REPORT

# Nuclear Power and the Clean Energy Transition

BY DANIEL SHEA

## What Role Will Nuclear Play in the Clean Energy Transition?

Nuclear power has served for decades as the backbone of carbon-free electricity in the United States.

Twenty years ago, nuclear power accounted for more than 70% of carbon-free electricity, with the balance consisting largely of hydropower. In the ensuing years, state and federal policies to decarbonize electricity generation have prioritized the development of renewable wind and solar resources, bringing significant new carbon-free capacity to the grid.

Nuclear power still represents nearly half of all carbon-free electricity in the U.S. Its reduced share is not solely the result of new renewable projects coming online, but also the premature closure of existing nuclear power plants and a limited amount of added nuclear capacity.

However, there are signs the tide may be shifting in favor of a resurgent nuclear industry. Decarbonization has become a widely accepted public policy priority—one that is not only favored by a clear majority of Americans, but that is also being implemented by the U.S. electric utility sector even in the absence of policy mandates. And while public opinion on nuclear power remains complicated, there are indications that support may be growing.

As states begin to chart their course to a clean energy future, a handful have started to reckon with the role—if any—that nuclear power will play in the transition. While some states have firmly ruled out nuclear, others have enacted policies to support existing nuclear power plants and establish pathways to develop next generation nuclear reactors. Still, nearly a dozen states haven't taken a definitive stance—opting to simply open the door to clean energy technologies wide enough to accommodate nuclear and an array of other carbon-free resources that meet their policy goals.

The issue is likely to find its way into state policy discussions over the coming years, with recently enacted federal policies potentially changing the dynamics around new nuclear. Financing new nuclear projects has been a major impediment to development, but provisions in the Inflation Reduction Act could neutralize those long-standing barriers. Ultimately, states will have a critical voice in whether new nuclear projects move forward and to what degree nuclear power will contribute to the clean energy transition.

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# Overview of Nuclear Power

Commercial nuclear reactors employ nuclear fission to produce heat, which is used to create steam to spin turbines that generate electricity. Conceptually, it's not dissimilar to other thermoelectric generating resources, like coal-fired power plants, aside from their emissions profiles. Coal and nuclear have served for decades as "baseload resources"—the generators that delivered steady, around-the-clock electricity to serve the bulk of power demand and provide the backbone for grid reliability.

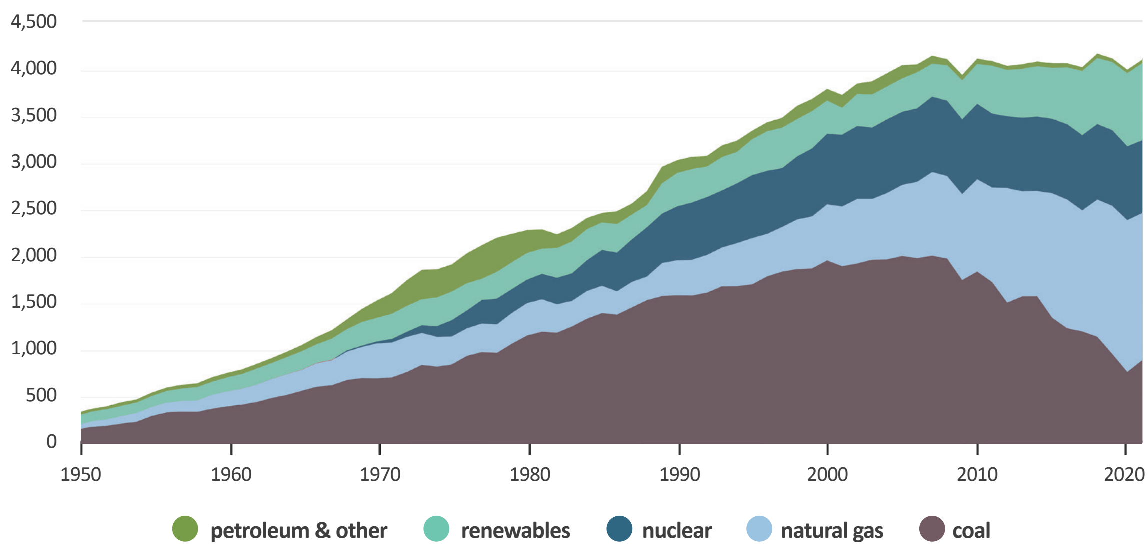
While coal use has dropped dramatically over the past decade—going from around half of electricity generation in 2008 to around 20% today—nuclear has remained remarkably steady, generating around 19% of U.S. electricity throughout the past two decades. In part, nuclear's stability is simply the result of a stagnant industry—U.S. electric utilities didn't bring online any new nuclear reactors between 1996 and 2016.

However, that's only part of the story, as reactor closures over the past decade threatened to reduce nuclear power's contributions. Instead, industry-led initiatives to enhance operational efficiencies enabled a smaller fleet of reactors to contribute around the same volume of electricity, largely by reducing the amount of time reactors were offline and adding capacity through upgrades to the existing fleet. So, while nuclear power only accounted for around 8% of total electric generating capacity in the U.S. in 2021, it actually contributed 19% of total electricity.

As coal has declined, natural gas and renewables have filled in to make up the difference. However, the operational characteristics of these two resources are very different from the baseload power they're replacing. Wind and solar provide variable output based on the weather, while natural gas works in a complementary capacity, as its flexibility enables it to respond to fluctuations in renewable generation by ramping up or down.

### U.S. Electricity Generation by Major Energy Source, 1950–2021

*billion kilowatt hours*




*Source: U.S. Energy Information Administration*

In short, the grid is changing. Grid operations are increasingly dynamic, and the nuclear power industry is being forced to adapt to the current operational, political and economic realities. However, several events in recent years have underscored the benefit of dispatchable power to provide reliability and resilience during the clean energy transition. The fact that the existing fleet of reactors can provide electricity whenever called upon—and do so without carbon emissions—has been a key argument for supporting their continued operations through mid-century.

That argument has also been applied to support the expanded use of nuclear power. At the same time, the prospects for new large-scale reactor projects in the U.S. appear bleak—in part because demand growth has slowed and large reactors are costly. In light of these dynamics, many experts anticipate a shift away from the traditional, large-scale reactors—often with capacities over 1,000 megawatts (MW)—and toward smaller, modular reactors with capacities that are normally under 350 MW.

There has been demonstrated interest at the state and federal level to support this next generation of nuclear technologies, which claim to be designed with enhanced safety and modern control systems. It appears increasingly likely that the next decade could prove to be a tipping point—one way or the other—that will determine how much nuclear power contributes to the clean energy transition in the U.S.

## WHAT ARE THE ATTRIBUTES OF NUCLEAR POWER?

Nuclear power has a number of attributes that, in combination, make it a fairly unique electric generating resource. For starters, it's a carbon-free resource at scaled capacity that provides significant baseload power, and it has done so at reasonably low prices over the past decade. It has also proven to be a reliable and steady performer on several fronts. Not only are nuclear power plants reliable operators that consistently deliver power when the grid is stressed, but their operating expenses are remarkably stable over time. And many of the existing fleet of nuclear reactors are preparing to extend their operating lives to 80 years—far longer than most generating facilities.

Nuclear proponents argue these characteristics have not been adequately valued in utility and grid planning, while opponents argue that safety concerns, high capital costs for construction and the impasse over spent nuclear fuel storage and disposition continue to be challenges that should limit the build-out of additional reactors.

A discussion of each of these attributes can be found below:

- **Carbon-Free:** Nuclear power has been the largest source of carbon-free electricity in the U.S. for decades, accounting for around 70% of carbon-free power in 2003. Today, nuclear power plants provide around half of the carbon-free power in the U.S., as substantial wind and solar capacity has come online. For many years, hydropower was the only other carbon-free generator delivering electricity at capacity in the U.S. Hydropower currently generates around 30% of the carbon-free power in the U.S., with other renewables like wind and solar accounting for the remaining 20%.

