FINAL REPORT

STUDY ON SMALL MODULAR REACTOR TECHNOLOGY AND ITS IMPACT FOR INDIANA

Prepared for

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ABSTRACT

Purdue University, in collaboration with a team of experts, performed an extensive study that analyzes Small Modular Reactor (SMR) technology applications and its impacts for the State of Indiana. The study was performed by gathering quantitative and qualitative data covering a comprehensive topic related to SMR applications, including the current state of SMR technology development, regulatory framework, potential economic impacts, considerations on site selection, safety review, opportunities and challenges for nuclear workforce development, and community engagement. The study culminates in a report outlining key findings for the State, including recommendations on best practices for sharing the results with all stakeholders.

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LIST OF ABBREVIATIONS

AGR	– Advanced Gas Reactor
ALARA	– As Low As Reasonably Achievable
ARC	– Advanced Reactor Concept
ACRS	– Advisory Committee on Reactor Safeguards
ARDP	– Advanced Reactor Demonstration Program
ARE	– Aircraft Reactor Experiment
ASZ	– Anna Seismic Zone
BANR	– BWXT Advanced Nuclear Reactor
BWR	– Boiling Water Reactor
BWXT	– BWX Technologies
CAA	– Clean Air Act
CFPP	– Carbon Free Power Project
CFR	– Code of Federal Regulations
Co.	– Company
COL	– Combined License
COLA	– Combined License Application
CPCN	– Certificate of Public Convenience and Necessity
DC	– Direct Current or Design Certification
DCA	– Design Certification Application
DiD	– Defense in Depth
DOE	– US Department of Energy
EA	– Exclusion Area
EIS	– Environmental Impact Statement
EPA	– Environmental Protection Agency
EPC	– Engineering Procurement and Construction
EPD	– Extended Planning Distance
EPR	– Emergency Preparedness and Response
EPZ	– Emergency Planning Zone
ESBWR	– Economic Simplified Boiling Water Reactor
ESP	– Early Site Permit
ETSZ	– East Tennessee Seismic Zone
FAA	– Federal Aviation Administration
FCM	– Fully Ceramic Micro-Encapsulated
FOAK	– First of a Kind
GDA	– Generic Design Assessment
GE	– General Electric
GNF-2	– Global Nuclear Fuel-2
GW	– Gigawatt

HALEU – High Assay Low Enriched Uranium
HI-STORM UMAX – Holtec International Storage Module Underground MAXimum Safety
HLRW – High Level Radioactive Waste
HRCQ – Highway Route Controlled Quantity
HTGR – High-Temperature Gas-Cooled Reactor
HV – High Voltage
HVAC – Heating, Ventilation, and Air Conditioning
I&C – Instrumentation and Control
I&M – Indiana-Michigan Power Co.
IAC – Indiana Administrative Code
IAEA – International Atomic Energy Agency
ICPD – Ingestion and Commodities Planning Distance
IDEM – Indiana Department of Environmental Management
IDNR – Indiana Department of Natural Resources
IMPA – Indiana Municipal Power Agency
IMSR – Integral Molten Salt Reactor
INDOT – Indiana Department of Transportation
INL – Idaho National Laboratory
IPL – Indianapolis Power & Light (Now known as The AES Corporation)
IPyC – Inner Pyrolytic Carbon
IRP – Integrated Resource Plan
ISO – Independent System Operator
IURC – Indiana Utility Regulatory Commission
KP-FHR – Kairos Power Fluoride-Salt-Cooled High Temperature Reactor
LEU – Low Enriched Uranium
LFR – Lead-Cooled Fast Reactor
LFTR – Liquid Fluoride Thorium Reactor
LLRW – Low Level Radioactive Waste
LLC – Limited Liability Corporation
LOCA – Loss of Coolant Accident
LPZ – Longer-term Protective Action Zone or Low Population Zone
LTP – License Termination Plan
LW – Light Water
LWA – Limited Work Authorization
LWR – Light Water Reactor
MCFR – Molten Chloride Fast Reactor
MISO – Midcontinent Independent System Operator
MIT – Massachusetts Institute of Technology
MMR – Micro-Modular Reactor

MR	– Microreactor
MSR	– Molten Salt Reactor
MSRE	– Molten Salt Reactor Experiment
MWe	– Megawatts of Electrical Power
MWth	– Megawatts of Thermal Power
NPDES	– National Pollutant Discharge Elimination System
NEA	– Nuclear Energy Agency
NEPA	– National Environmental Policy Act
NGNP	– Next Generation Nuclear Plant
NIPSCO	– Northern Indiana Public Service Company
NPM	– NuScale Power Module
NPP	– Nuclear Power Plant
NRC	– Nuclear Regulatory Commission
OBE	– Operating Basis Event
OECD	– Organization for Economic Co-operation and Development
OPyC	– Outer Pyrolytic Carbon
ORNL	– Oak Ridge National Laboratory
PJM	– Pennsylvania, New Jersey, Maryland
PCCS	– Passive Containment Cooling System
PLC	– Programmable Logic Controller
PRISM	– Power Reactor Innovative Small Module
PWR	– Pressurized Water Reactor
PyC	– Pyrolytic Carbon
RPS	– Reactor Protection System
RPV	– Reactor Pressure Vessel
ROI	– Return on Investment
ROI*	– Region of Interest
RR SMR	– Rolls-Royce Small Modular Reactor
SC-HTGR	– Steam Cycle High-Temperature Gas-Cooled Reactor
SDA	– Standard Design Approval
SGSZ	– St. Genevieve Seismic Zone
SiC	– Silicon Carbide
SMR	– Small Modular Reactor
TRISO	– Tri-structural Isotropic
TVA	– Tennessee Valley Authority
U.S.	– United States
UAMPS	– Utah Associated Municipal Power Systems
USNC	– Ultra Safe Nuclear Corporation
WNA	– World Nuclear Association
WVSZ	– Wabash Valley Seismic Zone

WVPA – Wabash Valley Power Alliance

EXECUTIVE SUMMARY

The present study investigates the feasibility of adopting SMR technology in Indiana. Commissioned by the Indiana Office of Energy Development, Purdue University in collaboration with other experts explores SMR technology, economic and regulatory considerations, safety assessments, and the broader potential of integrating SMRs into Indiana's energy portfolio. The report presents a careful yet informed analysis, reflecting the complexities of nuclear energy deployment in a state with no current nuclear infrastructure.

SMRs are compact nuclear reactors with electric generating capacity typically less than 500 Megawatts of Electrical Power (MWe) and designed to offer scalable energy solutions with enhanced safety features compared to traditional nuclear plants. These reactors are flexible in design, allowing for modular construction, reduced land use, and smaller emergency planning zones (EPZs). This flexibility, combined with advances in passive safety systems, positions SMRs as a potentially viable option for meeting Indiana's future energy needs. The report examines key SMR designs, ranging from light-water based to non-light-water based SMR technologies, assessing their scalability, potential costs and benefits, economic impacts, site selection criteria, current status on workforce development and future needs, and community engagement.

Although Indiana currently has no reactors within its borders, Indiana has shown increasing interest in nuclear energy and specifically in SMRs as demonstrated by the introduction of new policies, most notably Senate Bill 271, which allows SMR construction in retired coal plant sites. An initial site analysis of existing and former coal plants within the state shows there are at least eight of these sites that are ripe for further investigation to locate an SMR. Furthermore, this study found that there would be a number of benefits from the deployment of one or more SMR within the state, particularly coal-to-nuclear opportunities. These include the creation of a 24/7 dispatchable source of carbon free electricity to meet the expected load growth of 1.5-3% from 2022 to 2030 (a big change compared to the 0.2% annual growth rate over the prior decade), the creation of high paying jobs during both the construction and operation of the facility, increasing the tax base in the state, as well as the potential to increase employment throughout the state by various supply chain providers, including the nuclear manufacturing.

The economic impacts for a 300-500 MWe SMR are also expected to be significant. This study found that the construction of a new 500 MWe SMR would employ approximately 2,000 workers over the 4-year construction period directly and could have a total economic impact of more than $500 million per year. It is noted that nuclear power plants create roughly double the number of local jobs compared to coal plants with the same capacity. An operating 500 MWe SMR plant would employ about 140 workers directly, earning 18% more than coal plant workers on average and have a total ongoing economic impact of $352 million per year, more than twice the total economic impact of a 500 MWe coal plant. In total, the economic output of a 300-500 MWe SMR is expected to be two times higher than the economic output of a coal plant of the same size in communities with more than 90,000 people.

While SMRs are expected to offer certain advantages, including shorter construction timelines, capacity factors above 90%, load following capabilities, and the ability to repurpose existing coal plant sites mitigating the economic and environmental impacts (Indiana was found to have 8-10 coal plants suitable for the repurposing, the second most of any state, with only Texas having more suitable coal power plant sites), the authors acknowledge that SMRs remain a relatively new technology. Therefore, Indiana must approach their deployment with caution, ensuring comprehensive studies are conducted to assess site suitability, cost, workforce development, environmental impact, and community engagement.

This study found that major obstacles to fully committing to go forward with the implementation appear to be the construction and supply chain uncertainties. Like all technologies, the first-of-a-kind (FOAK) is expected to be the costliest deployment, with costs lowering over time according to a learning curve. Two key government incentives mitigate these costs, one of which reduces the capital costs by up to 50% and another of which reduces the financing costs. Repurposing coal plant sites could reduce costs by 7-26% while n^{th}-of-a-kind (NOAK) could reduce costs by an additional 40%. Since it is unlikely that any single state, utility, or company would place a large enough order to take full advantage of multiple SMR deployments to benefit from NOAK savings, an agreement between various states, companies, and utilities to share the total costs of the construction of a number of SMRs located in various locations might be a solution.

Supply chain uncertainties, similarly, could be mitigated by an order of multiple SMRs of the same type to be constructed on a given schedule. This would give the vendors some certainty that the investment that they would need to make to supply specialty equipment, such as the reactor vessel, and large components, such that the main turbine and main generator, would be recovered. Similar to the FOAK risks discussed above, it would likely require an agreement between a number of states, utilities, and/or companies to make this strategy work as no single entity is likely to place an order large enough for the vendors to make the necessary investment to keep the price of the equipment necessarily reasonable.

The report concludes that, while SMRs present an intriguing opportunity for Indiana’s future energy strategy, their deployment should be approached with a full understanding of both the benefits and risks of such an endeavor. Comprehensive feasibility studies, regulatory alignment, workforce development, and community engagement are all necessary components to ensure the successful and safe integration of SMRs into Indiana’s energy landscape. By addressing the financial, workforce, and supply chain challenges associated with SMRs, Indiana can position itself to take advantage of this emerging technology while maintaining a balanced and conservative approach to its energy needs.

CHAPTER 1. INTRODUCTION

Various small modular reactor SMR technologies exist today, and understanding their current status as well as their future prospects in terms of development and deployment is the first step in a broader exploration of SMR feasibility in the State of Indiana. Through a literature review of recent publications, research papers, interviews with industry experts, and reports related to SMRs, this report provides an overview of (i) the current landscape of SMR technologies (including some major developments among international vendors), (ii) information on SMR design principles, features, and advantages; details on different types of SMRs and their respective characteristics; various design options available for SMRs, including different technologies, megawatt capacity, range of capacities and variations across different designs; fuel types; and cooling methods, (iii) a summary of relevant state and federal laws related to SMRs, (iv) potential costs and benefits, economic impacts, and site selection criteria including a use case scenario, (v) current status on workforce development and future needs, and (v) community engagement

1.1 Research Background

While Indiana invests in a diverse energy supply including coal, natural gas, wind, and solar, no nuclear power plants exist in the state with the benefit of producing zero carbon emissions. In view of this, Purdue University, in partnership with a carefully selected team of experts, was selected by the Indiana Office of Energy Development (IOED) to perform a comprehensive study that analyzes SMR technology applications and their impacts for the State of Indiana, including an assessment of SMR costs and benefits. The broad focus areas of the study included gathering quantitative and qualitative data on the current state of SMR technology, projected safety of the proposed technology, potential regional and national economic impact, community engagement, and opportunities for workforce development. The present study not only leverages the findings from the year-long SMR feasibility study by Purdue University [1], but it is also a natural next step toward diversifying and modernizing the state's energy portfolio, bringing reliable, affordable, and sustainable energy to the people of Indiana, enabling a workforce that is nuclear technology ready, and representing a potential national model for implementation.

The key objective of the proposed study is to provide the information needed to better understand SMR technology as a resource for electricity generation and assist IOED in the development of a comprehensive energy plan and policies to enable a diverse and balanced portfolio of energy resources that benefit all Hoosiers. Thus, this study will deepen our understanding in all aspects of SMR technologies, including economic costs and benefits, regulatory conditions, and potential regional and community site options, and offer a more in-depth technology assessment.

The project team, in coordination with IOED, includes the School of Nuclear Engineering at Purdue University, Purdue Administrative Operations, Purdue Polytechnic Institute (Polytechnic), Purdue Extension Community Development (CDExt) office, Purdue Center for Regional Development (PCRD), Ivy Tech Community College of Indiana (Ivy Tech), the Energy Systems

Network (ESN), and Argonne National Laboratory (ANL). The organizational chart of the project team and the distribution of tasks are shown in Figure 1.

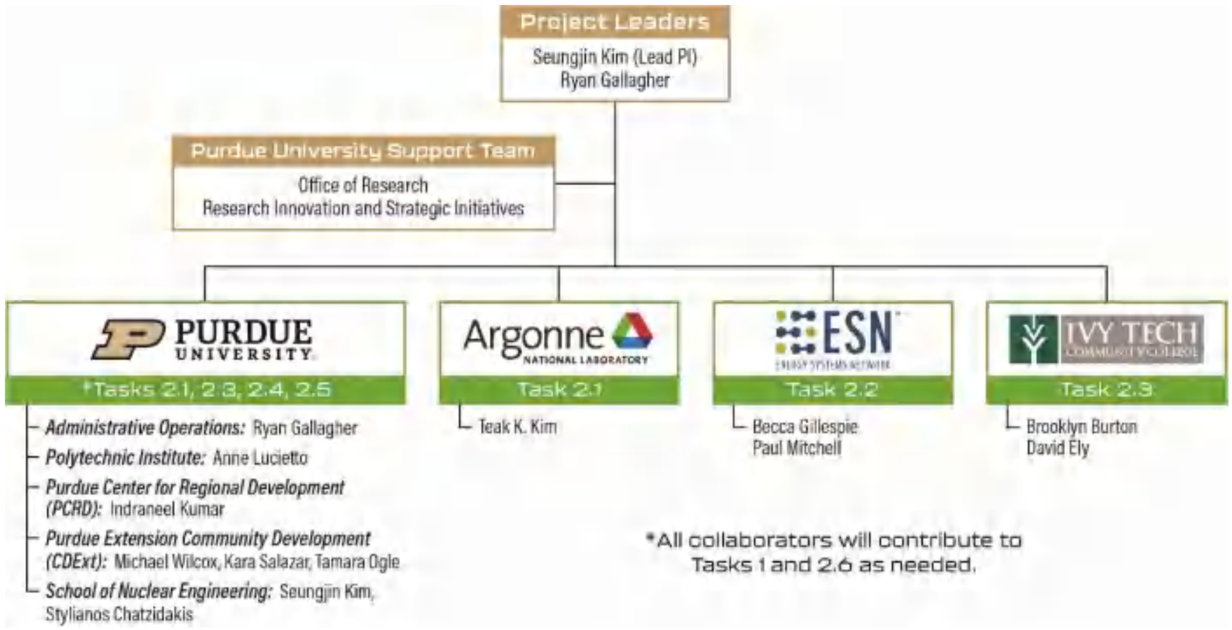

Figure 1. SMR Study Team Organizational Chart

1.2 What is an SMR

SMRs are a relatively new technology, and there is not a universally accepted definition yet. By summarizing and comparing various definitions from national and international agencies and organizations, a more complete understanding is formed of what an SMR can be. For the purpose of this Indiana-focused feasibility study, this report uses the definitions of SMR defined by Indiana State Bill 271 (2022) and 176 (2023) as shown below.

SMR definition in Indiana Senate Bill 271 (2022) and Indiana Senate Bill 176 (2023):
Indiana Senate Bill 271 defines an SMR as a reactor that *"…has a rated electric generating capacity of not more than 350 MWe…"* [2]. Indiana Senate Bill 176, amended the SMR power capacity definition to 470 MWe capacity [3].

SMR definition by the U.S. Department of Energy (DOE):
The U.S. DOE's Office of Nuclear Energy defines SMRs as *"These advanced reactors, envisioned to vary in size from tens of megawatts up to hundreds of megawatts, can be used for power generation, process heat, desalination, or other industrial uses. SMR designs may employ light water as a coolant or other non-light water coolants such as a gas, liquid metal, or molten salt"* [4].

SMR definition by the U.S. Nuclear Regulatory Commission (NRC):
The U.S. NRC defines SMR as *"...the class of power reactors having a licensed thermal power rating less than or equal to 1000 MWth per module. This rating is based on the thermal power equivalent of an SMR with an electrical power generating capacity of 300 MWe or less per module…".* In addition to the definition of an SMR, the NRC defines an SMR site as the location of at least one SMR, in which this location is geographically bounded [5].

SMR definition by the International Atomic Energy Agency (IAEA):
The IAEA defines SMRs as *"...advanced nuclear reactors that have a power capacity of up to 300 MWe per unit…".* The IAEA defines each word in the acronym individually: small, meaning a fraction of conventional reactor size; modular, meaning the possibility for components of the reactor to be assembled at a factory and completely transported to be installed; and reactor, meaning "…harnessing nuclear fission to generate heat to produce energy…" [6].

SMR definition by the Nuclear Energy Agency (NEA):
The NEA defines SMRs *"...by their smaller size, but there exists considerable variety within this class of reactors; they vary by power output, outlet temperature, technology, and fuel cycle…They offer a range of sizes, from as small as 1 MWe to up to 300 MWe, and a range of temperatures, from 100°C to more than 850°C…"* [7]. The NEA also defines each word in the acronym individually: small, meaning small in physical size as well as an electrical power generating capacity between 1 and 300 MWe; modular, meaning the SMR is designed to be modularly manufactured, portable, and scalable for being deployed; and reactor, meaning the use of fission to generate heat that further generates electricity or is directly used [7].

SMR definition by the World Nuclear Association (WNA):
The WNA defines SMRs as *"...nuclear reactors generally 300 MWe equivalent or less, designed with modular technology using module factory fabrication, pursuing economies of series production and short construction times…"* [8].

SMR definition by U.S. DOE National Laboratories:
Idaho National Lab (INL) defines SMR as a *"...nuclear fission reactor that features factory-built-and-assembled modules in a variety of configurations and electricity outputs. About 1/10 to 1/4 the size of a traditional nuclear energy plant, SMRs feature compact, simplified designs with advanced safety features…"* [9]. Pacific Northwest National Laboratory (PNNL), aligning with the National Defense Authorization Act for Fiscal Year 2023, defines SMRs and Microreactors (MRs) as "…*advanced nuclear fission reactors constructed using modular assemblies with a much smaller power capacity and physical footprint than currently operating large conventional reactors*…" [10]. Other national laboratories, including Oak Ridge National Laboratory (ORNL), Argonne National Laboratory, and Princeton Plasma Physics Laboratory, haven't published specific definitions for SMRs.

These various definitions of SMR are summarized in Table 1. In general, definitions of SMRs typically highlight a power capability between 300-350 MWe, advanced safety features, and modular construction.

Table 1. Summary of SMR definitions.

Sources	Brief summary of the SMR definitions in one or two sentences
Indiana Senate Bills	"SMRs are nuclear reactors that operate at less than 470 MWe" [2]
DOE	"SMRs designed from advanced and innovative concepts, using non-LWR coolants such as liquid metal, helium or liquid salt, may offer added functionality and affordability" [4]
NRC	"SMRs nuclear reactors that generate at most 300 MWe of electric power" [5]
IAEA	SMRs "are advanced nuclear reactors that have a power capacity of up to 300 MWe per unit" [6]
NEA	SMRs are "Smaller [in] size, but there exists considerable variety within this class of reactors …from as small as 1 MWe to over 300 MWe, and a range of temperatures, from 100°C to more than 850°C" [7]
WNA	SMRs have a capacity of "…300 MWe equivalent or less, designed with modular technology using module factory fabrication, pursuing economies of series production and short construction times" [8]
INL	An SMR is "…a nuclear fission reactor that features factory-built-and-assembled modules in a variety of configurations and electricity outputs" [9]

1.3 SMR Studies Performed in Other U.S. States

SMR feasibility reports performed in other states are available in the public domain, including studies based in Michigan, Kentucky, New Hampshire, Connecticut, Virginia, and Maryland.

<u>Michigan Feasibility Study</u>:
Enercon Services East P.C. (ENERCON) conducted a feasibility study in 2024, initiated by Public Act 166 of 2022 [11] of the Michigan state legislature, which directed the Michigan Public Service Commission (MPSC) to engage an outside firm to examine the viability of nuclear power generation in Michigan [12]. The study focuses on economic and environmental impacts and the use of local workers and products. It highlights Michigan's historical and current nuclear power infrastructure, potential economic benefits through job creation and local workforce development, and evaluates advanced reactor designs and siting considerations. The report addresses design characteristics, environmental impacts, safety, socioeconomic impacts, workforce development,

and policy recommendations, and explores repurposing coal plants for nuclear, hydrogen production, and direct air capture.

Key findings and recommendations include:

- Energy provided by nuclear power can provide substantial benefits and capabilities to its users. However, nuclear power has not been demonstrated to be inexpensive.
- Nuclear power construction and operation can provide direct jobs at the plant and indirect jobs resulting from the spending of the employees of the plants.
- There is a growing, bipartisan support for the nuclear industry as shown by the increasing number of federal and state nuclear policies that have been enacted in recent years.
- There is a need for special considerations for working with FOAK designs toward both timeline and cost.
- There is a need for early/immediate planning for nuclear energy to mitigate long timelines and support upcoming clean energy goals.
- Explore potential partnership opportunities with neighboring states to mitigate costs.

<u>Kentucky Feasibility Study</u>:
The Kentucky Office of Energy Policy conducted a feasibility study in 2023, initiated by Senate Joint Resolution 79, to assess Kentucky's past, present, and future energy landscape with a focus on nuclear power. The study aimed to identify barriers to nuclear power deployment, consult with stakeholders, and develop recommendations for a permanent nuclear energy commission. It comprehensively evaluated Kentucky's energy landscape, identifying key challenges and potential solutions, covering regulatory and statutory hurdles, financial considerations, social and environmental impacts, workforce education and development, safety and security, and policies at state and federal levels.

Key findings and recommendations include:

- There are no insurmountable barriers to nuclear energy development.
- Challenges may include regulatory, statutory, financial, social, environmental, workforce, safety, security, and coordinated efforts from various government entities in relation to nuclear proliferation.
- The necessity of establishing a Nuclear Energy Development Authority to lead the state's nuclear initiatives.

<u>New Hampshire Feasibility Study</u>:
The "Commission to Investigate the Implementation of Next-Generation Nuclear Reactor Technology in New Hampshire" was initiated by the New Hampshire Legislature in 2022 to explore the feasibility of next-generation nuclear reactor technology in the state [13]. The report aimed to summarize current and upcoming nuclear technologies, projects, and companies, and to offer policy recommendations to the New Hampshire Legislature. The study evaluates 15 SMR

designs, covering light water reactors, high-temperature gas reactors, molten salt reactors, fast neutron reactors, and microreactors. Additionally, it addresses supply chain concerns, particularly the reliance on Russian-controlled materials, and explores non-electrical applications such as hydrogen production, medical isotope creation, and industrial heat generation.

Key findings and recommendations include:

- It was concluded that advanced nuclear power is necessary for meaningfully reducing emissions. However, deployments may not be realized until the late 2020s or early 2030s.
- Benefits of advanced nuclear technologies include the economic viability and transportability of standardized, modular designs; the use of high-density fuels for long-term power; and the potential for load-following capabilities and passive safety systems.
- State policy recommendations include designating nuclear as "clean" energy, conducting feasibility studies, streamlining regulations, and urging Independent System Operator (ISO) New England to solicit advanced nuclear proposals.

<u>Connecticut Feasibility Study</u>:
The Connecticut Department of Energy and Environmental Protection (DEEP) conducted a feasibility study on SMRs, advanced nuclear technology, and fusion potential in response to Section 35 of Public Act 23-102, signed into law on June 14, 2023 [14]. This act aimed to strengthen protections for Connecticut energy consumers and included nuclear power as a renewable energy source under specific conditions. The study, summarized in a draft published on February 20, 2024, assesses the affordability, fuel accessibility, renewable integration, and reliability of SMRs, especially in the context of the ISO New England grid.

Key findings and recommendations include:

- Benefits of SMRs are identified in terms of modularization, fuel supply, integration with renewables, and winter reliability.
- Potential challenges include high construction costs and extended return on investment (ROI) periods.
- The report recommends continuous analysis of advanced nuclear technologies, monitoring policies, and advocating for federal funding to support nuclear development.

<u>Virginia Feasibility Study:</u>
Dominion Engineering conducted a feasibility study in March 2024, commissioned by the LENOWISCO Planning District Commission, to outline the supply chains needed for implementing SMRs in Virginia [15]. This study, initiated due to Virginia's growing interest in nuclear energy as a means to meet future energy demands and decarbonization goals, highlights the LENOWISCO Region of Interest (ROI*) as an ideal hub for developing SMR supply chains. The report addresses political challenges and opportunities, methods for growing the labor and operator force, organizing private industry, and key features specific to Virginia. It identifies

opportunities for establishing corporate headquarters for SMR vendors, constructing integration facilities, developing a skilled workforce, and building SMRs.

Key findings and recommendations include:

- The importance of building supply chains through regions eligible for government subsidies and leveraging existing organizations for workforce development and legislative connections.
- The LENOWISCO ROI is ideal for SMR development due to its central location, existing skilled workforce, and potential for partnerships and grants.

Maryland Feasibility Study:
X-energy, contracted by MPR Associates under a grant from the Maryland Energy Administration (MEA), conducted a feasibility assessment in November 2022 for implementing an Xe-100 advanced SMR at an existing coal plant site in Maryland [16]. This study was initiated to explore repurposing coal-fired power plants to reduce greenhouse gas emissions, enhance energy resilience, and promote economic growth and job sustainability. The assessment considered engineering factors, regulatory compliance, economic impacts, and a community engagement plan.

Key findings and recommendations include:

- While the standard Xe-100 unit configuration is feasible, modifications would be necessary to fit the site and reduce costs.
- The existing infrastructure at the coal plant cannot be repurposed due to differences in operating steam conditions and electrical output.
- The projected 10-year schedule for repurposing includes site-specific engineering, construction, and decommissioning activities.
- The economic evaluation highlighted competitive costs (compared to other sources) and recommended further evaluations to optimize reactor deployment and revenue sources.
- The strategic communication plan emphasized educating the public about SMR benefits and engaging the community through various outreach methods.
- The study's methodologies and findings provide a framework that can be replicated in other states, including Indiana, using local data, subsidies, and similar legislative frameworks.

1.4 Real-world Case Studies

Recent developments have been made in the deployment of nuclear reactors, the understanding of which helps contextualize the state of nuclear in the U.S. and around the world as of 2024.

1.4.1. Domestic Case Studies

NuScale-UAMPS:
In 2014, the Utah Associated Municipal Power Systems (UAMPS) announced the Carbon Free Power Project (CFPP) in response to the expected closure of coal-based power plants within the

following years. The goal was to replace these retiring plants with clean energy sources that could provide base-load power to the electrical grid. The CFPP considered SMRs as a potential pathway forward, and UAMPS began working with NuScale to develop an SMR within the service area [17]. NuScale and UAMPS would continue working together for nearly a decade, achieving several key milestones in the development of SMRs in the United States, the most critical being the certification of the first SMR design by the U.S. NRC. In November 2022, however, this project was mutually terminated by both NuScale and UAMPS, citing financial challenges [18].

