PURDUE UNIVERSITY

DUKE ENERGY

MAY 2023 | Purdue University and Duke Energy

SMALL MODULAR REACTOR AND ADVANCED REACTOR

Feasibility Study Interim Report

A MESSAGE FROM **PURDUE UNIVERSITY PRESIDENT MUNG CHIANG AND DUKE ENERGY INDIANA PRESIDENT STAN PINEGAR**

A mutual interest in carbon-free, reliable energy brought Duke Energy and Purdue University together to explore the promising technology of small modular nuclear reactors. It has been a groundbreaking collaboration that makes sense – pairing the nation's largest operator of regulated nuclear power plants with one of the country's top nuclear engineering schools. As former Purdue University President Mitch Daniels said when he initiated this collaboration, "We see enough promise in these new technologies to undertake an exploration of their practicality, and few places are better positioned to do it."

Indiana's elected leaders also have recognized the importance of looking for practical solutions to the challenge of our state's transition to cleaner energy. Indiana Gov. Eric Holcomb and legislative leaders such as Indiana Senate Utilities Chairman Eric Koch and Indiana House Utilities Chairman Ed Soliday have supported public policies to advance new nuclear technology. According to the International Atomic Energy Agency, small modular reactors are among the most promising emerging technologies in nuclear power. While still under development, they offer a zero-emissions technology that could help us achieve a carbon-free future with reliable energy 24 hours a day, while also complementing other carbon-free energy sources, such as solar and wind power.

Following the first year of our joint study, we determined that small modular reactor and advanced reactor technology is a potential solution to achieving zero emissions at Purdue University's West Lafayette campus. Additional exploration and work are required around important considerations such as economic benefits, costs, technologies and locations.

Check out the video lecture series online to hear more about the technologies and the associated benefits and challenges of nuclear energy.

The study looked at the feasibility of advanced nuclear technology supplying power to Purdue University, with the excess energy exported to the state's energy grid. Revolutionary in part because of their modular nature, portions of small modular nuclear reactors can be prefabricated off-site, thereby saving time and money in construction. They offer improved safety features and significantly lower costs compared to traditional, large-scale nuclear power plants.

Compiled here is a summary of our study, which looked at some key challenges and opportunities of the potential for advanced nuclear technology to supply Purdue University's as well as the state's long-term power needs.

One of the positive outcomes of our collaboration has been public education. A co-sponsored six-part lecture series, "Understanding Tomorrow's Nuclear Energy," August 2022-February 2023, featured professors and international industry and policy experts who helped advance public understanding of nuclear energy and recent advances in the field. More than 4,900 people participated in the series, either online or in person, demonstrating a high level of interest in the technology and its possibilities for the state.

This report outlines recommendations, including further state and federal policy advocacy and continued public education, as critical next steps. We look forward to continued collaboration and exploration into small modular reactor and advanced reactor technology as a way to progress toward a carbon-free energy future.

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&

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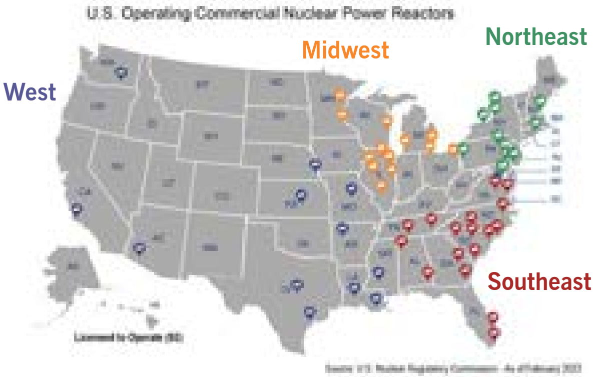
Executive Summary

Purdue University and Duke Energy have formed a groundbreaking partnership to perform a feasibility study on the prospect of using advanced nuclear power to provide the electricity, heating and cooling needs of the Purdue campus and the Indiana grid. The study determined that small modular reactor and advanced reactor technology is a potential solution to achieving zero emissions at Purdue University's West Lafayette campus, and that further exploration should be undertaken.

Electricity from nuclear power plants is currently the only baseload carbon-free source of energy that is safe, reliable and available 24 hours a day (baseload) regardless of weather conditions. While Indiana has a diverse portfolio of energy supply today from traditional coal, natural gas and, increasingly, wind, solar and storage sources, Indiana does not have an operating nuclear energy plant located in the state.

Providing uninterrupted availability of energy at an affordable price while achieving net-zero carbon emissions by 2050 is not possible without new nuclear power plants or other technology advancements. Therefore, considering advanced nuclear technology to replace the fossil fuel-powered generation used today is imperative. Both Purdue and Duke Energy are in pursuit of technology to reduce carbon emissions, making for a natural innovative partnership.



Purdue University and Duke Energy Indiana also have a long history of cooperation and partnership providing for the energy needs of the community in a safe, reliable, affordable and increasingly clean manner. Today, Purdue self-generates electricity, steam and chilled water to serve campus.

Nuclear power plants are the only carbon-free source of energy that is safe, reliable and available 24 hours a day regardless of weather conditions.

Purdue University West Lafayette Campus FY22 Usage

July 2021-June 2022

ELECTRIC:

Total usage: 324,324 MWh

Purdue generated: 149,154 MWh

Purchased from Duke Energy: 175,143 MWh

STEAM:

Total: 3,851,319 MMBtu

Purdue generated: 3,437,550 MMBtu

Purchased from Duke Energy: 413,769 MMBtu*

**Duke Energy CHP Plant came online in March 2022 and accounted for ~40% of the steam usage from March through June.*

As a strategic partner, Duke Energy Indiana supplies Purdue with roughly one-half of campus electric needs. Purdue purchases 40% of the university's steam from an on-campus combined heat and power plant that is owned and operated by Duke Energy Indiana. A 1.6-MW solar plant in the Purdue Research Park is another example of the collaborative Purdue and Duke Energy partnership.

Purdue and Duke Energy have a common objective of reducing greenhouse gas emissions to meet sustainability goals, while prioritizing safe, reliable and affordable energy service. To further that objective, the two organizations partnered on a study in April 2022 to determine the feasibility of using advanced small modular reactor (SMR) and advanced reactor (AR) nuclear technology to meet the long-term energy needs of the university as well as provide excess power to the state's electric grid. SMRs and ARs show great promise due to their advanced safety features, construction savings due to off-site factory production, flexible siting and scalable size. SMRs and ARs also provide community and economic benefits, such as high-wage job creation and increased property taxes that fund local schools and governmental services.

Before delving into what this study represents, let's first describe what it is not. The study is not designed to come to a firm decision on whether to build or where to site an SMR or AR at Purdue University or in the state of Indiana. It is not a formal study of the specific economic benefits that an SMR or AR could provide to the university, local community or state. It is also not an economic analysis of the costs of SMRs or ARs in comparison to other technology choices either for Purdue's electric and steam needs or for Duke Energy Indiana's greater electric service territory.

This study is, however, an important **first step** in the exploration of whether SMR or AR technology is feasible to help meet the needs of Purdue University and Duke Energy Indiana in the 2030s and beyond.

Achieving net-zero carbon emissions by 2050 is not possible without new nuclear power plants or other technology advancements.

The study concludes that SMR or AR technology is a potential option to zero carbon emissions at Purdue University and should be considered to meet the future power needs of Purdue and the Indiana grid. Importantly, for SMR or AR deployment to be successful, the study puts forward policy and funding recommendations to advance research, workforce development, technology demonstration, siting, regulatory reform and tax issues relevant to advancing nuclear energy.

Advanced Nuclear Technology:

Small Modular Reactors and Advanced Reactors

Advanced nuclear reactor technology includes small modular reactors (SMRs) that are cooled by water (known as light-water reactors), like the operating nuclear plants in the U.S. today, and advanced reactors (ARs) that are cooled using molten salts (chloride or fluoride), liquid metal (sodium or lead) or gas (helium) (known as non-light-water reactors). Microreactors are also part of the advanced nuclear energy mix but were not evaluated as part of this study.

SMRs and ARs have many similarities and differences, and their benefits are inherently linked to the nature of their design. Passive safety systems rely on physical phenomena, such as natural circulation, condensation, gravity and self-pressurization, depending on the design of the SMR or AR. Due to higher operating temperatures, some units can be used more efficiently for purposes other than generating electricity, such as providing process steam for industrial applications or to produce hydrogen. This is particularly true for AR technology.

Though ARs show some promise, they currently have more timeline uncertainty than SMRs due to differences in regulatory requirements, technology development and fuel availability.

SMRs have many advantages over today's large commercial light-water reactors. SMRs typically have a power capacity of up to 300 megawatts electric (MWe) per unit, which is about one-third of the generating capacity of traditional nuclear power reactors. Some newer SMR designs have higher generating capacities, with Indiana law defining SMR electric generating capacity as not more than 470 MWe.

Small modular reactors and advanced reactors are safe

Cooled by water, some SMRs will operate like traditional nuclear plants that have a proven safety record and history of operational excellence.

If an event occurs that requires safe shutdown of the reactor, passive safety systems will automatically shut down and continuously cool the reactor without external power or operator action.

Due to their small size and added safety features, emergency planning zones for SMRs and ARs will likely be much smaller than those of traditional nuclear plants and might not extend beyond the site boundary.

Small modular reactors and advanced reactors offer economic benefits.

Due to their smaller size, SMRs and ARs will use more commercially available off-the-shelf equipment, and some components could be prefabricated off-site – making SMRs and ARs easier, faster and more affordable to build.

Small modular reactors and advanced reactors offer operational flexibility.

SMRs and ARs offer operators flexibility to increase or decrease energy output to match customer demand.

In comparison to existing reactors, SMR and AR designs are generally simpler and rely on passive safety response systems, meaning no human intervention or external power is required to shut down the reactor and maintain adequate core cooling for decay heat removal. These increased safety margins significantly reduce, or in some cases eliminate, the potential for unsafe releases of radioactivity to the environment in the unlikely event of an emergency.