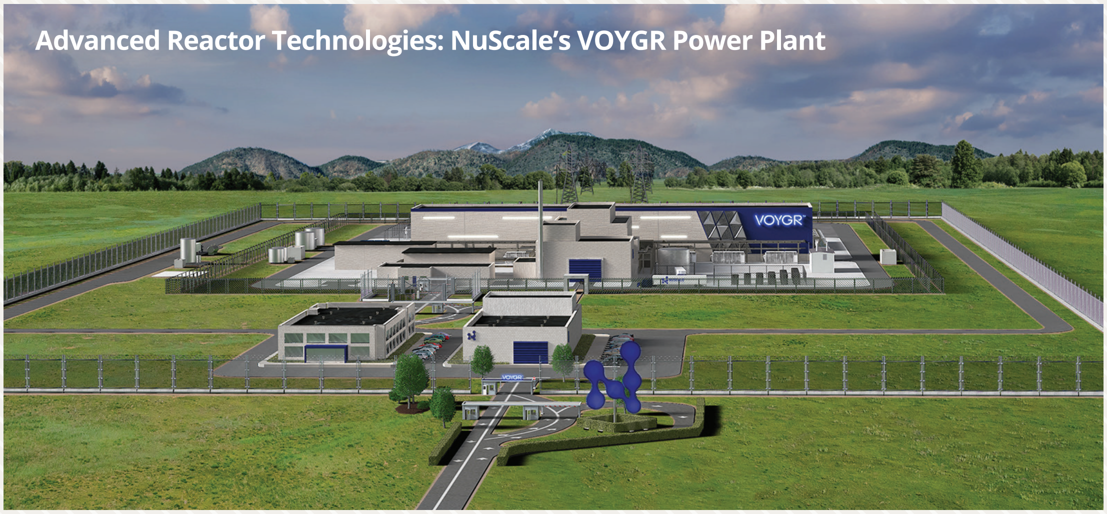
## Advanced Reactor Technologies: Oklo's Aurora Powerhouse

Oklo's Aurora Powerhouse is a microreactor designed to provide up to 15 MW of electricity through a single core of high-assay low-enriched uranium in metal form. Oklo's reactor has been designed to run continuously for 10 years or longer on fuel fabricated from recycled spent nuclear fuel generated from traditional largescale reactors. The company has said the reactors may be used to provide heat and power for industrial, defense or remote community microgrids, and can offer black start capabilities that can help restore the grid after a major outage. Oklo received a site use permit from the Idaho National Laboratory to develop the first Aurora Powerhouse, which is scheduled to be complete by 2027. The U.S. Department of Energy also selected Oklo for three awards to assist in developing spent fuel recycling technology that the company plans to use in the development of its fuel. *Image: Gensler. Provided by Oklo.*

- **Dispatchable:** Nuclear power is not unique in its ability to deliver dispatchable power—a term that refers to a generating resource's ability to respond to grid requirements when called upon. Nuclear, coal, natural gas, hydropower—these resources are all dispatchable, designed to deliver a certain amount of electricity when asked to, regardless of the weather. By contrast, variable or intermittent generation—primarily from wind and solar resources—are only able to deliver electricity when weather conditions are favorable. As wind and solar projects are paired with energy storage technologies, they may be considered dispatchable under certain circumstances.
- **Reliable:** Nuclear power plants have, by far, the highest capacity factor of any generating resource. Capacity factor is a measure of how often a resource delivers its maximum operating capacity—basically, how often it's fully utilized and able to deliver electricity. In 2021, nuclear plants in the U.S. had a capacity factor of nearly 93%, meaning they generated at maximum capacity around 93% of the time. That's nearly twice the capacity factor of coal and natural gas, and triple that of wind and solar. That's how nuclear plants, at only 8% of total electric generating capacity in the U.S., can actually generate 19% of total electricity.
- **Fuel-Secure:** In traditional nuclear plants, fuel is only replaced every 18 to 24 months. This, in part, is how nuclear plants maintain such high capacity factors. However, it also makes nuclear plants fuel-secure resources, because they do not require rail or pipelines for fuel deliveries like coal and natural gas plants which can be impacted by weather and other events.

- **Resilient:** While nuclear plants have often been noted for their reliable operations during normal conditions, their track record in the face of extreme weather conditions hasn't been discussed as widely. However, given the increase in weather-related outages in recent years, this may be an important factor for policymakers to consider. A recent report from the Electric Power Research Institute looked at how nuclear power plants fared during extreme weather events between 2011 and 2020, and concluded that "it is rare that extreme weather events have a significant direct impact on nuclear plant generation," with an average of less than a 0.1% loss in capacity factor. The report concludes this can partly be attributed to the fact that nuclear power plants are required to be designed to withstand events that are far more severe than most other critical infrastructure, which enables them to continue operating through conditions that may take other generators offline.
- **Cost Stability:** Over the course of the past decade, operating costs at nuclear power plants remained remarkably stable—hitting a high of $27.42 per megawatt-hour (MWh) in 2012 before steadily dropping to a low of $21.92 per MWh in 2020. This is largely because nuclear plant operations and maintenance costs make up the majority of operating expenses, when compared with fuel costs. The opposite is true for natural gas-fired power plants. Fuel costs account for the bulk of operating costs for natural gas turbines, which experienced major cost fluctuations over the course of the last decade. While natural gas prices appeared to have stabilized for several years around the $2 million to $3 per million British thermal units (MMBtu), prices have been volatile since 2021, nearly hitting $9 per MMBtu in late 2022. With natural gas supplying a larger share of electricity in recent years, its price volatility has driven the recent rise in energy costs in the U.S.
- **Energy Density:** Nuclear fuel assemblies pack a lot of energy into a small package. In fact, the energy density of nuclear fuel is around 2 million times higher than other energy sources. This density allows nuclear power plants to operate around-the-clock for 18 to 24 months before the reactor has to be shut down for refueling. It also means that nuclear power plants require less land to generate the same amount of power than other resources. The average solar facility requires more than 30 times the amount of land to generate the same amount of power as a nuclear plant, while the average wind facility requires over 170 times more land than a nuclear plant.
- **Spent Nuclear Fuel:** Spent nuclear fuel is a contentious issue. On the one hand, nuclear advocates tend to highlight it as another positive attribute for the industry. After all, because nuclear fuel is so energy dense, the entirety of the commercial spent nuclear fuel generated by the nuclear industry since the 1950s—around 90,000 metric tons—could fit inside a football field at a depth of less than 30 feet. Spent nuclear fuel also maintains around 90% of its original potential energy and could be recycled or reprocessed to develop new fuel and byproducts. It has been safely stored at more than 70 sites across the country for decades and more than 2,500 cask shipments have been transported across the country without radiological release. On the other hand, opponents point to the fact that spent nuclear fuel is highly radioactive, with certain elements requiring tens of thousands of years of containment before they return to safe levels. Similarly, the U.S. has for decades been at an impasse on the final disposition of commercial spent nuclear fuel. While federal law dictates that it should be stored at a deep geologic repository at Yucca Mountain in Nevada, political realities have spoiled those plans, leaving each reactor site as a temporary storage facility. This topic will be addressed further in a subsequent section.
- **High Regulatory Costs:** To ensure public health and safety, and preserve the environment, nuclear power projects are heavily regulated by the U.S. Nuclear Regulatory Commission (NRC). The regulatory burdens on reactor developers are high—a practical response to ensure high degrees of safety in design, construction, operations and maintenance. However, these regulatory burdens come at significant cost and add to the lengthy timelines in developing and constructing new reactor projects.
- **High Capital Costs:** When combined with the extensive lead-time for traditional large-scale reactor projects, which are built to specification on-site, the cost of financing can be hard to overcome for many potential developers. The two reactors at Plant Vogtle in Georgia that are nearing completion now have a combined cost of $30 billion, more than double the original estimates. These obstacles have discouraged new reactor development. However, small modular reactor (SMR) companies claim their model of factory fabricated components that are assembled on-site will reduce construction costs.