TerraPower Natrium:
In 2023, TerraPower announced the purchase of land in Kemmerer, Wyoming where their Natrium Reactor Demonstration Project will be built. Kemmerer is a town of approximately 2,700 residents, greatly affected by the retirement of the local coal in 2025. The goal of the project is not only to provide a 345 MWe power source to the electric grid but also to revitalize the local economy by introducing 1,600 construction jobs and 250 full-time jobs for operating the facility [19]. The Natrium design deviated from more traditional reactor designs with its molten-salt-based coolant. The construction of the plant began on June 10, 2024, with TerraPower expecting construction to span five years. [20]

X-energy/ Dow Chemical:
In August 2022, Dow and X-energy signed a Letter of Intent, followed by the announcement of a Joint Development Agreement in March 2023 under the DOE's Advanced Reactor Demonstration Program (ARDP) [21]. In May 2023, Dow selected its Seadrift manufacturing site to develop a four-SMR unit Xe-100 high-temperature gas-cooled reactor (HTGR) facility. The project aims to provide low-carbon power and steam to Dow's industrial operations. This project is stipulated to lower the Seadrift site's emissions by approximately 440,000 megatons of carbon dioxide per year [22]. Dow and X-energy plan to prepare the Construction Permit application in 2024, with plant construction expected to begin in 2026. The partnership also aims to develop a framework for licensing SMRs for other industrial customers linked to Dow Chemical.

Vogtle Units 3 and 4:
The Vogtle Power Plant in Waynesboro, Georgia consists of four units, with Unit 3 and Unit 4 entering commercial operation on July 31, 2023, and April 29, 2024, respectively [23]. The construction of these units was not without challenges, as delays and construction issues grew the original budget of $14 billion to more than $30 billion. These AP1000 nuclear reactors were the first Generation III+ reactors to enter commercial operation in the United States. Generation III+ reactors are similar to the standard Boiling Water Reactors (BWRs) and Pressurized Water Reactors (PWRs) utilized in the current fleet but with notable improvements in safety features. The AP1000 design improves upon the earlier designs with passive safety features that allow shutting down and management of the reactor without external power or human intervention in case of unlikely scenarios of reactor accidents [23]. It should be noted that the Vogtle Power Plant is not an SMR nor an Advanced Reactor (Generation IV) but rather a traditionally sized nuclear

power plant. Its significance lies in being the most recent nuclear power plant with enhanced safety features constructed in the United States since 2016.

TVA Watts Bar Unit 2:

The Watts Bar Nuclear Plant, located near Spring City, Tennessee, consists of two units, with Unit 1 entering commercial operation in May 1996 and Unit 2 on October 19, 2016. The construction of Unit 2 was not without its challenges, with the project spanning several decades and facing various delays [24]. Initially halted in the 1980s due to economic conditions, construction resumed in 2007, culminating in the first new nuclear power plant to become operational in the United States in 20 years. The total cost of the project reached $4.7 billion [25]. Watts Bar Unit 2 is a PWR and, along with Unit 1, contributes to the Tennessee Valley Authority’s (TVA) efforts to generate carbon-free energy. The traditionally sized plant’s dual units now provide approximately 2,300 megawatts of electricity—enough to power about 1.3 million homes. This contribution is a vital part of TVA’s strategy to reduce carbon emissions, which have decreased by 30% since 2005, with a target of 60% by 2020 [26].

MARVEL Microreactor:

The Microreactor Applications Research Validation and Evaluation Project (MARVEL) is a U.S. Department of Energy (DOE) microreactor ($\leq$ 100 kWth rated) program led by INL [27]. This project would be installed and operated on the INL Idaho Falls campus. [27]. Set for operation in late 2026, it would be INL’s first new reactor in 50 years [28]. Currently in its development phase, MARVEL has achieved 90% of its final design as of late 2023. MARVEL would produce about 85 kW of thermal power (0.085 Megawatts of thermal power (MWth)), converting to approximately 20 kW of electricity (0.02 MWe). Studies have shown that the estimated cost of the development and two-year operation of the MARVEL project is roughly $81-85 million [29].

Project Pele:

The 2016 Defense Science Board study reports that the Department of Defense (DoD) requires a mobile, reliable, sustainable, and resilient power source, which kicked off Project Pele [30]. In 2022, the DoD Strategic Capabilities Office (SCO), in line with Project Pele, awarded BWX Technologies (BWXT) a contract to lead a team comprising Northrop Grumman, Aerojet Rocketdyne, Rolls-Royce LibertyWorks, and Torch Technologies, Inc. in developing the United States’ first advanced nuclear microreactor [31]. The cost-type contract, valued at $300 million, will support 120 employees for two years of development and construction at BWXT facilities in Lynchburg, Virginia, and Euclid, Ohio. Postulated for completion, delivery, and eventual testing at INL in 2024, the microreactor is categorized as a HTGR that utilizes High Assay Low Enriched Uranium (HALEU) tri-structural isotropic (TRISO) fuel to deliver a power rating of 1 to 5 MWe. As of September 2023, the DoD awarded a contract to X-energy, valued at $17.49 million, to develop a second mobile HTGR microreactor for Project Pele [32].

1.4.2. International Case Studies

In other parts of the world, outside the United States, SMRs are recognized as essential for addressing climate change and play a crucial role in diversifying long-term energy portfolios. The following information provides a high-level overview of the breadth and extent of SMR deployment in various countries.

China:

The first commercial onshore SMR, the Linglong One, rated 125 MWe, was completed and constructed by the China National Nuclear Corporation (CNNC) as of March 2024 [33]. In addition, China's CNNC and Tsinghua University's HTR-PM, a 125 MWe HTGR-type SMR, began commercial operation in December 2023 after a year of full-power testing [34] [35]. China also operates a fleet of small reactors, classified as non-modular PWRs, known as the CNP-300, developed by CNNC, each with a capacity of 300 MWe. The CNP-300 is also the first Chinese nuclear reactor to be exported abroad, with up to five units installed in Punjab, Pakistan [36].

Argentina:

An SMR called the CAREM plant is being constructed near Zarate in Argentina. Entirely designed and financed by the state, construction began in 2014 and is postulated to be completed by 2028 [37]. The CAREM plant will undergo validation and qualification processes as a FOAK reactor and, as a result, will initially be rated at a lower 32 MWe [38]. When in operation, the CAREM plant will also produce up to 20% of the world's demand for the radioisotope molybdenum-99, which is used to produce Technicium for medical diagnostic imaging procedures such as SPECT scans [37]. However, the project's future is uncertain due to recent budget cuts and cost-cutting measures imposed by the government, which have stalled construction and strained the National Atomic Energy Commission's (CNEA) finances [39].

Korea:

The Korean Atomic Energy Research Institute (KAERI) and its partnerships, most notably with Hyundai and Atomic Energy of Canada Limited, have developed the 100 MWe-rated System-integrated Modular Advanced Reactor (SMART) [40]. The SMART100 is a PWR designed for electricity generation and potential thermal applications, such as seawater desalination. The SMART100 was granted standard design approval by South Korea's Safety and Security Commission in September 2024 [41].

Japan:

The Japan Atomic Energy Research Institute (JAERI) has conducted decades-long research on advanced reactors (molten-salt, liquid-metal, and high-temperature gas-cooled reactors) in Japan [42]. Most notably, JAERI has been operating as the only SMR in the nation. The high-temperature engineering test reactor (HTTR), graphite-moderated, gas-cooled research reactor has been in operation since 2001 [43]. Other Japanese entities, such as Mitsubishi Heavy Industries, Ltd (MHI), have entered the SMR market through ongoing research and development in 30 MWe to

300 MWe class reactors [44]. In 2021, Japan's JGC Holdings agreed to invest $40 million as an engineering procurement and construction contractor to deploy NuScale SMRs in partnership with Fluor [45].

1.5 Existing Nuclear Power Supply to Indiana

1.5.1. Overview of Donald C. Cook Nuclear Plant

The Donald C. Cook Nuclear Plant, located on a 650-acre site in Michigan, consists of two PWR units owned and operated by the American Electric Power Company, Inc. [46]. Unit 1, with a net capacity of 1030 MWe, began commercial operation in 1975, while Unit 2, with a net capacity of 1168 MWe, started in 1978. Together, these reactors generate electricity for approximately 1.5 million homes. The plant has supplied over 631 TWh of electricity throughout its lifetime, with an operational efficiency reflected in a lifetime load factor of around 73%. The NRC licensed both units in 1977, with their licenses renewed in 2005, set to expire in 2034 [47] and 2037 [48], respectively. A map of the plant with corresponding emergency preparedness can be found in Figure 2.

The Cook Nuclear Plant's power is distributed primarily to Northwest and Central Indiana (Unit 2), as well as Southwest Michigan (Unit 1), managed by Indiana-Michigan Power (I&M), a sector of American Electric Power (AEP) [49], as can be found in Figure 2. DC Cook generates more than 40% of I&M's overall electricity, contributing significantly to the region's low-carbon energy mix, which includes solar, wind, and hydropower. This distribution spans regions, including Fort Wayne, Indiana, where I&M's headquarters are located.

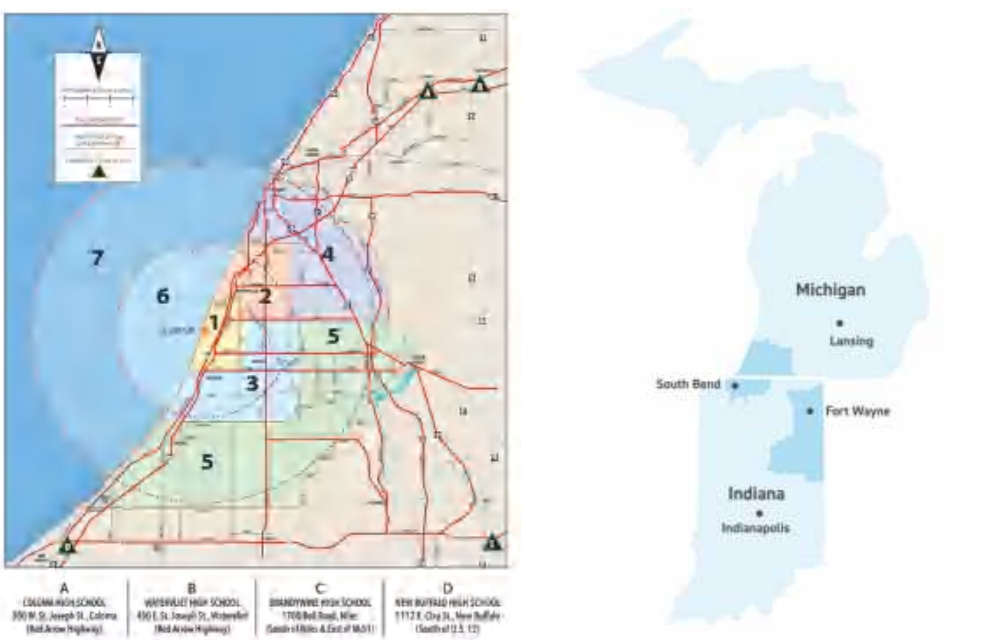

Figure 2. Left: Cook Nuclear Plant emergency preparedness map [50]. Right: Grid Coverage of Indiana Michigan Power [49]

1.5.2. Related Electric Utility Framework in Indiana

In Indiana, the electric utility landscape is governed by two Regional Transmission Organizations (RTOs): Midcontinent Independent System Operator (MISO) and Pennsylvania, New Jersey, Maryland (PJM). The majority of electric utilities in Indiana fall under MISO, except for certain generation assets of the Indiana Municipal Power Agency (IMPA), Wabash Valley Power Alliance (WVPA), and American Electric Power’s I&M, which operate under PJM. The Indiana Utility Regulatory Commission (IURC) allows I&M to supply energy from Michigan to Indiana, despite the location of the plant in Michigan.

CHAPTER 2. OVERVIEW ON SMR TECHNOLOGY

There are many variations in SMR designs and technology. Some SMRs are designed as smaller versions of traditional power plants, utilizing low-enriched uranium (LEU) fuel and a light water coolant. Other designs implement newer fuel options, such as HALEU or TRISO fuel pebbles. LEU has a U-235 enrichment percentage of 5% or less. HALEU, on the other hand, has a higher U-235 enrichment percentage of between 5 and 20%. All currently operating commercial nuclear power plants in the United States are LWRs and thus also use LEUs. These reactors are classified as Generation II to III+ reactors, with the latest one built being the 1 GWe-rated AP1000 at the Vogtle Power Plant in Georgia. Various coolant types besides light water, including high-temperature gas or liquid metal, have also been proposed. SMR designs typically range from low-power units of roughly 70 MWe, allowing the choice to operate several units at a single site, to designs producing roughly 450 MWe from a single reactor.

The present study reviewed seventeen U.S.-based SMR designs and two international SMR designs, with further analysis of six U.S.-based designs and one international design. The review focuses on design principles, features and advantages, potential issues and shortcomings, progress to deployment, and comparison to traditional nuclear technology. These designs are shown in Figure 3 and Figure 4, sorted by coolant type and reactor power, respectively.

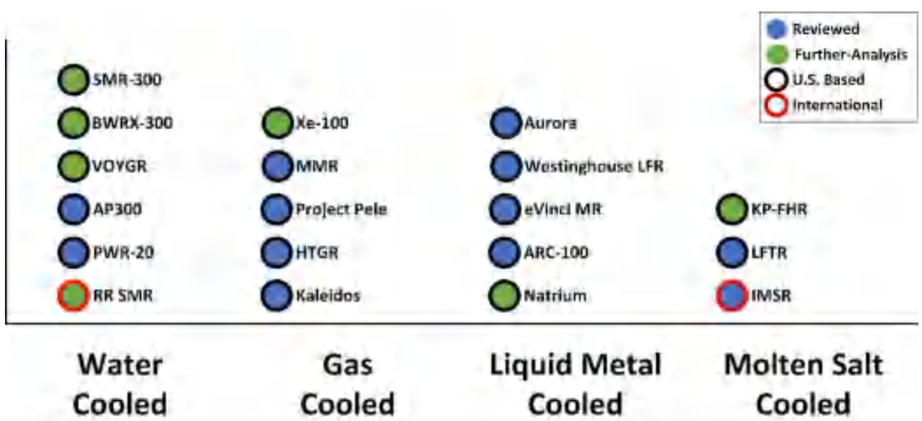

Figure 3. Reactors reviewed in this study, sorted by coolant type [7]

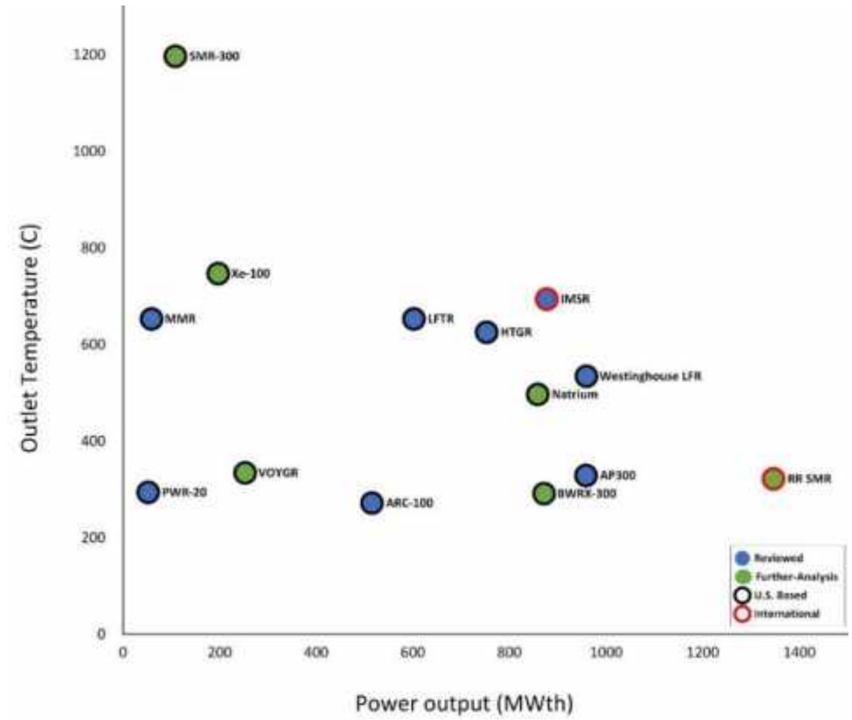

Figure 4. Reactors reviewed in this study, as a function of both outlet temperature and power outputs (MWth) [7]

2.1 Current SMR Landscape

The Organization of Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA) SMR dashboard provides an overview of global progress toward the commercial deployment of SMRs across six key dimensions: licensing, siting, financing, supply chain, engagement, and fuel. Of the 98 SMRs identified by the second edition of the SMR dashboard, 56 SMRs were singled out as being in active development for further analysis, as shown in Figure 5 below.

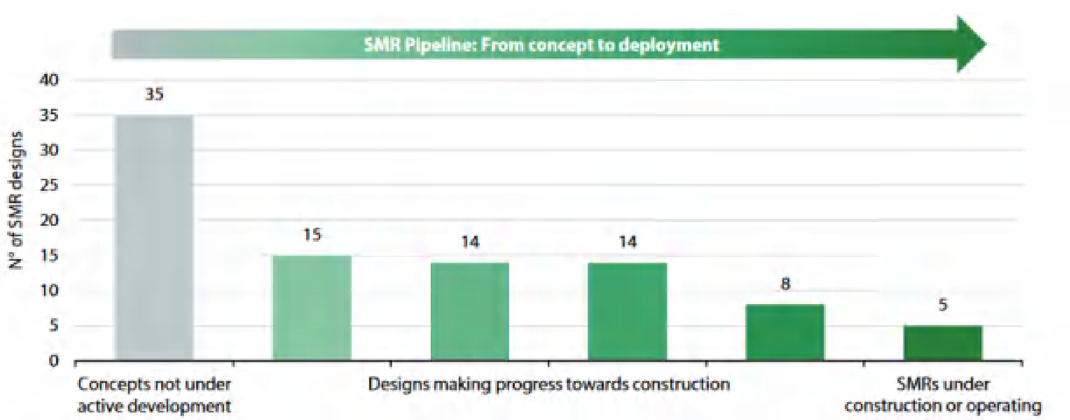

Figure 5. Status of SMR type pipeline identified by NEA SMR dashboard [7]

Table 2. Summary of reactor designs compiled by the NEA [7]

Reactor configuration	Land based	49
	Marine based	7
Location of designer headquarters	U.S.	15
	Canada	3
	France	7
	China	4
	Japan	2
	Russia	2
Reactor type (as defined by the NEA)	Water-cooled	18
	Gas-cooled	14
	Fast neutron spectrum	14
	Microreactor	12
	Molten-salt cooled	10
Fuel type	HALEU	29
	LEU	19
	Natural uranium	8
Siting progress	No reported siting progress	18
	Non-binding agreements with site owners	14
	Selected for deployment	17
	Has construction permit	1
	Commenced on-site construction	6
Publicly available information	Has publicly available information	33
	No publicly available information	23

Apart from the NEA dashboard on current SMR development and market in the 2020s, SMRs have come a long way from their roots in the late 1940s. From their conception within the military Aircraft Nuclear Propulsion Program (ANP) and Navy Nuclear Power Program (NNPP) to their use in the commercial space as prototype test reactors for larger designs, SMRs have a design history of more than half a century. Table 3 shows significant events in the developmental history of SMRs in the United States from 1946 to 2009.

The timeline illustrates SMR development as a recurring response to events such as the 1973 Oil Crisis and the early 2000s Nuclear Renaissance. However, financial instability has often hindered progress, leading companies to abandon projects due to lack of investment. Public protest and the perception of nuclear power as politically contentious, fueled by the Three Mile Island, Chernobyl, and Fukushima incidents, have also been significant obstacles. Despite these challenges, design features and lessons learned from each project have contributed to current SMR designs, which are examined further in this report. Figure 6 shows the overall licensing progress of various SMR designs and Figure 7 breaks down the progress of these designs by country. The history of HTGRs traces back to the Peach Bottom Unit-1 reactor in the United States, which served as a 40 MWe demonstration plant [51]. This plant paved the way for the Fort St. Vrain Generating Station, a commercially operated HTGR that was active from 1979 until its decommissioning in 1989 due to economic reasons [52]. As of 2021, China began the only commercial operation of the HTGR SMR with its 210 MWe HTR-PM design [53]. The following sections summarize different SMR designs based on coolant types, as shown in Figure 8.

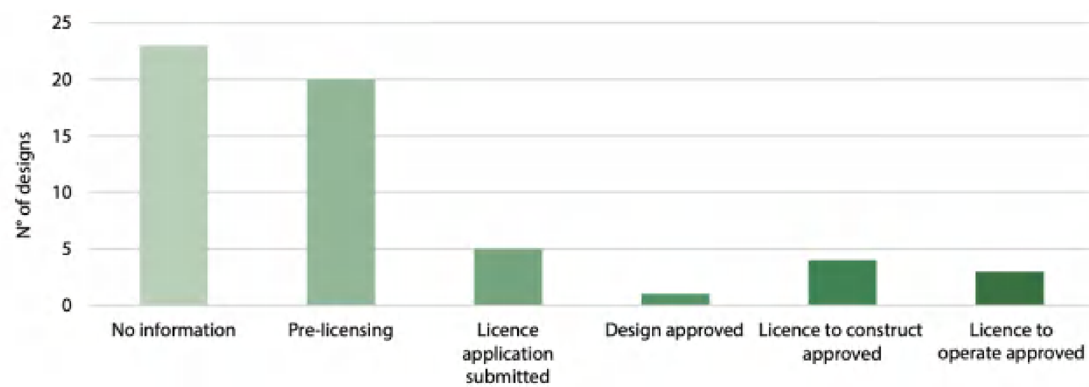

Figure 6. Licensing progress of SMRs identified by NEA SMR dashboard. [7]

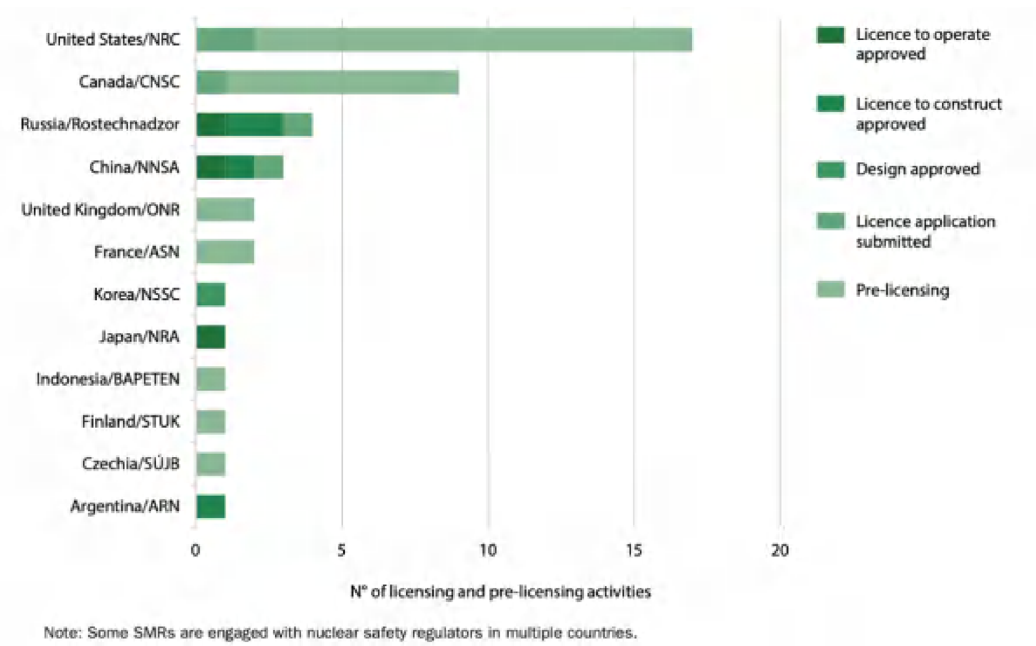

Figure 7. Distribution of SMR licensing activities across various countries' nuclear safety regulators. [7]

Table 3. History of early efforts in small reactor development in the United States [54]

Year	Project/ Program Manager	Background Information	Technical Specifications	Status
1946	**Aircraft Nuclear Propulsion Program**, ORNL, INL	Air Force (USAF) explored the use of small reactors to power long-range bombers [55]	Six small reactors were built to test and validate a 3 MWe reactor fitted on a Convair B-36H bomber	Terminated by President Eisenhower
1947	**Naval Nuclear Power Program**	Navy (USN) Admiral Hyman G. Rickover spearheaded the program to develop small reactors for Navy propulsion	NA	Results in two parallel projects: USS Nautilus and USS Seawolf Propulsion systems
1954	**USS Nautilus, Westinghouse**	The first nuclear-powered submarine	Pressurized water reactor (S1W, S2W)	Operated for 26 years, decommissioned in 1980
1954	**U.S. Army Nuclear Program**	Army research identified nuclear power as an opportunity to power remote installations [56]	Five 1-2 MWe PWRs, One 1 MWe BWR, One 10 MWe barge-mounted PWR, One 0.5 MWe gas-cooled reactor	Since its termination in 1976, lessons learned and design choices have been transferred to SMRs
1957	**USS Seawolf, General Electric**	The second nuclear-powered submarine [57]	Sodium-cooled reactor (S2G), Later pressurized water reactor (S2Wa)	Operated for 30 years, decommissioned in 1987
1957	**Shippingport Atomic Power Station**	The first full-scale nuclear power plant for peacetime and public use [58]	60 MWe scaled up version of naval reactors (PWR)	Decommissioned after 25 years of operation in 1985
1957	**Vallecitos Nuclear Center**, General Electric (Now Hitachi)	Demonstration plant for BWRs and pilot plant for Dresden Plant [59]	5 MWe BWR	The site decommissioned in 2023
1960	**Dresden Plant**, General Electric	First privately financed nuclear power plant [60]	200 MWe BWR	Decommissioned in 1978
1960	**Indian Point Unit 1 (IP-1)** Babcock & Wilcox	First thorium fueled commercial reactor [58]	275 MWe scaled up version of naval reactors (PWR)	Decommissioned in 1974 after failing to meet new Nuclear Regulatory Commission standards.
1962	**NS Savannah**	President Eisenhower's Atoms for Peace initiative launched the first nuclear-powered merchant ship [61]	69 MWt PWR	Traveled to 78 domestic and foreign ports.
1978	**Fast Flux Test Facility (FFTF),** DOE	Testing and validation of Fast Spectrum reactor design for nuclear fuel breeding [62]	400 MWt liquid-metal (sodium) cooled fast-breeder reactor	Decommissioned in 2006
1980	**Clinch River Breeder Reactor**, DOE	Aimed to be the United States' first large-scale breeder reactor plant [63]	375 MWe demonstration plant liquid-metal (sodium) cooled fast-breeder reactor	Opposed by President Carter and terminated in 1983

1982	**AP-600**, Westinghouse, DOE & EPRI Advanced Light Water Reactor Program (ALWR)	Final design certification received in 1999 [64]	600 MWe PWR utilizing passive (non-engineered) safety systems	No orders were placed, resulting in a rebranding as the AP-1000 program
1982	**SBWR**, General Electric (Now Hitachi), DOE & EPRI ALWR	Up rated to 1500 MWe Economic Simplified Boiling Water Reactor (ESBWR) [65]	600 MWe BWR utilizing passive safety systems	ESBWR design certified by NRC in 2014; design considerations utilized in BWRX-300
1984	**PRISM**, General Electric (Now Hitachi), DOE Advanced Light Metal Reactor Program	Design based on Argonne National Labs Experimental Breeder Reactor 2 [66]	Nine 160 MWe power modules for 400 MWe plant with passive safety systems, sodium-cooled fast-breeder reactor	Design transferred to private companies (Terrapower Natrium and ARC-100)
1988	**Safe Integral Reactor (SIR),** ABB Combustion Engineering, Rolls Royce, AEA Technology	Proposed as Candidate for DOE ALWR Program but lost out to AP-600 and SBWR [67]	320 MWe PWR	Design features carried over to Westinghouse and Rolls Royce SMRs
1999	**IRIS**, Westinghouse consortium	DOE Nuclear Energy Research Initiative (NERI) winner (3-year grant) [68]	50-200 MWe integral PWR, passive safety, <4 cents/ kW cost	Westinghouse left the consortium in 2010, resulting in termination
1999	**MASLWR**, INL, Oregon State University, Bechtel	DOE Nuclear Energy Research Initiative (NERI) winner (3-year grant) [69]	30 modules of 35 MWe integral PWR, passive safety, <4 cents/ kW cost	NuScale has been seeking to commercialize this design since 2007
2008	**GEM-50**, Babcock & Wilcox,	Response to USAF request for Nuclear Power on Domestic Bases [70]	50 MWe Integral PWR	Department of Defense feasibility study results in reluctance to move forward
2009	**mPower**, Babcock & Wilcox, Bechtel	A continuation of the GEM-50 programs for commercial use [70]	Two 180 MWe reactor modules (integral PWR)	Bechtel withdrew from the joint venture in 2017, resulting in termination
2006	**DOE Next Generation Nuclear Plant (NGNP) Program**	To develop the very high-temperature reactor concept among Gen-4 reactors for process-heat industrial applications [71]	250 - 300 MWe Westinghouse - Pebble Bed Modular Reactor, General Atomics - Modular High-Temperature Reactor, Areva - Prismatic Block Modular High-Temperature Reactor	Terminated in 2012, but 3 designs were developed that are viable for future deployment