Due to their smaller size and added safety features, emergency planning zones for SMRs and ARs are also expected to be much smaller than those of traditional nuclear plants. The U.S. Department of Energy defines an emergency planning zone as a zone identified to facilitate a pre-planned strategy for protective actions during a defined emergency. Depending on siting, emergency planning zones may not be required to extend beyond the plant's site boundary – making locating SMRs and ARs closer to populated areas, including university campuses, possible and more acceptable.

Given their smaller footprint, SMRs and ARs can be sited on locations not suitable for larger nuclear power plants. Prefabricated modules of SMRs and ARs can be manufactured off-site in a factory setting to provide cost and quality control benefits and then shipped and assembled on-site. These innovations are expected to improve efficiency and reduce construction costs compared to traditional nuclear reactors. SMRs and ARs are capable of flexible operations (i.e., load following) to vary their output to match the customer demand. This is important for the reliability and stability of the grid of the future, as more variable renewables like wind and solar become a larger percentage of the energy generation mix.

Some ARs can also provide efficient thermal storage, giving power plant operators flexibility to increase or decrease power output to meet customer needs. When renewable output from solar or wind generation is high, ARs can decrease power output and store the energy to use later, when renewables are not available or when customer demand is high.

Because energy from nuclear plants is carbon-free, current nuclear plant operations avoid the release of millions of tons of carbon dioxide across the U.S. each year. And because nuclear energy is always available even when the sun is not shining and the wind is not blowing, it complements renewables like solar and wind.

Small modular reactors and advanced reactors complement variable renewables like wind and solar.

Siting

A critical milestone in the two organizations' efforts to bring nuclear energy to Indiana will be a robust siting analysis to determine where the technology can be safely and reliably located to meet the needs of the campus and larger community.

As the first stage of this siting exercise, an initial feasibility study was performed to evaluate the critical siting factors for nuclear plants, such as access to water, transmission infrastructure, favorable soil structure, seismic potential and meteorological conditions. Additionally, this study focused on hypothetical site locations, layout and sizing to determine which advanced nuclear technologies might be feasible at conceptual locations on campus, near campus and at remote sites.

On-campus sites: On-campus sites would allow Purdue to transition from its current reliance on fossil fuel-produced steam, chilled water and electricity to providing the same service using carbon-free nuclear technology. However, the study determined that on-campus sites are not feasible for the location of SMR or AR technology, primarily due to space availability, flooding, ground liquefaction concerns and proximity to the airport.

Near-campus sites: Near-campus sites could potentially allow Purdue to transition its existing steam, chilled water and electricity service to carbon-free nuclear technology. Based on preliminary data, the feasibility study finds that near-campus sites could be suitable for advanced nuclear technology. The study identified access to suitable water resources, existing transmission infrastructure, favorable soil structure and sufficient distance between potential sites and populated areas. Further, with the leading advanced nuclear technology designs, passive safety features and expected smaller emergency planning zone requirements, gaining community and stakeholder support of a near-campus site is more likely than an on-campus site.

On-campus, near-campus and remote sites offer pros and cons. The most viable site options are either near-campus or remote.

Remote sites: Based on preliminary data, the study found remote siting opportunities in the West Lafayette area that could be suitable for SMR or AR technology. Remote sites have access to suitable water resources, existing transmission, favorable soil structure and sufficient distance between potential sites and populated areas. An SMR or AR at a remote site would not allow for direct steam delivery to power Purdue's existing steam and chilled water systems. To meet its long-term sustainability goals, Purdue would need to transition to electric boilers and chillers and contract with Duke Energy Indiana in order to use carbon-free electricity.

Like near-campus sites, remote sites are more likely to gain community and stakeholder support because ARs offer passive safety features and are expected to have smaller emergency planning zone requirements. Remote sites also provide much more flexibility in terms of sizing and technology selection, and they also offer economies of scale, which allow multiple units to be built on one site. Taking advantage of this flexibility, remote sites could provide carbon-free electricity to Indiana at large, in addition to the Purdue campus.

Ultimately, future in-depth site evaluations, community engagement, stakeholder education and support, and formal planning would be needed to identify appropriate SMR or AR sites that could potentially meet the long-term energy needs of Purdue University and Duke Energy.

ADVANTAGES OF VARIOUS SITES

Site Characteristics	On-Campus Sites	Near-Campus Sites	Remote Sites
Supports easy transition from fossil fuels to carbon-free technology for Purdue	✓	✓	X
Has access to water	✓	✓	✓
Has access to transmission infrastructure	✓	✓	✓
Has enough physical space	X	✓	✓
Has favorable soil structure, e.g., no flooding or earthquake concerns	X	✓	✓
Has minimal impact to local population and possibility of community and stakeholder support	X	✓	✓
Offers flexibility, e.g., size, technology selection and design, economies of scale, etc.	X	X	✓

✓ = a criterion that's achievable   X = a criterion that is not achievable

Technology and Timing

The feasibility study team performed a review of the leading reactor technologies to understand the designs and the attributes needed in siting. The review included technologies associated with some of the more mature advanced nuclear designs, but no specific technology was selected. Instead, the technology evaluation shows how some of the current designs could support or present challenges with the various conceptual siting options. A more formal and fulsome technology review will be needed to choose an SMR or AR technology once a site is determined and a decision to proceed is made.

Technologies that are expected to be commercially viable in 2035-2040 were reviewed, including both light-water and non-light-water designs.

Light-water SMR designs: Light-water SMRs use similar technology as the existing U.S. nuclear reactor fleet, though SMRs are scaled down in size and power and allow for modularity of fabrication and installation. SMRs are also designed with enhanced passive safety features that allow the plant to shut down and cool down automatically without the need for an external power source or an operator taking action.

Light-water reactors use readily available standard-assay low-enriched uranium (LEU) for fuel, which is up to 5% enriched uranium-235. This fuel is used in the existing fleet of commercial reactors, providing confidence fuel manufacturers can manage the fuel supply for these designs.

It is anticipated that SMRs would store their used nuclear fuel on-site using dry cask storage facilities like those already in operation at existing nuclear reactor sites in the U.S.

All U.S. nuclear plants store used nuclear fuel in intermediate fuel pools or dry casks because the U.S. does not have a licensed federal long-term storage repository for the nation's used nuclear fuel.

Dry cask storage facilities are safe, proven and licensed by the U.S. Nuclear Regulatory Commission (NRC). Used fuel assemblies are sealed in steel canisters housed in robust concrete structures without power supplies, cooling water, pumps or motors. The self-contained facility is designed to withstand human-made and natural disasters, including tornadoes and hurricanes.

SMR designs are expected to have fewer technical hurdles in gaining approval from the NRC due to the similarity in their base technology with the current operating nuclear fleet. This allows for an earlier deployment for SMRs, with the first units in the U.S. expected to come online by the end of this decade.

Non-light-water advanced reactor (AR) designs: Many design variations for ARs use different methods for cooling other than water. Some AR technologies use molten salts, liquid metal or gas for core cooling. Some operate at higher temperatures, offer thermal storage options and have advanced fuel designs for enhanced safety.

Thermal storage integrated with nuclear power is expected to be a valuable service as the grid transitions to more variable renewable energy sources like wind and solar. Thermal storage will allow utilities to increase power output when renewables are not available or when customer demand is high. Non-light-water ARs are also designed with enhanced passive safety features that allow the plant to shut down and cool down automatically without the need for an external power source or an operator taking action.

Most ARs use high-assay low-enriched uranium (HALEU), which is greater than 5% and less than 20% enriched uranium-235. Rosatom, a Russian state nuclear company, provides approximately 35% of the global commercial supply of low-enriched uranium (LEU) and is the sole source for HALEU.

AR vendors in the U.S. had plans to source HALEU from Rosatom for their demonstration plants; however, concerns related to providing uninterrupted availability of energy at an affordable price and the reliability of the AR fuel supply have changed this approach. The U.S. Department of Energy (DOE) has committed to source the initial fuel loads for two advanced reactors in its Advanced Reactor Demonstration Program (ARDP) using government supplies of HALEU. In addition, the Inflation Reduction Act (IRA) appropriated approximately $700 million to accelerate the availability of commercially produced HALEU from domestic sources. The DOE is working with U.S. fuel-enrichment facilities to support HALEU development. However, building capacity to produce enough fuel to supply future reactor deployments will take a few years.

Some ARs offer advanced fuel designs that provide additional safety features. TRISO, or tri-structural isotropic, fuel has been tested to very high temperatures and cannot melt down in any postulated operating event. TRISO fuel uses HALEU. Therefore, these designs will require a significant build-out of enrichment facilities to supply the fuel that will be needed in the late 2020s and 2030s to serve the expected demand of new AR technologies.

In terms of used nuclear fuel storage, ARs have varying designs for long-term on-site storage that are being integrated into the plant development. The required NRC emergency planning zone for these ARs is also expected to be smaller and potentially only encompass the physical plant site, allowing closer proximity to more populated areas. Because these newer non-light-water reactor technologies are different from the licensed nuclear plants today, they are expected to need more extensive NRC review. Thus, the licensing path for first-of-a-kind light-water SMRs will have an initial timeline advantage over the non-light-water AR designs.

The licensing path for first-of-a-kind small light-water modular reactor designs will have an initial advantage over advanced reactor designs.

Light-water small modular reactors will operate like traditional nuclear plants that have a proven safety record and history of operational excellence.

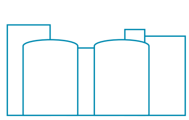
PROS AND CONS OF SMR AND AR DESIGNS

Designs	Pros	Cons
Light-water small modular reactors	Safe and proven technology Standard fuel Accessible and stable fuel supply Enhanced passive safety features Smaller emergency planning zones Fewer technical and regulatory hurdles because design mirrors that of existing nuclear plants	No thermal storage options
Non-light-water advanced reactors	Offers thermal storage options Enhanced passive safety features Smaller emergency planning zones Advanced fuel designs using TRISO fuel will not melt in any hypothesized emergency	High-assay low-enriched uranium fuel source not readily available in the U.S. and development will take a few years Design differences call for more extensive technical and regulatory review processes to license

Technology siting and timing considerations: Remote sites will not have the same restrictions in physical size as those on campus or near campus; as such, either the SMR or AR designs would be feasible. Remote sites have the advantage of allowing a multi-unit plant for economies of scale and the potential addition of thermal storage.