## Advanced Reactor Technologies: NuScale's VOYGR Power Plant



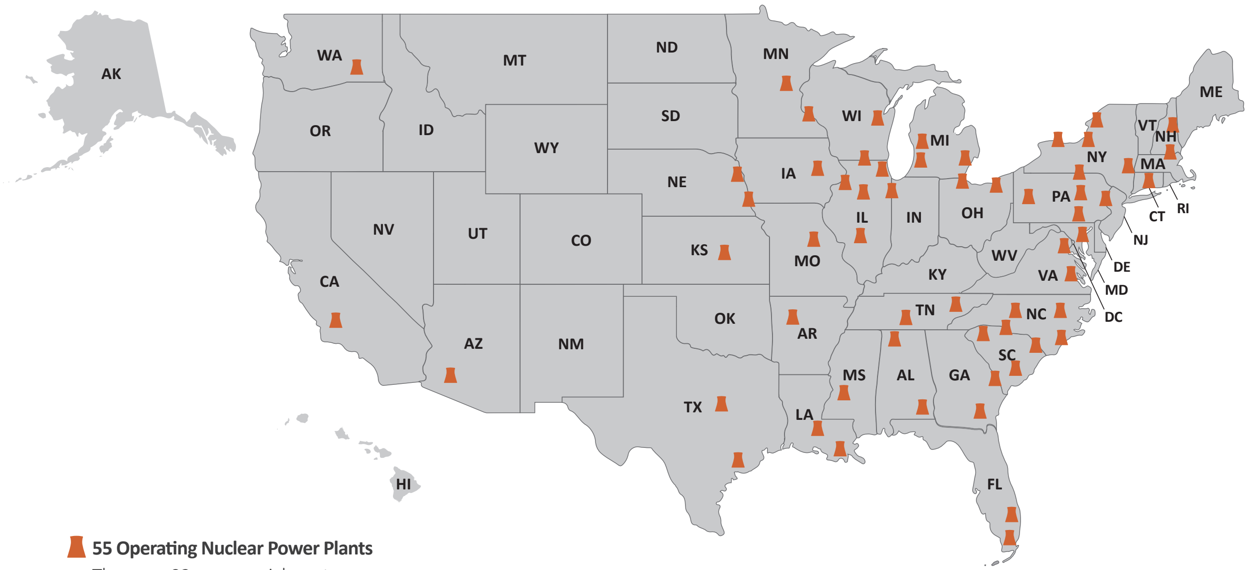

NuScale Power's VOYGR small modular reactor plants are designed to be powered by NuScale Power Modules, which are the first and only small modular reactor to receive design approval from the U.S. Nuclear Regulatory Commission. The NuScale Power Module has a 77 MW electric generating capacity using modernized pressurized water-cooled reactor technologies, and designed to have components factory fabricated and shipped to be assembled on-site. The VOYGR power plants may be built to various scales by packaging multiple reactors together. For example, a 12-unit VOYGR plant's full operating capacity would be 924 MW, while a 6-unit plant would generate 462 MW. NuScale's first VOYGR power plant is schedule to be built near Idaho Falls, Idaho, in collaboration with the Utah Associated Municipal Power Systems; it is currently projected to come online in 2029. *Image provided by NuScale Power; may not be copied or repurposed without NuScale's express permission.*

## WHAT IS THE CURRENT STATE OF NUCLEAR POWER IN THE U.S.?

Currently,  92 nuclear reactors with a combined generating capacity of more than 95 gigawatts (GW) at 55 power plants in 28 states are operating in the U.S. The continued operation of the existing fleet of reactors through mid-century is considered by many experts and organizations to be instrumental in addressing climate change and rapidly decarbonizing the electricity sector.

Commercial nuclear reactors receive an initial 40-year operating license from the NRC. As that 40-year period nears its end, the plant owner can apply for a 20-year license extension. Most of the existing fleet is operating on this license extension which can take a reactor's operating life to 60 years. More recently, the focus has been on "subsequent license renewals," which would authorize a reactor to operate for 80 years. So far, the NRC has approved subsequent license renewals for six reactors at three power plants and is reviewing applications for another eight reactors at five power plants. Four additional nuclear plant operators have notified the NRC they intend to submit applications for an additional eight reactors.

## U.S. Operating Commercial Nuclear Power Plant Sites




**55 Operating Nuclear Power Plants**
There are 92 commercial reactors licensed to operate at these power plants.

*Source: U.S. Nuclear Regulatory Commission*

Often as part of the license renewal process, nuclear plant owners will invest in upgrades and maintenance, both to satisfy NRC relicensing requirements and enhance operational efficiency. In some cases, these result in power uprates—NRC-approved increases to the maximum capacity at which a nuclear plant can operate. There are three primary categories of uprates, two of which don't require major plant modifications and which can result in capacity increases of up to 7%. However, in some cases, plant owners invest in new equipment that enables more efficient use of the energy produced at a reactor, such as high-pressure turbines, condensate pumps and motors, or main generators. In these cases, a nuclear plant can apply to increase its capacity by up to 20%. Over the course of its history, the NRC has approved 171 power uprates, which have added a cumulative 8 GW of electric generating capacity to the reactor fleet.

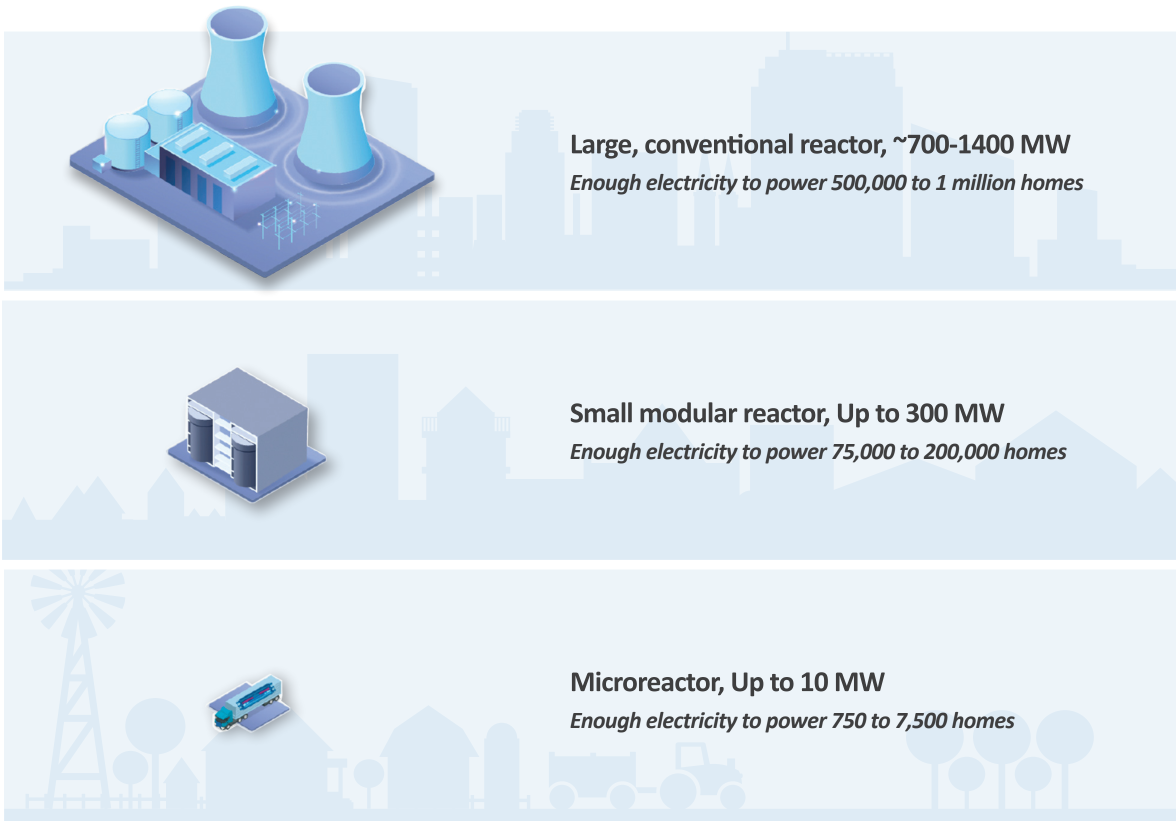
Both subsequent license extensions and power uprates will be important factors in the current fleet's ability to support the clean energy transition. However, these options have not been enough to prevent reactor closures in recent years. The U.S. reactor fleet peaked in 2012, when there were 104 reactors with a combined capacity of 102 GW. That decline can be attributed to several factors.