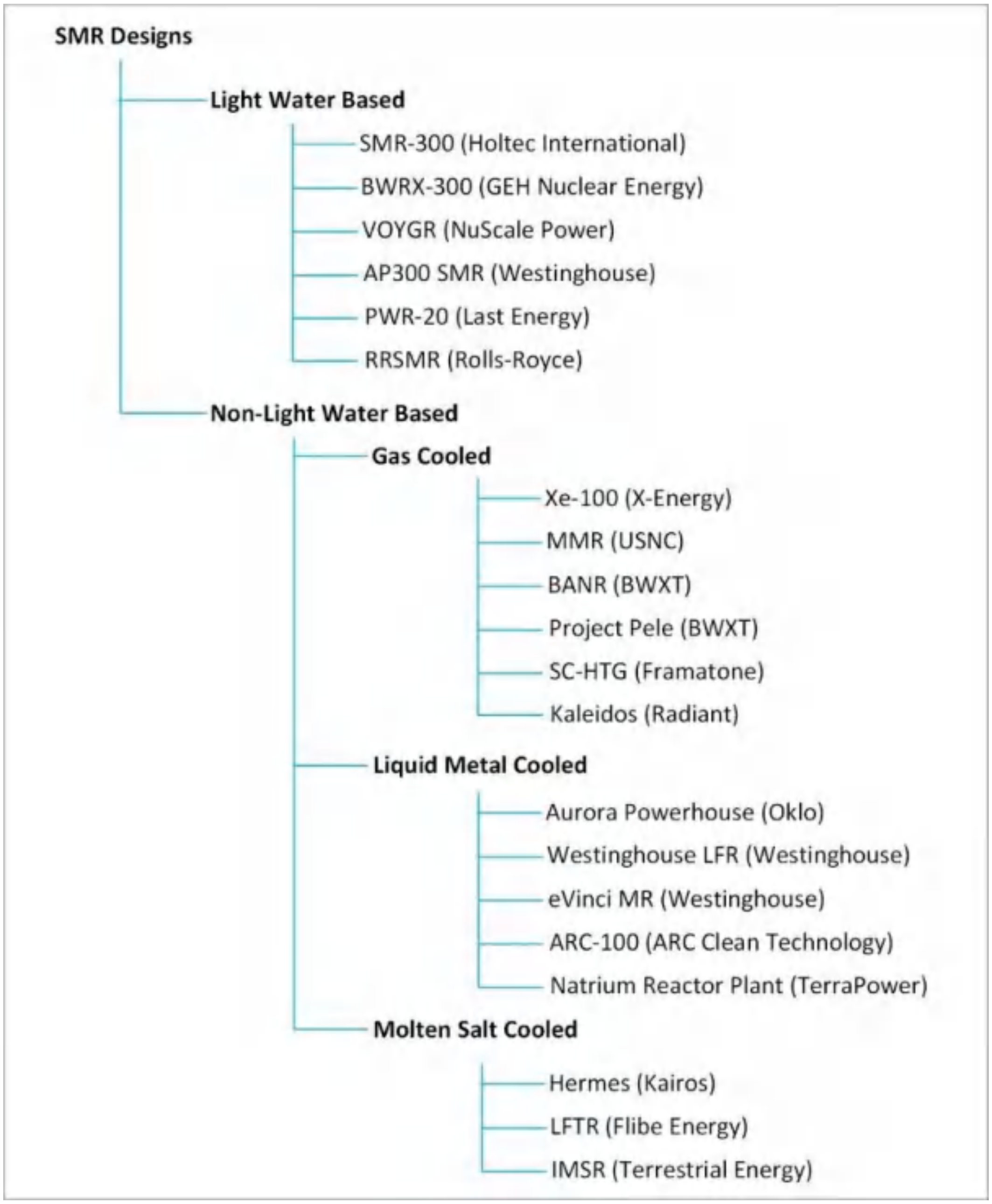

Figure 8. An example list of various SMR designs, organized by coolant type

2.1.1. Light-Water (LW) Based SMRs

All operating reactors in the U.S. are one of two types of LWR designs: PWRs or BWRs. PWRs keep water under high pressure to prevent it from boiling and use separate steam generators to produce steam, whereas BWRs boil water directly inside the reactor vessel to produce steam, with both types driving turbines [72]. In the present study, six LW SMRs are reviewed, including the five U.S.-based designs and one international design: SMR-300 (Holtec International), BWRX-300 (GE Vernova), VOYGR (NuScale Power), AP300 (Westinghouse Electric Company), and PWR-20 (Last Energy). The international LW-based SMR is the Rolls-Royce SMR (RR SMR) in the U.K. The SMR-300, BWRX-300, and AP300 have approximately 300 MWe capacities, while the VOYGR and PWR-20 can be scaled as multi-module designs to achieve the desired power or cost constraint. The RR SMR is designed to produce electricity of 470 MWe. A summary of the different LW-based SMRs can be found in Table 4.

2.1.2. Non-Light Water Based SMRs

Existing non-LWRs, which are largely experimental and research-based in the United States, utilize liquid metal, molten salt, or gas coolants and are classified by the NRC as advanced reactors. These non-light water coolants offer inherent safety features such as passive cooling and lower operational pressures and enable higher thermal efficiencies and cost-effective fuel utilization. Regarding fuel utilization, some liquid metal reactors in this study operate on the fast spectrum, which can increase energy yield and burn long-lived actinides found in high-level nuclear waste, thereby reducing its lifecycle radiotoxicity.

2.1.2.1. Gas Cooled SMR

HTGRs are reactors that can operate at very high temperatures, above 1000°C, and nominally use a graphite-moderated gas-cooled nuclear reactor with a once-through uranium fuel cycle. This fuel cycle utilizes fuel in the form of TRISO fuel pebbles [73]. TRISO fuel decreases reactor size by allowing for fission product retainment for each individual particle due to the coated layers that comprise the TRISO particles, rather than needing a general containment of the system [66]. More information on the TRISO fuel types and advantages are discussed in subsequent sections of this report. Another design feature of the HTGR is that high-temperature gas can achieve greater thermal efficiency [73].

This report has reviewed six reactor designs currently in development that leverage the HTGR system: Xe-100 (X-energy), Micro-Modular Reactor (MMR) (Ultra Safe Nuclear Corporation (USNC)), BWXT Advanced Nuclear Reactor (BANR), Project Pele (BWXT), Steam Cycle High-Temperature Gas-Cooled Reactor (SC-HTGR) (Framatome), and Kaleidos (Radiant Industries). Each of these reactors is at a different stage of development, but they are all on track toward production. A summary of the different gas-cooled SMRs can be found in Table 5.

2.1.2.2. Liquid Metal-Cooled SMR

The liquid metal-cooled SMRs use liquid metal as their main reactor core coolant. Liquid metal has a higher thermal conductivity allowing for more effective heat removal and higher power densities when compared to water [74]. This also allows the coolant to run at atmospheric pressure and greatly reduces the water needs of an SMR. Liquid metal SMRs can operate on the fast neutron spectrum (negating the need for moderation) whereas most contemporary designs remain on the thermal neutron spectrum [75]. [76] The history of the liquid metal-cooled SMR design can be traced back to the USS Seawolf S2G, FFTF, Clinch River Breeder Reactor, and PRISM as noted in the Table 3 timeline. Within this report, five liquid metal-cooled SMRs within today's market are reviewed, which include Aurora Powerhouse (Oklo), Westinghouse Lead Cooled Fast Reactor (LFR) (Westinghouse Electric Company), eVinci microreactor (MR) (Westinghouse Electric Company), ARC-100 (ARC Clean Technology), and Natrium Reactor Plant (TerraPower). A summary of the different liquid metal-cooled SMRs can be found in Table 6.

2.1.2.3. Molten Salt-Cooled SMR

Molten salt reactors (MSRs) utilize molten salts for their core cooling mechanism. This unique design feature offers potential advantages in terms of efficiency and suitability for various non-electric applications. The concept of MSRs traces back to the research conducted at the ORNL in the U.S. The development began with the Aircraft Reactor Experiment (ARE), which stemmed from the Aircraft Nuclear Propulsion Program (see Table 3) in the 1950s, followed by the Molten-Salt Reactor Experiment (MSRE) conducted from 1965 to 1969. During this trial, ORNL successfully operated an experimental 7.34 MWth MSR, demonstrating the feasibility of reactors powered by liquid fuel and cooled by molten salts. One of the key advantages of using molten salt coolants is their exceptional heat absorption capacity. This characteristic enables MSRs to operate at extremely high temperatures, facilitating the production of high-grade heat essential for driving industrial processes, including hydrogen production. This capability holds promise for expanding the scope of applications for MSRs beyond electricity generation. Three molten salt-cooled SMRs are reviewed, which include Hermes (Kairos Power), Liquid Fluoride Thorium Reactor (LFTR) (Flibe Energy), and Integral Molten Salt Reactor (IMSR) (Terrestrial Energy). A summary of the different molten salt-cooled SMRs can be found in Table 7.

Table 4. Light Water Based SMR Summary [7]

SMR	Reactor description	Thermal Power (MWth)	Electric Output (MWe)	Outlet temperature (℃)	Fuel type	Deployment progress (Under NEA standards)
SMR-300 (Holtec International) [7]	"Land-based pressurized" LWR	1050	300	N/A	UO_2 pellets (LEU)	Overall low progress with licensing, siting, financing, and engagement; overall medium progress with supply chain and fuel
BWRX-300 (GE Vernova) [77]	Small, less complex boiling water reactor (BWR) design	870	300	287	GNF-2 (LEU)	Currently in the process of being deployed outside the U.S., such as Canada. Working to be deployed in many other countries and U.S.
VOYGR (NuScale Power) [7]	"Integral multi-module pressurized water reactor" (PWR)	250	77 per module	321	UO_2 pellets (LEU)	Overall medium progress with licensing, siting, financing, supply chain, and fuel; overall excellent progress with engagement
AP300 SMR (Westinghouse Electric Company) [7]	"One-loop pressurized" LWR based on AP1000	990	300	325	UO_2 pellets (LEU)	Overall low progress with licensing, siting, and financing; overall medium progress with supply chain and fuel; overall excellent progress with engagement
PWR-20 (Last Energy)	"Micro pressurized" LWR	60	20	300	UO_2 pellets (LEU)	Overall low progress with licensing and siting; overall medium progress with financing, supply chain, engagement, and fuel
RR S47	PWR system with redundant cooling and steam generators	1358	440-470	325	UO_2 pellets (LEU)	Still in design and licensing phase

Table 5. Gas-Cooled SMR Summary [7]

SMR	Reactor description	Thermal Power (MWth)	Electric Output (MWe)	Outlet temperature (℃)	Coolant type	Fuel type	Deployment progress (Under NEA standards)
Xe-100 (X-energy)	HTGR using graphite as moderator and helium as coolant	200	80	750	Helium	HALEU TRISO-X pebble	Xe-100 is involved in pre-licensing in the U.S. and Canada; X-Energy has the funding and supply chain in place for implementation, and there are customers ready to purchase the reactor. However, the fuel is not yet accessible
MMR (USNC)	HTGR with TRISO fuel in fully ceramic micro-encapsulated (FCM) pellets	10 to 50	3.5-15	660	Helium	TRISO	Overall low progress with licensing; medium progress with siting, financing, supply chain and fuel; overall excellent progress engagement
Project Pele (BWXT)	Micro mobile gas-cooled demo reactor for government and potential commercial use.	N/A	1-5	N/A	Gas	TRISO	Overall low progress with licensing and engagement; medium progress with siting, financing, supply chain and fuel
SC-HTGR (Framatome)	A steam generating, gas-cooled reactor	625	4	750	Helium	TRISO	Working to start the construction of the reactor in 2027 at the earliest, expecting 13 years from initial concept
Kaleidos (Radiant)	An MR designed to be transportable in a shipping container.	1.9	N/A	700	Helium	TRISO	This design is still being licensed and will be worked on in the INL once approved

Table 6. Liquid Metal Cooled SMR Summary [7]

SMR	Reactor description	Thermal Power (MWth)	Outlet temperature (°C)	Coolant type	Fuel type	Spectrum (thermal/ fast)	Deployment progress (Under NEA standards)
Aurora Powerhouse (Oklo)	Liquid metal-cooled, small-scale SMR project	40	500	Liquid metal	HALEU	Fast	Lacking licensing and funding. Fuel and siting are significantly further along.
Westinghouse LFR (Westinghouse Electric Company)	Medium-scale SMR, lead-cooled	950	Phase 1: 530 Phase 2: 1650	Lead	HALEU for UO_2 pellets	Fast	Little progress on nearly all aspects
eVinci MR (Westinghouse Electric Company)	TRISO-fueled MR with high-temperature sodium heat pipe, offering a minimum eight-year refueling interval	15	750-800	Liquid sodium	HALEU (TRISO)	Thermal	Current target entry slated for 2030 in Canada
ARC-100 (ARC Clean Technology)	Sodium-cooled fast reactor with metallic uranium alloy fuel, featuring a 20-year refueling cycle	286	510	Liquid sodium	HALEU (Metallic-Zr Alloy)	Fast	Final deployment phase will run from 2027 to 2030
Natrium Reactor Plant (TerraPower)	Sodium fast reactor integrated with a molten salt energy storage system for dispatchable power supply	840	500	Liquid sodium	HALEU-TRISO (Metallic-Zr Alloy)	Fast	Officials expect deployment as early as 2030 in Kemmerer, Wyoming

Table 7. Molten Salt Cooled SMR Summary [7]

SMR	Reactor description	Thermal Power (MWth)	Outlet temperature (℃)	Coolant type	Fuel type	Spectrum (thermal/fast)	Deployment progress (Under NEA standards)
KP-FHR (Kairos)	TRISO pebble-fueled demonstration reactor cooled by high-temperature fluoride salt	35	650	Fluoride salt	TRISO	Thermal	Overall medium progress with licensing, siting, supply chain and fuel; overall excellent progress with financing and engagement.
LFTR (Flibe Energy)	Lithium fluoride reactor for power and isotope production, fueled by uranium and breeding thorium	600	650	Molten salt	LEU, Thorium		Little progress on nearly all aspects
IMSR (Terrestrial Energy)	Fluoride MSR with LEU and graphite moderation	884	700	Molten salt	LEU		Overall low progress with licensing, siting, and fuel; overall medium progress with financing and supply chain; overall excellent progress with engagement

2.2 Comparisons of Major SMR Designs

Based on the above landscape and DOE's Advanced Reactor Demonstration Program, seven SMR designs have been selected for a more in-depth comparison.

- **SMR-300:** Holtec International's SMR-300 is a pressurized LWR with a 300 MWe capacity. It has a thermal power output of 1050 MWth and uses LEU UO_2 fuel pellets.
- **BWRX-300:** The BWRX-300 is a BWR designed by GE Vernova. It has a 300 MWe capacity, a thermal power output of 870 MWth, and uses LEU GNF-2 fuel.
- **VOYGR:** NuScale's VOYGR is a multi-module PWR that has a 77 MWe capacity and 250 MWth thermal power output per module. Designed in 4, 6, or 12 module configurations, this SMR uses LEU UO_2 fuel pellets.
- **RR SMR:** Rolls-Royce's RR SMR is a PWR with approximately 450 MWe capacity. It has a thermal power output of 1358 MWth and uses LEU UO_2 fuel pellets.
- **Xe-100:** The Xe-100 is a helium-cooled HTGR designed by X-Energy. It has an 80 MWe capacity, a thermal power output of 200 MWth, and uses TRISO-X fuel.
- **Natrium:** TerraPower's Natrium is a sodium-cooled fast reactor with a 338 MWe capacity. It has a thermal power output of 840 MWth and uses TRISO fuel.
- **KP-FHR:** The KP-FHR is a fluoride salt-cooled reactor designed by Kairos Power. It has a 140 MWe capacity, a thermal power output of 35 MWth, and uses TRISO fuel.

2.2.1. SMR-300 (Holtec International)

The SMR-300 is a land-based pressurized LWR that produces 300 MWe, has a 1050 MWth power output, and operates using standard LEU UO_2 fuel. Multiple units can be used for areas with a higher power requirement. Each component of the SMR-300 is designed to be 12 feet in diameter or less [78]. This eases production costs and allows flexibility in the manufacturing process. The design has an option to use air-cooled condensers to eliminate the need to be located near a large body of water for a heat sink [79]. Figure 9 shows a diagram of the SMR-300 reactor.

2.2.1.1. Design Principles

The main design philosophy of SMR-300 is to provide a robust passive safety system to achieve a highly reliable design that protects the reactor from all postulated accidents resulting from human actions. The SMR-300 design is "walk-away safe" – no operator action is needed to cope with design-basis accidents.

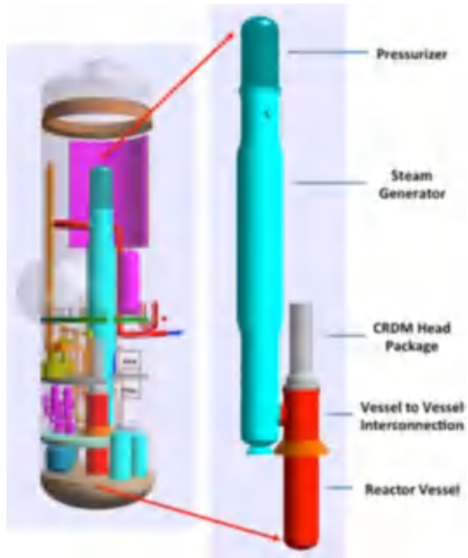

Figure 9. SMR-300 Reactor [80]

2.2.1.2. Design Features

- **Defense-in-depth:** All safety systems are redundant and located inside a robust containment enclosure. All water needed for a postulated loss of coolant accident is inside containment and another large inventory of water outside containment provides long-term decay heat removal for an unlimited period following a design basis accident.
- **Passive safety:** The design is a walk-away safe reactor. In the case of natural disasters or other events, no action from the operator is necessary to shut down the reactor [81]. Also, air-cooled condensers provide the option to reject waste heat into the atmosphere, instead of requiring a large body of water to use as a heat sink. [81]
- **Simplicity:** The design is greatly simplified relative to conventional nuclear power plants to improve fabricability, constructability, and maintainability. Design involves fewer and simpler components than traditional nuclear power plants (NPPs), decreasing the time needed for construction and operating expenses [82, 83].
- **Modularity:** Design focuses on modular construction of main components prior to arrival at a site. Both the reactor and its fuel storage are designed to be underground.
- **Waste management:** Fuel waste storage is located in an underground, vertically ventilated, on-site cavity licensed by the NRC called the Holtec International Storage Module Underground MAXimum Safety (HI-STORM UMAX) [81].
- **Refueling schedule & reactor life:** The refuel schedule is designed to discharge approximately one-third of fuel assemblies in the core each refueling cycle, and the reactor has a plant design life of 80 years, which is twice as long as traditional NPPs.

2.2.1.3. Potential Opportunities and Challenges [7]

- **Licensing:** Limitations may arise concerning the deployment of the SMR-300. According to the NEA, the SMR-300 has made only low to medium progress in development when considering licensing, siting, financing, supply chains, engagement, and fuel. In 2018, the

SMR-300 made it through “Phase 1 of the pre-licensing Vendor Design Review with the Canadian Nuclear Safety Commission” and was in the pre-licensing phase with the NRC. However, no approvals or licensing have been completed since. In 2023, Holtec applied to the “UK Office for Nuclear Regulation to enter step 1 of the Generic Design Assessment (GDA)”; however, it has not begun the GDA process [7].

- **Siting:** In 2023, Holtec met with the NRC to discuss deploying the SMR-300 at its Palisades site in Michigan, acquired in 2022. However, no site has been selected for deployment of SMR-300 as of 2024. Holtec is also considering deploying an SMR at its Oyster Creek nuclear site in New Jersey.
- **Financing:** Holtec has secured $116 million from the U.S. Department of Energy (DOE) Advanced Reactor Demonstration Program to advance early-stage design, engineering, and licensing.
- **Supply chain:** Holtec has partnerships in place and in-house nuclear engineering, manufacturing, and construction capabilities.
- **Fuel:** SMR-300 uses LEU fuel, which is used in most existing light water reactors. In 2020, Holtec signed a contract with Framatome, a French nuclear fuel manufacturer, to supply nuclear fuel for their SMR.

2.2.2. BWRX-300 (GE Vernova)

2.2.2.1. Design Principles

The BWRX-300 is a 300 MWe BWR with an open-top design, allowing it to be built in 24 to 36 months. It features a 90% volume reduction compared to the ESBWR, GE-Vernova's Generation 3+ BWR. The BWRX-300 uses LEU, UO_2 fuel, which is readily available, and does not pose the proliferation risks associated with HALEU [84]. The BWRX-300 uses a dry containment to stop the release of any products of a Loss of Coolant Accident (LOCA), such as steam, water, or fission products into the environment. The BWRX-300 was intentionally designed for low electrical output to enable commercial use and lower costs to be economically competitive [85]. The entire reactor pressure vessel (RPV) can be observed in Figure 10.

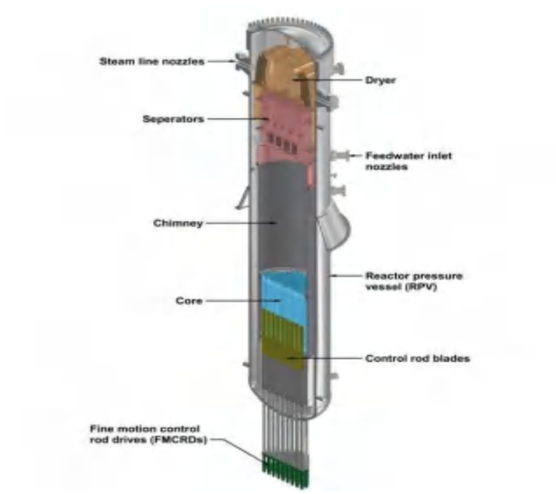

Figure 10. The BWRX-300 RPV Internal diagram [62]

2.2.2.2. Design Features

- **Defense-in-depth:** The design was developed following the IAEA Defense-in-Depth guidelines using fundamental safety functions (FSF). Therefore, in an emergency scenario, physical barriers will stay effective. These involve two passive cooling systems and a containment surrounding the reactor pressure vessel, piping systems, and isolation valves. The safety components of the reactor are all kept in the reactor building, and the reactor is built underground.
- **Passive safety:** The design features a fully passive approach to safety systems and is a walk-away safe reactor. After reactor isolation events, the isolation condenser system (ICS) works to remove decay heat from the reactor. In the case of design-basis accidents, the passive containment cooling system (PCCS) works to remove decay heat as well as maintain the pressure inside the containment through low-pressure heat exchangers [81].
- **Simplicity:** The reactor is designed to simplify and reduce the cost of construction and operation as well as reactor maintenance, staffing, and eventual decommissioning. It is the simplest BWR design and uses proven components, such as a reactor pressure vessel, control rods, and natural circulation. [81]
- **Modularity:** This design uses modular construction to optimize costs and maintenance. The reactor is designed to be underground.
- **Waste management:** Once fuel is removed from the core, it is kept in a fuel pool, located in the reactor building for 6 to 8 years. Then it is moved into storage casks that are loaded in the reactor room and transported outside [81].
- **Refueling schedule & reactor life:** The refueling schedule is the same as a standard BWR. Between 15% and 25% of the fuel bundles are replaced with fresh fuel during refueling outages. This reactor has a design life of 60 years.

2.2.2.3. Potential Opportunities and Challenges [7]

- **Licensing:** GE-Vernova has submitted five topical reports regarding the BWRX-300 to the U.S. NRC and has completed a vendor design review with the Canadian Nuclear Safety Commission.
- **Siting:** Ontario Power Generation has begun preparing for the construction of a BWRX-300. The design has been selected for potential deployment in Canada, Estonia, and Poland, and GE-Vernova has partnered with the Tennessee Valley Authority for potential deployment in the U.S.
- **Financing:** GE-Vernova has received nearly $768 million in public financing from the Canadian federal government, and through a regulatory amendment set by the Province of Ontario, can recover costs incurred through the construction and operation of the reactor. Through working with the Tennessee Valley Authority, Ontario Power Generation, and Synthos Green Energy, an additional $400 million investment is anticipated. [86]
- **Supply chain:** GE-Vernova has developed similar BWR designs in the past, and potentially could leverage existing supply chains.

- **Fuel:** The BWRX-300 uses LEU UO_2 fuel, a widely used fuel in most current light water reactors.

2.2.3. VOYGR (NuScale Power)

2.2.3.1. Design Principles

The VOYGR is a multi-module PWR with each module having an output of 250 MWth and 77 MWe. The VOYGR uses LEU UO_2 fuel and has a refueling cycle of 21 months [87]. Designed in three different models, each VOYGR plant can generate a different amount of power based on its number of modules. The VOYGR-12, with 12 modules, generates a total output of 924 MWe, the VOYGR-,6, with 6 modules, generates a total output of 462 MWe; and the VOYGR-4, with 4 modules, generates a total output of 308 MWe [87]. Components of a VOYGR module include a reactor vessel, pressurizer, containment, and multiple steam generators [88]. Figure 11 shows a diagram of a single VOYGR reactor module.

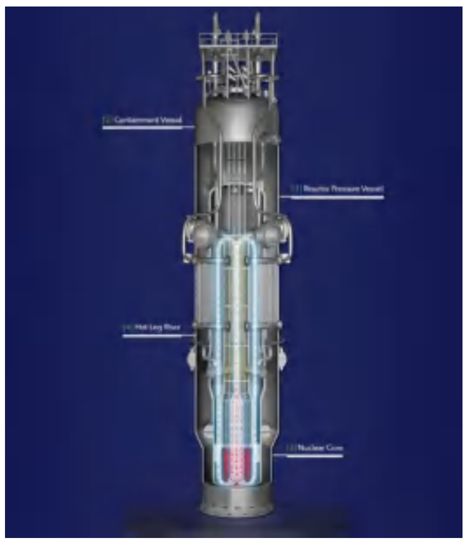

Figure 11. VOYGR Reactor Module [88]

2.2.3.2. Design Features

- **Defense-in-depth:** The reactor is designed to operate without any power, human action, or makeup water in a design basis accident for an unlimited amount of time. The design involves many simple and redundant safety systems that can work independently of each other, such as a decay heat removal system, emergency core cooling system, and containment vessel.
- **Passive safety:** The design is walk-away safe and includes a passive heat removal system. One decay heat removal system is attached to each steam generator loop and can remove 100% of the decay heat load. Each system includes a passive condenser in the reactor pool. The containment vessel is also immersed in the pool, providing a passive heat sink for heat removal in LOCA conditions [81]

- **Simplicity:** The reactor uses a simplified design compared to traditional power plants. It includes proven LWR systems, a modular steam supply system, natural circulation for coolant flow, and a fully digital control system. These components decrease the number of new technologies and construction time for the reactor.
- **Modularity:** The reactor design is meant to be scalable to produce incremented power outputs by adding modules. Each module adds 60 MWe of power to the output, with a maximum of 720 MWe, or 12 modules. The modules are identical to each other, self-contained, and operate independently of the others. They are factory-fabricated, transported to the reactor site, and managed from a single control room.
- **Waste management:** Fuel waste is cooled in a used-fuel pool, then stored on-site in dry storage casks. Each cask can store five fuel assemblies and other affected reactor core components. Final disposal is planned to go to a national repository once created. [81].
- **Refueling schedule & reactor life:** A three-batch refueling system is completed every 24 months, where one-third of the fuel is removed and placed in a spent fuel pool. A module is disconnected from its operations bay and moved to a refueling location in a shared reactor pool. This reactor has a design life of 60 years.