For on-campus and near-campus sites, and sites closer to more heavily populated areas, AR designs are better suited due to their physical footprint, capacity size, reduced emergency planning zone and passive safety features. However, these technologies are still being developed and will require additional review from the U.S. Nuclear Regulatory Commission. As such, it is anticipated that the soonest an AR could serve the Purdue/West Lafayette area would be in the late 2030s.

For both technology design types, community engagement efforts coupled with developing a strategy to provide long-term used fuel storage would help advance deployment of SMRs and ARs.



Remote sites are best suited for small modular reactors or advanced reactors – and potentially offer economies of scale and thermal storage.

Advanced Nuclear Technologies

This table describes leading small modular reactor and advance reactor designs that are expected to be in service in the U.S. between 2026 and 2030, including designs that are part of the DOE's ARDP.

CURRENT LEADING SMALL MODULAR REACTOR AND ADVANCED REACTOR DESIGNS

Developers	Technologies	DOE Funding	Utilities	Locations	Sizes	Projected Year Online (First Unit)
Prototype Plants						
TerraPower with Southern Company	Molten Chloride Reactor Experiment (MCRE)	ARDP* Risk Reduction	Southern Company	Idaho Falls, Idaho (INL)	< 1 MWe	2026
Kairos Power	KP-FHR Reactor Fluoride Salt-Cooled "Hermes Reactor"	ARDP* Risk Reduction	None	Oak Ridge, Tennessee	15 MWe	2026
First-of-a-Kind Plants						
GE Hitachi	BWRX-300 Reactor Light-Water-Cooled (BWR)	None	Ontario Power Generation (OPG)	Clarington, Ontario (Darlington site)	300 MWe	2029
X-energy	Xe-100 Reactor Helium Gas-Cooled	ARDP* Demonstration	None	Gulf Coast Dow Chemical Facility	320 MWe (Four reactors at 80 MWe each)	2029
NuScale	VOYGR Reactor Light-Water-Cooled (PWR)	Carbon-Free Power Project	UAMPS	Idaho Falls, Idaho (INL)	462 MWe (Six reactors at 77 MWe each)	2029
TerraPower & GE Hitachi	Natrium Reactor Liquid Sodium-Cooled	ARDP* Demonstration	PacifiCorp	Kemmerer, Wyoming	345 MWe Up to 500 MWe with thermal storage	2030

**U.S. Department of Energy's Advanced Reactor Demonstration Program*

Another authoritative resource for worldwide SMR technologies was recently published by the Nuclear Energy Agency (NEA) – the NEA Small Modular Reactor Dashboard.[1] The NEA identifies 21 SMR technologies, including a 470 MWe SMR in development by Rolls-Royce, and plans more additions in the coming months, demonstrating how the industry is continuing to evolve.

1 NEA (2023), Nuclear Energy Agency (NEA) - The NEA Small Modular Reactor Dashboard (oecd-nea.org).

Safety Considerations

SMRs and ARs have designs with significant safety improvements over currently operating nuclear plants. When these improvements are combined with their smaller size and reduced radioactive material, the results are that SMRs and ARs are many orders of magnitude safer than the current fleet when evaluated using the NRC-approved methodology for calculating the potential for core damage.

SMR and AR designs advance the already proven safety features that are part of the current fleet, including systems that automatically regulate pressure, isolate the pressure vessel and otherwise protect against pipe rupture failures.

Additionally, SMRs and ARs feature passive safety systems, which require no human intervention or external power in the unlikely event of an emergency. The following are some methods that are being employed to achieve this improved safety performance:

- Cooling by natural circulation – Nuclear power plants continue to produce significant heat from nuclear reactions, known as decay heat, even after they are shut down. The new SMR and AR designs use natural circulation or convection as the means for decay heat removal. Therefore, although diesel generators are typically used for backup power for light-water reactors, no AC or DC power equipment is deemed critical for safety.
- Low-pressure coolants – Current nuclear reactors operate at high pressures to optimize thermodynamic properties of water for steam production. However, some ARs use coolant that can operate at lower pressures. These coolants eliminate the high-energy, pipe-break events that must be designed for in existing light-water reactors.
- TRISO fuel – In tri-structural isotropic particle fuel design, each ~1mm uranium fuel kernel is encapsulated by three layers of carbon- and ceramic-based materials that act as the containment structure for radioactive material. This fuel design has been proven not to melt under any postulated event and also acts as containment to eliminate need for a containment building.
- Deeply embedded reactor building – Many SMR and AR designs have the reactor building sited below ground level, thereby making it inherently more resistant to security hazards.

Today's operating nuclear reactors have been safely storing used fuel on-site for decades. SMRs and ARs are being designed to have on-site storage and most are expected to have less used fuel than today's larger plants. However, federal policy for a long-term used-fuel storage solution would be helpful in gaining public confidence in the ongoing safety of new nuclear sites.

Cost to Build

No advanced SMRs or ARs have been built in the U.S. to date so no precedent for these new technologies exists to provide confidence in a cost estimate at this time. Due to the small size and modular construction, SMRs and ARs are expected to cost significantly less as they are developed over time than the historical, large light-water projects. As with most new technologies, the first-of-a-kind plants are expected to cost more than future builds, with the costs decreasing as lessons learned are incorporated and the designs are refined and finalized. Therefore, allowing the lead demonstration plants to be completed first lowers the risks for fast followers.

While capital investment for SMRs is anticipated to be higher than for traditional fossil fuel plants, when considering generation options, it is important to examine the overall value a nuclear generation project can bring to the state – benefits like safe, reliable, stable, controllable, home-grown and carbon-free energy – in addition to the central concern of affordability. Much of the cost of nuclear energy is in the labor required to operate the plants safely, rather than in ongoing fuel costs. This boosts the benefits to the local community with high-paying and sustainable employment.

Further, as the first-of-a-kind demonstration projects come online and lessons learned are incorporated into next generation projects, clarity around capital cost estimates will continue to evolve. As the Purdue and Duke Energy partnership on the feasibility of nuclear SMRs and ARs continues after this interim report, more detailed analysis of technology and capital costs is expected. It is simply too soon in the technology's development to provide a reliable estimate of costs.[2]

There has also been progress on the policy front to improve the overall economics of nuclear energy. The 2022 Inflation Reduction Act provides significant incentives for any plant that reduces

2 A recent report details a broad range of cost estimates from current technology providers. The Nuclear Innovation Alliance's "Modeling Advanced Nuclear Energy Technologies, Gas and Opportunities" recommends using an initial capital cost range of $3,600-$7,500/kWe in 2020 dollars. Using this cost range, a 300-MWe plant could have initial capital costs between $1.1 billion and $2.25 billion. Nuclear Innovation Alliance (2023), Modeling Advanced Nuclear Energy Technologies: Gaps and Opportunities | NIA (nuclearinnovationalliance.org).

Small modular reactors and advanced reactors don't exist in the U.S. today; therefore, costs are indeterminate. First-of-a-kind plants cost more than future builds. A prudent strategy is to be a fast follower to take advantage of completed designs and lessons learned.

greenhouse gas emissions and is placed into service after Dec. 31, 2024, by way of the clean energy production tax credit (PTC) or investment tax credit (ITC). These tax credits cannot be claimed until the plant is placed into service and will phase out in either 2032 or when the U.S. annual greenhouse gas emissions from electrical generation have been reduced 75% from 2022 levels, whichever is later. The 75% reduction is expected to occur much later than 2032, but a new plant may need to be online by the early 2040s to take full advantage of these credits.

Additionally, significant increases in the credits are provided if a project meets prevailing wage and apprenticeship standards, is located in an energy community (e.g., a retired coal site, decommissioned nuclear site or brownfield site), a low-income community or on tribal land, or meets a domestic content standard (e.g., a requirement that project iron and steel products are produced in the U.S.).

In addition to the cost to construct the plant, the cost to license a plant is significant. A combined construction and operating license application takes approximately two years to develop and another three years for the U.S. Nuclear Regulatory Commission (NRC) to review and approve.

One way of lowering licensing risk is to obtain an early site permit (ESP). The ESP application allows for upfront resolution of environmental and site safety issues for a selected site before choosing a technology or committing to build a new nuclear plant. An ESP takes approximately four years to obtain, with two years to develop and another two years for NRC reviews. The estimated cost to pursue an ESP application is up to $75 million. More details about the ESP and the licensing process can be found in the Licensing and Regulatory Approvals section of the report.

As the first-of-a-kind projects that are in progress or being planned move forward, the final designs of those technologies will become more complete. A design that has been through the NRC licensing process and approved can then be used in a site-specific application, which will reduce the costs associated with both the licensing and construction of a future new nuclear plant. Duke Energy will remain engaged in supporting industry efforts to advance the development of SMR and AR technologies and will work to improve regulations and policies to minimize costs, if a decision to proceed is made.

Small modular reactors and advanced reactors are a potential option to help Purdue University achieve zero carbon emissions.

Environmental Drivers and Impact

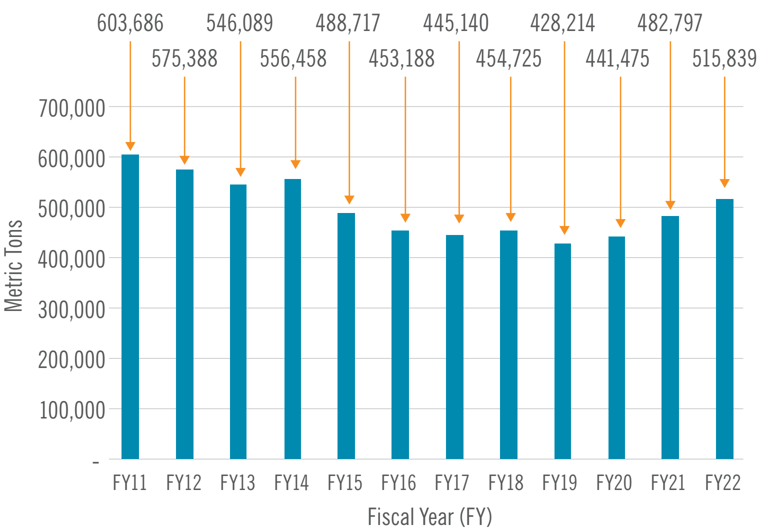
The impetus of the feasibility study is a desire by Purdue University and Duke Energy to achieve a lower-carbon footprint through reduced reliance on fossil-fueled generation while providing safe, reliable and affordable energy service to the campus and Duke Energy Indiana customers.

