate climate change.

For more information, please visit: https://nuclearinnovationalliance.org/safety

NUCLEAR INNOVATION ALLIANCE

Spent Fuel Management and Advanced Reactors

Summary

- Existing spent nuclear fuel is currently stored safely at reactor sites across the U.S.
- Eventually there will need to be a permanent repository for spent nuclear fuel, which some countries are starting to develop.
- Advanced reactors are being designed to minimize waste through greater fuel efficiency or recycling, reducing spent fuel volumes requiring permanent storage.

Overview

Since the nuclear industry emerged over half a century ago, management of spent fuel has been conducted safely. Following decades of operations, around 84,000 tonnes of commercial spent nuclear fuel is currently stored at nuclear power plants in the U.S. Comparably, coal plants produce almost 100 million tonnes annually of just coal ash. Even as the waste debate continues in the U.S., no member of the public has ever been harmed by commercial the used nuclear fuel stored in 35 states. Globally, Finland is currently constructing a long-term storage facility for used commercial nuclear fuel and Sweden is planning one. Countries have also built and are operating disposal facilities for less radioactive commercial and defense waste streams. As advanced reactor developers design the next generation of nuclear energy power plants, they are implementing innovations that can mitigate spent fuel challenges.

Today, numerous proven methods for the handling of used commercial nuclear fuel are in practice all over the world or are being pursued. These methods include:

- **Short-term storage**: The dominant method for addressing spent fuel is storing it at the reactor site after use, first in a spent fuel pool and then in dry casks. The U.S. has 34 states with at least one spent fuel storage installation with dry storage.
- **Interim storage**: The U.S. Nuclear Regulatory Commission (NRC) is considering two license applications for a Consolidated Interim Storage Facility (CISF).
- **Fuel recycling**: While the United States does not currently pursue reprocessing due to proliferation concerns, other countries have successfully closed the fuel cycle, and innovative approaches to fuel recycling can reduce proliferation concerns.
- **Long-term isolation**: Eventually, some portion of spent nuclear fuel will need to be stored permanently in geological repositories. While Finland and Sweden are moving to establish the first commercial high-level repositories with consent-based solutions, U.S. progress focused on Yucca Mountain has stalled. Private companies, like Deep Isolation, are also exploring innovative methods to dispose of used nuclear fuel.

Advanced reactors offer opportunities to change the conversation about nuclear waste and potentially new pathways for disposal. Numerous advanced reactor designs being pursued by U.S. developers could eventually run on fuel recycled from existing stockpiles using innovative methods. Additionally, advanced reactor designs generally offer greater efficiency and better utilization of nuclear fuel, reducing the rate at which waste is generated per unit of nuclear energy produced. Decreased waste yields from advanced reactors would limit growth in spent fuel stockpiles, easing the management of expanded use of nuclear technology.

For more information, please visit: https://nuclearinnovationalliance.org/fuel-cycle

Conclusion

Deep decarbonization models show that without investing in firm generation sources like advanced nuclear energy the road to a zero-carbon electricity sector by 2035 and a zero-carbon economy by 2050 will be more difficult and more expensive. Local communities and state policymakers have already taken notice and have begun to invest their time and effort in including advanced nuclear energy in their energy portfolios. State legislatures have passed tax credits to spur advanced nuclear deployment and have also lifted moratoria in order to entice advanced nuclear projects to come to their state. Advanced nuclear energy is flexible, safe, and economical, but more effort, both at the state and federal level, are required to unlock its full potential.

List of Resources

Nuclear Innovation Alliance

Gateway for Accelerated Innovation in Nuclear

National Reactor Innovation Center

Nuclear Regulatory Commission

Advanced Reactor Demonstration Program

MIT: *The Future of Nuclear Energy in a Carbon-Constrained World*