2.2.3.3. Potential Opportunities and Challenges

- **Licensing:** NuScale's original 50 MWe design became the first SMR design to be certified by the U.S. NRC, taking effect on February 21, 2023. [89]
- **Siting**: In 2023, plans for the siting of the reactor at Idaho National Laboratories were terminated by NuScale and the Utah Associated Municipal Power Systems.
- **Financing:** Limitations arise in the funding of the reactor design. The design was originally set to cost \$5.32 billion for 12 modules. However, when the power output was increased the cost of the reactor became \$9.3 billion for only 6 modules [90].
- **Supply chain:** NuScale has contracts and agreements with many different companies and universities to aid with testing and review.
- **Fuel:** VOYGR uses LEU UO_2 fuel, a widely used fuel in most current light water reactors.

2.2.4. RR SMR (Rolls-Royce)

2.2.4.1. Design Principles

The Rolls-Royce SMR (RR SMR) is an LWR that uses LEU UO_2 fuel in a 17x17 array and produces 470 MWe. The design is a smaller version of a traditional PWR reactor and will use light water as coolant, pressurized to 15.5MPa. The coolant circulates using three centrifugal reactor coolant pumps (RCP) connected to three Vertical U-Tube Steam Generators. The SMR will be able to run for 18 to 24 months before needing to be refueled [91].

2.2.4.2. Design Features

- **Defense-in-depth:** The reactor island contains a robust and modular PWR design. Within the module, multiple active and passive safety systems, with internal redundancy, provide several layers of defense against a potential accident. [92]

- **Passive safety:** The design contains several passive safety features, such as a passive residual heat removal system and a gravity-driven water-cooling system. [93]
- **Simplicity:** The design consists of three distinct areas: a reactor island incorporating the reactor itself, a turbine island containing a turbine and generator set, and a cooling water module containing both direct and indirect water-based cooling methods. [92]
- **Modularity:** The majority of the plant will be factory-built and arrive at the site in prefabricated, pre-tested modules. These modules will be assembled on-site within a “site assembly factory”. [92]
- **Waste management:** Radioactive waste generated by the reactor is stored and managed at the site. [94]
- **Refueling schedule & reactor life:** The reactor has a fuel cycle of 18 months, with a design life of 60 years. [92]

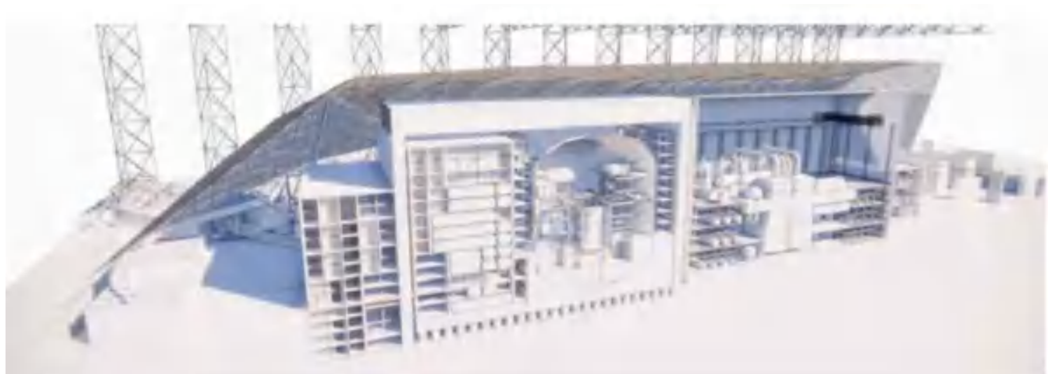

Figure 12. Rolls-Royce SMR power station [92]

2.2.4.3. Potential Opportunities and Challenges [7]:

- **Licensing:** Rolls Royce has not begun licensing with the U.S. NRC but has submitted a design certification application to the U.K. Office for Nuclear Regulation for review.
- **Siting:** Rolls Royce has not performed any publicly available siting within the U.S. Rolls-Royce is exploring several options within the U.K. including using U.K. Nuclear Decommissioning Authority land and was selected as the preferred technology for an SMR deployment in West Cumbria, U.K.
- **Financing:** Rolls Royce has garnered roughly $616 million in public and private funding. This includes funds through the U.K. Research and Innovation, as well as equity investments from several business partners.
- **Supply chain:** Rolls Royce is currently supported by the U.K. National Nuclear Laboratory as well as several British engineering companies but aims to develop its own factories to design its SMR components.
- **Fuel:** RR SMR uses LEU fuel, which is used in most existing light water reactors. In 2023, Rolls Royce signed an agreement with Westinghouse Electric Company to work on the design of RR SMR nuclear fuel.

2.2.5. Xe-100 (X-Energy)

2.2.5.1. Design Principles

X-Energy's Xe-100 is an 80 MWe/ 200 MWth reactor using graphite as a moderator, helium as a coolant, and 15.5% enriched HALEU TRISO fuel pebbles [95, 96]. The Xe-100 reactor generates superheated steam at 565 °C and 16.5 MPa [97]. The core of the Xe-100 is comprised of individual pebbles, acting as their own containment, eliminating the risk of a meltdown. Thus, the Xe-100 is considered a Generation-IV reactor. The goal for the design was to balance "size, cost & build time" [95]. The result will be the creation of a power plant using a "four-pack" of 80 MWe reactor vessels [95]. This allows for geographic flexibility of the plant by deploying "off the shelf" components using existing roads and rails which lead to decreased overall cost. X-Energy's Xe-100 features a two-loop design similar to a PWR; however, the Xe-100 uses Helium to superheat water vapor before generating electricity at an efficiency of 42.3% [98]. A diagram showing the TRISO fuel pebbles and reactor core is shown in Figure 13.

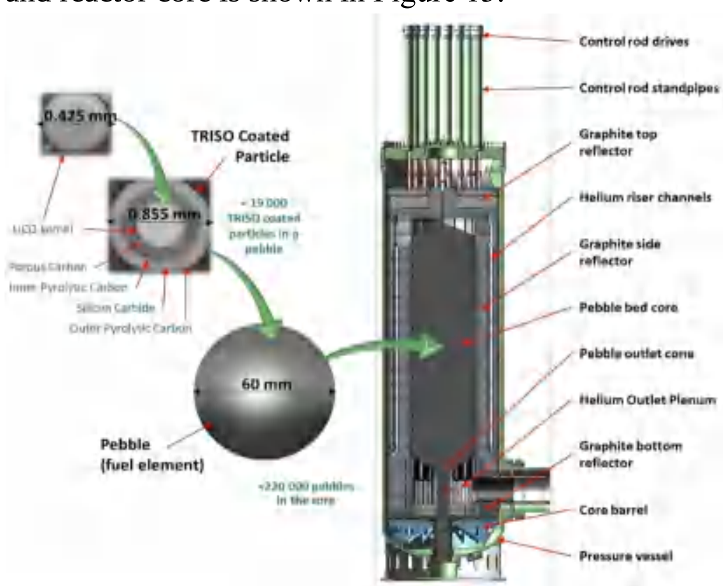

Figure 13. Xe-100 Fuel and Core Diagram [98].

2.2.5.2. Design Features

- **Defense-in-depth:** The reactor is designed with many redundant safety systems. TRISO fuel acts as its own containment. The geometry of the core, along with its graphite support structures, is able to passively remove decay heat even in the most severe accidents. These components would be able to independently protect the reactor and the public alone; however, redundancy is observed in the addition of a reactor cavity cooling system (RCSS) and RPV.
- **Passive safety:** TRISO fuel itself provides a passive safety system and aids in making the reactor walk-away safe. The makeup of the fuel pebbles acts as the primary containment for radioactive release and is able to remove decay heat through conduction. The design

also includes an RCSS and an RPV to passively remove decay heat and contain and release radioactivity. [81]

- **Simplicity:** The reactor design aims to decrease costs through a simplified design. This will decrease the time and cost of fabrication and construction [81].
- **Modularity:** The goal of the design is component modularity. Components for the reactor will be factory fabricated and transported to the site where they will be assembled. This reduces the time and cost of construction.
- **Waste management:** Fuel pebbles are either placed in the spent fuel cask or, if not fully spent, are recycled through the reactor and stay in the fuel until they are. These casks are located onsite. [81].
- **Refueling schedule & reactor life:** The fuel cycle utilizes online fuel loading, where fresh fuel pebbles are added to the core while the reactor is still operating. The fuel is removed once fully spent and placed into storage casks. This design has a design life of 60 years.

2.2.5.3. Potential Opportunities and Challenges

- **Licensing:** A potential issue in licensing involves the enrichment of the fuel. Where a typical light water reactor has an enrichment of approximately between 3.40-4.95% [99], the Xe-100 has an enrichment of 15.5% [98]. While this should not be a design-ending issue, it does add to the complexity of the licensing process. The IAEA and the NRC both encourage enrichment to be less than 5% to assuage any concerns regarding proliferation [100].
- **Siting:** X-Energy is working with Dow Chemical to utilize four Xe-100 reactors for steam and power production at one of its manufacturing facilities in Texas. X-energy is working with the Maryland and Ontario governments to explore development in their respective regions. [7]
- **Financing:** X-Energy has received funding from both the public and private sectors toward the development of the Xe-300. The DOE has awarded $80 million in initial funding for the project and will award them a total of $1.23 billion across a seven-year period through their Advanced Reactor Demonstration Program [7].
- **Supply chain:** X-Energy has selected several contractors for various components for the reactor design. However, finding a supplier for their fuel proves challenging due to the recency of the technology [7].
- **Fuel:** TRISO fuel is a nontraditional fuel type with many benefits and drawbacks. In the core, the fuel pebbles are constantly moving, adding to the complexity of modeling the fuel [101]. In addition, because it is a newer fuel type, there are difficulties finding companies that manufacture TRISO fuel.

2.2.6. Natrium Reactor Plant (TerraPower-GE-Vernova)

2.2.6.1. Design Principles

The Natrium reactor design is a collaboration between TerraPower and GE-Vernova. Natrium is a pool-type molten chloride fast reactor (MCFR), using a molten salt energy storage system and HALEU, TRISO fuel [102]. The reactor's design combines features from the Power Reactor Innovative Small Module (PRISM) design and Travelling Wave design [103]. Its primary developer, TerraPower, boasts the heat transfer characteristics of sodium and operation at low pressures, allowing the use of compact and lightweight equipment. As shown in Figure 6 below, it is designed with a molten salt loop and hot pipe loop that transports heat from the reactor to other parts of the plant. These components leverage a simple and robust safety profile and minimize the equipment needed, reducing design and construction complexities.

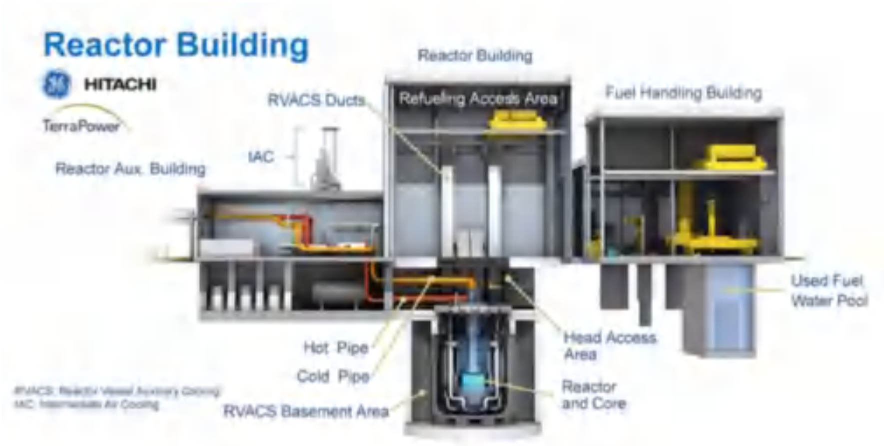

Figure 14. Natrium reactor building schematic [104]

2.2.6.2. Design Features

Features and advantages of TerraPower's Natrium reactor include:

- **Defense-in-depth:** The reactor design includes multiple passive safety systems that operate independently of each other. Redundancies in the design provide a high level of security in the event of an accident.
- **Passive safety:** The reactor design features a molten chloride coolant, which has a much higher boiling point and can operate at low pressures, limiting the risks of a meltdown. In addition, safety systems such as passive cooling to remove decay heat and a containment system to mitigate the release of radiation are included in the design. These serve as safety measures that can protect workers and the public from radiation without needing electricity or operator interaction. These make the reactor design walk-away safe.
- **Simplicity:** The design of the Natrium reactor promotes simplicity. It decreases the time and cost of construction. In addition, using HALEU fuel has the potential to decrease the amount of waste, simplifying the fuel cycle process.
- **Modularity:** Components of the Natrium reactor will be factory fabricated, then transported and assembled on site. This will reduce the time and cost of construction.

- **Waste management:** Spent fuel will be removed from the reactor and placed in a spent fuel pool for cooling. It will be placed into dry storage casks and eventually moved to a permanent national repository when one is developed.
- **Refueling schedule:** Refueling is done online while the reactor is in operation. Once spent, the fuel will be removed and placed into dry storage casks.

2.2.6.3. Potential Opportunities and Challenges

- **Licensing:** TerraPower is currently engaged in review activities for a construction permit for the Kemmerer Power Station in Lincoln County, Wyoming. [105]
- **Siting:** The reactor, as of now, will replace the Naughton Power Plant in Kemmerer, Wyoming. TerraPower purchased land in Kemmerer in August 2023, with plans to start construction in 2024.
- **Financing:** TerraPower was awarded $80 million in initial funding from the U.S. Department of Energy's ARDP in October 2020, with a total of $1.23 billion allocated over seven years for the demonstration. The Infrastructure Investment and Jobs Act of November 2021 secured funding for the program’s duration. Additionally, TerraPower raised over $830 million in private funding, marking a significant capital raise in the advanced nuclear industry.
- **Supply chain:** TerraPower has formed partnerships with various organizations including Bechtel, multiple universities, national laboratories, and companies for its Kemmerer project. It expanded agreements in 2023 with Japan Atomic Energy Agency, Mitsubishi Heavy Industries, Mitsubishi FBR Systems, and South Korea's SK Group.
- **Fuel**: Limitations arise when it comes to the fuel being used in this reactor design. As of 2023, HALEU lacks a commercial supply from OECD countries. However, a supply is expected in 2024.

2.2.7. KP-FHR (Kairos)

2.2.7.1. Design Principles

The KP-FHR, or Hermes reactor, is an SMR designed to prove the viability of the Kairos Power Fluoride-Salt-Cooled High Temperature Reactor (KP-FHR) [106]. The KP-FHR is known by two interchangeable names: KP-FHR and Hermes. Kairos plans on building KP-FHR at the East Tennessee Technology Park to prove the viability and safety of TRISO fuel and fluoride salt coolant. Fluoride salt coolant is used to transport thermal energy to a standard steam generator system. As this design is for a demonstration reactor, it will run at a relatively low power output of 35 MWe. The TRISO fuel used in the design is a pebble-type setup, allowing it to be refueled while still online [107].

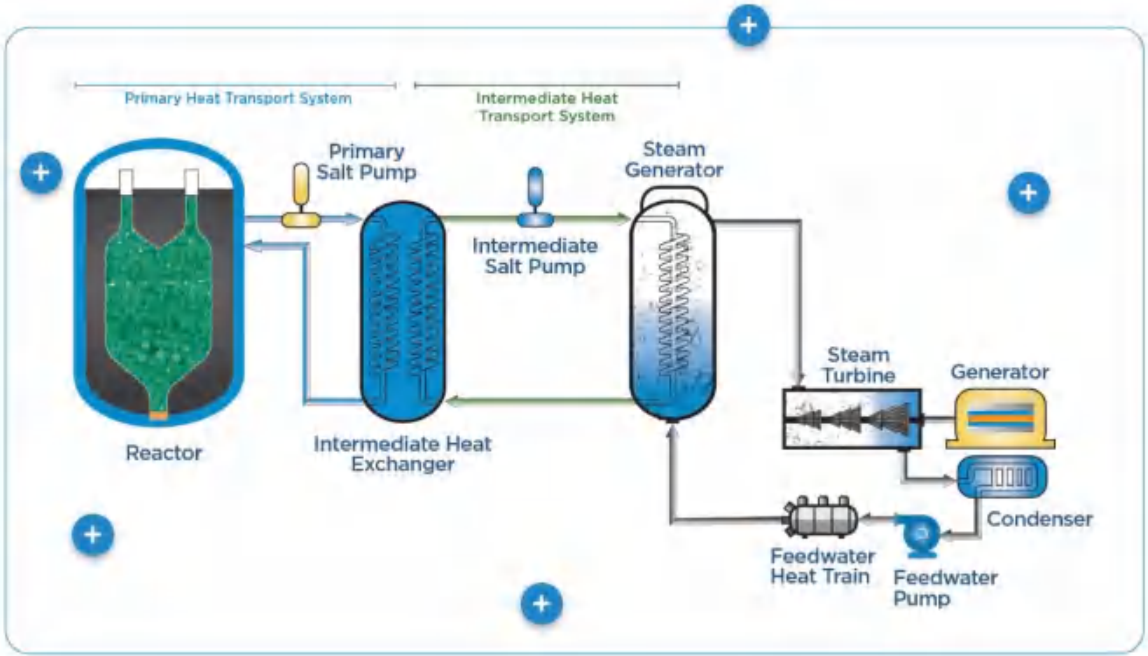

Figure 15. KP-FHR reactor design [110]

Figure 15 above shows Kairos's overall plan for the KP-FHR reactor. It shows the basic layout of the reactor core, including the pellet-based TRISO fuel inside of it. It also shows how the thermal loop is set up in two phases. One loop is used to exchange heat from the molten salt heated by the core to the steam generator, and the other uses the steam to turn the turbine and create power.

2.2.7.2. Design Features [108]

- **Defense-in-depth:** The reactor is designed with many independent safety systems. It uses TRISO fuel, which acts as its own containment, mitigating the risk of released radiation. The molten fluoride salt coolant allows the reactor to operate at low pressure, but high temperatures, limiting the chance of a meltdown. In addition, the reactor is designed with a Reactor Vessel Auxiliary Cooling System and graphite reflectors in the core.
- **Passive safety:** The combination of TRISO fuel and molten fluoride salt coolant creates a passive safety system in and of itself. This, paired with other passive safety systems built into the design, makes this reactor walk-away safe. The reactor vessel auxiliary cooling system (RVACS) provides shutdown decay heat removal during licensing basis events. A reserve shutdown system and a passive heat removal system limit temperatures in the reactor to remove heat in an accident. [81]
- **Simplicity:** Combining TRISO fuel and molten fluoride salt coolant simplifies the design of the reactor, as it reduces the number of necessary safety systems. TRISO fuel allows the reactor to operate at high temperatures, while the coolant allows it to work at low pressures. This eliminates the need for high-pressure containment structures and systems. The added

safety systems and components of the reactor leverage conventional technologies, in turn lowering capital costs [81]

- **Modularity:** The reactor is designed with modular components that can be fabricated in a factory and assembled at the reactor site. This aids in Kairos' goal to decrease the cost and maintenance of nuclear power.
- **Waste management:** Fuel waste is packaged for dry interim storage or off-site transportation for geological disposal or recycling. The remaining waste qualifies for low-level waste disposal. [81].
- **Refueling schedule & reactor life:** The fuel cycle involves online refueling and a once-through fuel cycle. Fresh fuel is added to the core and recirculated while the reactor is still operating. Fuel pebbles are removed when spent and placed in spent fuel storage casks. This design has a vessel design life of 20 years, and a plant design life of 80 years.

2.2.7.3. Potential Opportunities and Challenges

- **Licensing:** Kairos received licensing approval on a construction permit from the U.S. NRC for a build site in Oak Ridge, Tennessee in December of 2023. [109]
- **Siting:** A build site in Oak Ridge Tennessee was chosen and approved by the U.S. NRC in December of 2023 [109]. They are currently under review for a second construction permit application at the same site.
- **Financing:** Since 2019, Kairos Power has received over $1.3 million from the DOE to support the design, licensing, and construction of the KP-FHR reactor, with a potential total investment of up to $303 million through 2027.
- **Supply chain:** Kairos Power is working on supplying several key components for its design, including commissioning a molten salt purification plant and receiving certification to manufacture U-stamped pressure vessels. The largest issue regarding the supply chain is the lack of U.S.-based commercial suppliers of its fuel.
- **Fuel:** The KP-FHR reactor is designed to utilize HALEU TRISO fuel pebbles, which do not have an official supplier. Kairos Power's test reactor will receive fuel from the New Mexico Lab's Low Enriched Fuel Fabrication Facility as part of an agreement with Los Alamos National Laboratory.

2.3 Comparison of SMR to Traditional Nuclear Power Technology

<u>Plant Size Comparison:</u>

Depending on the SMR type and size, the reactor building can be 2 to 4 times smaller compared to a traditional reactor such as the AP1000 [99, 110]

<u>Required Acreage:</u>

For reactors such as VOYGR or Xe-100, the total plant size can differ depending on the number of modules used at a power plant. Even so, the required acreage for an SMR plant can be five to twenty times less than a traditional reactor [99, 110, 111]

Emergency Planning Zone (EPZ):

The initial guidelines for determining the EPZ for traditional reactors require that the radius stretches 10 miles for the plume exposure and 50 miles for potential ingestion exposure [111] . However, EPZ requirements for SMRs are expected to be lessened to match the diminished potential harm from an accident at an SMR [112].

Capacity:

SMR capacity (thermal and electric output) is smaller than a traditional nuclear power plant. Typically, an SMR will be 3-5 times smaller in thermal output. However, SMRs' modular design provides unique flexibility compared to NPPs. Multiple SMRs can be deployed incrementally, allowing utilities to scale capacity according to demand rather than committing to a large single-build plant, as with NPPs.

Fuel and Fuel Supply Chain:

All operating nuclear power reactors in the U.S. use LEU. While some SMR designs utilize LEU fuel, many are designed for HALEU fuel. HALEU fuel allows for smaller designs, longer operating cycles, and more power per unit volume of fuel compared to LEU [113]. However, there are currently no commercial suppliers of HALEU fuel in the U.S. The Energy Act of 2020 directed the creation of the HALEU availability program to spur demand for commercial HALEU production in the U.S. [113]. Some SMR designs also require TRISO fuel with HALEU which is a new form of fuel designed to be more structurally resistant to corrosion, oxidation, and high temperatures. Currently, TRISO fuel does not have a commercial supplier.

Defense-in-Depth:

Defense-in-depth strategies are used in all nuclear power plants to protect against accidental radiation release. These strategies include having many safety systems to provide a barrier against released radiation, including both inherent and passive safety features. SMRs also apply defense-in-depth and examples of these systems include having a compact core design, passive and active shutdown systems, control rods, emergency injection systems, and passive decay heat removal systems [114].

Safety Features:

All nuclear power plants feature safety systems to aid in protecting their employees and the public. These can include containment vessels, automated reactor shutdown systems, and emergency core cooling systems. SMRs have been designed with this in consideration and have taken steps to increase their safety. SMRs are designed with a smaller core, containing less nuclear material. Some designs utilize advanced fuels, e.g., TRISO, that can withstand higher temperatures and act as their own containment. Some designs utilize advanced coolants allowing for low-pressure operation. Some designs use passive systems allowing SMRs to be walk-away safe. These systems enhance the safety of nuclear power while reducing the amount of human interaction and power requirements during emergencies [7].

Coolants:

As stated by the DOE, "all commercial nuclear reactors in the United States are light-water reactors.” This means all power reactors in the United States use light water as a coolant. This differs from SMRs, as different designs feature a range of coolant types. Some are similar to traditional plants and use light water; however, others use high-temperature gases, molten salt, or molten chloride coolants. These offer many benefits, including operating at low pressures withstanding high temperatures [115].

Scalability:

Some SMRs are designed with the intent to construct multiple reactor modules in one site. These reactors have a capacity of only around 80 MWe [116, 87]. Alternatively, other SMRs are being designed to operate around 300 MWe to take advantage of economy of scale while retaining the title and benefits of an SMR [81, 117, 99].

Modularity:

SMRs are designed to be fabricated in factories and transported to the reactor site. They require a small amount of on-site preparation and construction. SMRs also have the ability to add additional modules to increase the power output. Some current power plants include factory-fabricated components; however, much fieldwork is still required when assembling the components at the power plant site [118].

Waste Management:

SMR spent nuclear fuel and waste is expected to be similar to traditional nuclear reactors but smaller in size. Differences would include the use of HALEU fuel instead of LEU and some new fuel variants such as TRISO for which there is no prior experience in waste management. Currently, traditional reactors have a spent fuel pool to cool the spent fuel rods and dry storage casks for long-term storage. It is expected that SMRs will follow similar waste management procedures including spent fuel pools and dry cask storage for managing spent fuel and other high-level waste.

2.4 Grid Integration

Nuclear energy has several benefits including 24/7 availability, capacity factors above 90%, and load following capability making it well-suited to meet the needs of a decarbonized grid. The unique qualifications of nuclear has led to a resurgence in interest in the U.S. and globally. In April of 2023, the U.S. Department of Energy (DOE) Nuclear Loan Program Office’s Liftoff report (2023) stated:

> *U.S. domestic nuclear capacity has the potential to scale from ~100 Gigawatt (GW) in 2023 to ~300 GW by 2050—driven by deployment of advanced nuclear technologies. Power system decarbonization modeling, regardless of level of renewables deployment, suggests that the U.S. will need ~550–770 GW of additional clean, firm capacity to reach net-zero; nuclear power is one of the few proven options that could deliver this at scale, while creating high-paying jobs with concentrated economic benefits for communities most impacted by the energy transition* [119].

In December 2023 at the COP 28 UN Climate Change Conference, the U.S., along with 25 other countries, pledged to triple the nuclear capacity by 2050, acknowledging the importance of nuclear in reaching global climate goals. Bloomberg New Energy Finance's New Energy Outlook 2024 likewise estimates that nuclear capacity will increase from 377 GW in 2023 to 1,025 GW in 2050 in their Net Zero by 2050 scenario [120]. The IEA's Net Zero Roadmap for 2023 includes more than doubling nuclear generation capacity globally by 2050; from 417 GW in 2022 to 916 GW in 2050 [121].

2.4.1. Demand for Electricity is Growing

U.S. electricity demand is growing for the first time in over a decade. Goldman Sachs estimates that electric load will grow by 2.4% in the U.S. from 2022 to 2030 [122]. This expected load growth is being spurred by data centers, the electrification of vehicles, other residential electrification, industrial process electrification, and manufacturing reshoring (See Figure 16).

Regionally, the electric grid is operated by ISOs, which control the electric grid and the wholesale electricity market in their regions. Most of Indiana is in MISO, which spans 15 states throughout the Midwest and South of the U.S. and Manitoba, Canada. According to MISO, energy consumption will grow by 1.7% per year from 2023 through 2030, a big change compared to the 0.2% annual growth rate over the prior decade. MISO analysis predicts that energy consumption will increase even further, to 3.9% per year between 2030 and 2040. Load Zone 6, which includes the parts of Indiana and Kentucky in MISO's territory, has an above-average expected growth rate, with an annual 2.1% increase in energy consumption expected between 2023 and 2030. This is partly due to an above-average data center load growth in Indiana.

Parts of Northeastern Indiana are in another ISO, PJM. PJM's territory extends throughout 13 states in the Mid-Atlantic and Midwest U.S. PJM's load forecast for 2024 shows an expected increase of 1.6% per year for summer peaks over the next 10 years and an increase of 2.3% per year of total energy consumption over that same period. PJM's Western Zone, which includes Indiana and most of the PJM territory west of central PA, has a slower-than-average load growth, with PJM Western only projected to have a 0.6% annual increase in the summer peak load. [123]

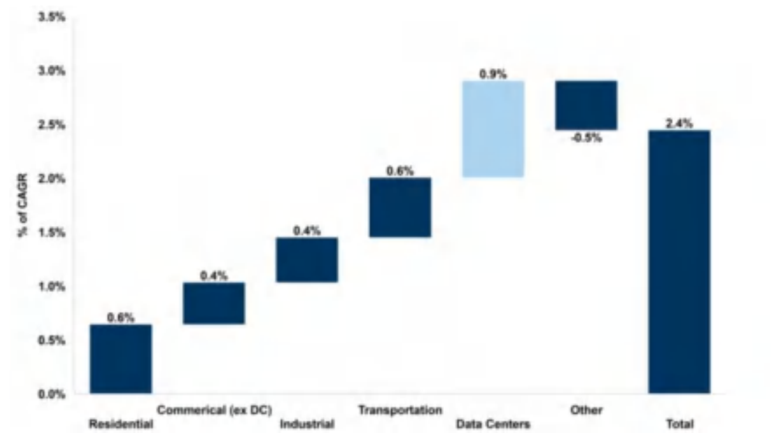

Figure 16. Factors Contributing to Expected U.S. Energy Consumption Growth from 2022 to 2030 [122]

2.4.2. Electricity Supply is Increasingly Dominated by Intermittent Generators

On the supply side, nationwide power capacity additions are hitting record highs; however, they are largely dominated by intermittent renewable additions (see Figure 17). Existing power plants, dominated by coal plants, are retiring as these new plants come online, offsetting the effects of the new additions.