For Purdue, the use of nuclear energy could eliminate the direct carbon dioxide (CO_2) emissions from its production of electricity, steam and chilled water. Figure 1 shows progress the university has made on reducing greenhouse gas emissions from fiscal years 2011-2022. The increase in greenhouse gas emissions from FY20-FY22 is the result of multiple factors, including increased ventilation within buildings as a health and safety measure to combat COVID-19 and a continued growth in campus population and square feet. Small modular reactors and advanced reactors could help make zero carbon dioxide emissions a reality for the campus.

FIGURE 1*

*Revised 5/16/2023

Purdue University | West Lafayette Campus
Greenhouse Gas (GHG) Emissions in Metric Tons



As Duke Energy Indiana continues its clean energy transition, the energy that Purdue purchases from Duke Energy Indiana will also increasingly move toward carbon neutrality.

For Duke Energy Indiana, the addition of nuclear power to its portfolio would help enable the retirement of coal-fired generation by the mid-2030s, while complementing the company's growing portfolio of renewables like solar and wind generation. A controllable, dispatchable carbon-free resource is needed to ensure the reliability of the grid, and nuclear can help fill that role, along with other technology advancements, such as hydrogen fuel, carbon capture utilization and storage, and advanced long-duration energy storage. Energy security is also enhanced by the addition of home-grown nuclear power.

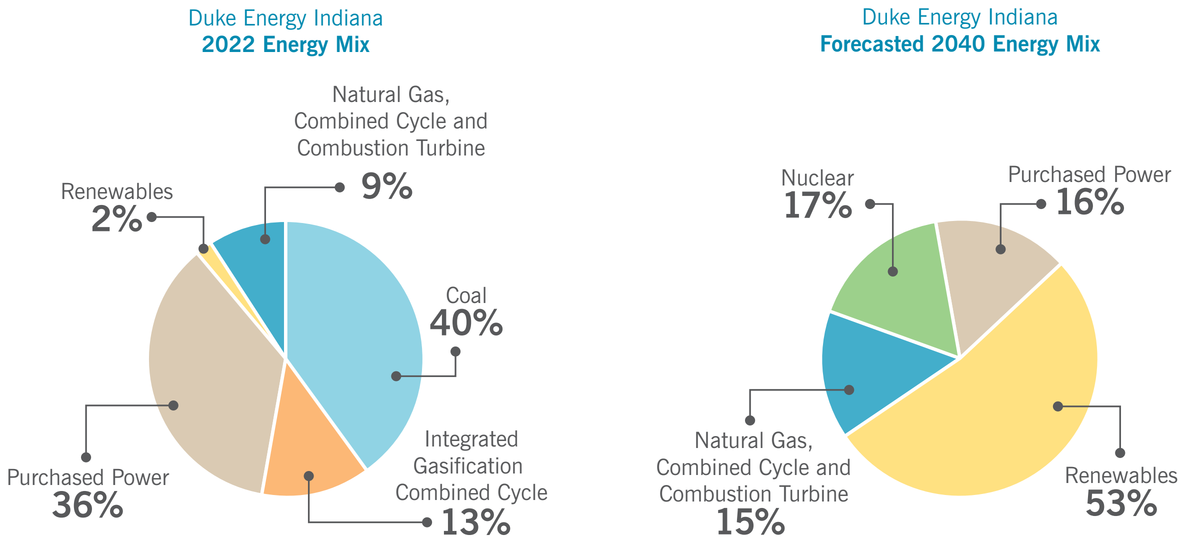
Duke Energy has set ambitious clean energy transformation goals, striving to achieve a 50% reduction in CO_2 emissions (from 2005 levels) from electricity generation by 2030 and net-zero CO_2 emissions by 2050. In the company's North Carolina service territory, the 2030 carbon reduction goal is set at 70% (from 2005 levels), established by North Carolina House Bill 951.

The company's transition plan calls for balancing reliability, affordability and environmental sustainability while collaborating with stakeholders before making decisions.

Some of the plan's strategies include:

- Adopting an "all of the above" generation approach for carbon reduction that provides a diverse energy portfolio of new nuclear generation, renewables like wind and solar, and natural gas as a bridge until technology advances.
- Ensuring the clean energy transition happens at the lowest cost to customers, with equal or greater reliability.
- Prioritizing existing plant sites for replacement generation, employing our existing transmission, workforce and infrastructure.
- Creating jobs and a new tax base in communities across Indiana as the company builds new infrastructure and invests in new technologies.
- Investing in carbon-free generation to help employers meet their sustainability commitments, attracting new jobs and facilitating industry expansions in the state.
- Maximizing the Inflation Reduction Act, Infrastructure Investment and Jobs Act and any other opportunities to save customers money.

FIGURE 2



In addition to the environmental benefits provided by carbon-free nuclear energy, the team reviewed the requirements for an environmental report that would be submitted to the U.S. Nuclear Regulatory Commission (NRC). The NRC follows the National Environmental Policy Act (NEPA) by reviewing and evaluating the potential environmental impacts and benefits of proposed plants.

The components of an environmental report include the following:

1. Environmental description: Water, ecology, socioeconomics, geology, meteorology, air quality and noise
2. Plant description: Water use, cooling system, radioactive and non-radioactive waste management systems, power transmission, transportation of radioactive materials, construction activities and workforce characterization
3. Environmental impacts of construction: Land use, water-related, ecological, socioeconomic, radiation exposure, measures and controls, and cumulative impacts
4. Environmental impacts of station operation: Land use, water-related, cooling system, radiological impacts of normal operation, environmental impacts of waste, transmission system, uranium fuel cycle and transportation, socioeconomics, decommissioning, measures and controls, and cumulative impacts
5. Environmental measurements and monitoring programs: Thermal, radiological, hydrological, meteorological, ecological, chemical and summary of monitoring programs
6. Environmental impacts of postulated accidents involving radioactive materials, design-basis accidents, severe accidents, severe accident mitigation alternatives and transportation accidents
7. Need for power
8. Alternatives: No-action alternative, energy alternatives, alternative sites and alternative plant systems
9. Environmental consequences of the proposed action: Environmental justice screen, unavoidable adverse environmental impacts, irreversible and irretrievable commitments of resources, relationship between short-term uses and long-term productivity of the human environment and benefit-cost balance

The environmental impact to a potential new nuclear generation site has not been assessed, and any location will be thoroughly evaluated if a decision to move forward is made.

This study identified the Greater Lafayette area groundwater aquifer as a valuable natural resource, providing drinking water for the community and supplying local industries with water. Some SMR and AR designs require below-grade reactor construction and placement, which will require special considerations to ensure the aquifer is not impacted.

Licensing and Regulatory Approvals

Key licensing and regulatory approvals would be required from the U.S. Nuclear Regulatory Commission, Indiana Utility Regulatory Commission, Indiana Department of Environmental Management, Department of Natural Resources and the Midcontinent Independent System Operator interconnection process.

U.S. Nuclear Regulatory Commission (NRC)

The NRC currently has a two-step (10 CFR 50) and a one-step (10 CFR 52) licensing process, and another option is under development (10 CFR 53). Each process is estimated to take five years to complete, with two years for development and three years for NRC review and approval.

The two-step process (Part 50) consists of obtaining a construction permit first and then requesting an operating license as the plant is under construction. This option allows for the project to be online as soon as possible but carries higher risk for the licensee. That is because construction activities would be underway (a significant capital investment) prior to receiving finality on the regulatory decision related to safety and the environment.

The one-step licensing process (Part 52) consists of requesting approval of a combined construction and operating license at the same time. This approach allows early resolution of safety and environmental issues before field work begins. This option also provides the opportunity to shorten the overall construction timeline and reduce project risk by delaying field activities until the design is completed and all regulatory approvals are received.

Permitting Basics and Considerations

The siting, permitting, regulatory approval and community engagement process for any new advanced nuclear project is complex – requiring support from local, state and federal decision-makers.

Timing, design completeness, risk tolerance and cost will all be considered when selecting which regulatory option would best support a new nuclear generation project.

CONCEPTUAL NEW NUCLEAR GENERATION TIMELINE

The below illustration shows milestones associated with a Part 52 licensing process that takes about 10 years to complete.

U.S. Nuclear Regulatory Commission (Cont.)

A new licensing process (Part 53) is being designed for advanced nuclear reactors, which considers the lessons learned from the one-step and two-step processes to ease the regulatory burden and potentially reduce the timeline. However, the new process is not expected to be in place until mid-2025. As such, the new advanced nuclear technologies that are expected to be the first to be built will likely use either the existing Part 50 or Part 52 process.

The NRC has developed methods to reduce the regulatory risk and increase the efficiency of the process through its early site permit, limited work authorization, design certification, standard design approval and licensing topical reports as optional parts of the licensing process. Each can play a part in reducing the regulatory risk, but the design certification, standard design approval and licensing topical reports are part of technology development and will be dependent on the reactor vendor to accomplish.

If a decision is made to move forward with a project, regulatory options will be evaluated to determine the best path forward. Timing, design completeness, risk tolerance and cost will all contribute to the path chosen.

Indiana Utility Regulatory Commission (IURC)

The IURC must approve construction of new generating facilities in the state through its certificate of public convenience and necessity (CPCN) process (Ind. Code 8-1-8.5 et seq). In reviewing a petition for a CPCN, the IURC considers the applicant's current and potential arrangement with other electric utilities for the interchange of power, the pooling of facilities, the purchase of power and joint ownership of facilities. The IURC also considers other methods for providing reliable, efficient and economical electric service, including the refurbishment of existing facilities, conservation, load management, cogeneration and renewable energy sources.