Over the past decade, natural gas has taken on a larger share of the electricity mix—growing to account for nearly 40% of total electricity generation today. With the shale revolution, natural gas prices dropped and drove down the cost of electricity in wholesale markets alongside another increasingly cheap power source that has benefited from greater government support: renewable energy. The lower prices caused some reactors to run on increasingly thin margins. Ultimately, 13 nuclear reactors closed prematurely due to these market conditions.

At the same time, the nuclear industry went two decades without bringing any new reactors online. There was a brief period after the passage of the 2005 Energy Policy Act when many anticipated a "nuclear renaissance" due to several provisions to assist utilities in developing new reactors with loan guarantees, cost-overrun support and a production tax credit. Following its passage, the NRC received applications for construction and operating licenses to build nearly 30 new reactors.

However, all of that came to a halt in March 2011 with the disaster at the Fukushima Daiichi nuclear power plant in Japan. Ultimately, only four of the new reactors broke ground—two at Plant Vogtle in Georgia and two at the V.C. Summer Nuclear Station in South Carolina. Financial troubles at V.C. Summer led to the abandonment of the project in 2017. And although the Vogtle project has seen its share of setbacks, the plant's two new reactors—Units 3 and 4—are expected to come online this year.

**A comparison of large conventional, small modular and micro reactors**




*Source: International Atomic Energy Agency*

The only reactor to come online so far in the 21st century is at the Tennessee Valley Authority's Watts Bar nuclear plant in Tennessee. TVA originally began construction of Watts Bar Unit 2 in 1973, alongside Unit 1. The reactor was 60% complete when TVA decided to mothball Unit 2 in 1985. However, in 2007, TVA announced it would complete Unit 2, which became operational in 2016.

These events have contributed to a broad shift away from large reactor projects. The high upfront costs of capital, along with cost-overruns and long timelines have discouraged utilities from pursuing new nuclear. However, a new generation of advanced reactor technologies and SMR designs have promised to change those dynamics over the coming decades, revitalizing discussions over the role nuclear power can play in the clean energy transition.

## WHAT IS THE FUTURE OF NUCLEAR POWER?

The future of nuclear power in the U.S. looks to be increasingly small and modular. A handful of SMR projects are under various stages of development, and recently enacted state and federal policies could spur development further. Cumulatively, these smaller scale projects could represent a huge increase in nuclear generating capacity.

Many projects are at various stages of technical development. In some cases, they're moving through the NRC's design review and licensing process while simultaneously embarking on demonstration projects funded by the U.S. Department of Energy (DOE). Only one SMR company, NuScale Power, has received a design certification from the NRC, which approves its reactor design for use in the U.S. NuScale is currently developing its first power plant in Idaho under an agreement with the Utah Associated Municipal Power Systems. It aims to begin operations in 2029.

However, several additional reactor companies and technologies are moving toward building their first reactors, and many more competing to be part of the clean energy buildout. Two projects that received funding from the DOE's Advanced Reactor Demonstration Program are X-energy's partnership with Dow Inc. to build a pebble bed heliumcooled reactor project on the Gulf Coast, and TerraPower's partnership with PacifiCorp to build its liquid sodium fast reactor in Wyoming. At least seven other projects have been announced with timelines projecting completion by 2030.

The TerraPower project has drawn particular interest because the reactor will be developed at the site of a retiring coal-fired power plant. This type of "coal-to-nuclear" conversion has been a topic of discussion for some time, but has picked up in the past couple years. Logical similarities exist; after all, both nuclear and coal generators are thermoelectric power plants. Many SMRs would fit on the footprint of existing coal power plants. Existing infrastructure, such as transmission lines, switchyards and water rights, could be leveraged to reduce the new reactor project's costs and permitting hurdles. The existing labor force could be retained through retraining opportunities, helping to soften the impact of the clean energy transition on fossil fuel communities.

Recently, the DOE added to the discussion with a study exploring the potential challenges and benefits of coal-to-nuclear conversions. The study claims that 80% of the nearly 400 retired and operating coal plants identified by the authors would be good candidates to host SMRs. Furthermore, these sites could potentially host up to 265 GW in generating capacity—more than two-and-a-half times the current fleet's capacity.

PacifiCorp, an investor-owned utility serving several Western states, has since announced plans to explore the potential of deploying up to five additional TerraPower reactors at other sites across the utility's service territory by 2035, with an emphasis on coal-to-nuclear conversions.

These projects represent the companies that are at the most advanced stages of development, but there are many other designs and technologies aiming to be part of the resource mix in the future. A recent report details 18 reactor designs, most of which represent a significant departure from the existing fleet of large reactors operating in the U.S. and around the world. These designs are mostly SMRs, with capacities under 300 MW—although at least three reactors have capacities listed above that threshold.

At the same time, five of the reactors in the report are under 10 MW—an emerging classification called "microreactors." And while every nuclear reactor in the U.S. is currently a water-cooled reactor, most of these advanced reactors are non-water-cooled technologies, which means they rely on gases and materials like molten salts and liquid metals as heat moderators.

### Advanced Reactor Technologies: X-energy's Xe-100

X-energy's Xe-100 is a high-temperature, pebble-bed reactor that runs at lower pressures than water-based designs and uses inert helium as the coolant. The Xe-100 is projected to generate 80 megawatts of electricity; its high temperatures also produce steam that can be captured and used for industrial applications, including hydrogen production and process heat. The company has proposed scaling up to four Xe-100 reactors together, capable of producing up to 320 MW. X-energy has also developed its own fuel, TRISO-X, which allows the reactor to be continuously fueled while operating, thereby eliminating refueling outages. X-energy has received funding from the U.S. Department of Energy's Advanced Reactor Demonstration Program and has partnered with Dow Inc. to develop its first Xe-100 reactor at Dow's Seadrift Operations manufacturing site in Texas to reduce the facility's carbon footprint through electricity and steam generation. *Image provided by X-energy.*

There are many distinguishing features to these new designs, but enhanced safety, system engineering and modularity are common elements. The modular design is intended to allow for factory fabrication and streamlined on-site construction to reduce costs and delays. Not only is the technology changing, but the way nuclear reactors are used could also be changing. For example, the DOE has funded several demonstrations to use nuclear power at existing reactors to produce clean hydrogen. Advanced reactors could also be used for clean hydrogen, but because many designs also operate at higher temperatures, they could provide process heat for industrial applications. Many of the new technologies will be able to operate more flexibly to pair with variable renewable generation and some have been designed with "black start" capabilities that are integral to restoring grid operations following a significant blackout.