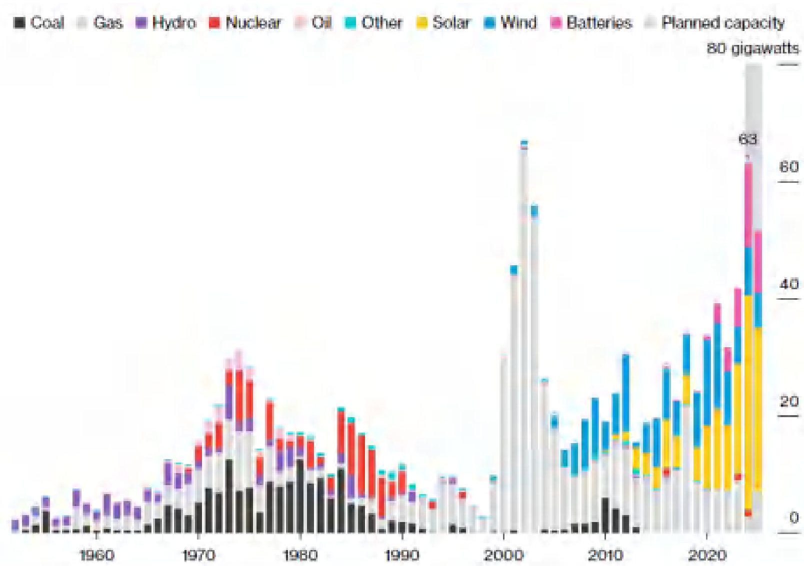

Figure 17. US Capacity Additions since 1950 [124]

MISO is observing similar trends in the generation resources available to that market. In 2024, MISO had a scheduled net addition of 11,080 MW, with 12,448 MWe of new generation coming online and only 1,368 MWe retiring. The 12,449 MWe of new capacity includes 8,555 MWe of solar, 3,149 MWe of wind and 731 MWe of energy storage. The retirements consist of coal (559 MWe) and natural gas plants (739 MWe). Despite having net growth in terms of nameplate capacity, wind and solar contribute less total capacity compared to dispatchable resources such as coal, nuclear and natural gas due to their intermittent nature. Due to the effect of this trend over time, MISO's projected reserve margins, which is the amount of capacity they have online compared to their projected peak, were 7.5% for the summer of 2024, far below the standard reserve margin benchmark of 15%. [125] MISO further anticipates 7 GW of coal to retire over the coming 3 years, which, according to MISO, will keep their reserve margins tight in coming years [125]. Similarly, Indiana's electricity generation mix has altered significantly over the past decade as a result of the changing generation resources in the state. In 2023, intermittent renewables (wind and solar) made up 13% of Indiana's generation mix, whereas 10 years before in 2013, only 3% of the electricity generated in Indiana came from intermittent renewables (wind) [126]. Overall, generation in Indiana has fallen by 26% over the past two decades although electricity consumption has stayed relatively steady, only decreasing by 3% over the same time period [127]. The remaining electricity has been imported; in 2023, about 14% of all electricity consumed in the state was imported from out-of-state generators [126], [127].

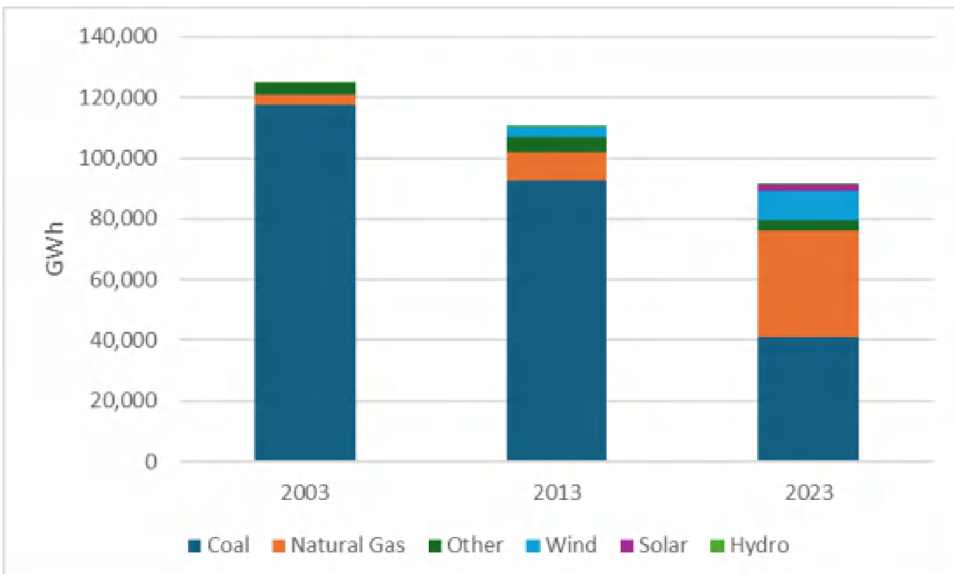

Figure 18. Electricity Generation by Fuel Type in Indiana [126]

2.4.3. NPPs Typically Provide Reliable Baseload

Nuclear power plants have high fixed costs and low fuel costs relative to other fossil-fuel power plants. Therefore, to maximize their economic efficiency, nuclear power plants are commonly run at their maximum capacity, only taking outages as required for maintenance and repairs. Running constantly is often referred to as providing "baseload power." In the past, baseload power has been provided by fossil fuel plants in addition to nuclear power plants. NPPs are meant to provide firm, reliable baseload power to any energy grid they support.

2.4.4. NPP Capacity Value

To ensure that the load and generation can always be balanced, the grid must have sufficient generation capacity to meet their system-wide peaks. Nuclear power plants, similar to the fossil fuel fleet, are considered dispatchable resources. Unlike wind and solar, which can only produce power when their respective renewable resources are available, nuclear power plants can always produce power, except during plant downtimes. Because nuclear power plants can be relied upon to provide power when needed, utilities and the ISO can count almost the entire nameplate capacity of the plant towards their peak capacity needs.

MISO monitors the capacity assets and requirements for its entire territory. MISO accredits the capacity of the thermal generators in its footprint using the 5-year forced outage rate during previous system-wide peaks [128]. By this measure, the nuclear fleet can get close to its entire capacity accredited as capacity value, e.g., a 300 MWe nuclear SMR would have a capacity value of about 270-290 MWe. Solar and wind plants, on the contrary, have accredited capacity values well below their nameplate capacity. Their capacity value will reflect the amount that resource is able to contribute during MISO's system-wide peaks [128].

Because nuclear power plants are typically run as much as possible in the U.S., their capacity factor, or energy produced divided by the total energy they would have produced if they had run at peak power, is a good proxy for their overall availability. Over the past decade (between 2014 and 2023), the overall capacity factor of the existing US nuclear fleet has ranged from 91.7% to 92.8% [129]. Most of the downtime is due to scheduled outages. During scheduled outages, plants typically refuel and perform regular maintenance tasks. Repairs and upgrades also take place during scheduled outages, when possible, to minimize the plant's downtime. Planned outages typically occur during the "shoulder months", April, May, September, and October, when loads are lower. Figure 19 shows the total outage rate of the nuclear fleet from 2019-2023, with most outages occurring in shoulder months.

Figure 19. Outages of Nuclear Power Plants by Month [130]

Some outages are forced or unplanned outages. In energy systems, WEFOR stands for the Weighted Equivalent Forced Outage Rate. It's a metric used to gauge the reliability of power generation units by measuring the probability that units won't meet their required generation due to forced outages or operational derates. This rate is "weighted," meaning that larger generating units contribute more to the metric, providing a representative measure of overall grid reliability.

There were 35 forced outages for commercial NPPs in 2022 [131], resulting in a WEFOR of about 2% throughout the year [132]. As seen in Figure 20, the Weighted Equivalent Forced Outage Rate, as defined by NERC, is lower for nuclear power plants than for other fuel types in recent years, sitting around 2%.

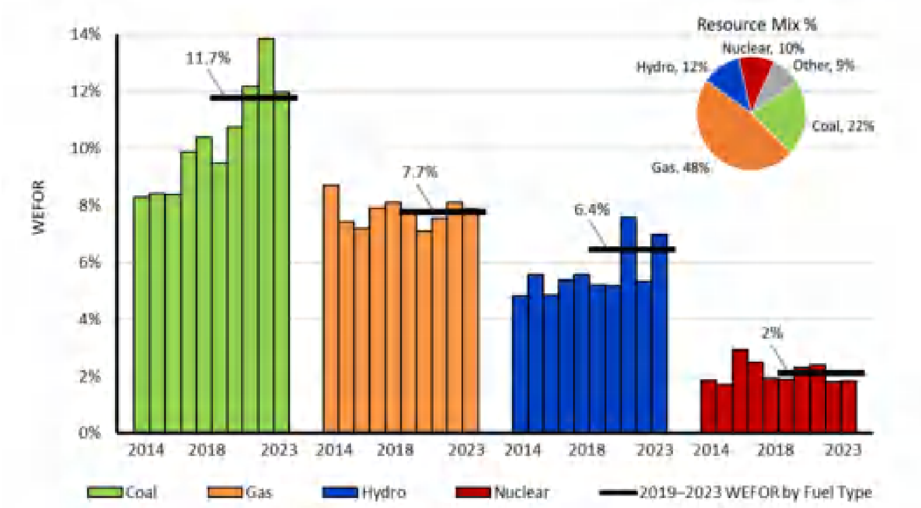

Figure 20. Weighted Equivalent Forced Outage Rates [132]

SMR and newer designs tend to promise lower overall outage rates due to quicker scheduled maintenance and longer refueling cycles. AP-1000, for example, promises 93% availability due in part to a long, 18-month refueling cycle and a shortened refueling operation timeline. SMR vendors, likewise, expect their outages to be shorter than those of large LWR in the existing fleet, though there is not yet data to support those claims.

While in past capacity auctions, the price of capacity has been low in Indiana, a MISO market change that went into effect in September 2024 is expected to dramatically increase the value of capacity in this region in coming years. According to MISO’s calculations, the 2024-2025 capacity market, which cleared at an average price of $20/MW-day would have cleared at an average of $52/MW-day under the new rules [133]. It is difficult to predict the MISO market capacity value for 2030 and beyond, years when an SMR could be feasibly completed. If more new generators come online, the value of capacity may fall again, but the changes that have driven the higher prices are expected to persist. If these capacity values do persist, a 300 MWe nuclear power plant would earn roughly $7.4 million per year for their capacity service.

Utilities, tasked with maintaining sufficient capacity for the loads they serve, and electricity consumers that opt to buy their own electricity through Power Purchase Agreements (PPAs) will be making long-term decisions in the context of this new pricing paradigm. According to MISO, the net cost of new generation in Indiana would be about $76,800/yr for each MW, or $20 million per year for a 300 MWe system in Indiana [134]. When faced with the prospect of building new generation utilities, off takers would likely value new capacity at or around that amount.

2.4.5. SMR Energy Value

The second key value of a nuclear power plant is the value of the energy that is produced. The energy prices at the Indiana hub, a weighted average of many Indiana price nodes in the MISO system, are a good way to approximate the average value of energy in the wholesale market in Indiana. Although, energy can be bought and sold in other ways, including under a PPA or by being provided directly to a utility's customers. Locational Marginal Pricing (LMP) represents the cost of delivering the next megawatt-hour (MWh) of electricity to a specific location, factoring in generation costs, transmission congestion, and energy losses. Calculated in dollars per megawatt-hour ($/MWh), LMP varies by location and time, reflecting real-time demand and grid conditions. High LMP values indicate constraints or high demand, signaling where additional resources might be needed, while low LMP values suggest ample supply relative to demand at a given location.

Using the LMP as a reference, the energy price at the Indiana hub has been relatively stable for several years, with 2022 being an exceptionally high year (See Figure 21). The average day-ahead energy price in Indiana for 2023 was $32/MWh, and 2024 is on track for a similar average price. Although prices go up and down throughout the days and months, nuclear power plants will typically observe the average prices as they tend to operate at full-rated power most of the time.

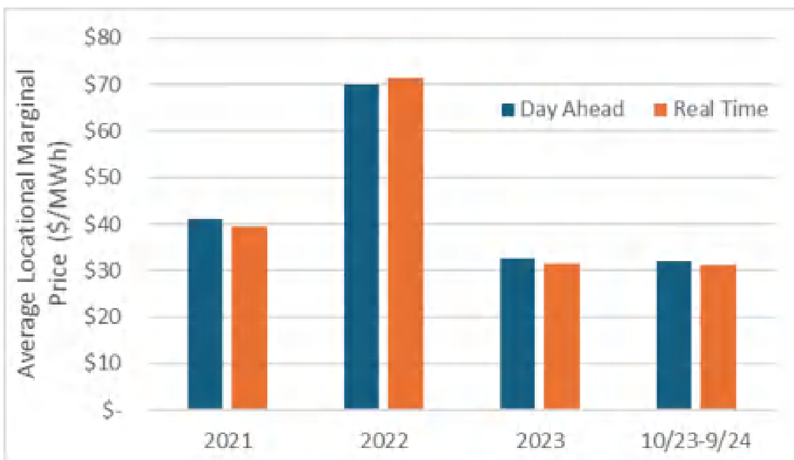

Figure 21. Day-Ahead and Real-Time Prices at Indiana Hub (2021-2023) [135]

If a 300 MWe SMR had been operating at full capacity (with a 92% capacity factor to account for planned and unplanned outages), that plant would earn about $80 million per year with energy prices at $33/MWh. By taking scheduled outages during months with lower average energy prices, and by turning down generation during negative price events, the plant would earn slightly more than the average energy cost.

2.4.6. SMR Load Following Capability

Although nuclear power plants have traditionally been operating at their full-rated power to provide constant baseload power, they are capable of load following. Load following is ramping power up and down throughout the day to meet the needs of the grid. The load changes throughout the day, along with the power from the intermittent renewable fleet. The load, net the intermittent renewable power, "net load," is what must be met by the dispatchable resources. As more renewable power comes online, the net load curve has greater and greater movement, requiring a significant load following, or "ramping" from the dispatchable fleet.

Two parameters typically determine a plant's ability to load follow:

- A power plant's minimum power setting, which determines the range of MWe of load following the plant can provide.
- The plant's ramp rate, or rate at which it can change its power output.

In nuclear power plants, there is a distinction made between the ability to ramp the reactor's thermal power output and the ability of the turbine to ramp its electrical output. In France, nuclear power is about 75% of the total generation capacity, and therefore, French nuclear reactors have engaged in load following as early as 2010 [136], even before there was significant intermittent renewable generation on the electric grid, as shown in Figure 22.

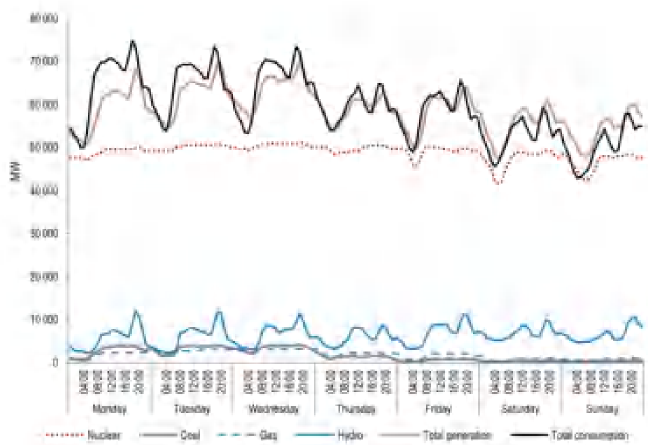

Figure 22. Load Following by Nuclear Reactors in France in November of 2010 [136]

Conventional NPPs reduce the power output by inserting control rods or neutron absorbers, with waste of potential energy and thermo-mechanical stress on the power plant. BWRs can also use recirculating flow to reduce their power output dynamically, which is the preferred method of reducing power output from BWRs. The power output from SMRs can be adjusted more easily due to the modular design. For example, the power rates of a four-unit SMR plant can be kept around 0%, 25%, 50%, 75% and 100%, suitable for realizing the load following at site level. Furthermore, the load following can also be realized by diverting 100% of the electricity or 100% of the thermal power generated from some SMR units to different cogeneration purposes and letting the remaining units produce electricity [137].

In 2001 the European Utilities Requirements (EUR) added a standard for new nuclear capacity that included load following capabilities. In the EUR standard, new nuclear must be capable of continuous operation between 50% and 100% of its nameplate power, and it must have a ramp rate of at least 3% per minute up and down [136]. In 2011, EPRI issued guidelines for new nuclear in the U.S. that align with the European requirements. [136].

The AP-1000, a new Gen III+ large LWR, is capable of a ramp rate of 5% per minute up or down and a minimum power of 15% of full power [138]. SMRs have even greater flexibility within each reactor. The NuScale SMR reactor, for example, has ramp rate of 10% per minute up and down by using turbine bypass. NuScale can change each reactor's thermal power output at a ramp rate of 40% per hour [139].

Nuclear reactors do not typically save much cost when they reduce their output: 90% of a NPP's costs are fixed costs, and even the fuel costs are not reduced by much when the power output is reduced. For example, reducing the power by 50% would only allow the plant to save 4-5% of their fuel costs [137].

Load following is not a specific product in the MISO market or the PJM market. The value is derived from the plant's ability to change its power output to follow the movement of the energy prices through time. Because there are nearly no cost savings to the plants when they reduce their output, nuclear power plants will typically not respond to energy price changes when the price is positive. When wind generation is high and the load levels are low, MISO's real time market prices turn negative for short periods. In those negative energy priced hours or minutes, the nuclear power plant would be able to ramp down to earn money, which will, in turn, help the grid stop generating more electricity than is needed. Using data over the past year, load following would not result in significant savings at Indiana hub prices and has only marginal changes to the revenue (~1%) at Minnesota hub, the hub with the most negative price events [135]. As more wind comes online, negative price events may be more frequent and responding to them may have stronger incentives.

2.4.7. SMR Participation in Other Ancillary Services

The grid requires other ancillary services to properly operate including Frequency Regulation, Spinning Reserves (also known as Synchronized) and Non-Spinning Reserves (also known as Non-Synchronized Reserves). While nuclear power plants can provide some measure of each of these, the prices for those products have been low in recent years, and the cost of a NPP providing those services is higher than the cost of other generators or battery energy storage system providing those services. It seems unlikely that SMRs will use any of those ancillary services as a primary source of income nor is it likely that they will engage in performing those services extensively.

2.5 Repurposing Coal to SMR

The Department of Energy released two reports since 2022 highlighting the benefits and considerations for converting existing coal plants to nuclear plants [140] [141]. Key benefits cited by the DOE for coal-to-nuclear (C2N) include the following:

- Mitigate the economic impacts of closing a coal plant, instead turning it into an opportunity
- Need for carbon-free baseload power throughout the country

- Existing site, minimizing environmental impacts of new site
- Existing workforce with some relevant skill sets
- Existing infrastructure: roads, water, grid interconnection equipment and ancillary site improvements such as office buildings, fencing, and security.
- Possible reuse of plant components such as the heat sink and the electric plant equipment.

Furthermore, when a coal plant is replaced with nuclear, it is replacing a baseload power resource directly and can serve the same load as the coal plant served previously. Also, most coal plant sites are located in energy communities, as designated by the DOE, since the closure of a coal plant is one way in which those communities are defined. This designation allows nuclear plants in that zone to earn an extra 10% adder on their Investment Tax Credit (ITC).

Appendix A demonstrates in detail that the overnight capital costs (OCC) of an SMR located where a coal plant was previously located would be 7-26% lower than locating it on a greenfield site.

2.5.1. Opportunity in Indiana

The first DOE Coal-to-Nuclear report, from 2022, found that Indiana has the second most coal plants that are suitable for conversion to nuclear power plants. Indiana was found to have 8-10 coal plants suitable for the development of nuclear according to the screening tool used by the DOE, the Oak Ridge Siting Analysis tool for Power Generation Expansion (OR-SAGE).[1] This is the second most of any state, with only Texas having more suitable coal power plant sites with 14-15 suitable sites. That report also evaluated recently retired coal sites, where Indiana had 9 sites suitable for a nuclear power plant according to the OR-SAGE screening tool, among the top handful of states with Pennsylvania having the most, 11 sites, Michigan and Ohio each having 10 sites, and Indiana and Kentucky each with 9 sites.

2.5.2. Trends in Coal to Nuclear

There are currently two projects in the planning phases for coal-to-nuclear conversion:

- Duke Energy has begun its early site permit process for the Belew’s Creek Site in North Carolina.
- TerraPower’s demonstration project, funding the DOE’s Advanced Reactor Demonstration Program, is planned for the Kemmerer site in Wyoming.

2.6 Regulatory Framework for Licensing

Relevant state and federal laws and regulations related to SMRs cover licensing requirements, safety standards, and environmental regulations.

The licensing and approval process for an SMR requires numerous certifications on both the federal and state level. At the federal level, the NRC oversees all the licensing, which includes the pre-licensing engagement, design certification (DC), construction permits, and operating licenses.

[1] Indiana had 8 sites with an OR-SAGE score of 0, and 2 sites with an OR-SAGE score of 1. By either measure, Indiana is second to Texas.

On a state level, the IURC requires a Certificate of Public Convenience and Necessity (CPCN) for a utility company to use an SMR for power generation. Environmental permits and approvals are required at both the state levels, e.g., Indiana Department of Environmental Management and the Indiana Department of Natural Resources, and federal, Environmental Protection Agency. Finally, the regional transmission organizations (i.e., MISO and PJM) study the interconnection of SMRs onto the transmission grid. This process includes different phases and steps for the application to ensure the reliability of the energy source and compliance with the standard issued by the grid [142]. An overview of the regulatory bodies that require licenses and approvals can be seen in Figure 23.

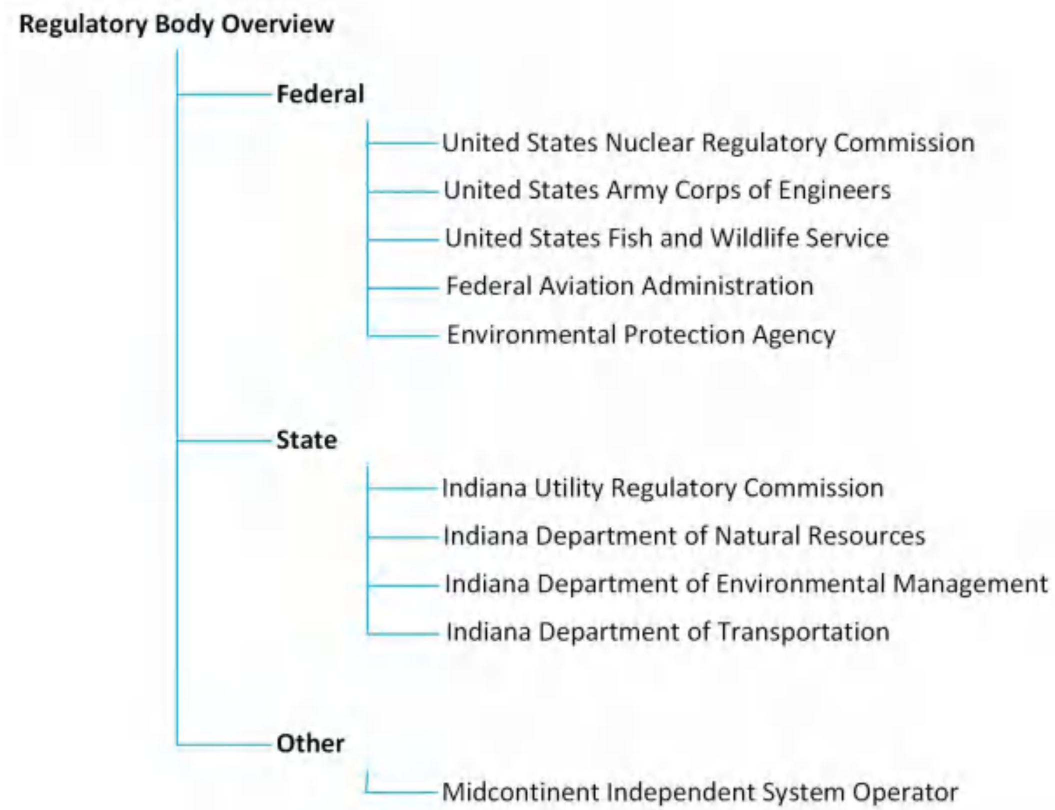

Figure 23. Overview of licensing and approvals requirements

2.6.1. Federal Licenses and Permits

2.6.1.1. U.S. Nuclear Regulatory Commission

All nuclear reactors must obtain a construction permit from the U.S. NRC before construction and an operating license before commencing operations. The traditional, two-step licensing pathway is described in the Code of Federal Regulations (CFR) Title 10 CFR Part 50 ("Part 50"). In Part 50, the NRC first reviews and approves the project's construction permit application and then, typically after construction has started, the NRC reviews and approves the site's operating license application [143].

2.6.1.1.1. Part 50 Licensing Process

The construction license requires that the project has selected a preliminary design and has conducted a thorough environmental study, including a detailed analysis of the geology, meteorology, hydrology, ecology, socioeconomics, land use, demography, archaeology, noise, visual, and emergency planning at the site. Collecting the data and preparing the application for the NRC will take about two years, as the submission requires two years of meteorology data. Once the application is submitted to the NRC, it will take about three years for the NRC to review and approve the application [144]. In one recent example, the KAIROS Hermes 1 project, an SMR demonstration project, obtained its construction license two-years after applying (October 2021-December 2023) in part because, according to the NRC, the team had robust pre-application engagement prior to submitting the application and was extremely responsive and prepared during the review [145]. The construction permit process is shown in Figure 24.

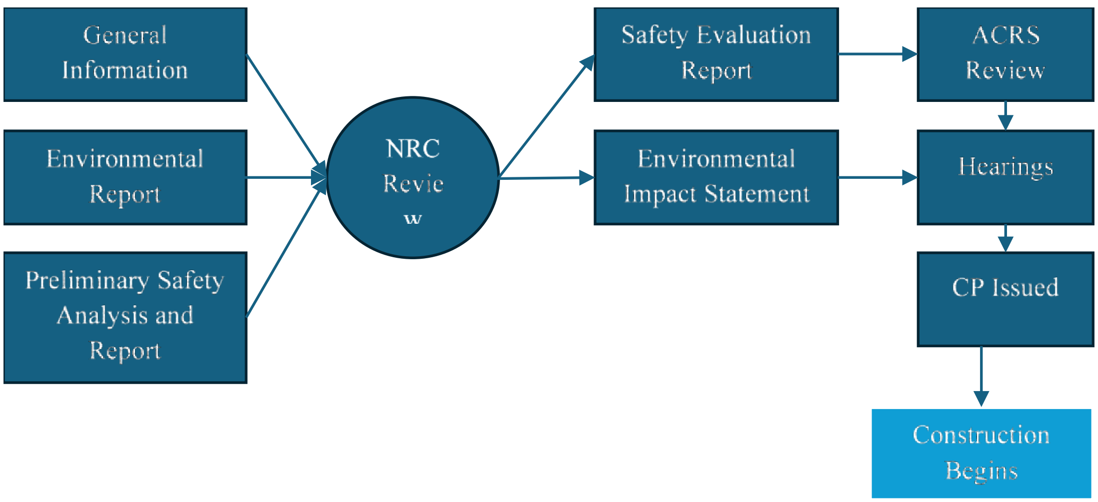

Figure 24. Construction Permit Process [146]

In the Part 50 process, after the construction permit is completed, the project will begin the operating license application. To submit the operating license, the design must be finalized [145]. Many projects begin construction before submitting the operating license, as new designs are often changed during the build to address constructability issues. The operating license process is shown in Figure 25. The NRC expects the review of the operating license to take 42 months [144].