The IURC must determine that the applicant has provided the best estimate of construction cost and has a need for the capacity consistent with the statewide or utility-specific resource plan. For larger generating plants of 80 megawatts or more, the IURC must find the costs are the result of competitively bid engineering, procurement or construction contracts. If the applicant is an electricity supplier, the IURC will also confirm that the applicant accepted bids for the construction of the proposed facility. Finally, the IURC must consider the factors of reliability and whether the applicant solicited competitive bids to obtain purchased-power capacity and acquire energy from alternative suppliers.

For the construction of SMRs, the IURC must consider whether the nuclear unit will replace an existing Indiana coal or natural gas facility and whether the unit will be located on the same site or near the existing facility to be replaced. The IURC will also consider the potential opportunities to use land and existing infrastructure, facilities already owned or under the control of the public utility or facilities that create new employment opportunities for displaced workers. The IURC may grant a CPCN for locations other than those described above.

The IURC may not grant a CPCN unless the applicant for an SMR provides its plan to apply for required licenses from the NRC, Environmental Protection Agency and Indiana Department of Environmental Management or another relevant state or federal agency. The utility must agree to provide the IURC various notices and reports sent to the NRC and follow NRC rules related to storage of used nuclear fuel and high-level radioactive waste.

Once a CPCN is issued, a utility shall recover through rates the actual costs the utility has incurred in reliance on the CPCN, absent a finding of fraud, concealment or gross mismanagement.

The Indiana General Assembly recently passed legislation that provides various financial incentives for utilities to invest in SMRs, including timely cost recovery during construction and operation of the plant and other financial incentives as proposed by the utility and approved by the IURC.

Finally, the IURC would have jurisdiction to approve any special contract related to an SMR that would serve the Purdue campus with electricity or steam.

Environmental Permits and Approvals

Various environmental permits will be required for the operation of SMRs in Indiana, requiring approvals from environmental regulators.

Permitting associated with the siting, licensing and construction of SMRs in Indiana will include comprehensive efforts to satisfy federal, state and applicable local regulatory requirements aimed at the protection of the environment and health and safety of the public. At the federal level, permitting and licensing pursuant to the NRC includes an early site permit (ESP) application, if an ESP path is chosen, and an environmental report as part of the construction or operating license applications.

Other federal permits include a National Environmental Policy Act (NEPA) review, which includes environmental impact statements; U.S. Army Corps of Engineers permits for any dredge or fill activities in waters of the U.S.; and an evaluation of rare, threatened and endangered species and migratory birds under the auspices of the U.S. Fish and Wildlife Service.

The Indiana General Assembly passed legislation that provides various financial incentives for utilities to invest in small modular reactors, including timely cost recovery during construction and operation of the plant.

The U.S. Environmental Protection Agency will govern the development of a spill prevention, control and countermeasures plan for the management of oil storage. A facility response plan may also be required if certain thresholds of oil will be present on-site. In addition, permitting may be required from the Federal Aviation Administration for structures exceeding certain height thresholds.

At the state level, numerous permits must be obtained from the Indiana Department of Environmental Management (IDEM), including Title V construction and operating permits for air emissions, National Pollutant Discharge Elimination System (NPDES) construction and operating permits for water management and discharges, cultural resource assessments and various construction management permits. The IDEM may also require permitting pursuant to the Indiana Environmental Policy Act in conjunction with the federal NEPA process. In addition, construction in floodway permits must be obtained from the Indiana Department of Natural Resources (IDNR) as well as permits for water well construction abandonment. IDEM also requires wetlands evaluations, and other state-level agency mandates may be required by the Indiana Department of Transportation (INDOT).

Midcontinent Independent System Operator (MISO)

To connect to the transmission grid, a generator interconnection agreement from MISO will be required for any SMR. MISO conducts an annual study of all generator interconnect requests and determines what grid network upgrades are required to interconnect the generator to the transmission grid.

Any network upgrade costs are the responsibility of the SMR owner, in addition to any costs required to physically interconnect the SMR to the grid, e.g., transmission line expansion and substation upgrades. The interconnection study process is designed to be completed in approximately 16 months, but more recent experience has demonstrated a two- to five-year timeline. The ultimate costs of interconnecting to the grid are not known until a resource has gone through the entire study period and been provided a generator interconnection agreement.

A variety of local, state and federal entities will be involved in the environmental permitting process to build and operate a small modular reactor in Indiana, including (but not limited to):

✓	**Approvals Needed Include:**
	U.S. Nuclear Regulatory Commission
	U.S. Army Corps of Engineers
	U.S. Fish and Wildlife Service
	U.S. Environmental Protection Agency
	Federal Aviation Administration
	Indiana Department of Environmental Management
	Indiana Department of Natural Resources
	Indiana Department of Transportation
	Midcontinent Independent System Operator

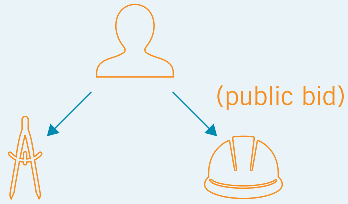
Construction and Workforce Development

Project Construction Methods

The feasibility study reviewed various construction methods including design-bid-build, design-build, design-negotiate-bid and construction manager-at-risk. The design-bid-build method is the most traditional project delivery method. With this method, the owner hires an architect who completes the design and after bidding hires a contractor who completes construction.

Any of these methods could potentially be used for the construction of a nuclear plant. As the new SMR designs take hold, it is likely that new project construction and procurement methods will be developed and tailored to account for factory production and to reduce project delivery timelines and overall project construction costs.

Design-Bid-Build

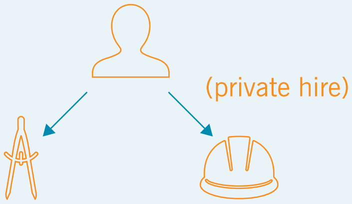


Owner hires architect; owner publicly bids work to hire contractor

Design-Build

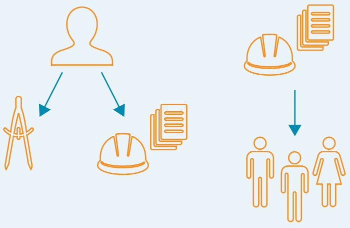
Owner hires contractor; contractor hires architect

Design-Negotiate-Bid



Owner hires architect; owner hires contractor privately

Construction Manager-at-Risk



Owner hires construction manager; construction manager hires subcontractors; owner hires architect

Workforce Development

Skilled workforce and industrial capacities for new nuclear reactors appear to be in short supply globally. In the U.S., this problem may be even more critical. Nearly four decades of minimal activity in designing and constructing new nuclear power reactors has resulted in a dearth of skilled technicians and engineers. Though interest in new nuclear and related areas of manufacturing has increased in recent years, addressing the shortage of nuclear workers is a critical priority for building any new advanced nuclear power plants.

The construction and operation of an SMR or AR project will require a skilled workforce. A project could create as many as 1,000-2,000 temporary construction jobs and last for six to 10 years, depending on the reactor design and the number of units built. Workforce needs would ramp up over two years, maintain at peak for three or more years and then decrease to normal operational levels over one to two years. If multiple SMR units are being built at the same site, a 12- to 18-month staggered construction schedule would require the full construction workforce for an extended period.

Permanent operating staff levels vary widely depending on the SMR or AR design. For a single 300- to 350-megawatt SMR or AR, 100-250 employees would be needed. For a bundle of SMR or AR units totaling 1,000-1,400 megawatts, the projected staffing would be 250-500, depending on the design selected.

Nuclear energy jobs create a unique opportunity for retaining and retraining coal plant workers as utilities make the coal-to-nuclear transition. A nuclear plant provides an opportunity for high-paying and sustainable employment for local communities, with much of the operational costs being labor-related, as opposed to fossil fuel plants, which have higher fuel costs. Thus, the long-term economic benefits of nuclear plants (e.g., jobs and tax base) remain in the local community.

Workforce Development Benefits of SMRs and ARs

1. Small modular reactor and advanced reactor projects provide economic benefits by creating high-wage jobs.

2a. Building multiple SMRs or ARs at one site would generate 1,000-1,200 megawatts of clean energy.

2b. This would create about 250-500 permanent high-wage jobs.

2c. It would also create 1,000-2,000 temporary construction jobs for six to 10 years, depending on the design selected and staggered construction schedule.

3. Purdue University is uniquely positioned to train and educate the next generation of nuclear plant workers through its top engineering and science programs.

A 2022 U.S. Department of Energy study indicates that SMRs could create an incremental 180 jobs in fields such as nuclear and electrical engineering, operations and maintenance, security, leadership, training and development.[3]

Universities and community colleges, of course, will play a vital role in providing skilled workers for an operating nuclear plant. In addition to the above skill sets, specialized training would be valuable to nuclear plant workers for these positions:

- Heating, ventilation and air conditioning (HVAC) technicians
- Welders
- Electricians
- Instrumentation technicians
- Health safety representatives
- Information technology technicians
- Health physics (radiation) specialists

The university has one of the nation's top nuclear engineering programs – and the first and only nuclear reactor being used for research and education in Indiana. The university also has many other closely related engineering and science programs. Purdue is uniquely positioned to help educate and train a new nuclear workforce. Some of the major programs at Purdue University that could fulfill this need include:

- College of Engineering: nuclear, civil, construction, mechanical, materials, electrical, computer and industrial engineering
- Purdue Polytechnic Institute
- College of Health and Human Science: health science

Pursuing SMR or AR technology at Purdue would solidify Purdue as a leading-edge nuclear research university while providing unprecedented ongoing support and training opportunities for its technical programs for future generations.

3 Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants, U.S. Department of Energy Systems Analysis and Integration, J. Hansen, W. Jenson, A. Wrobel (INL) N. Stauff, K. Biegel, T. Kim (ANL) R. Belles, F. Omitaomu (ORNL) Sept. 13, 2022, INL/RPT-22-67964, DOE/ID-Number (inl.gov), **p. 65**.