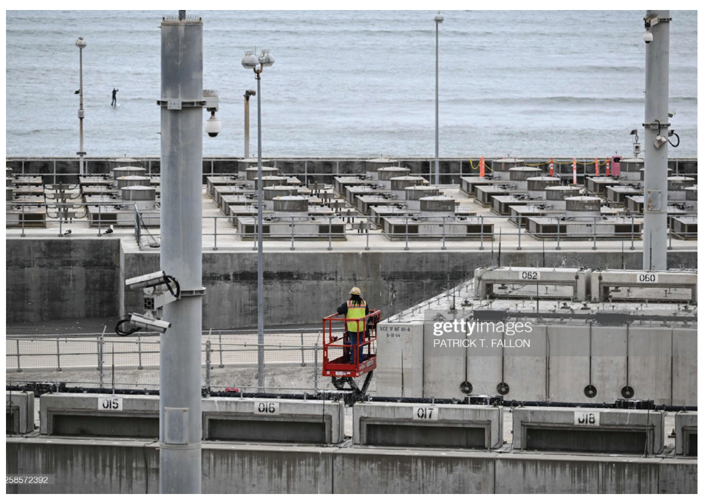
While there is no crystal ball, the future of nuclear will undoubtedly represent a shift away from the past and present. Many of the existing fleet of reactors will apply for and receive license renewals that will enable them to operate throughout the next few decades. Whether new reactors are developed in the meantime will have significant implications for the future of the domestic nuclear industry, the future of the electric grid and the country's ability to address climate change through decarbonization.

## THE WASTE ISSUE: BRIEFLY EXPLAINED

Resolving the impasse around spent nuclear fuel—often referred to as nuclear waste—has proven to be a politically challenging task. The Nuclear Waste Policy Act of 1982 (NWPA) directed the DOE to pursue a deep geologic repository for the disposal of commercial spent nuclear fuel and high-level radioactive waste, establishing procedures to evaluate and select sites. A 1987 amendment to the NWPA identified Yucca Mountain in Nevada as the primary repository site. Congress directed the DOE to build and operate the repository, and to begin taking ownership of commercial spent nuclear fuel in 1998. This work was to be funded through a surcharge paid by nuclear power plants' customers since the 1980s.

So far, the Nuclear Waste Fund has collected more than $44 billion from customers, but it remains largely untouched because of long-standing opposition to developing the repository at Yucca Mountain. The Obama administration suspended work on Yucca Mountain in 2009 and established the Blue Ribbon Commission on America's Nuclear Future (BRC), which issued recommendations in 2012. Chief among the recommendations was to identify sites for storage and disposal facilities using a consent-based process. The BRC described a consent-based process as one that afforded affected communities the opportunity to decide whether to accept a facility, provided transparency to allow all stakeholders around key decisions and the opportunity to engage, and was governed by partnerships or agreements between the DOE and host states, tribes and local communities. The DOE began to engage in a consent-based siting approach based on the BRC's recommendations in 2015, only for that process to be suspended by the Trump administration the following year.

The Biden administration restarted the consent-based process in 2021, which is being pursued alongside private initiatives to develop consolidated interim storage facilities. Under federal law, the DOE can proceed with a consent-based siting process, negotiate a consent-based agreement with a host community and seek a license for a federal interim storage facility. However, Congress would need to provide additional authorization for the DOE to construct and operate such a facility. The DOE announced plans to engage with communities in 2023 that are interested in learning more about consent-based siting, the management of spent nuclear fuel and considerations around interim storage facilities. This engagement will help the DOE refine the consent-based siting



Spent nuclear fuel is stored in specially designed facilities on site at nuclear power plants, including several years in a cooling pool followed by dry cask storage.

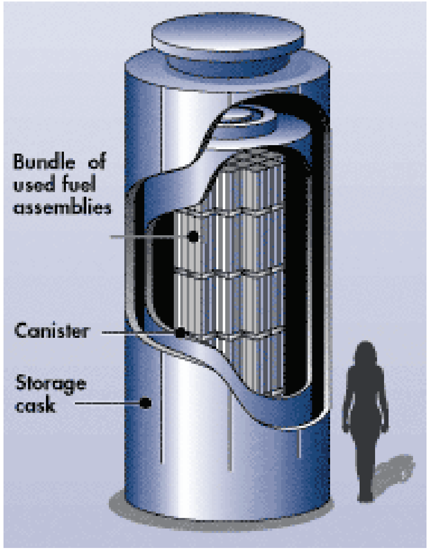
process before the department issues a call for volunteer communities, which will then work with the department to determine whether hosting a facility is a good fit.

In the meantime, spent fuel will continue to be safely stored at more than 70 reactor sites in 35 states. After a fuel assembly is removed from a reactor, it spends several years in an on-site spent fuel pool—a specially designed pool that circulates cool water and shields workers from radioactivity. Later, the fuel assembly is transferred out of the pool and into dry cask storage on-site. Dry cask storage involves encapsulating fuel assemblies inside steel cylinders that provide leak-tight containment, which are then further encapsulated by steel or concrete to provide radiation shielding. In some cases, these casks are also designed for eventual transportation of the spent fuel off-site. To date, even after a nuclear power plant has been decommissioned and everything else has been demolished, the dry cask storage facility remains.

Spent fuel will remain in dry cask storage at nuclear power plant sites until one of two things happen: the DOE sites and builds a permanent repository, or a consolidated interim storage facility becomes operational. Since the DOE has restarted the consent-based siting process, it appears increasingly likely that a consolidated interim waste storage facility—essentially a dry cask storage facility that's big enough to accommodate casks from across the country—will become the first step in this process. The NRC has reviewed applications for interim storage facilities in New Mexico and Texas, issuing final environmental impact statements in favor of both facilities in 2022. The NRC has also issued a license to the Texas project. However, state officials in New Mexico and Texas have expressed opposition to these projects, which are being developed by private companies, and it's unclear how that opposition could affect their development. Legislatures in both states have enacted legislation (Texas H.B. 7 in 2021, and New Mexico S.B. 53 in 2023) aimed at prohibiting the transportation and storage of spent nuclear fuel in their states.

Another development could shift the thinking around spent nuclear fuel in the U.S. Given that spent nuclear fuel retains around 90% of its energy potential, France decided to establish a spent fuel reprocessing program that breaks down the spent fuel and reuses remaining fissile components by blending them into new fuel assemblies. While the U.S. has not pursued spent fuel reprocessing, it has reemerged as a potential source of fuel for some advanced reactor technologies. One advanced reactor company, Oklo, has submitted a plan to the NRC to license a nuclear fuel recycling facility to fabricate fuel for its reactors. While even widescale deployment of spent fuel reprocessing would not obviate the need for a permanent repository, it could shift the dynamics around how decisionmakers and the public consider spent nuclear fuel.

**Dry cask storage systems are used to safely store spent nuclear fuel at sites across the country**




*Source: U.S. Nuclear Regulatory Commission*

# The State Role

State legislatures play a significant role in shaping the energy sector through policy decisions. While state public utility commissions (PUCs) serve as utility industry regulators, state legislators establish the regulatory framework and priorities that PUCs implement. In overseeing the regulatory environment in which electric utilities operate, state legislative policies affect how utilities plan for the future, recover costs and make investments. State legislative policies are largely responsible for significant utility investments in energy efficiency and renewable energy over the past decade.