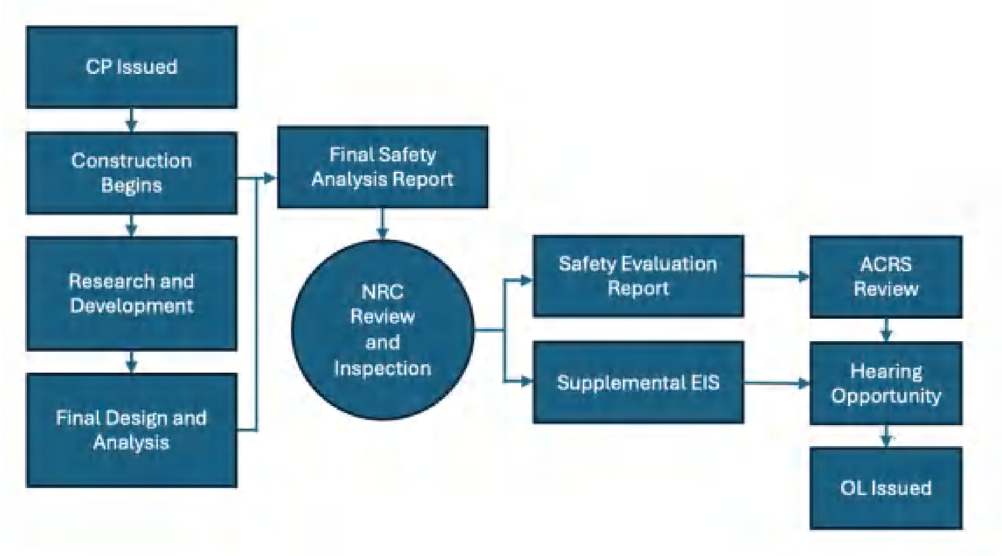

Figure 25. Operating License Process [146]

2.6.1.1.2. Part 52 Licensing Process

In 1989 the NRC devised a second, streamlined licensing pathway that is described in 10 CFR Part 52 ("Part 52") [147]. This licensing pathway is designed to speed up the process and is recommended when the project developer is planning to use a standardized design and doesn't expect to make any design changes during the process. In Part 52, the developer submits for the construction and operating licenses in a single combined license application (COLA). Because the reactor is not being constructed during the operating license process, as it is in the Part 50 process, the operating license is issued with a contingency: the reactor must undergo a battery of inspections, tests, analyses, and acceptance criteria (ITAAC) after construction and before operations commence. The ITAAC will demonstrate to the NRC that the design complies with the parameters laid out in the operating license [146].

The generic timeline for the COLA processing depends upon whether the design is certified or not and whether the design is an LWR or not, according to Table 8. Either way, the Part 52 timelines are shorter than the sum of the construction permit timeline and the operating license timeline in the Part 50 process.

Table 8. Generic Timeline for COLA [144]

Combined [3] (LWR or non-LWR referencing a certified design) – Part 52	30 months
Combined[3] (LWR not referencing a certified design) – Part 52	42 months
Combined[3] (non-LWR not referencing a certified design) – Part 52	36 months

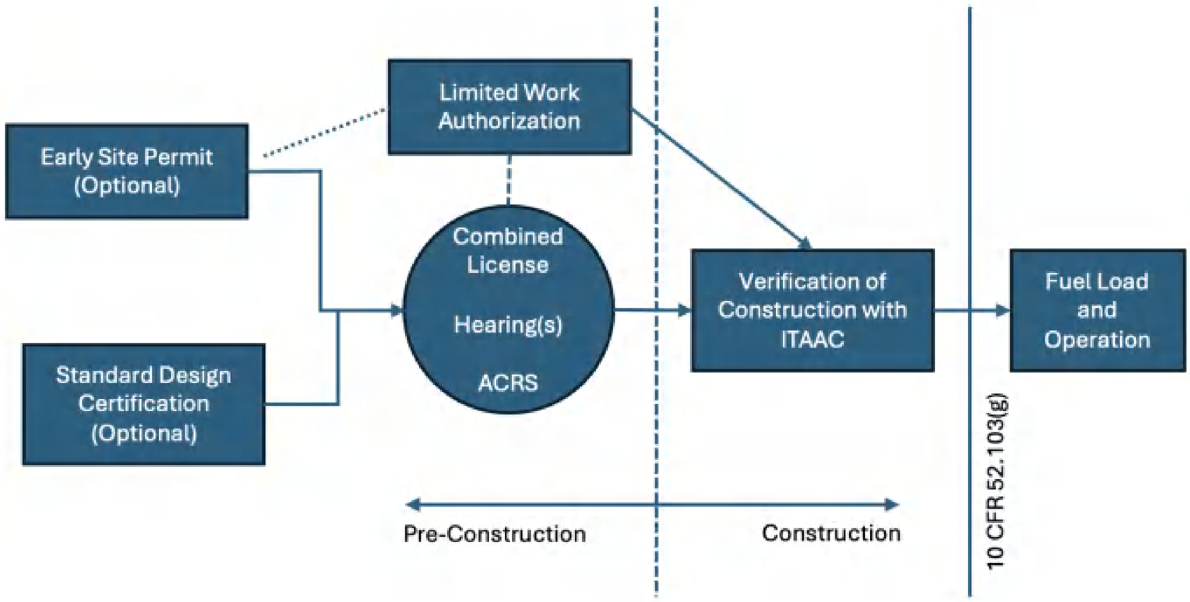

Figure 26. COLA Process [146]

2.6.1.1.3. Early Site Permit, an Optional Precursor to Licensing:

Before beginning the COLA, some projects opt to conduct an early site permit (ESP), which is an optional process where the site is validated by the NRC for nuclear development, but the technology is not yet selected. In an ESP the reactor must be described as an "envelope," which encompasses the broad scale of the reactor that will eventually be deployed at that site. The specific technology does not need to be spelled out in the ESP application. For example, TVA recently completed their ESP for the Clinch River site, where they have permission to deploy up to 800 MWe of nuclear reactors (total), in the form of two or more smaller reactors.[2] The ESP application includes the results from a variety of site-specific technical studies that are required in the construction permit application including meteorology, geology, hydrology, ecology, socioeconomics, land use, demography, archaeology, noise, visual, and emergency planning [143]. An ESP is valid for up to 20 years [143]. A site with an ESP can enter the Part 50 or Part 52 process; in either case, the ESP will reduce the timeline and effort required to get the construction permit.

Like the construction permit, the ESP application will take about two years to prepare. The NRC generic schedules estimate that ESP approval should take about 24 months to approve after the application has been submitted [144]. TVA's ESP for the Clinch River site took three years to be

[2] They have since announced that they plan to install two GE-Hitachi SMRs for a total of 600 MWe of electrical generation. The ESP, however, was open to various technologies.

approved. They submitted the ESP application in May of 2016. The NRC accepted the application in December of 2016. The ESP was issued three years later in December of 2019.

2.6.1.1.4. Standard Design Certification, an Optional Precursor to Licensing

Before a COLA, some projects may opt to complete a standard design certification for their reactor design [143]. By completing this certification, the project will have a greatly simplified operating license process and application. According to the generic schedule, the design certification takes 36 months for non-LWR designs and 42 months for LWR designs [144].

There are three certified designs, only one of which is an SMR: NuScale's US600 SMR, a 50 MWe design that was approved on September 11, 2020 [148]. NuScale is currently applying for a new design certification for their newer, 77 MWe unit VOYGR, which is scheduled to be completed in September 2025 [149]. Westinghouse plans to submit their design certification application for the AP-300 at the end of 2025 [146].

2.6.1.1.5. Part 50 and Part 52 comparison:

The advantage of Part 50 is that construction can begin while the operating license application is being finalized [146]. For a new design, this allows for design changes during construction, which are often required when building a new design. It also allows a stepwise investment on the part of the project developer as they move along the process. Current SMR projects in the NRC application process are all using the Part 50 process. The Hermes 1 project (Kairos Reactor) has already completed the construction permit [150], and the construction permit for the Hermes 2 project is nearly complete [151]. Terra Power's Kemmerer Power Station Project has begun their construction permit process [152]. Holtec has begun pre-licensing activities for a construction permit for their SMR-300 [153] and has indicated their interest in pursuing Part 50 [154]. TVA, which is building a GE-Hitachi Reactor at their Clinch River site, has also begun pre-application activities for their construction permit [155].

Part 52 has the advantage of reducing the regulatory risk, since the entire design is certified before the construction begins [146]. However, being certified as a safe design by the NRC does not mean the NRC has certified that the design will be constructable, so projects that use Part 52 and need to make design changes during construction must get amendments to their design certification. The now-cancelled UAMPS project, a plant comprised of twelve 50 MWe NuScale reactors was in the pre-application stage for a COLA (Part 52) using their certified design when the project was cancelled in 2023 [155]. While there are no active pre-application discussions for another NuScale-based project currently, unlike other reactor designs, NuScale is pursuing design certification for their new design, the VOYGR. Future NuScale-based projects may try to use Part 52. Only one project has ever used the Part 52 process, which was the Vogtle Project. Although they did attempt to derisk the project by obtaining a design certification for the Westinghouse AP-1000 design before construction began, they were still forced to make many changes to the design during construction, which resulted in delays. Due to the changes, the NRC had to amend the license over 180 times for each of the two reactors [156].

New SMR designs are most likely to be built under Part 50 since designs are not usually finalized before they have been built. If later projects re-use the same SMR design, the Part 52 process may make sense and allow the project to move more quickly.

2.6.1.2. U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers is a military branch composed of both soldiers and civilians dedicated to providing vital engineering solutions to the public. The U.S. Army Corps of Engineers regulates the discharge of the water, ensuring the reduction of pollutants in the U.S. The Clean Air Act (CAA) follows a similar structure, but instead would regulate the air and the potential pollutants the SMR would emit. A permit that the National Environmental Policy Act (NEPA) process would require for an SMR to operate includes the Clean Water Act permit [157].

2.6.1.3. U.S. Fish and Wildlife Service

The U.S. Fish and Wildlife Service is a government agency responsible for regulating the protection and conservation of birds, fish, and other wildlife. To deploy an SMR, a permit that would be issued under the U.S. Fish and Wildlife Service, enforced by NEPA, would evaluate the impact the structure poses against endangered species [157].

2.6.1.4. Federal Aviation Administration (FAA)

The FAA regulates both civil and commercial aviation and air traffic. This includes creating regulations for air traffic and airports and developing programs to educate the U.S. on aviation safety. A federal permit potentially required is the obstruction evaluation issued by the FAA, separate from NEPA. This permit must be issued, and the FAA notified if the SMR construction exceeds certain heights over highway, railroads, etc., or the structure emits certain frequencies not included in FAA policy, when the SMR structure might affect a navigation reception, the structure exceeds 200 ft above ground, or simply upon request by the FAA [158].

2.6.1.5. Environmental Protection Agency (EPA)

The EPA is a federal government agency committed to protecting human health and preserving the environment. Outside of NEPA, the EPA requires permits to promote a safe environment with little to no human impact from the SMR. If the site has oil present on site, depending on the quantity of oil, the U.S. EPA can require the site to issue a facility response plan. They also are responsible for evaluating the oil and spill prevention control. This serves to prevent the oil from reaching water and can be achieved by implementing the Spill Prevention Control and Countermeasure Plan depending on the amount of oil [158].

2.6.2. State Regulatory Process

2.6.2.1. Indiana Utility Regulatory Commission (IURC)

The IURC is an Indiana state agency that oversees public utilities. IURC serves as the state level regulatory authority responsible for determining which utilities are implemented on the grid based on reliability, pricing, and demand. In addition, the utility company must show they will apply for the additional licenses needed by the NRC, EPA, and Indiana Department of Environmental Management (IDEM), along with all the additional agencies that need approval [159, 160]. The IURC requires any public utility that would like to use an SMR to provide power to Indiana customers to secure a CPCN [161].

Following this certificate, the applicant would also be required to follow the proposed rules of 170 Indiana Administrative Code (IAC) 4-11 if they intend on constructing or using an SMR for Indiana customers [162]. This is a section of the Indiana Administrative code that focuses on the cogeneration and alternate energy production facilities, the category that SMRs may fall under. This part is additional to the CPCN and must be provided by the utility company alongside all the CPCN supporting evidence.

Once the CPCN is granted, the IURC works to oversee the project and its development to ensure that it continues to comply with those state regulations and licensing restrictions. Especially if any of the conditions might change during the process or during construction. For operations, the IURC serves as the local regulatory authority that will review the requirements that are reported to them.

The IURC requires utility companies to create integrated resource plans (IRPs) every three years to prove to the IURC that they will have enough power to meet the customers' needs in an effective manner, outline potential changes that could affect the resources of the utility company, and then hold a minimum of three public meetings (the majority of which are held in the territory of operation) to listen to the voices of the Indiana customers about how and what they would like to spend their money on in terms of electricity [163].

2.6.2.2. Indiana Department of Transportation (INDOT)

The INDOT is a state agency for overseeing transportation and transportation-related state-owned buildings, including state highways, airports, and railroads. For example, an INDOT permit will allow for the utility company to construct the SMR and operate anywhere around the state highway or within utility easements of INDOT. Any construction obstructing a state highway will require an INDOT permit. [164].

2.6.2.3. Indiana Department of Natural Resources (IDNR)

The IDNR is a state agency that protects and preserves both natural and cultural resources for Indiana residents. The IDNR would issue a permit for Construction in a Floodway to a new SMR. This will protect Indiana citizens from any flood damage or hazards by ensuring that the channels are not obstructed by anything. When obtaining a permit, the IDNR will evaluate the actual floodway and its capacity and safety in addition to the fish and wildlife nearby [159].

2.6.2.4. Indiana Department of Environmental Management

The IDEM works to enforce regulations to protect the environment and human health. This is achieved through the issuance of permits to regulate air, water, and waste discharged within Indiana. Another IDEM set of permits is the National Pollutant Discharge Elimination System (NPDES) [159]. This permitting program puts limits on the number of permissible pollutants discharged into the waters. Within the NPDES there are three different types of permits: municipal, industrial, and wet weather. The municipal permit facilitates any minor or major municipals in addition to semipublic facilities, state owned facilities, and federal facilities. The industrial section issues permit regarding any major or minor dischargers that are classified in their respective field. This is in addition to any general permits that the SMR falls under such as the temporary wastewater discharge or the once-through non-contact cooling water permit. The industrial section also includes permits for any cooling water, public water supply, and processed wastewater. The final set of permits required by the NPDES is for wet weather, an example of which is a permit required to monitor any storm water related wastewater or sewer overflow water.

2.6.3. Interconnection Agreement from Grid Operator

To connect the SMR to the transmission grid, the utility company must obtain an interconnection agreement from the grid operator (MISO or PJM, depending on the location of the plant). The Interconnection process takes 1 to 5 years to complete and may require the transmission provider to make network upgrades before the plant can come online. The process can be streamlined by re-using an existing interconnection agreement, for example, from an existing coal plant that is planning to retire." [165].

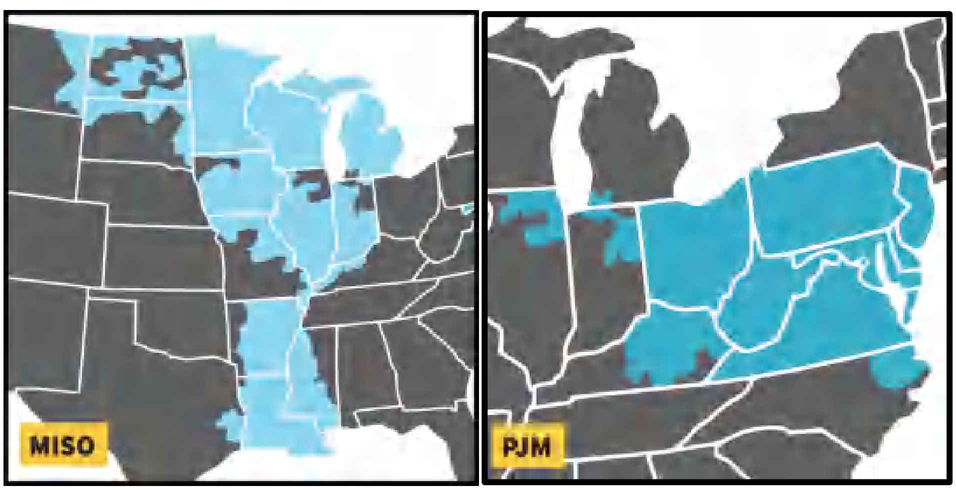

Figure 27. Left: U.S. Regional Area served by MISO [166]. Right: U.S. Regional Area served by PJM Interconnection [167]

2.7 Estimated Timeline for SMR Deployment

An accurate timeline is important for a company or government to aid in project planning. By comparing the varying SMR design timelines, it will allow for observations of key differences and prevent reoccurring issues that might have been an obstacle for past designs. This comparison will mitigate risks in the deployment schedule and allow future developers to take proactive measures to ensure success. A clear timeline fosters a stronger understanding and communication between vendors and stakeholders, building trust on both sides of the project.

The basic outline of a program life cycle follows the structure of a preconcept, leading to a conceptual design. From there, a design will be developed, and after going through proper integration and approval by the government, undergo construction. After the reactor is commissioned, it can undergo standard operations and continue to operate until it is decommissioned. This process is shown in Figure 28 below.

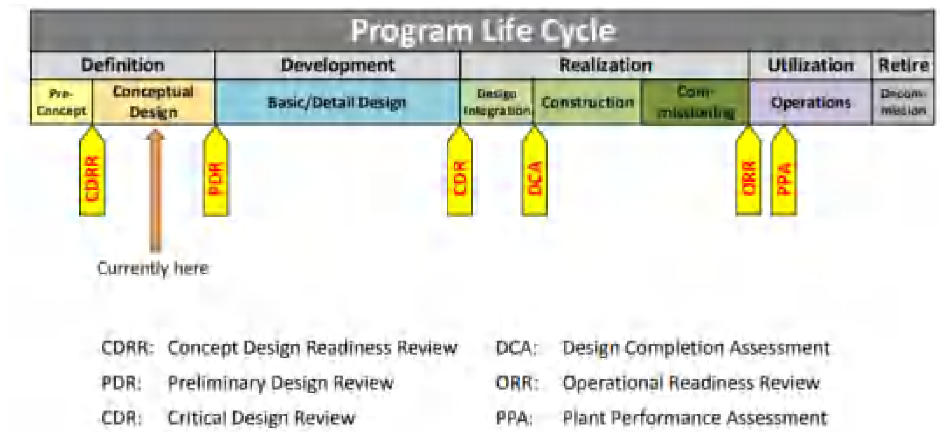

Figure 28. Simplified Example of the Life Cycle of Reactor [168] (the block size in the figure is not correlated with time required for each process)

A useful case-study for understanding the SMR development timeline is the UAMPS project, which was planning to deploy NuScale's VOYGR design. Figure 29 shows the original timeline NuScale proposed in 2018.

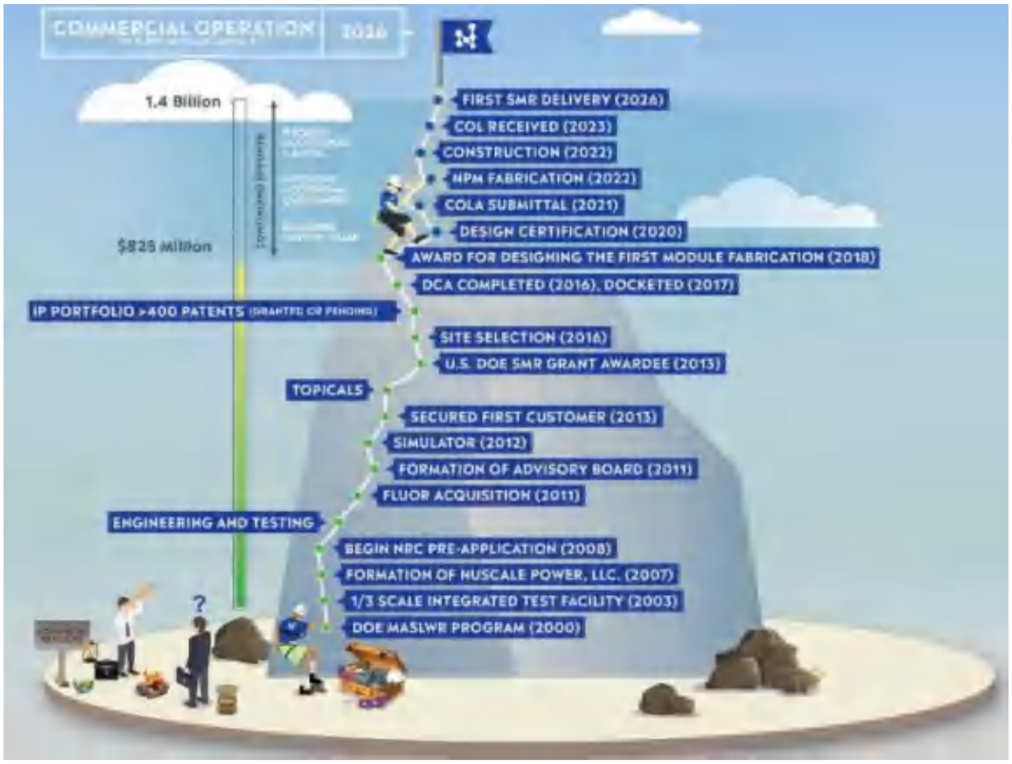

Figure 29. NuScale's Projected Timeline in 2018 [169]

However, as the project progressed, complications arose, causing the timeline to shift and the overall costs of the project to increase substantially, eventually leading to the project's termination. The actual timeline for the project is summarized below in Table 9.

Table 9. NuScale's Actual Timeline of VOYGR [169, 170, 171, 172, 173, 174, 175]

Year, Month	**Event and Significance**
2007	NuScale Power Limited Liability Corporation (LLC) is founded and granted rights to study SMR technology
2008	NuScale notifies NRC of intent for an SMR DC
2011	NuScale partners with Fluor Corporation and receives over $30 million in investments
2012	First SMR control room simulation to model the 12-unit design
2013	U.S. DOE SMR grant awardee receiving $226 million to help with developing SMR designs
2014	NuScale announces it will build the SMR at INL on the CFPP
2014	NuScale partners with Enercon Services Inc. to aid in the design certification application (DCA)
2015	Collaboration with Framatome to design, test, and manufacture fuel assemblies

	- Completed a model for a full-scale upper module of NuScale Power Module (NPM)
2015	UAMPS launches the CFPP
2015	DOE grants $16.7 million to NuScale to aid in the Combined License (COL) for UAMPS
2016	Site selection at the INL
2016, December	December: DCA submitted to NRC for the 12-unit, 50 MWe design - 14 topical reports
2017, March	NRC docketed and reviewed the DCA
2018	NRC completes first phase of review for the DCA
2018	NuScale receives two funds from DOE, one for $40 million and one for $7 million
2019	NRC completes Phases 2, 3, and 4 of the review processes
2020, August	NRC issues final technical review, safety evaluation report
2020, September	NRC grants standard design approval (SDA)
2020	Project costs rise significantly due to inflationary pressures on supply chains, meaning that some manufacturers had prices rise between 50-100%
2020	NRC approves 50 MWe design (first ever SMR to receive design approval)
2020	NuScale discovers that the initial design can produce 25% more power, meaning each module is actually 77 Mwe
2020	DOE awards NuScale $263 million to complete the design
2021, July	UAMPS reduces the 12-module design to 6-unit, 77 MWe module
2021	NuScale receives a total of $200 million more in investments from a combination of several companies
2021	NuScale works alongside UAMPS to prepare a COLA for the CFPP - Includes an analysis of the site and seismic hazards (geological evaluation) - NuScale will receive another grant from DOE for $1.355 billion
2021, December	NuScale SMR plant is named VOYGR
2022	EPZ methodology validated by NRC; VOYGR’s smaller EPZ is also approved later this year
2023, January	NRC votes to certify the design, in turn approving the design for use
2023, January	NuScale submits a new SDA of the updated 6-unit, 77 Mwe design
2023	NuScale receives DC from NRC

2023	NuScale submits limited work authorization (LWA) of 6-unit, 77Mwe design, first part of the COLA (plans to submit COL by 2024)
2023, January	NuScale lays off 154 employees
2023, January	NuScale updates target power price and changes the cost from \$55/MWh to \$89/MWh
2023, March	NRC docketed 6-unit design, 77 MWe application
2023, August	NRC accepts SDA application for the formal review
2023	UAMPS begins working on COL application for the 6-unit, 77 MWe module
2023, November	NuScale and UAMPS decide to terminate the CFPP

The DOE recently issued a sample timeline, which ties together the project and licensing activities, shown in Figure 30. It is important to note that developing an accurate timeline is challenging. As demonstrated by the VOYGR design, complications may arise during the development, licensing, or construction process.

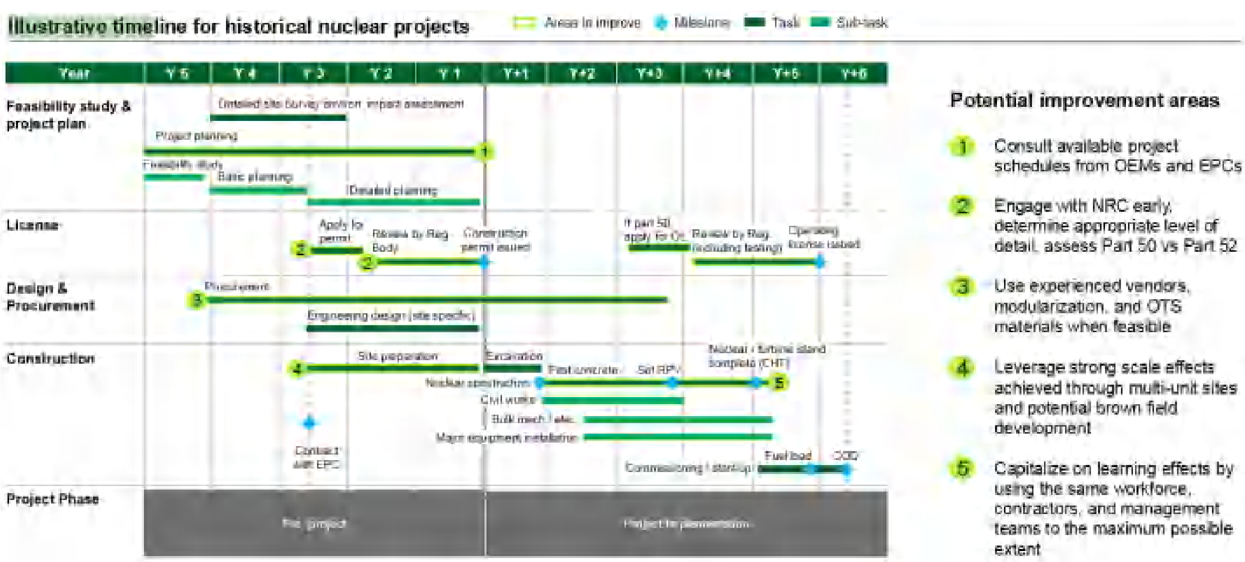

Figure 30. Illustrative timeline for nuclear projects [176]

CHAPTER 3. COST, FINANCING AND ECONOMIC IMPACTS

3.1 Cost of Nuclear

The total cost of nuclear energy includes capital costs (CapEx), operational costs (OpEx) and financing costs. Nuclear power plants, in general, cost much more upfront than fossil fuel power plants, with Cap-Ex costs running 2-10 times that of a similarly sized combined cycle gas plant [177]. Nuclear power's OpEx, to the contrary, is roughly half of the OpEx of a fossil fuel plant. The costs of a new nuclear power plant are mitigated by two key government incentives, one of which reduces the CapEx by up to 50% and another of which reduces the financing costs.

Putting together the CapEx, OpEx, incentives, and financing costs, then dividing the total by the energy that the plant is expected to produce allows us to estimate the levelized cost of energy (LCOE) for new nuclear power plants. LCOE is a useful, but not perfect, metric to compare energy costs between different power plant types.

3.1.1. CapEx

CapEx is broken down into overnight capital costs (OCC), typically 80-90% of the total CapEx, and construction financing costs. This allows us to separate out the effects of the schedule and financing rates from the hard costs associated with the construction. The OCC is meant to represent the cost that would be expended if the entire licensing, design, build, and commissioning were completed "overnight." However, many construction-schedule-dependent costs, such as those of salaried engineers and warehousing costs, are still included in the OCC, meaning it isn't entirely independent of construction time.