Cogeneration Considerations

Purdue's energy and utility system utilizes district heating and cooling where steam and chilled water produced at a centralized location are distributed and used to heat and cool campus buildings.

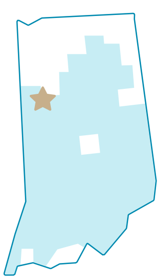
From July 2021-June 2022, Purdue's West Lafayette campus used 3.85 million MMBTU of steam energy and 324,000 MWh of electricity produced at the Wade Utility Plant and the on-campus Duke Energy combined heat and power plant. The steam was used for campus heating and chilled water production in addition to generating 149,000 MWh of electricity (46% of the total) throughout the same time period. Purdue's peak usage is 62MWe and 640kpph for electricity and steam, respectively.

The cogeneration of process steam in addition to electricity is a possibility in an SMR project depending on the proximity of the plant to the location where the steam is needed. Cogeneration is only an option for potential on-campus and near-campus SMR sites. For these scenarios, the plant would be sized to exceed the long-term projected peak demand of the campus for both steam and power, which is about 300 megawatts. Projections of future growth in demand show that an SMR or AR could be sized to fit future campus needs with some excess capacity. The plant could generate electricity as a baseload unit for power 24 hours a day, and the power that is not supplied to campus could be supplied to the grid. All steam would be used to supply campus needs for electric power generation, heat and chilled water production. In this scenario, Purdue would anticipate being a direct off-taker from the plant for both electricity and steam.

Cogeneration at Purdue

Purdue's Wade Utility Plant is a combined heat and power (CHP) plant that uses cogeneration to make the most of fuel by producing thermal energy and power concurrently, which results in lower amounts of greenhouse gases than if they were produced separately.

Boilers produce steam, which is used to provide heat and hot water to campus. Before the steam is distributed to campus, it is used to produce electricity and chilled water.



Purdue University West Lafayette campus

Duke Energy Indiana's service territory

Potential Plant Size and Cost Drivers

For remote-site scenarios, Purdue's campus consumption needs would generally not be a factor in sizing the plant. Duke Energy Indiana's economics will be most favorable with the largest practical SMR or AR, or multiple SMRs or ARs, for a given site.

Purdue's current peak demand could increase by about 200 megawatts if existing fossil-fuel boilers are replaced with electric boilers. The peak electric use would shift to the winter season instead of the summer season. Purdue could potentially work with Duke Energy Indiana to be a virtual off-taker of the carbon-free power produced by SMRs or ARs at a remote site. Under the remote-site scenario with Purdue installing electric boilers, additional substation capacity would be required for the campus. Additional transmission capacity would also be required to support the additional campus load.

Indiana is a regulated state for electricity generation, with certified electric service territories split among the electric utilities in the state. Duke Energy Indiana is the electric utility that serves the Purdue campus as well as a large portion of the state, including parts of 69 counties.

At the utility level, the economic analysis for generating resources is conducted as part of the utility's Integrated Resource Plan (IRP) process and presented to the Indiana Utilities Regulatory Commission (IURC) in a certificate of public convenience and necessity (CPCN) proceeding. Duke Energy Indiana conducts a comprehensive stakeholder engagement process and submits an IRP to the IURC at least every three years. The IRP is a comprehensive planning document used to forecast customer demand for electricity and the utility's response to that demand. The company's goal is to provide affordable, reliable and clean energy for its customers today and in the future.

With each IRP, Duke Energy Indiana starts by updating various inputs, including the electric load forecast, fuel costs, capital and operating costs of resources, required Midcontinent Independent System Operator (MISO) reserve margins by season, available tax credits, etc. The company then uses economic models to determine a preferred portfolio of generating and demand-side resources to meet the electric needs of customers considering various futures and risks. The determination of which portfolio to pursue includes a review of a combination of metrics to ensure reliability, resiliency, stability, executability, environmental sustainability and affordability.

Duke Energy Indiana's most recent IRP was submitted in 2021 and provides for an orderly transition to cleaner energy, including the addition of renewable generation, battery storage and natural gas. The IRP also calls for retiring all coal units by 2035 with the

Why Now?

Purdue University and Duke Energy Indiana have a mutual interest in providing safe, reliable and clean energy, which brought them together to explore the feasibility of bringing advanced nuclear technology to Indiana. Duke Energy Indiana refreshed its 20-year Integrated Resource Plan in 2023, and for the first time, small modular reactors are part of the plan.

Why now? The Inflation Reduction Act provides production and investment tax credits to utilities to offset clean energy transformation costs for customers. These tax incentives make small modular reactors and advanced reactors potentially affordable by 2035.

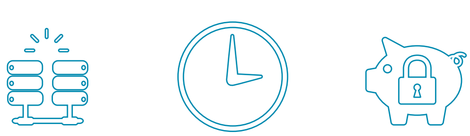
Edwardsport integrated gasification combined-cycle (IGCC) plant continuing to run either on natural gas or with carbon capture and storage technology. The 2021 portfolio did not include nuclear or SMR technology and instead assumed hydrogen-capable combustion turbines (CTs) would be in operation in the 2030s to meet the utility's carbon-free energy needs.

Duke Energy Indiana has recently updated its 2021 IRP analysis to reflect benefits of the 2022 Inflation Reduction Act (IRA), results from a generation request for proposals (RFP), MISO's new seasonal accreditation capacity construct and updated fuel price, capital costs and load forecasts.

The costs and availability of SMR technology were considered. For example, in its latest updated analysis of the 2021 IRP, Duke Energy Indiana assumed that SMRs or ARs would not be available for use in Indiana until at least 2035 given the current state of the technology and U.S. Nuclear Regulatory Commission (NRC) review and approval process. Interestingly, the 2021 IRP did not include SMR technology due to the cost, but given the availability of IRA production and investment tax credits, the updated 2023 analysis reflects the economic selection of SMRs starting in the 2035 time frame.

The 2023 refreshed analysis of the 2021 IRP resulted in an updated preferred portfolio, which is similar to the 2021 preferred portfolio but includes more wind generation, natural gas combustion turbines sooner and the addition of SMRs in 2035. Whether SMRs will be an economic option for Duke Energy Indiana's customers is unknown given current technology, timing and cost uncertainty.

Today, four first-of-a-kind advanced nuclear plants are scheduled to be online by 2030. As these projects progress in the regulatory and construction process, Duke Energy Indiana will have much better cost estimates to include in updated modeling, which could support an eventual early site permit application and combined construction and operating license application to the NRC along with a CPCN filing for SMRs with the IURC in the future.



Technology, timing and cost certainty are needed to move forward.

Cost estimates for new nuclear technology are not yet developed enough to accurately compare it to other sources of energy.

Specific to Purdue, two nuclear scenarios have potential with different capital and operating cost profiles driven by the steam and electric needs of the campus.

The near-campus scenario requires expenditures to integrate steam into Purdue's systems. The remote-site scenario requires expenditures to decarbonize the existing fossil-fuel boilers, potentially by upgrading them to electric boilers, and becoming an off-taker of carbon-free electricity from Duke Energy Indiana.

The economics of these options will need to be developed, refined and updated as more is known about the actual costs and timelines of advanced nuclear technology projects. Additionally, the total cost estimates of the various SMR and AR designs have not yet progressed enough to provide a reasonably accurate cost estimate. As the four first-of-a-kind projects proceed to completion and the other designs develop, cost estimates for advanced nuclear projects will be more accurate and will enable reliable comparison to other generation sources.

Community Economic Benefits

The economic benefits to a community from an advanced nuclear construction project and ongoing nuclear plant operation will be many. A recent Department of Energy (DOE) report details the community benefits, including the employment impact and the direct, indirect and induced economic impacts due to the transition from coal plants to nuclear plants.[4] The DOE study determined an additional 180 jobs will be created in addition to the existing coal plant employees. This will be increased when additional units are built on the same site.

The long-term economic benefits of locating a nuclear plant in a local community are also significant. These benefits include a large tax base, above-average wages, support needed from local educational institutions (e.g., trade schools, community colleges and universities) and the addition of local businesses to support the plant and the workers.

These new businesses may include parts fabricators, equipment rental companies, gas or chemical providers, hotels and restaurants, among others. Additionally, new jobs are created as byproducts of the plant, such as teachers, firefighters and police officers.

One of this study's key recommendations is to further identify, detail and analyze the specific economic benefits for the community, state and region.

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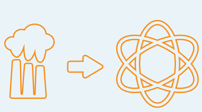
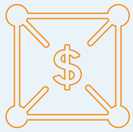
4 Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants, U.S. Department of Energy Systems Analysis and Integration, J. Hansen, W. Jenson, A. Wrobel (INL) N. Stauff, K. Biegel, T. Kim (ANL) R. Belles, F. Omitaomu (ORNL) Sept. 13, 2022, INL/RPT-22-67964, DOE/ID-Number (inl.gov).



Coal-to-nuclear transition – A U.S. Department of Energy study determined advanced nuclear projects would create 180 jobs in addition to employment numbers at existing coal plants.



Advanced nuclear projects would create thousands of temporary construction jobs and millions in new property taxes to benefit local services.

Power plant workers are also known for making financial contributions to nonprofits and offering their time and talent volunteering to help agencies advance their mission.

Conducting an economic benefits study is recommended.

Stakeholder Engagement and Communications

Purdue University and Duke Energy recognize the value and necessity of extended community education about the safety and community benefits of SMRs and ARs – and the engagement efforts needed to solicit feedback from stakeholders. This is particularly acute for states like Indiana with no existing nuclear generation. In one sense, stakeholder engagement and community education have just started and ongoing efforts will be essential to the success of future SMR and AR initiatives.

Purdue University and Duke Energy publicly announced the feasibility study in April 2022 and then held a six-part lecture series, "Understanding Tomorrow's Nuclear Energy," on campus August 2022-February 2023.