Recently, NCSL has tracked an increase in state legislation related to nuclear energy—up from 74 bills considered in 2016 to more than 160 bills considered in 2022. Early developments in 2023 suggest that these trends will continue through the current legislative session as well. These policies address nuclear power from a few different vantage points; while some states have enacted policies to insulate their existing fleet of reactors from premature closure, a growing number of states have worked to develop new nuclear capacity. However, the bulk of state action has been less direct. At least seven states have decided to promote clean energy technologies in a way that's inclusive of nuclear, while another four have repealed restrictions on developing new nuclear. While these policies don't explicitly carve out a place for nuclear power, they tend to remove barriers to development or recognize nuclear's carbon-free attributes in a way that previous policies haven't. The following sections will review each of these policies in more detail.

## PRESERVING THE EXISTING FLEET

The current fleet of commercial reactors generates around half of all carbon-free electricity in the U.S.  A number of organizations—including some that are opposed to new nuclear—have called for these reactors to continue operations through mid-century or longer to support a cost-conscious and reliable clean energy transition. Many of these reactors are beginning to apply for a second 20-year license renewal from the NRC, which will allow them to reach an 80-year operating life. In several cases, states have enacted policies to support that process, which may require equipment upgrades and other capital expenses.

The premature closure of several nuclear power plants in the early 2010s proved a wakeup call to many industry observers who took their continued operation for granted. The shale revolution led to a period of sustained, low natural gas prices that drove down wholesale electricity prices. Nuclear plants operating in those competitive electricity markets struggled to stay profitable.

This dynamic played out as many states worked to bring more renewable capacity online through policies like renewable portfolio standards (RPS) that require regulated utilities to sell a certain amount of electricity from renewable resource by specific dates. As decarbonizing the energy sector became a growing priority, some policymakers decided action was needed to keep these large, reliable sources of carbon-free power operating.

Currently, five states—California, Connecticut, Illinois, New Jersey and New York—have policies to provide financial support to struggling nuclear power plants, while several other states debated doing the same. Connecticut, Illinois, New Jersey and New York provide additional revenue to nuclear plants that demonstrate they would likely shut down without state assistance. The primary justification underlying several of these policies was that natural gas-fired generation would likely replace retired nuclear capacity, causing an increase in carbon emissions.

Zero emissions credits (ZECs) policies have been the most commonly considered and enacted. ZECs provide qualifying reactors with a supplemental payment—in addition to what they receive in the wholesale market—for every megawatt-hour (MWh) of carbon-free electricity sold. While Illinois was one of the first states to enact a ZECs policy, the legislature decided to expand its support for the state's nuclear fleet with the passage of the Climate and Equitable Jobs Act in 2021. The state now supports five nuclear power plants through ZECs-style policies—up from two that were supported under the 2016 legislation.

Through the Infrastructure Investment and Jobs Act (IIJA), Congress established a federal program that is substantially similar to these state ZECs programs: the Civil Nuclear Credit Program (CNCP). The CNCP will be available to struggling nuclear power plants across the nation, and it didn't take long for states without ZECs policies to take notice.

In 2022, the California legislature enacted both A.B. 205 and S.B. 846 to extend the operating life of the state's last remaining nuclear power plant. This was done primarily to address reliability concerns, with the state's electric grid experiencing several periods of significant stress over the past several years due to capacity shortfalls, leading to rolling blackouts. Pacific Gas & Electric's Diablo Canyon nuclear power plant has two reactors with 2,250 MW of generating capacity—together they contribute about 9% of the state's total electricity. Diablo Canyon's two reactors were scheduled to shut down in 2024 and 2025 under an agreement between PG&E, the state and environmental groups, but state legislators decided its capacity was necessary to support reliability without increasing the use of natural gas-fired generation.

With A.B. 205, the legislature provided up to $75 million for a Strategic Reliability Reserve that would enable the state Department of Water Resources to purchase power from any facility that would enhance electric reliability in the state—including from Diablo Canyon. Meanwhile, S.B. 846 allows Diablo Canyon to operate through 2030, so long as it applies for financial support under the CNCP and relicenses the two reactors. The state also provided up to $1.4 billion in forgivable loans to support these endeavors. By the end of 2022, the DOE announced that Diablo Canyon had been conditionally selected to receive up to $1.1 billion in credits from CNCP, which should pave the way for the plant's continued operation.

## SUPPORT FOR ADVANCED REACTORS

More recently, a growing number of states have begun exploring and enacting policies to support the development of the next generation of nuclear reactors. In some cases, these are states that do not have commercial nuclear reactors—several, in fact, have very long economic ties to the coal industry, such as Indiana, Montana and Wyoming.

As states consider their future energy mix, nuclear power has proven an attractive proposition to states looking to develop clean energy resources that can not only replace the capacity of retired fossil fuel-fired generation, but also the jobs and other economic benefits that are lost when a power plant shuts down. This is one of the reasons that coal-to-nuclear policies have been adopted over the past few years. Lawmakers are working to soften the impact of the clean energy transition on fossil fuel communities by swapping out an emitting resource for a carbon-free resource, ideally doing so while retaining the workforce and tax benefits.

So far, Indiana and Wyoming have enacted coal-to-nuclear policies, while Montana adopted a resolution to study the feasibility of replacing coal units with SMRs. Wyoming H.B. 74 (enacted, 2020) was the first coal-to-nuclear policy in the U.S., requiring the state PUC to develop rules and regulations to grant certificates for the construction and operation of SMRs at retired coal- or natural gas-fired power plants. About a year later, TerraPower and PacifiCorp announced their plan to build a new reactor at a retired coal plant in the state. In 2022, Wyoming lawmakers amended the law with the passage of H.B. 131, which removed the requirement that SMRs be sited at retired coal- or natural gas-fired power plants, along with the PUC's mandate to establish rules and regulations specific to SMRs. Instead, the law now simply requires prospective developers to submit a report to the state addressing job creation, state tax implications and other benefits and impacts that will affect the state and local economy.

Indiana's S.B. 271 (enacted, 2022) requires the state PUC to develop rules to grant certificates for the construction and operation of SMRs. The new law does not require SMRs to replace coal- or natural gas-fired generation, but does require the state and developer to consider siting SMRs at retiring facilities to address workforce issues and make use of existing land and infrastructure. It also authorizes utilities to receive Construction Work in Progress (CWIP) financing to develop SMRs, which enables utilities to incrementally collect costs from customers throughout the course of construction, with approval and oversight from the state PUC.

CWIP policies lower the risk to utilities and shareholders and can reduce the overall amount needed to finance a project, but they have been criticized for shifting too much risk onto customers. Missouri has considered enabling CWIP for new nuclear and renewables projects over 200 MW in recent years, while Georgia and South Carolina repealed their CWIP laws following cost-overruns at the large reactor build projects in their states.