The CapEx for SMRs in the U.S. are not widely agreed upon, as none have been constructed in the U.S. to date, and only a few in the world have been completed. Therefore, this analysis relies upon the somewhat better understood costs of nuclear power plants, generally. However, even for large NPPs, costs are not widely agreed upon. Most recent cost studies[3] cite the cost of nuclear power plants generally for the US, instead of breaking it down by technology or reactor size. It is assumed that SMRs will not play a role in the nuclear power plant market if they are not cost competitive on a per kilowatt basis compared to traditional large reactors, and so, understanding the CapEx of traditional reactors is a useful starting point.

3.1.1.1. OCC Estimates for Nuclear Reactors, Generally

For U.S. nuclear OCC estimates generally, many studies use a normalized cost of building the Vogtle Reactors, a pair of large Westinghouse AP-1000 reactors built in Georgia at an existing nuclear site that came online in mid-2023 (Vogtle 3) and early 2024 (Vogtle 4), These reactors were the FOAK in the U.S., meaning it was the first time a Westinghouse AP-1000 was built in the U.S. The OCC for the Vogtle Plants was about $11,000/kW, according to the DOE loan

[3] Resources using Vogtle's Costs to represent U.S. nuclear costs include Bloomberg new energy finance, Lazards Levelized cost of Energy, and DOE's Loan Program Office Nuclear Liftoff Report.

program office's Nuclear Liftoff Report [119], with estimates varying from $9,000-13,000/kW in different resources. This cost makes building nuclear in the U.S. the most expensive in the world by far, with OCC averages from China, Japan, South Korea, India, and Russia reportedly a fraction of that cost at $2,500-3,400/kW (Figure 7) [178].

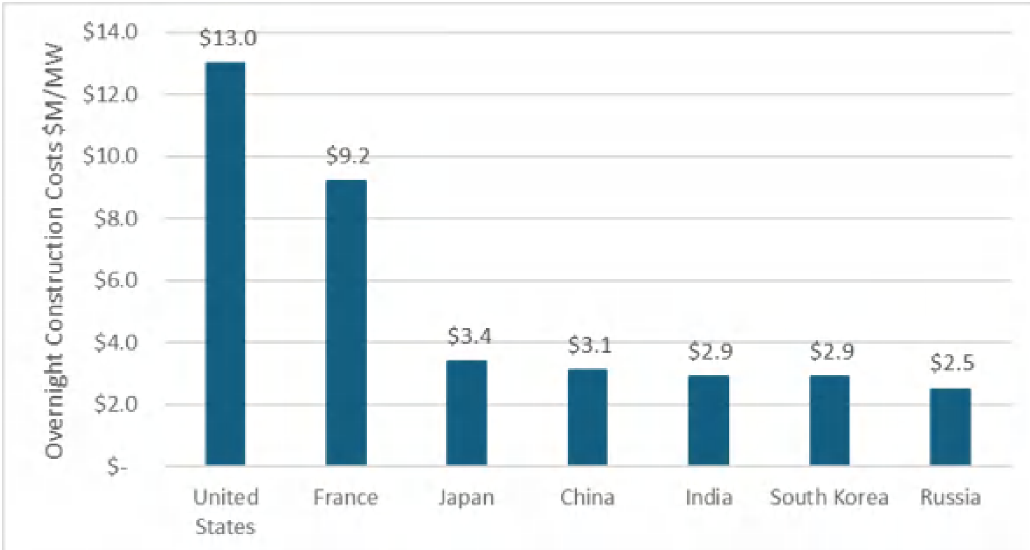

Figure 31. Global Cost of New Nuclear Construction, Since 2000 [178]

China and South Korea have been more active building nuclear power plants over the past 20 years (Figure 32) and have focused on building a standardized design, helping them to keep their costs low. Even France, with a similarly priced cost of labor compared to the U.S., and a similar lack of recent build experience, has been building their newest reactors at an OCC 30% lower than the U.S. [178]. France's project may have lower costs, in part, because they are building a standardized design, the European Pressurized Reactor, which has also been built in China.

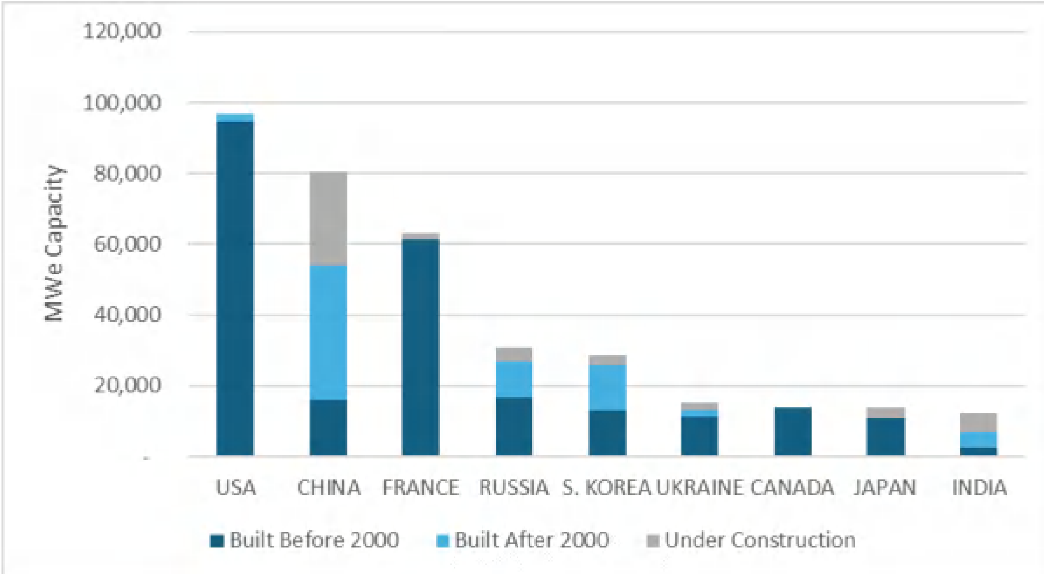

Figure 32. Reactors Built by Country [179]

Like all technologies, the FOAK is expected to be the costliest deployment, with costs lowering over time according to a learning curve. One of the key drivers of this effect is that the first time a design is built, the NRC must review and provide feedback on the new design, often with licensing activities and feedback, and the ensuing redesigns are ongoing as the project is under construction. But also, like all technologies, second and third implementations, or later implementations, also called nth-of-a-kind (NOAK), are less expensive because the design is finalized, the supply chain is secured and vetted, the engineering processes are streamlined, and the process is beginning to benefit from economies of scale.

The DOE Loan Program Office (LPO) Liftoff Report examined the ways in which the costs of a "Best Practices FOAK" should be expected to be 30-40% lower than the OCC of the Vogtle Project, or $6,200/kW [119]. Additionally, there are significant opportunities for savings between the FOAK and the NOAK that could reduce costs by another 40% (See Figure 33) [119].

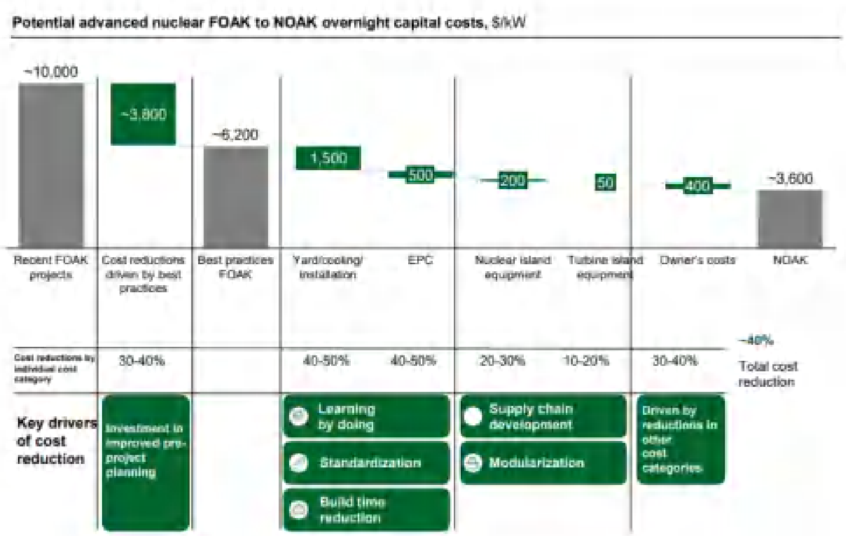

Figure 33. Categorizations for how advanced nuclear OCC could decrease from FOAK to NOAK deployments, $/kW [119]

The effect of OCC lowering between a FOAK and a NOAK project can be seen in the real world. Korea demonstrated cost reductions of 40-50% between its first reactor projects in the 1970s and the early 2000s.

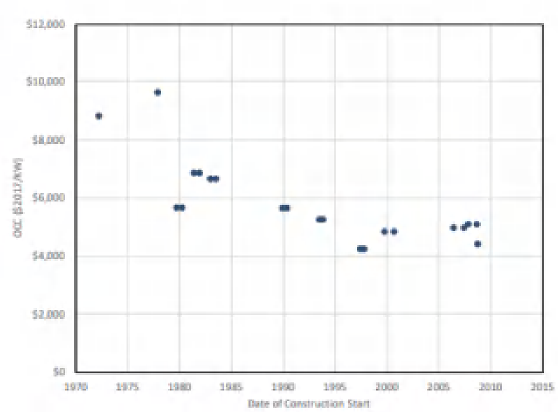

Figure 34. OCC as a function of Construction Start Date for Korean Nuclear Projects [180]

3.1.1.2. OCC Estimates for SMRs

Because very few SMRs have been built in the world and none are completed in the U.S., few resources attempt to characterize the cost of SMRs and advanced reactors separately. In October 2023, the DOE published a Literature Review of Advanced Reactor Cost Estimates. The study estimated the OCC for SMR builds between the FOAK and the NOAK at $4,000 to $7,000/kW. The study estimated that FOAK SMR builds will be 30% to 110% higher than $7,000/kW [181].

The preliminary integrated resource plan (IRP) from Duke Energy largely agrees with these numbers, as seen in Figure 35 [182]. Duke Energy estimates SMR prices will start around $9,000-$10,000/kW and reach $4,000/kW in the 2040s when the NOAK prices begin to prevail.

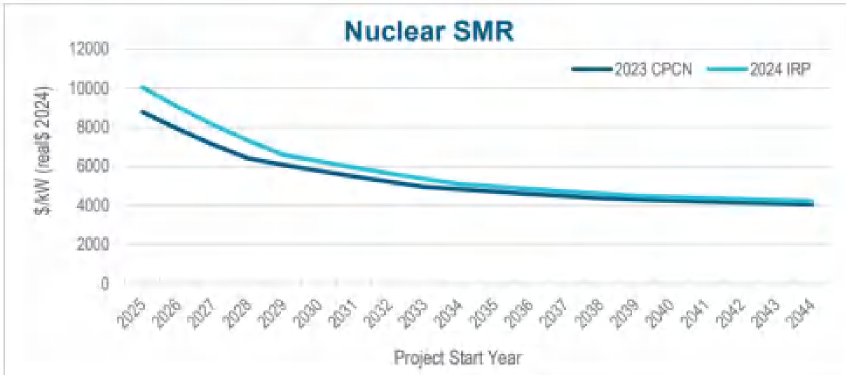

Figure 35. Nuclear SMR price prediction over time [182]

While there are no SMRs in the U.S., China completed its first SMR in 2021, Linglong-1, with a cost of only $4,200/kW, which is very low in comparison to the U.S. estimates. When compared to conventional reactors being built in China at the same time, the SMR was 1.5 to 2 times more expensive on a per kW basis (See Figure 36) [183] due to the higher costs for a FOAK reactor.

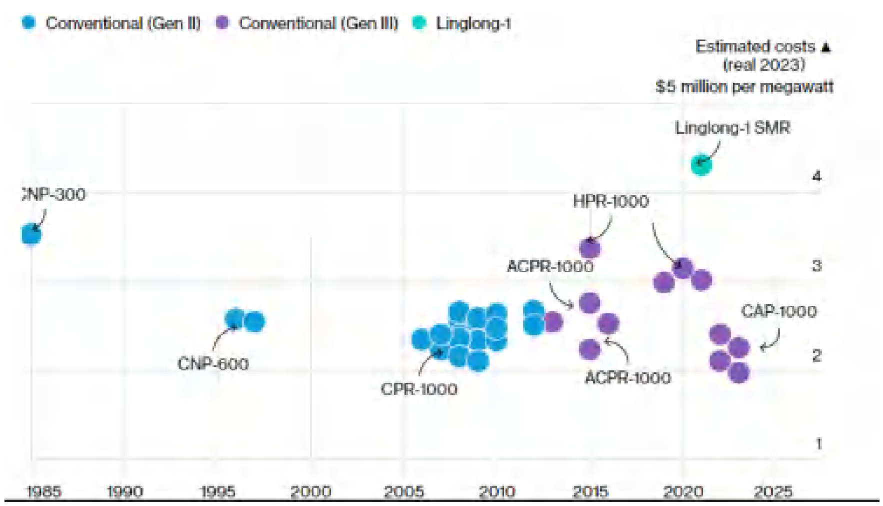

Figure 36. The cost of China's first SMR compared to contemporaneous large reactors [183]

It is unclear at this time whether SMRs will have higher or lower normalized costs in the long run compared to large, traditionally sized reactors. Large reactors benefit from economies of scale in many cases. For instance, the licensing process costs about the same for an SMR as it does for a large reactor, and so, for a large reactor, it is a smaller percentage of the total costs. Project management costs can be shared across the project. The nuclear island uses fewer materials and fewer parts per kW for a large reactor. As a larger purchaser of construction materials, a large reactor may be able to negotiate better deals for their materials and supplies as well.

On the other hand, SMRs have cost advantages that make their size more appealing and possibly, in the long run, less expensive than traditional reactors. That is, reverse economies of scale may outweigh the aforementioned economies of scale.

3.1.1.2.1. Potential Cost Benefit of the SMR

SMRs are designed to be small and modular so that many of the pieces can be manufactured in a factory setting where the processes are controlled, repeatable, and less expensive than field construction activities.

By standardizing the design and maximizing the factory build, SMRs offer promise to reduce construction time. The Electric Power Research Institute (EPRI) identified the key drivers of cost and the ones with the most room for improvement for nuclear power plants generally. EPRI states that the most significant cost reduction strategies are those that reduce the construction time and not those that optimize the costs of the nuclear island itself. They state that an OCC of $3,431/kW is achievable when projects improve design constructability, reduce the time spent in the field, and finalize the plant design before construction [180]. All three of these suggestions could be met by using standardized designs and minimizing field construction time, as SMRs propose to do. Even before the advent of SMRs, there was a slightly positive correlation between project size and normalized cost, implying that even without the modularity at play, above a certain size, the projects became too complicated to manage, which led to expensive schedule delays [180].

Even if an SMR has the same normalized cost as a large reactor, because the total cost is less, it may be easier for the project to begin. Due to their modularity, SMRs can be grown over time, so if the financing is only available for one third of the project, it may be possible to build one third of the project until the remaining money becomes available [119]. Because of their lower total cost, the projects may be easier to finance and quicker to deploy, and thus SMRs may reach NOAK pricing before large reactors do [119].

The DOE’s Liftoff Report noted that the construction schedules carry great financial risk and so SMRs tend to have a smaller cost range compared to large reactors as cost overruns are relatively smaller for SMRs [119] as shown in Figure 37. While the majority of large reactors cost less on a per kW basis than the small reactors, the outliers for large reactors can be much more expensive making the overall average come out the same and making investment in large reactors riskier.

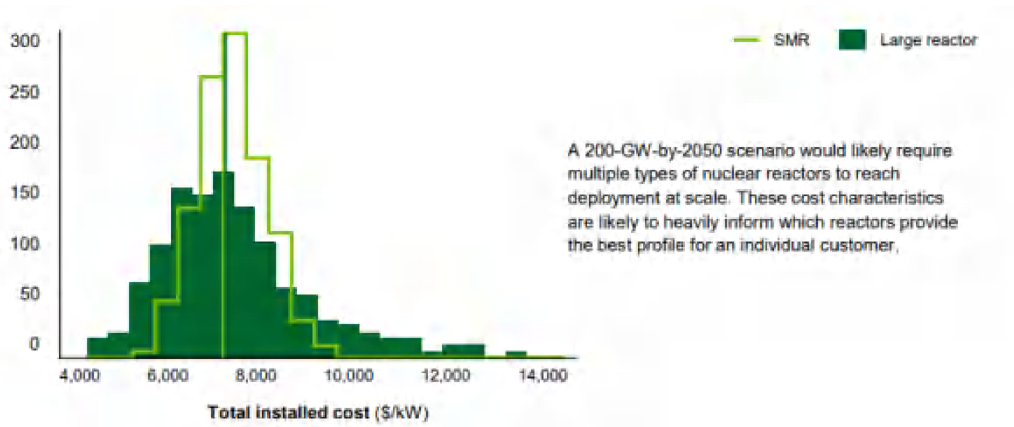

Figure 37. OCC cost estimations for a large BWR and a small modular BWR. [119]

3.1.1.3. Risk and Uncertainty in OCC Estimates

One difficulty facing nuclear project developers is the uncertainty around the cost of building a new nuclear reactor. Although the cost of construction was relatively stable throughout the 1970s, in the mid-1990s after the Three Mile Island (TMI) incident, the OCC of completed reactors began to grow rapidly, with reactor costs coming in five times higher than the costs a decade earlier [180] (Figure 38).

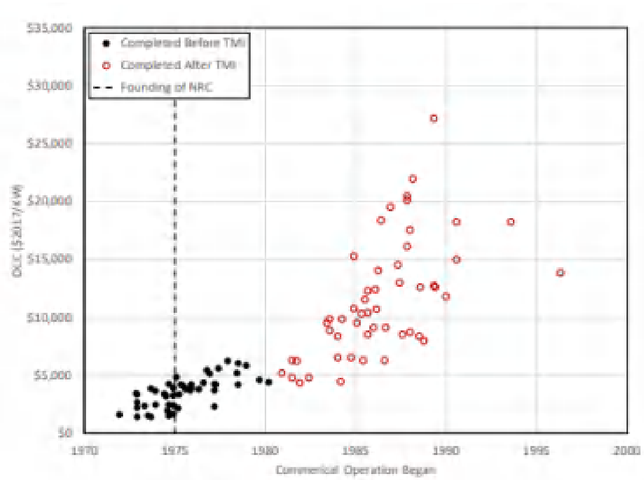

Figure 38. Overnight Construction Costs of Reactors Completed in the US [180]

Between 1996 and 2023, no reactors were completed in the U.S. In 2023, the 1.1 GW Vogtle Reactor 3 came online; in 2024, the 1.1 GW Vogtle Reactor 4 came online. The two reactors cost more than double the initially estimated cost and took twice as long to complete as was initially promised. The two Vogtle reactors, with a combined capacity of 2,234 MW, had an OCC of $25 billion, for a normalized cost of $11,000/kW, with initial OCC estimates of $9 billion total for both reactors [119]. The construction delays also ballooned the cost of construction financing from the initial estimate of $4 billion to the final cost of $7 billion [119].

As shown in Figure 39, various troubles plagued the project, which caused repeated schedule delays and cost increases. While some of the cost increases can be tied to causes outside of the control of the project, e.g., changing regulatory requirements after the Fukushima disaster in 2011 and construction delays during COVID-19, most of the cost increases were caused internally by the project or due to the decision to seek NRC design approval in parallel with construction activities [184]. There were problems with the oversight and quality control at the factory that was manufacturing the major components, among a handful of other design and construction issues [185]. The bankruptcy of Westinghouse in 2017 caused the owners to lose their fixed-price contract at which point the cost estimates increased by $9 billion in a single quarter [119].

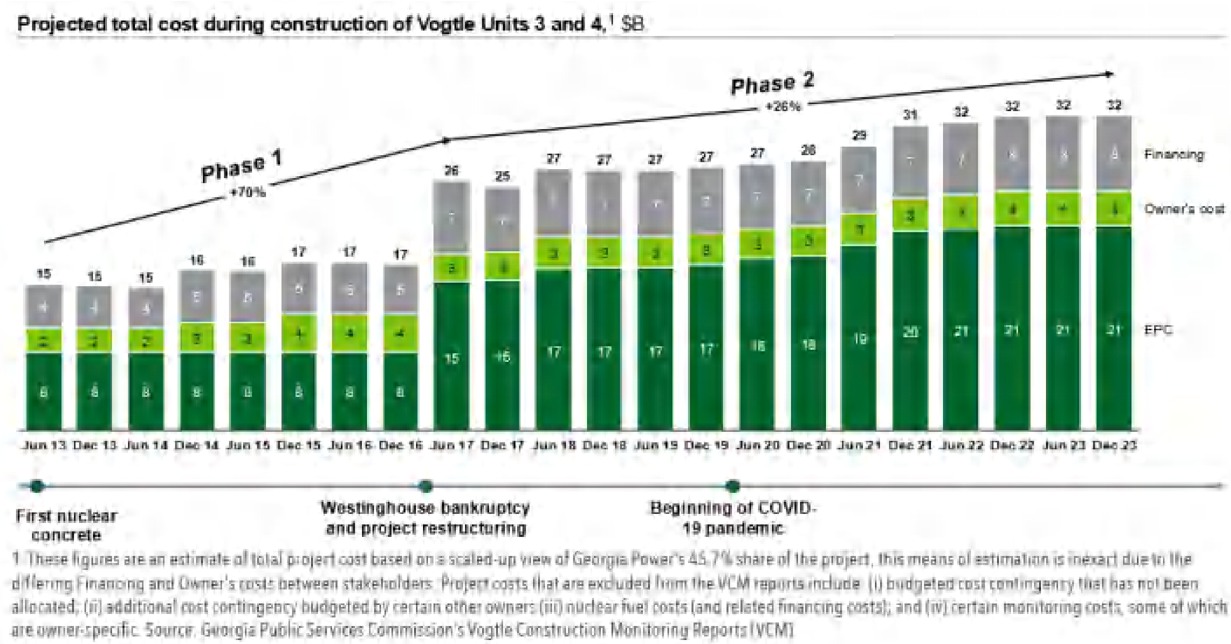

Figure 39. Vogtle Units 3&4 Cost Estimates in $billion throughout the Project Lifetime [176]

A similar story unfolded with the cost estimates of the NuScale UAMPS project, a new SMR design with a plan to deploy six to twelve 77 MWe units to a site in Idaho. The cost estimates rose throughout the project lifetime, more than doubling the levelized cost of energy from $55/MWh in 2016 to $119/MWh in January of 2023 [186]. The project was ultimately cancelled in November 2023, citing the increase in their construction cost estimates, which had increased by 75% between the 2021 report and the 2023 report.

These two recent examples of changing cost estimates, along with the cancellation of a long-planned nuclear project at Virgil Summers Plant, have made it difficult for financiers to trust cost and schedule estimates for nuclear projects in the U.S.

3.1.1.4. Early OCC Expenditures in a Nuclear Project: Licensing, Permitting and Interconnection

Nuclear power plants, besides having a high OCC overall compared to other technologies, also have costs that must be expended well before project construction begins including licensing, interconnection, and permitting costs. These upfront costs are a relatively small part of the total OCC, amounting to 1-3% of the total OCC [187]. Nevertheless, they are important to break out because they are expended multiple years before the plant begins to make money, and they are at risk of being lost if a project is canceled or found to be unfeasible mid-process. The riskiness and long timeline also make the upfront costs difficult to finance. The bulk of the upfront costs are NRC licensing costs. A breakdown of the NRC licensing costs can be found in Appendix F.

Licensing costs are highly variable. Dominion reported a much higher cost and spent roughly $600 million in their pursuit of both the ESP and the COL on their new VC Summer Reactors (which never came to fruition) [188].

Licensing costs tend to be fixed; that is, they will be $150-$300 million regardless of the size of the reactor. SMRs may have some slight cost reductions in the licensing process compared to large GW-scale reactors because they do have a much smaller planning area. TVA’s Clinch River site, for example, had a 2-mile planning zone, which is much smaller than TVA’s larger, GW-scale reactors: Watts Bar I, II; Sequoyah I, II; and Browns Ferry I, II, III, which has a 10-mile planning zone. This reduces the public engagement footprint and the emergency planning footprint, which can save significant upfront costs. However, the licensing costs are not expected to be different between a 100 MWe reactor and a 300 MWe reactor because of the reactor size.

Licensing costs are dependent on whether the design is new or not. Therefore, if SMRs become more standardized and repeatable over time, the operating license costs could be expected to go down over time, reducing dramatically once the design becomes certified.

3.1.1.4.1. Interconnection Costs

Interconnection costs, i.e., the cost to upgrade the grid to meet a new generator’s need to export their power, are highly variable and depend upon many other factors that affect the loading of the grid along the transmission lines. According to a Berkley study [189] the completed projects in MISO territory with interconnection studies from 2019-2021 had an average cost of $102/kW and active projects (which aren’t yet completed) with studies in that same year had an average cost of $156/kW in 2022 dollars. Withdrawn projects in that same study year period had much higher average costs of $452/kW. However, it is worth noting that these are averages across MISO, wherein the entire study period (2000-2021), Indiana typically had lower prices. Also, larger generators tend to have some economies of scale; large-scale projects typically have half the normalized interconnection costs of medium-scale projects. Therefore, for an SMR of 300 MW, the cost for the interconnection would likely be from $30 to $45 million. Due to the variability, and the tendency of interconnection costs to have large step changes, there is a chance that any one site could have a much higher interconnection cost. It would be worth securing that agreement and rate early enough in the project development to avoid that risk. This may be able to be avoided or mitigated in part by using the existing interconnection agreement from a coal plant, if this were a coal-to-nuclear project. Also, processing the interconnections in clusters, as MISO does now, somewhat mitigates these large step changes.

Interconnection costs are expected to be relatively even throughout the state. The availability of interconnections is low throughout Indiana (see map in Figure 40), and all interconnecting generators are levied some costs.

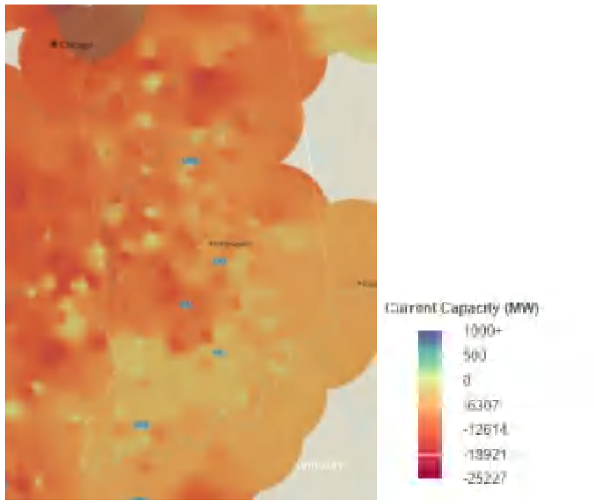

Figure 40. Interconnection Availability in Indiana (Source: MISO)

3.1.1.4.2. Permitting Costs

In order for the state to approve a site, the project will go through state environmental permitting. To accept federal grant funding, the project will also likely require a NEPA review. Both of these environmental permits typically use the same information that is required for NRC licensing; however, they still require some fees and document preparation for submission and approval. Furthermore, the owner will typically have to reimburse the state for their activities associated with permitting the nuclear site and for their ongoing monitoring of the site after operation commences. The cost estimates for these activities are assumed in the previously cited costs for NRC licensing as these permit applications tend to happen concurrently, and the utilities do not report them separately.

3.1.1.5. OCC Savings from Siting New Nuclear at an Existing or Retired Coal Plant Site

Siting a new nuclear plant at a retired coal power plant (CPP) location can save 7-26% of the overnight capital costs (See Appendix A). These savings come when parts of the CPP can be reused, including electrical equipment, site preparation/security, office buildings, and heat sink components.

3.1.1.6. Construction Financing Costs

Construction financing costs make up the balance of the CapEx costs of a new nuclear build. Construction financing depends upon the financing rates, the length of the construction period, and the timing of the expenses. Reducing the construction period and delaying large purchases as long as possible will keep financing costs down. That said, delaying purchases may increase the risk to the schedule and should be considered carefully. For the Vogtle Plant, construction financing costs started at $4 billion, or 30% of the total capital cost, and ended at $7 billion, or 22% of the total capital cost [119]. This is counter-intuitive given that the schedule delays should have made construction financing costs increase, however the DOE Loan Program Office had stepped in to help them lower their rates, which ultimately kept construction financing costs to only 22% of the total costs.