With a goal to provide a platform to share information with stakeholders and start building awareness of new nuclear generation topics, the feasibility study and lecture series spurred a yearlong conversation about the future of clean energy in the U.S., in the Hoosier state and for the Purdue Boilermakers.

This outreach positioned Purdue and Duke Energy as thought leaders, and an evaluation of the outreach shows significant interest in new nuclear generation topics.

Purdue and Duke Energy engaged stakeholders through proactive traditional and social media platforms and the lecture series that the university hosted.

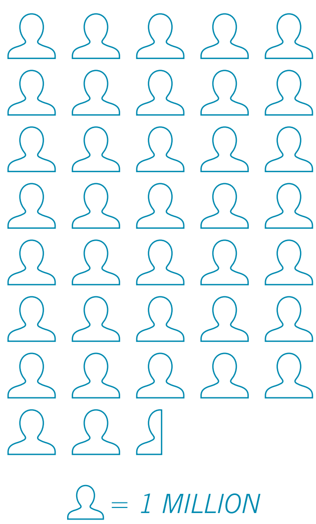
In all, the team sent seven news releases, two on the feasibility study and five on the lecture series, resulting in 192 media placements with 37.4 million views.

On Purdue's social media platforms, five posts announcing the feasibility study in April 2022 resulted in 102,526 impressions (which measure the number of people who saw a post) and 5,384 engagements (which measure the number of people who liked, commented or shared a post).

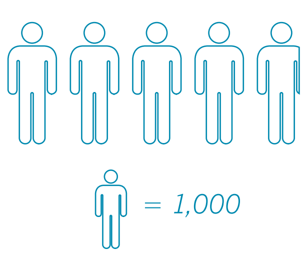
On Duke Energy's social media platforms, outreach spurred productive dialogue with nearly 500 measurable mentions of the study and lecture series.

The lecture series kept the conversation active on social media for six months, and more than 4,900 attended a lecture either in person or online.

TOTAL VIEWS:
37.4 MILLION



TOTAL LECTURE ATTENDEES: ***4,900***



SPEAKERS, TOPICS AND ATTENDANCE BREAKDOWN

	Speakers	Topics	Attendance*
1.	**Arden Bement, Ph.D.** David A. Ross Distinguished Professor Emeritus of Nuclear Engineering *Purdue University*	**Clean Nuclear Energy:** Past, Present and Future	In person: 185 Online views: 876 **Total: 1,061**
2.	**Maria Korsnick** president and CEO *Nuclear Energy Institute*	**A New Landscape for New Nuclear**	In person: 210 Online views: 1,300 **Total: 1,510**
3.	**William D. Magwood IV** director-general *Nuclear Energy Agency*	**The 21st Century Nuclear Resurgence:** Opportunities and Challenges	In person: 150 Online views: 590 **Total: 740**
4.	**Richard K. Lester, Ph.D.** associate provost *Massachusetts Institute of Technology*	**Tough Tech' for Climate:** Innovation Challenges, University Responsibilities and Some Comments on the Nuclear Role	In person: 204 Online views: 179 **Total: 383**
5.	**Kathryn D. Huff, Ph.D.** assistant secretary *Department of Energy's Office of Nuclear Energy*	**Nuclear Power in 2050**	In person: 200 Online views: 442 **Total: 642**
6.	**Tim Hanley** senior vice president and chief operating officer *Constellation Nuclear* **Luis Reyes** former executive director for operations *U.S. Nuclear Regulatory Commission* **Ahmet Tokpinar** principal vice president and general manager of Nuclear *Bechtel Power* **Moderator: Chris Nolan** vice president, New Nuclear Generation Strategy and Regulatory Engagement *Duke Energy*	**Implementing Advanced Nuclear Technology:** A panel of industry experts, who shared their thoughts on policy, technical, commercial and other requirements to make the use of small modular reactors a reality	In person: 215 Online views: 375 **Total: 590**

* Data as of May 1, 2023

If the time comes to build small modular reactors near the Purdue University campus or elsewhere in Indiana in the 2030s or beyond, all stakeholders – state and federal policymakers; elected officials; community leaders; project neighbors; university faculty, staff and students; and Duke Energy Indiana customers, among others – will be an important part of the process.

Purdue University and Duke Energy commit to continuing to:

- Engage stakeholders regularly and effectively
- Communicate proactively and transparently using a variety of one-way and two-way multimedia channels that reflect the needs and preferences of different stakeholders
- Listen and learn before making decisions
- Provide concise and easy-to-understand information
- Align outreach with best industry and public relations practices and standards
- Meet or exceed regulatory, community and industry expectations

As SMR and AR technology advances, ongoing education about advanced nuclear reactor technology will be available, particularly in the areas of safety, reliability, affordability, economic benefits and used fuel storage.

Challenges and Policy Support

Technology development and regulatory approval processes are underway to support advanced nuclear development in the U.S. That said, continued federal, state and local policy support will be vital to ensure future small modular reactor and advanced reactor deployment success. Recent and historical incidents of canceled or failed nuclear projects provide lessons learned on policy and economic support needed to make advanced nuclear energy a reality. The key challenges are categorized into seven areas where constructive policy is needed.

1

Ongoing and consistent community outreach and education – and platforms for receiving feedback – will be important to the ultimate success of any advanced nuclear project.

1. **Local acceptance (Will the community support advanced nuclear?)**

   Local community acceptance of advanced nuclear projects will be critical to their success. A key activity will be continued education and stakeholder engagement about the safety, reliability, carbon reduction and economic benefits of SMRs and ARs to the local community as well as listening to and addressing community concerns. Additional studies will be needed to define specific benefits of having an advanced nuclear power plant to the local, regional and statewide community. In addition to providing reliable energy, typical local community benefits created by SMRs and ARs are anticipated to include an increasing tax base, high-paying jobs, boosting the local supply chain and attracting other development to the area. Continuing and consistent community outreach, education and solicitation of feedback will be important to the ultimate success of any SMR or AR project.

2

For regulated utilities, first-of-a-kind technology risk is significant and potentially costly. One way to mitigate this risk is to create a state certificate of need law that allows ongoing review and approval of costs at various stages of advanced nuclear development.

2. **Technology (Will small modular reactors and advanced reactors work?)**

   The first-of-a-kind technology risk associated with SMRs and ARs is a major barrier to new technology development and implementation. The U.S. Department of Energy (DOE) has supported SMR and AR technology developers through its Advanced Reactor Demonstration Program by cost-sharing and testing support at the national laboratory system. The program focuses on demonstration projects and seeks to test, license and build operational reactors within seven years; reduce risk by solving technical, operational and regulatory challenges to support additional demonstration projects within 14 years; and solidify advanced reactor concepts into mature technology for demonstration by the mid-2030s.

   For regulated utilities, this first-of-a-kind risk can be substantial as it amplifies other risks – and obtaining assurance of reasonable recovery of costs in a scenario where first-of-a-kind technology fails would be challenging under current federal programs and policies. As such, many utilities will be following the first demonstration projects closely to determine if and when to make their own investments once the technology is proven.

Duke Energy is closely monitoring the developing technologies and meeting with the lead reactor vendors to perform detailed design reviews. Duke Energy also continues to be a partner with TerraPower and GE Hitachi on the Natrium reactor to be built in Wyoming as part of the Advanced Reactor Demonstration Program. To keep up to date with the advancement of these technologies, Duke Energy is actively engaged in numerous technical advisory boards, industry working groups and technology task forces.

From a policy standpoint, a state certificate of need law that provides for ongoing review and approval of costs at various stages of advanced nuclear development is essential for a utility to pursue a nuclear facility.

3

Increased training and education programs will be important to the successful construction and operation of new nuclear facilities.

3. Workforce development (Will an adequate skilled workforce be developed?)

To meet the needs of advanced nuclear development in the U.S., a focus on workforce development will be required. There is a need for increased training and education at all levels to support the expected increase in skilled nuclear power plant workers as the new nuclear SMR and AR technologies evolve. This is true for both nuclear plant construction-related jobs and ongoing operations. The workforce will need to be enhanced in areas such as HVAC technicians, welders, electricians, nuclear engineering, digital instrumentation and control, advanced nuclear manufacturing, operations and maintenance, cyber and physical security, training and development, leadership and more. Universities, vocational schools and the private sector will need to grow programs and opportunities to meet these needs.

4

Tax credits or other financial incentives that recognize the unique value nuclear technology can provide to the energy grid would be helpful, particularly policies designed to reduce risk during the planning, development and construction phases.

4. Construction and cost (Will SMRs and ARs be cost competitive?)

For regulated utilities, construction cost overruns of nuclear reactor projects can be a challenging risk; therefore, utilities will tend to opt for proven technologies. If the first-of-a-kind SMR and AR projects are successful, they will provide the needed evidence of the actual costs to construct and operate the advanced nuclear technology. This information can then be used to confidently evaluate the economics and value of this technology compared to other energy sources.

Policies that mitigate the cost of SMRs and ARs and recognize their unique value to the grid are needed. Nuclear energy provides uninterrupted availability of energy at an affordable price, energy security, reliability and carbon-free controllable baseload power available 24 hours a day. Policies designed to recognize and incentivize the positive attributes of SMRs and ARs will be important to the future acceptance and implementation of advanced nuclear technology.

The federal government has recently provided policy support to mitigate some of the risk associated with nuclear facilities. On the national level, the Inflation Reduction Act (IRA) provides needed production tax credits and investment tax credits for carbon-free generation, including advanced nuclear. Because nuclear technology operates continuously at high-capacity factors, the production tax credits are helpful when economically comparing the costs of SMR or AR technology to alternatives without the tax credits. This policy will lower the cost of nuclear to customers once the plant is operating; however, the IRA does not address the significant planning, development and construction cost risks a utility must incur to bring the plant online.

Tax credits or other financial incentives that support the unique value advanced nuclear technology provides to the grid are needed to help create the business and market environment needed to expedite SMR and AR deployment in the U.S. In particular, policies designed that establish a reasonable balance of the financial risks among the government, private utilities, advanced nuclear technology vendors and construction companies during the planning, development and construction phases will be essential to meet the SMR and AR development timelines desired by the DOE.