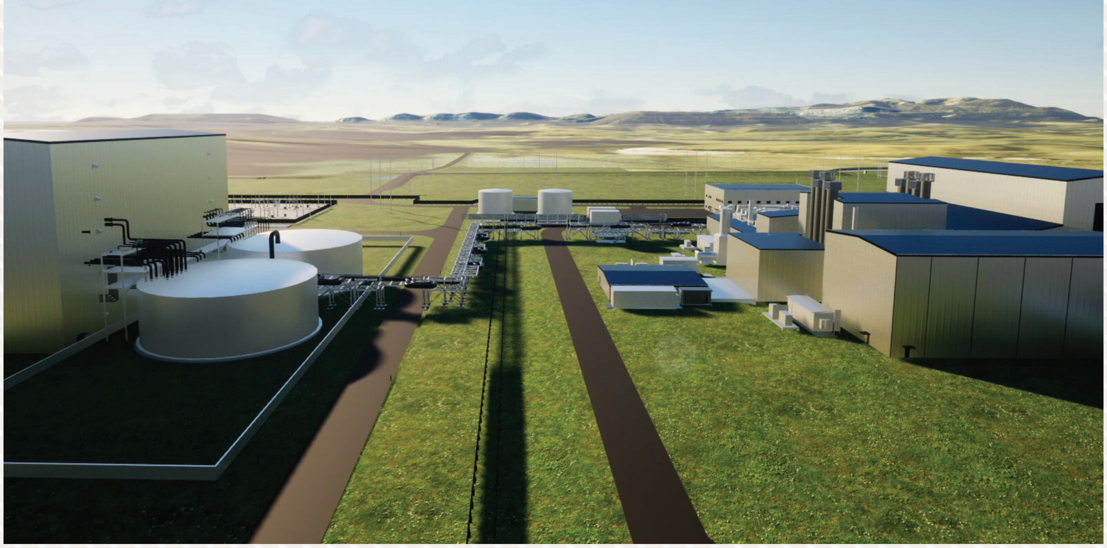
Other states have also taken steps to support advanced nuclear. Alaska's S.B. 177 (enacted, 2022) aims to streamline the permitting process for microreactors, defined in the statute as reactors with a generating capacity of 50 MW or less, while Connecticut's H.B. 5202 allows the state's lone nuclear plant to expand and construct an SMR at the site. Nebraska L.B. 84 (enacted, 2021) extended existing incentives for renewable projects to apply to advanced reactor companies, and Virginia H.B. 894 (enacted, 2022) directs state agencies to convene stakeholders to identify strategies and policies to promote SMR development in the state.

At least five states—Maryland, Michigan, Montana, Nebraska and New Hampshire—have commissioned studies to explore everything from coal-to-nuclear and siting possible locations for new reactors, to the role new nuclear power can play in the energy transition. The reports commissioned by Maryland and Montana which focus on coal-to-nuclear conversions have since been published.

These trends have continued into 2023, with several states enacting notable legislation. Kentucky adopted S.J.R. 79, which establishes a Nuclear Energy Development Working Group to identify barriers to nuclear power in the state, consult with stakeholders and issue a report to the governor and legislature with recommendations on how the state can support nuclear development. Virginia moved several bills aimed at supporting new nuclear development and the advanced nuclear industry. Virginia H.B. 1779 (enacted) creates a Virginia Power Innovation Program and Fund to award competitive grants for research and development of innovative electric system technologies, including nuclear power. Virginia H.B. 2333 would have established an SMR pilot program that aimed to develop and promote SMRs in the state, with the goal of having the first SMR operational by 2032. While versions of the bill passed both chambers, the House and Senate were unable to resolve differences over how these projects would be financed.

Finally, Virginia, West Virginia and Wyoming all enacted legislation aimed at developing a qualified workforce to support advanced nuclear development through grants, training opportunities, collaboratives between institutions of higher education and other initiatives.

### Advanced Reactor Technologies: TerraPower's Natrium Reactor



TerraPower's Natrium Reactor is a sodium-cooled "fast" reactor, designed to use metallic fuel rods made of a zirconium alloy and uranium, which sit in a pool of liquid sodium serving as the coolant. The natrium reactors are larger than many other SMRs, at 345 MW electric generating capacity. However, when paired with molten salt energy storage, as currently designed, the reactors can boost output to 500 MW for more than five hours or scale down to as little as 170 MW output on the grid. TerraPower has received funding from the U.S. Department of Energy's Advanced Reactor Demonstration Program, and has partnered with PacifiCorp, a large investor-owned utility, to convert a retiring coal-fired power plant into the first natrium reactor in Kemmerer, Wyoming. *Image provided by TerraPower.*

## OPENING THE DOOR TO NUCLEAR

Not every state is ready to be in the vanguard of new nuclear development. Some industry observers and policymakers have questioned whether the nuclear industry can deliver these new products at the envisioned costs. Even with this uncertainty, two recent policy trends demonstrate how a growing number of states have at least opened the door to nuclear power.

First, states have started to restructure their renewable portfolio standards (RPS) to include a wider array of carbon-free resources, often including nuclear energy. These new standards have been referred to as clean energy standards (CES). Over the past five years, states have increased the requirements under RPS and CES policies. Before 2016, most standards required between 10% and 25% of a utility's retail sales to come from renewable sources by a certain date. There are now at least 11 states, two territories and the District of Columbia, which have increased their standards to 100% of retail sales with deadlines ranging from 2030 to 2050; another three states increased their standards to 50% or greater.

At least nine states—California, Colorado, Minnesota, Nevada, New Mexico, New York, North Carolina, Oregon and Washington—now have CES policies, which could allow for carbon-free or carbon-neutral technologies like nuclear power or fossil generation with carbon capture and sequestration technology to satisfy a certain percent of the goal. Meanwhile, the Nebraska Public Power District—a state-owned electric utility, which is the largest electricity provider in the state—also established a goal to achieve 100% carbon-free power. It's worth noting that the bulk of these standards still consists of a robust RPS—often requiring renewables to make up 70% or more of retail sales.

However, in three states with CES policies, new nuclear reactors cannot currently be developed under state law. California, Minnesota and Oregon have imposed restrictions on the development of new nuclear power facilities dating back to the 1980s. While California and Oregon require that a repository for spent nuclear fuel be either licensed or in operation before a new nuclear power facility can be built, Minnesota is the only state to enact an outright ban on new nuclear.

Twelve states currently have restrictions on the construction of new nuclear power facilities, but that number has become smaller in recent years, which leads to the second policy development reflecting how states have opened the door to nuclear.

Since 2016, Kentucky, Montana, West Virginia and Wisconsin have all fully repealed similar restrictions, while Connecticut enacted a partial repeal by providing a narrow exemption to allow its current nuclear power plant to develop an SMR. These repeals do nothing more than remove a barrier to development; they offer no incentives or other accommodations.

Half of the remaining state restrictions are tied to identifying a permanent repository for spent nuclear fuel—similar to California and Oregon. The remaining states either require the state legislature or voters to approve a project, while Minnesota is the only state to have enacted an outright ban. New York, which also has a CES, has only prohibited the development of new nuclear on Long Island. Several additional states have considered legislation to repeal these restrictions in recent years.

In 2023, at least four states—California, Illinois, Minnesota and Oregon—have seen legislation to repeal these restrictions introduced. Several of these bills are notable in how they deviate from prior repeal efforts. For example, bills in California and Illinois not only repeal or create exemptions to state restrictions, but also direct state agencies to take steps toward developing new nuclear capacity. Meanwhile, Oregon legislation would be the first to put the question of whether to repeal the state's restrictions on new nuclear to voters in the next general election.

## ADDRESSING THE WASTE ISSUE

While it's not the role of states to solve the impasse around spent nuclear fuel, that doesn't mean the impasse hasn't affected states. As reflected in state restrictions around new nuclear, the federal government's failure to resolve this political roadblock has created uncertainty. As discussed earlier, the DOE restarted a consent-based siting process in 2021 to resolve some of these issues and provide a path forward with the support of affected communities. However, states continue to respond to private industry proposals to develop interim storage solutions.