5

Implementing cost recovery policies that allow utilities to recover from customers "construction work in progress" costs while the project is under construction is critical for large and long-duration construction projects like an SMR or AR.

Without timely recovery, a utility's ability to obtain credit on reasonable terms would be challenged.

5. Regulatory (Will the project be approved and have reasonable cost recovery?)

Regulatory risk can best be mitigated by providing approval and cost recovery certainty during the various phases of development, construction and operation. This allows a utility to move forward in a measured way while keeping the regulatory commission and its customers informed through periodic reviews of the construction project. Finalization of the U.S. Nuclear Regulatory Commission permitting reforms is needed and will assist in providing confidence that a project can proceed through completion without needing major and costly design or construction changes.

At the state level, upfront cost recovery for an early site permit application would help a utility take the first step in bringing the benefits of SMRs to its customers. In Indiana, the General Assembly recently passed various incentives for SMR construction and operation, including timely recovery of the costs (e.g., construction work in progress, or CWIP, and tracker recovery) and other incentives the Indiana Utilities Regulatory Commission may deem appropriate.

CWIP cost recovery while an advanced nuclear project is under construction is critical for large and long-duration construction projects like an SMR. Otherwise, a utility's ability to obtain credit on reasonable terms is difficult. Indiana also has a constructive certificate of public convenience and necessity (CPCN) law that provides for cost recovery.

Continued constructive legislative and regulatory policy that provides approval and cost certainty as utilities investigate SMRs is critical to the technology's ultimate success in the state.

6

Federal policy support is essential to ensuring adequate and timely supply of high-assay low-enriched uranium (HALEU) fuel.

6. Fuel supply (Will a utility be able to get fuel to operate SMRs and ARs?)

Fuel supply challenges vary by technology type, with the newer advanced reactor fuel designs having more uncertainty. Federal policy support in this area is essential to ensuring an adequate and timely supply of high-assay low-enriched uranium (HALEU) fuel and onshoring more traditional nuclear fuel options to provide uninterrupted availability of energy and promote national energy security. The Department of Energy is currently providing funding to U.S. manufacturers to support the higher enrichments needed for HALEU fuel used in advanced nuclear designs.

7

The U.S. does not have a licensed federal repository for the nation's used nuclear fuel.

Utilities have safely stored used nuclear fuel on-site in fuel pools or in dry cask storage facilities for more than 40 years.

Policy direction and permanent long-term storage are needed because on-site fuel storage can be a barrier to gaining community support.

7. Used fuel management (Where can a utility safely store used fuel long term?)

SMRs and ARs hold great promise in that they can have a smaller physical footprint and be located closer to communities, minimizing costs of an individual project and transmission investment. The nuclear industry has demonstrated that used fuel can be safely stored on-site and has done so for more than 40 years. However, the lack of national policy on centralized locations for long-term used fuel storage will be challenging as SMRs and ARs attempt to site near population centers. While the safety of the technology has been enhanced, the long-term storage risk of used fuel is still a barrier for many communities' support.

Policy direction and a permanent long-term solution are needed to de-risk advanced nuclear deployment in the U.S. The Department of Energy is funding interested communities to help them learn more about consent-based siting of used nuclear fuel management and interim storage, which is a step in the right direction.[5]

5 U.S. Department of Energy, Consent-Based Siting for Interim Storage Program – Community Engagement Opportunities Funding Opportunity Number: DE-FOA-0002575.

Conclusion: Key Learnings and Recommendations

This SMR and AR feasibility study interim report provides a starting point for Purdue University and Duke Energy to explore whether advanced nuclear technology could meet the future energy needs of the university and Duke Energy Indiana customers. Along the way, key learnings have been discovered and recommendations developed.

Most importantly, the study found small modular reactors and advanced reactors are a viable option that warrant continued exploration to meet the future carbon-free energy needs of Purdue University and Duke Energy Indiana. As such, continuing collaboration is planned to move nuclear energy forward in the state by focusing on advocating for policy recommendations identified below.

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Key Learnings

- **Technology and siting:** The study demonstrated that several developing advanced nuclear technology options would prove viable for remote sites, and at least one developing technology could be a fit with a near-campus site. The smaller size, physical footprint and safety elements of the developing advanced nuclear technologies could allow for location of a project closer to population centers, including college campuses.
- **Safety:** The safety systems (both passive and enhanced safety features) of advanced nuclear technologies are impressive and should assist in obtaining community acceptance of a future project.
- **Workforce:** Advanced nuclear projects provide excellent opportunities for retaining and retraining workers from retired coal plants or other generation sources. Continued workforce development within the private sector, higher education and vocational schools to meet the needs of advanced nuclear development is essential.
- **Policy:** Federal and Indiana law and policy are currently supportive of advanced nuclear development, but more support will be needed, as described in the below recommendations section.

Recommendations

This SMR and AR feasibility study interim report is the first step in a long process to consider the viability of nuclear as a clean energy solution for Purdue and the state. Purdue and Duke Energy are excited to continue working together to pursue the following recommendations:

1. **Policy recommendations:** Advocate at the federal and state levels for constructive regulatory outcomes and economic incentives for advanced nuclear planning, development, construction and operation. Such policies should prioritize the benefits of abundant and dispatchable nuclear energy that offers the grid safe, carbon-free, reliable and available energy at an affordable price.

   Specific Indiana state policy recommendations include:

   - **State regulatory support for advanced nuclear exploration:** While Indiana has made initial strides in policy support for nuclear energy, additional legislative and regulatory policy support for early movers of advanced nuclear technology in the state should be considered, such as regulatory policies encouraging funding and reasonable and timely cost recovery for initial nuclear planning and development activities.
   - **State funding of studies:** The state should consider public funding of studies needed to expedite moving nuclear energy forward. Specific state opportunities could include funding:
     » *An independent, university-led study of the positive economic impact of the deployment of new nuclear in Indiana and the economic development that it would create*
     » *A study on workforce development needs for the state to specifically take advantage of the new nuclear and clean energy transformation*
     » *Funding and support for early site permit applications*
     » *Community outreach programs*
   - **State tax credits:** Indiana should consider state tax credits for advanced nuclear technology given the technology would provide safe, uninterrupted availability of energy, energy security, reliability and clean-energy attributes.

Specific federal policy recommendations include:

- **Federally backed insurance:** Institute a new federal insurance program to cover a portion of potential cost overruns experienced due to new nuclear construction and regulatory challenges or delays to ensure that once started, a project continues to completion. This could speed the pace at which utilities are willing to move forward with new nuclear projects and provide for earlier carbon reductions.[6]
- **Federal early site permit funding:** Develop a federal funding program for early site permit work, particularly in states with no existing nuclear generation.
- **Federal public-private advanced reactor program:** A new program could provide grants to public-private partnerships to support siting and U.S. Nuclear Regulatory Commission licensing costs for advanced nuclear reactors, including small modular reactors and microreactors. The Department of Energy currently provides support to a few select nuclear industry vendors through the Advanced Reactor Demonstration Program (ARDP) – and support to research universities for research reactors. However, no program exists to support the deployment of commercial-scale advanced nuclear reactors in partnership with a utility, reactor vendor and research university.

6 U.S. Department of Energy, Report - Pathways to Commercial Liftoff - Advanced Nuclear - March 2023 UPDATED (energy.gov), **p. 41** (March 2023).

The program would help accelerate the uptake of advanced nuclear technology, reduce deployment risks and provide opportunities for workforce development and training.

- **Federal HALEU (high-assay low-enriched uranium) fuel availability program:** Continued funding is needed to support the Department of Energy's HALEU availability program. Most ARs under development in the U.S. require HALEU fuel to achieve smaller designs, longer operating cycles and increased efficiencies. Commercial-scale HALEU is currently not available from domestic suppliers. A lack of this commercial supply chain could significantly impact the development and deployment of U.S. ARs and increase the risk and uncertainty for private investment in the production of HALEU.
- **Maintenance of tax credits:** The federal clean electricity tax credits provided by the Inflation Reduction Act should be maintained as they are essential to the success of advanced nuclear technology. Additionally, the clean electricity tax credits could be evaluated for a timeline extension, especially if the time frame for technology demonstration projects is ultimately extended.

2. **Community engagement:** Continue regular public and stakeholder education related to the benefits of advanced nuclear technology, including development of a community and stakeholder benefits plan that includes robust community outreach and feedback opportunities. Pursue creation of additional university-led symposium and educational opportunities about nuclear energy.
3. **Technology evaluation:** Continue monitoring the developments in the SMR and AR technologies with a goal of performing a more detailed technology evaluation as the designs progress and the first-of-a-kind projects advance.
4. **Siting study:** Develop a site screening study and timeline to identify the best location(s) for advanced nuclear to support Purdue University and the Indiana grid – and potentially develop an early site permit application for the selected site.
5. **Community benefits economic impact study:** Consider an independent study to quantify the economic development benefits of advanced nuclear deployment for the community, region and state.
6. **Workforce development:** Explore and advocate for workforce development needs to support construction, operation and maintenance of SMRs and ARs. The U.S. Department of Energy's (DOE's) Nuclear Energy University Partnership (NEUP) program is critically important in maintaining the nuclear workforce through grants to single researchers or small groups to tackle specific projects. DOE's NEUP program should be increased significantly, with a recommendation to at least double current funding from about $60 million a year to $120 million a year. In addition to funding, DOE could launch Centers of Excellence for Nuclear Workforce Development focused on long-term training and workforce development programs in consultation with nuclear reactor companies, utilities, universities and other private sector partners.
7. **Research needs:** Advocate for meaningful research – funded by the DOE and industry associations and performed by universities – to advance nuclear technologies and minimize cost and construction risk.

This SMR and AR feasibility study interim report confirms the viability of carbon-free nuclear generation to serve the energy future of Purdue University and Indiana. While significant progress is being made in the U.S., more detailed study and action are needed to address and overcome the current regulatory, financial and technological challenges outlined in the report. Purdue University and Duke Energy are committed to continuing efforts to pursue nuclear energy for a cleaner Indiana.

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