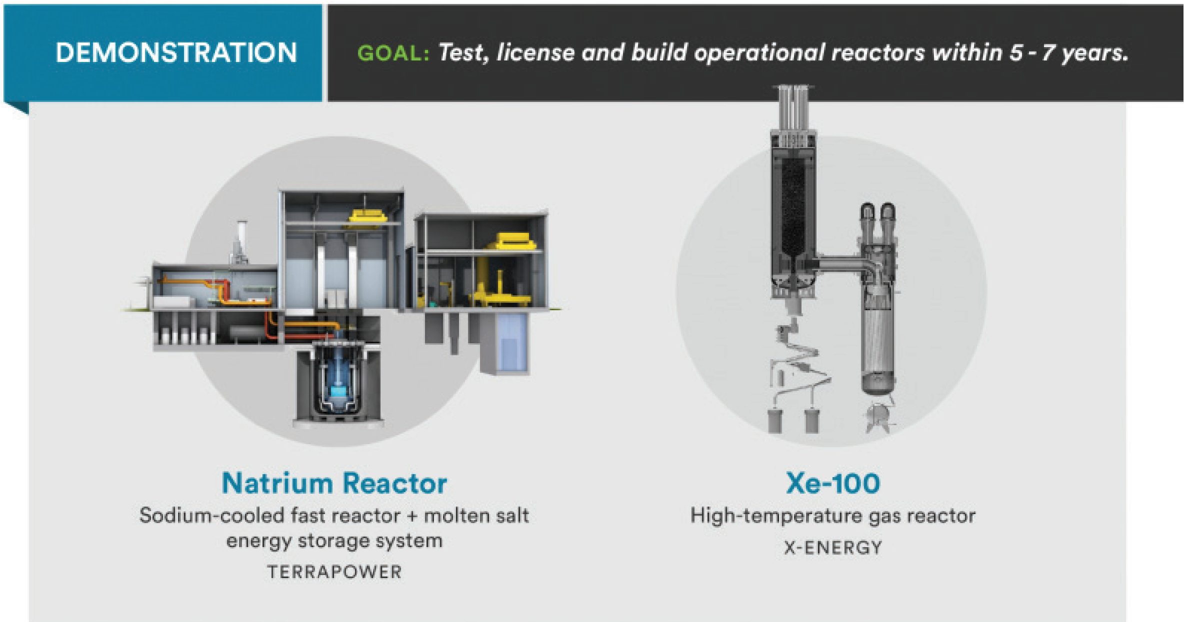
The two interim consolidated waste storage facilities with applications before the NRC have caused considerable debate within the states where they would be sited: New Mexico and Texas. Holtec International is pursuing an interim facility in southeastern New Mexico, while Interim Storage Partners is doing the same for a facility in western Texas.

State-level opposition appears to be considerable in both cases; Texas enacted H.B. 7 in 2021 and New Mexico enacted S.B. 53 in 2023, both of which aim to prohibit the transportation and storage of spent nuclear fuel in their states. It's unclear what effect these laws will have, given the NRC's primacy when it comes to permitting high-level radioactive storage facilities.

The NRC has continued to move forward with the applications for both facilities, but recently delayed by two months issuing a decision on licensing the Holtec facility in New Mexico due to resource constraints. All of this is unfolding alongside the DOE's restarted consent-based siting process, leading observers and advocates to discuss the meaning of consent—and what levels of government or communities are required to give their consent. Whether state-level opposition qualifies is a topic that continues to be discussed.

Conversely, the Arkansas legislature has advanced a policy that could lead to the state playing a role in spent fuel reprocessing, recycling and interim storage. Arkansas H.B. 1142 (enacted, 2023) sets in motion an initiative for the state to explore the technical and economic feasibility, along with federal funding opportunities, associated with spent fuel reprocessing, recycling and interim storage projects in the state. The state agency responsible for the analysis is required to present its findings to the legislature, after which legislative council will make recommendations to the governor.

**The U.S. Department of Energy's Advanced Reactor Demonstration Program is supporting 10 advanced reactor designs to help mature and demonstrate their technologies**




Source: *U.S. Department of Energy*

# Recent Federal Action

State legislation has and will continue to play an important role in determining what the future of nuclear power looks like in the U.S. At the same time, recent federal action is likely to change the dynamics across the energy sector, and the nuclear power industry is poised to benefit from this federal support.

One emerging area of support comes from the U.S. Department of Defense's interest in microreactors to support its operations and grid reliability at its bases. The department is working with several advanced reactor developers to design and demonstrate prototypes of transportable, mobile reactors that can be deployed to support DOD's mission-critical operations in remote environments. This type of support could help microreactor designs reach commercialization faster than would otherwise happen.

Similarly, Congress has enacted federal legislation that could support advanced reactors as they move toward commercialization. While Congress has taken action on nuclear issues in recent years—notably enacting legislation to streamline the NRC's regulations and licensing procedures to accommodate advanced reactor designs—none of those policies is anticipated to have the impact of the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA).

## INFRASTRUCTURE INVESTMENT AND JOBS ACT

With the IIJA, Congress invested $73 billion in efforts to decarbonize and improve the reliability of the energy sector. Several provisions, in particular, will support the nuclear power industry—both the existing fleet and new advanced reactors.

As previously discussed, the IIJA created the Civil Nuclear Credit Program (CNCP)—a DOE-administered program to provide financial support to existing nuclear power plants that could shut down prematurely due to economic conditions. The law allocates $6 billion for the CNCP, which is intended to support only nuclear power plants at risk of premature closure through supplemental payments for every MWh of electricity generated. These payments are intended to provide cost stability for the plants to enable their continued operation. Already, the Diablo Canyon nuclear power plant in California is expected to continue operations due, in part, to support from the CNCP. In March, the DOE issued official guidance on the second award cycle.

The IIJA also enhanced funding for the DOE's Advanced Reactor Demonstration Program (ARDP), which aims to accelerate commercialization of advanced reactor technologies. A prior cycle's ARDP funding is already supporting X-energy's demonstration project on the Gulf Coast and TerraPower's project in Wyoming. The IIJA provided an additional $2.5 billion through 2025 for these types of projects.

Several other provisions require the DOE to develop a report on how nuclear energy can contribute to meeting the nation's resilience and carbon-reduction goals, and requires the development of a standard for qualifying "clean hydrogen" from various sources of production, including nuclear power.

### INFLATION REDUCTION ACT

The IRA's focus is to get carbon-reducing projects of all kinds built, and the primary leverage point that Congress used to accomplish this is through tax incentives for private industry. Industry observers have claimed these tax incentives could reduce the cost of new nuclear projects enough to accelerate utility investment in these new technologies.

For the nuclear power industry, those tax incentives include the following:

- Investment tax credit for owners of new carbon-free generation, worth 30% of the amount paid to build a facility.
- A new clean electricity production tax credit for any carbon-free generator that begins construction in 2025 or later, worth at least $25 per MWh of electricity generated.
- Coal-to-nuclear bonus tax credit, offering a 10% addition for new facilities sited in coal and other fossil fuel communities that are affected by the clean energy transition.
- Clean hydrogen production tax credit based on the carbon-intensity of the hydrogen production.
- Nuclear power production tax credit for existing reactors of up to $15 per MWh from 2024 through 2032 to prevent premature closure.

The IRA also aims to bolster domestic nuclear fuel production capabilities. Currently, only around 5% of the uranium used by commercial reactors in the U.S. is domestically sourced; almost all of it comes from countries like Kazakhstan, Canada, Australia and Russia. Similarly, Russia is the leading producer of enriched uranium—supplying nearly 40% of the world's supply in 2020. Following Russia's invasion of Ukraine, many have called on the U.S. to invest in domestic enrichment capabilities.

The issue is even more problematic when considering the high-assay low-enriched uranium (HALEU) fuel, which will be required for many advanced reactor technologies. To support domestic HALEU production, the IRA provided $700 million for the DOE to support enrichment facilities in the U.S.

## Conclusion

While the role of nuclear power in the clean energy transition is not yet fully resolved, recent state and federal policies have created an environment that's more hospitable to nuclear energy than it has been in decades. Decarbonization has become a widely accepted public policy priority and states have begun to chart their course to a clean energy future. These state policies will help determine whether nuclear power plays a prominent role in addressing these challenges over the coming decades.

NCSL Contact:

**energy-info@ncsl.org**

NATIONAL CONFERENCE OF STATE LEGISLATURES

7700 East First Place, Denver, Colorado 80230, 303-364-7700 | 444 North Capitol Street, N.W., Suite 515, Washington, D.C. 20001, 202-624-5400

**ncsl.org**