3.1.2. Project Financing Costs

Because the CapEx of nuclear power plants is relatively high, project financing rates have a very large impact on the total cost of nuclear energy. For a typical privately financed power plant project, equity costs about 12% in the private market and will make up about 20-40% of the project CapEx [177]. Debt financing will cost about 8% on the private market and will make up the remaining 60-80% [177]. Financing rates are heavily dependent on general interest rates, the riskiness of the project, and the availability of capital. Since nuclear is perceived as a risky investment, financing rates could be higher but for the government subsidy mentioned below.

3.1.3. Government Incentives that Reduce Project Costs

The federal government offers two key incentives to help make nuclear power economically competitive.

1) **Investment Tax Credit (ITC):** Since the Inflation Reduction Act (IRA), new nuclear plants are eligible for either the ITC or the production tax credit (PTC) that had traditionally only been available to renewable resources. While many existing plants are now taking advantage of the production tax credit when they re-license their plants, new nuclear plants will be able to choose between the ITC and the PTC. It is not clear which will be the most economical decision, and it will likely depend on the interest rates and particulars of the site, its energy value, the technology, and other factors. For simplicity, in this analysis we assume that the project is using the ITC. The base ITC is 30% of CapEx, but it can be worth up to 50% of capital costs when including a 10% adder for being in an energy community and 10% adder for using domestic content (see Figure 42).
    a. Many of the sites analyzed in Chapter 4 are located in energy communities now or will be in the future. There are large parts of Indiana, however that are not eligible for this adder. (See Figure 41)
    b. The 10% domestic content adder would apply if the SMR, or the materials used in its construction, are manufactured in the U.S., according to the specific rules laid out by the U.S. Government.

c. The “low-income communities bonus allocated credit” shown in Figure 42, which appears to raise the ITC above 50%, is unlikely to apply to nuclear projects.[4]

Figure 41. Energy Community Tax Credit Bonus Map for Indiana (Source: DOE)

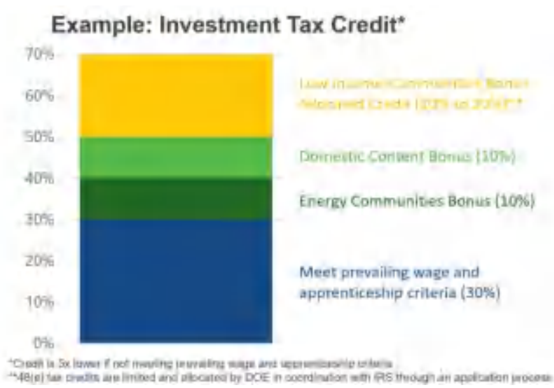

Figure 42. Additive Nature of Investment Tax Credit. (Source DOE)

2) **Department of Energy (DOE) Loan Program Office (LPO) Backing:** DOE’s Loan Program Office (LPO) offers loan guarantees on debt financing that can cover up to 80% of eligible project costs. The interest rates vary from project to project but are lower than typical interest rates for innovative energy projects, including new nuclear. The base rate for loans from the U.S. Government (Federal Finance Bank) will be the U.S. treasury bond rate plus about 2.4-2.6% in other charges. This amounts to an interest rate below 6%.

3.1.4. Operational Costs

Nuclear reactors in the U.S. are required to share information publicly on the cost of operations. While all existing reactors are large reactors, and not SMRs, the data offers some general insight

[4] Those credits are for behind the meter renewable projects benefitting low-income individuals, projects on tribal lands and projects selling power to low-income housing projects. One category, section 4a and 4b could be applied to nuclear power if an owner or off-taker used the capacity to serve a low-income community.

into the operational costs of nuclear power plants generally. The costs of operating a nuclear power plant tend to be about half of the operating costs of a gas turbine plant or coal plant of the same size. The operational costs of running a nuclear plant are about 75% operation and maintenance costs and 25% percent fuel. Conversely, the fuel costs are about 75% of the operating costs of a coal or gas plant, with the remaining 25% covering the cost of operation and maintenance [190]. The upside of having higher maintenance and operational costs is more of the operational costs go toward local jobs and the local supply chain. The downside of high operation and maintenance costs is salary costs and regular maintenance costs tend to be fixed so the power plant is not incentivized to operate flexibly. Between a high CapEx, and high fixed OpEx, nuclear reactors have mostly fixed costs and will usually operate at maximum capacity to recover those fixed costs, unless the local energy prices are below zero.

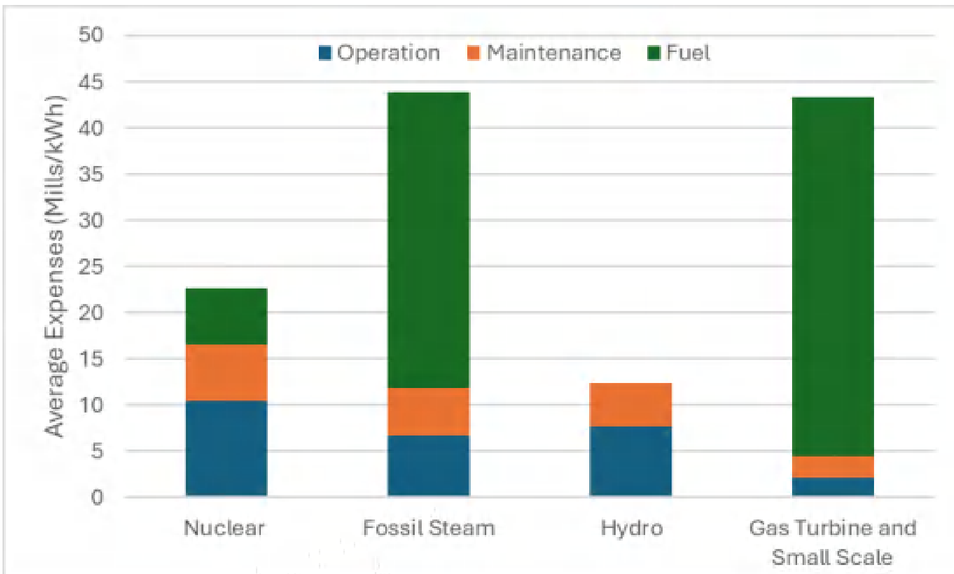

Figure 43. O&M Costs for Generators reported on Federal Energy Regulatory Commission (FERC) Form 1 in 2022 [190]

* Note that gas turbine O&M costs are combined with the costs of solar and wind plants, so the fuel costs are somewhat lower than they are for gas alone.

3.1.5. Cost Comparisons with Other Generators

The levelized cost of energy (LCOE) incorporates the CapEx, OpEx and financing costs into a single cost figure measured in $/MWh. The LCOE allows us to compare energy costs across a wide variety of technologies side-by-side. LCOE simply normalizes all the annualized costs by the annual energy produced. Lazard LCOE+ is an annual report that compares the LCOE for various technologies [177]. One issue with LCOE is that it ignores the value that is brought by the dispatchability of a resource, making non-dispatchable resources like wind and solar look much less expensive by comparison. Lazard somewhat controls for that simplification by including solar + storage or wind + storage in the LCOE analyses. A solar + storage or wind + storage project includes the cost of a 4-hour energy storage system with half the power capacity of the renewable resource. Although adding a 4-hour storage system to a renewable resource does not make the resource fully dispatchable at every hour of every day of the year, it does make them somewhat more comparable to traditional resources like gas or nuclear.

The first four columns in Table 10 show the key assumptions and results from the Lazard's unsubsidized analysis for new generators of various technologies. In Lazard's unsubsidized analysis, the LCOE range for new nuclear is well above the LCOE range for new gas. The addition of the ITC subsidy, and the LPO support changes that story. For nuclear projects able to claim a 50% ITC (e.g. using sufficient domestic content and located in an energy community), and able to leverage the LPO backing to finance 80% of the project at a low 5.5% interest rate, the LCOE range would be on par with the higher end costs of a combined cycle gas plant at $70-$103/MWh (see Table 10, 5th column). If an OCC were lower than Vogtle costs and aligned with the DOE's estimated "best practice FOAK" cost of $6,200/kW, nuclear power would decrease to $60-$65/MWh (see Table 10, 6th column) which puts it on par with new gas generators. Competing renewable + storage projects would also be able to claim about 30%-40% ITC so their LCOE could be 30-40% lower than the unsubsidized analysis results as well.

Table 10. LCOE of New Nuclear Compared to Other Technologies

	Lazard LCOE+ 2023 Unsubsidized Analysis				Adjusted Analysis	
	Utility Scale Solar + Storage	Utility Scale Onshore Wind + Storage	Gas Combined Cycle	Nuclear	Nuclear with Subsidies	Nuclear with Subsidies and Lower CapEx
Capacity	150	100	550	2200	2200	2200
Cap. Factor	27-20%	45%-30%		92-89%	92-89%	92-89%
CapEx ($/kW)	$1,075-$1,600	$1,375-$2,250	$650-$1,300	$8,475-$13,425	$8,475-$13,425	$6,200
ITC	0%	0%	0%	0%	50%	50%
Equity %	40%	40%	40%	40%	40%	40%
Equity Rate of Return	12%	12%	12%	12%	12%	12%
Debt Interest rate	8%	8%	8%	8%	8%	8%
Variable O&M Rate ($/MWh)	0		$2.75-$5.00	$4.25-$5.00	$4.25-$5.00	$4.25-$5.00
Fixed O&M Rate ($/kW-yr)	$20-$45	$32-$80	$10-$17	$131-$152	$131-$152	$131-$152
Fuel cost ($/MMBTu)			$3.45	$0.85	$0.85	$0.85
Heat Rate (kWh/MMBTU)			6,150-6,900	10,450	10,450	10,450
LCOE ($/MWh)	$46-$102	$42-$114	$39-$101	$141-$121	$71-$103	$60-$65

[i] Government Subsidies are assumed to be a 50% ITC and 5.5% Interest on Debt with 20% Equity/80% Debt

3.2 Nuclear Project Financing Feasibility

As described in previous sections, nuclear power plants are in demand for their unique ability to provide decarbonized energy on demand, which along with the government subsidies available is the key driver of financing feasibility. Financiers depend upon a steady stream of projected revenue. Therefore, if off-takers demand nuclear energy, and in turn they sign long-term PPAs, financing is feasible. Likewise, if utilities determine that nuclear energy is the best resource for their ratepayers, they can secure financing. Although hurdles to financing projects, for all end user types, still remain.

3.2.1. Project Financing Feasibility Hurdles

To create a successful nuclear project, there must be an owner willing to take on the risk and uncertainty of the project and willing to accept the long-term nature of the project returns. The price of nuclear when including incentives is comparable to alternative technologies. But because nuclear is still comparatively risky, there is not a widespread interest in investing in new nuclear projects. Even with the Loan Program Office backing up to 80% of the OCC, and with the Investment Tax Credit crediting over 10-50% of the Cap-Ex costs back to the owners, there are many project risks that turn away would-be owners, including the following:

- Potential for extreme cost overruns and/or schedule overruns, as occurred during the Vogtle project.
- Potential for cancelled projects, such as what happened during the first planned SMR deployment, the UAMPS project.
- Potential for federal, state, or company policy shifts that could impact the economics or desirability of the plant before construction is completed. Most importantly, uncertainty around the policies and incentives aimed at decarbonization.
- The potential difficulty finding the expertise to manage the project due to the low number of recent successful nuclear reactors deployed in the U.S.
- The potential reputational battering or legal challenges that could arise from anti-nuclear community advocates.
- Safety concerns around nuclear power on the part of the would-be owners.
- Potential owners are not incentivized or compelled to fully consider the community's economic impact in their own cost-benefit calculations.

To get a nuclear project started there will likely need to be a strong impetus from outside forces that make nuclear the most compelling choice. Some external factors that could help make nuclear power an attractive option include the following:

- Clarity around the ongoing nature of decarbonization policies including the following:
    - Clarity that the existing federal subsidies and incentives will persist. The federal incentives are a major contributor to the cost being competitive so nuclear projects will be much less attractive if those policies are discontinued.
    - Clarity that the decarbonization requirements from the federal level will persist including carbon-reducing policies that will limit new and existing fossil generators.
    - Clarity that the demand for decarbonized electricity in the private sector. The private sector may signal its ongoing demand through long-term PPA for clean energy by purchasing nuclear energy or making direct investment to the vendors.

- Clarity around the load growth expectations and the need for new capacity additions or direct investment from an energy end-user.
- Clear, long-term value ascribed to 24/7 resources, which are able to provide baseload power on demand, likely in the form of long-term capacity contracts, or direct investment from an energy end user load with 24/7 demand.
- Successful demonstrations of nuclear projects being delivered on time and on budget.
- Nuclear technology vendors or engineering procurement and construction (EPC) firms willing to sign fixed-price contracts.
- The NRC fulfilling their recent commitment to simplify and reduce the cost of their reviews.
- Value ascribed to the positive economic impact that a power plant can provide.
- Additional federal support in the form of grants, regulatory cost support and non-monetary project support.

At a project level, project developers can take the following actions to mitigate a project's risk and make nuclear a more attractive option:

- Find and engage with local communities that value nuclear power and are interested in bringing a nuclear power plant to their town/county.
- Find and engage with state governments that value nuclear power and are committed to working expeditiously with the project during state permitting.
- Derisking a site selection with careful expert input during the process and cost-conscious ramp-up towards project commitment.
- Select fixed price contracts with reputable technology providers, EPC firms, and key suppliers.
- Using known, well-developed designs. Ideally using designs that are already certified by the NRC and built, where possible, or using designs that are likely to be certified easily or quickly due to their design maturity and/or similarity to other certified designs.

With those factors favorable, a nuclear project becomes a compelling choice.

3.2.2. Demand for Nuclear Energy

Power projects in the state of Indiana are typically funded by utilities or private financers. However, due to the needs of many off-takers aligning well with the nature of nuclear's decarbonized 24/7 power and the nature of those companies' strategies, motivated off-takers may end up being a major driving force behind the adoption of new nuclear energy in the state of Indiana and throughout the country.

While the ITC and LPO cover most of the project costs, there is still the requirement of the project to come up with the 20% equity investment for a new nuclear power plant. For a 300 MWe SMR, with a conservatively high FOAK OCC of $9,000/kW, this would amount to 20% of $2.7 billion, or $540 million.

3.2.2.1. Investor-Owned Utilities

Indiana has five investor-owned utilities (IOUs): AES Indiana, CenterPoint Energy Indiana South, Duke Energy Indiana, Indiana Michigan Power, and Northern Indiana Public Service Co. Of these five utilities, only two, Duke Energy and Indiana Michigan Power, own and operate nuclear power plants in other states. Only Duke Energy has included new nuclear in their generation scenarios in their latest Indiana IRP.

At an April 2024 Integrated Resource Plan Meeting, Duke Energy suggested that SMRs, which for Duke Energy is defined as light water SMRs, will come online in Indiana in 2037 or later and advanced reactors will come online in 2039 or later [182]. While Duke Energy is not actively developing any nuclear projects in Indiana today [191], they are developing an SMR project at their North Carolina Belew's Creek site, which makes them a leader in the SMR space nationally. By implementing this first project, Duke Energy expects to gain clarity around the technology's ability to meet its expectations, schedule, and budget. Time will help them to gain certainty around the real load growth due to data centers and electrification. If nuclear proves its competitiveness and load growth proves to meet expectations, they can then deploy nuclear to their other states with less risk [191]. IOUs must apply for a CPCN before investing in a new plant. Duke Energy is able to make a CPCN justification in North Carolina due to the state's strict decarbonization requirements, but they would have more difficulty making the argument in Indiana due to the risk of schedule and cost overruns that nuclear plants still face [191].

Indiana Michigan Power owns and operates a nuclear power plant in Michigan, DC Cook, and while their Indiana IRP from 2021 includes plans to extend the license for that plant and calls out SMRs as a future possibility, it does not include new nuclear in its proposed forward-looking portfolios [192].

IOUs in the state of Indiana are faced with the requirement to maintain sufficient capacity and also comply with federal EPA requirements. EPA rules issued in April 2024 make the construction of many new power plants much more difficult and expensive and heavily restrict emissions from existing coal generators [193]. Principally:

1. Existing coal plants must sequester 90% of their carbon (a still relatively unproven technology) or close entirely by 2039
2. New gas plants must operate at less than 40% capacity factor or sequester 90% of their carbon emissions

Should these rules withstand court challenges, and if load growth continues as the IEA predicts, utilities may be forced to build new baseload generation resources. If locally available renewable power and storage assets are unable to meet the capacity needs that arise, utilities would have severely limited pathways that allow them to meet their obligation to serve, which would likely drive them toward nuclear reactors.

When utilities or other owners are looking for new firm generation resources in Indiana or elsewhere in the U.S., SMRs may be able to offer a cost competitive solution given the current incentives. However, care must be taken to ensure the risk of cost overruns, which are still high, and not to be borne by Indiana ratepayers. Project costs can be expected to be less risky as more SMRs are built if FOAK projects and early subsequent projects are built according to their budget and schedule. As such, Indiana utilities may choose to wait until the risk decreases.

For FOAK projects, the project risks are too high for utility ratepayers to bear alone. By using the ITC, the federal government would cover 50% of all cost overruns. While that mitigates risk, it has not yet spurred utilities into action, implying they will require more risk to be unloaded from their ratepayers for FOAK projects to start. If a utility does choose to build a FOAK reactor, they will likely seek other ways to derisk the project:

- They may seek additional federal funds, such as the Gen III+ SMR grant.
- They may use contract structures that unload the risk onto other, credible parties such as the technology provider or the EPC firm.
- They may further share the risk by working in consortia with other utilities, projects, or private off takers.

3.2.2.2. Indiana Electric Cooperatives (Co-ops)

Indiana's electric cooperatives, specifically the generation and transmission co-ops, also have the potential to be owners of nuclear power plants in the state. They, too, face increasing electric loads, often in the form of large requests that represent a large economic development opportunity for their territory, such as a proposal to site a factory in their territory. The Vogtle Reactors, completed in 2023/2024, for example have a roughly 30% ownership stake from Oglethorpe Power Corp, a corporation producing power for Georgia's Electric Membership Corporations [194]. Hoosier Energy, a generation cooperative in Indiana, has a long-term power purchase agreement (PPA) with the Palisades Nuclear Power Plant in Michigan. The nuclear plant will be the first recommissioned power plant in the U.S. and is scheduled to restart by the end of 2025, after a "permanent" closure in 2022 [195]. Most of the power from the Palisades plant is being sold under a long-term PPA to the Michigan r Generation Cooperative (Wolverine Power). However, electric cooperatives are sensitive on behalf of their members (in the case of generation and transmission cooperatives, their distribution cooperative members) to make prudent and low-risk investments and are often risk adverse when it comes to investing in new, unproven technologies like SMRs.

3.2.2.3. Independent Power Producers (IPP)

IPPs are investors that buy and build a plant at risk and make their return by selling the power through PPAs or directly into the wholesale market. This is the model by which most solar and wind capacity additions have been made over the last decade. Private financing is feasible for those technologies because solar and wind production profiles are well understood, solar and wind costs of construction and materials are well known, and the value of solar and wind in the market is well established. Therefore, the finance partner can easily complete their due diligence on a project's cost and profit analysis and then provide the equity financing. Project financers also may require the project to have PPAs negotiated upfront with committed off-takers of the power, but in some cases, they back the project based solely on market analysis and the prospect that the power can be sold to the wholesale markets or through later negotiated PPAs and earn a sufficient return. This type of financing is much more difficult to obtain for a nuclear power plant due to the high risk of cost and schedule overruns and low project experience. IPPs will likely only build new nuclear if they have specific nuclear-related knowledge, a strong PPA with a credible counterparty for nuclear power offtake and most likely other compelling reasons to enter into such an agreement, such as ownership of a nuclear technology company.

3.2.2.4. *Large Power Consumers*

All existing nuclear power plants were built, owned, and operated by electric utilities, and none were financed by power end-users or off-takers. Recently, however, due to an alignment between the needs of large power consumers, the nature of nuclear power, and the smaller size of SMRs, corporate off-takers have begun to invest in nuclear power plants for direct consumption or purchase under a PPA. Corporate off-takers, specifically big tech companies have been among the largest buyers of renewable energy in the world, typically by signing long term PPAs with independent power producers (See Figure 44)

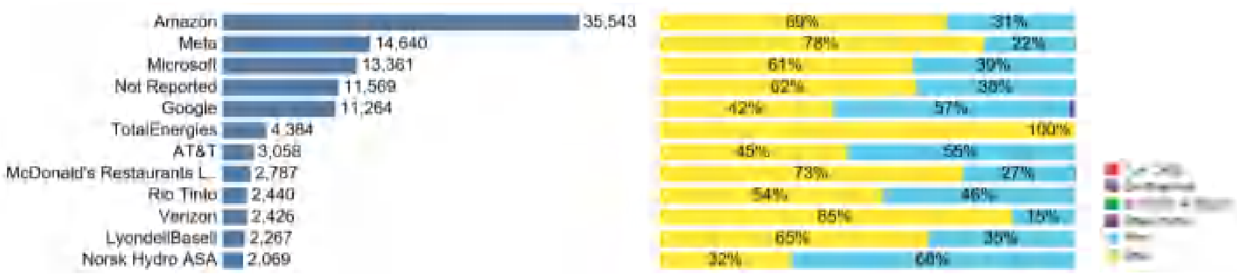

Figure 44. Top PPA Off-takers by Capacity (MW), broken down by Generation Technology [140]

Today, tech companies are increasingly facing difficulties building facilities such as data centers because of their high single-point load and 24/7 power requirements. Where a typical data center built between 2019-2023 would require 45 MWe, a data center built in 2024 requires 60-90 MWe and large data centers are requesting 300+ MWe for their largest data center campuses [196]. The IEA estimates the data center load in the U.S. will grow from 4.5% of total load in 2023 to 6% of total load in 2026 [197]. However, these projections are often considered with skepticism by utilities who are wary of overbuilding with insufficient evidence and unnecessarily increasing rates for their customers. In May, Duke Energy and AEP Ohio created new rules that change the way that new data centers are charged when they request service from their utility. The AEP Ohio tariff, for example, requires new data centers to commit to paying up to 90% of their predicted consumption for 10 years, regardless of their actual consumption [198]. Duke Energy's new supply contracts will include a similar concept with a "minimum take" clause, though the exact percentage required is not specified generally [199]. For a utility, this is meant to protect them from overbuilding at the request of a data center. However, for a data center, this may drive them toward behind-the-meter or privately negotiated PPAs. A privately negotiated PPA would require a similar long-term commitment but may come with more control over the technology selected or the project timeline.

For artificial intelligence investments, in particular, timeliness is critical, and waiting for a utility to go through the process of building a new power plant may mean the tech company will lose out on its original business opportunity. Because nuclear power plants have large generation capacity, low-carbon emissions, 24/7 power, and can be sited on relatively little land compared to solar and wind, they are uniquely suited to meet the needs of data centers and AI training and operations centers. Because technology companies have the capital and long-term planning horizon that will allow them to finance a nuclear power plant on their own, they are uniquely capable of financing nuclear power plants. Further, while data centers are being increasingly re-evaluated for their economic impact on the state in which they are located, a co-located nuclear power plant has the possibility to improve a data center's economic contribution to the state because of the nuclear power plant's positive economic impact. Nuclear power, however, is not a particularly fast turnaround investment, and if these companies do pursue contracts for nuclear power, schedule risk will be mitigated to the extent possible.

This trend has been observed in five recent announcements:

1. Reactor Unit 1 at Three Mile Island, which closed in 2019, will be restarted by its owner Constellation Energy and deliver all its power to Microsoft under a 20-year PPA. [200]
2. Standard Power, a nuclear developer, partially financed the relicensing of Beaver Valley Nuclear Power Plant in Pennsylvania with an offtake agreement from a data center that will be sited nearby.
3. Standard Power recently announced two SMR projects (PA and OH) both of which primarily serve on-site data center loads.
4. Talen Energy sold its 960 MWe data center campus, located at the Susquehanna Steam Electric Station, a nuclear power plant in Pennsylvania, to AWS in March of 2024 [201]
5. In April 2024, three major electricity consumers, Nucor, Microsoft, and Google, released a joint RFP seeking proposals for 24/7 carbon-free power, including nuclear, alongside technologies like geothermal and solar storage.

Indiana has had four major data center announcements in 2024, including a new $11 billion AWS facility in South Bend [202]. Working with data centers owners and operators may be a path for Indiana to be a leader in SMR deployment, without putting the financial risk onto the taxpayers or ratepayers in the state.

3.3 Economic Impacts of SMRs

3.3.1. Construction Phase

There are few resources with detailed analyses of the jobs created and the economic impact expected during the construction phase due to no SMRs having been built. The analysis for the UAMPS project in Idaho, which was cancelled in 2023, represents the most detailed analysis of a construction phase economic impact study for an SMR in the U.S. It is worth noting, however, that the size of the power plant (685 MWe) and some specifics of the NuScale technology (e.g., underground pool installation, multi-module concept etc.), as well as the many assumptions that were based upon the site's local economic factors, mean that the economic impact study may not be directly translatable to any SMR in Indiana.

At the time the economic impact study was conducted, the total UAMPS cost was estimated to be $2,469 million, excluding owners' costs and the total net capacity was planned to be 685 MWe. While the electrical capacity of the UAMPS project is much greater than a typical SMR project, the cost of $2,469 million is a realistic representation of a 300 MWe project, with an OCC of roughly $6,200/kW, the DOE's estimate for a "best practices FOAK" OCC. If one assumes that the project costs scale linearly when the higher OCC is used, this economic impact study is a good approximation of the impact of a 300 MWe project at $6,200/kW OCC.

The study used assumptions inherent in IMPLAN, an economic modelling tool that calculates the economic impact of certain activities using known input/output relationships. The study adjusted the model's inputs to reflect specifics known to the NuScale technology build requirements and the economy of Idaho [203]. The economic impact study regionalized the cost categories to input them into the economic impact model, as shown in Table 11. Of the $2,469 million capital costs, about 57% were expected to be spent in Idaho.[5]

The construction was estimated to take four years to complete, and it was projected to add 2,000 jobs (on average) and a total of $516 million in total economic output per year (on average) throughout the four years, as shown in Table 12.

In addition to the $516 million in economic output, the construction fiscal impacts were estimated to total $9 million in new state and local tax revenue per year during the construction phase. This figure, however, is heavily dependent upon the local taxes and regulations for that site and is not easily transferrable to an unknown site in Indiana. Fiscal impacts of a new power plant construction vary even from site to site within Indiana and will be better analyzed once the project-specific information is better known.

[5] Note that $131MM of owners' costs that were excluded from the capital costs are included in the regional costs since they were expected to have been expended locally.

Table 11. Cost of NuScale UAMPS Power Plant Regionalized to Idaho [203]

Cost Category Description	NuScale SMR Cost ($ Millions)	Expenditures Sourced or Originating within Idaho
Capitalized Direct Costs	$1,806	$745
Structures and Improvements	$612	$422
Reactor Plant Equipment	$869	$235
Turbine Plant equipment	$196	$53
Electric Plant equipment	$35	$9
Heat Rejection System	$63	$17
Misc Plant Equipment	$30	$8
Capitalized Indirect Costs		
Design Services at Home office	$131	$0
Field Construction Management	$61	$61
Field Construction Supervision	$247	$247
Field Indirect Costs	$225	$225
Owners Costs	$0	$131
Total	**$2,469**	**$1,408**

Table 12. Annual Economic Impacts of Construction of the UAMPS Power Plant

	Employment (jobs)	Labor Income ($ Millions)	Value Added ($ Millions)	**Total Output** ($ Millions)
Direct Effect	2,000	$111.4	$201.1	**$352.0**
Indirect Effect	521	$22.4	$35.0	**$71.4**
Induced	834	$27.2	$47.3	**$92.9**
Total	3,355	$161	$283	**$516**

3.3.2. Operational Phase

INL published a guidebook in 2024 that evaluated 300 possible scenarios for coal-to-nuclear transitions to estimate the ongoing economic impact of the new nuclear power plant on the regional economy during the operational phase [141]. They estimated a range of nuclear generator sizes and a range of community sizes to get a matrix of economic impacts across various scenarios. The study used economic data from 30 different counties across the U.S. where CPPs are currently operating and used the input-output model in IMPLAN to calculate the economic impacts. The study showed the average economic impact for each size of reactor and each size of community for each of the 300 scenarios. For a 300 MWe SMR, the INL report estimates 100 direct jobs, and 352 total jobs would be created. It further estimates that the total economic output of the community would increase by $212 Million per year.

Overall, a nuclear plant typically creates twice the number of local jobs compared to a similarly sized coal plant with nuclear plant workers earning 18% more than coal plant workers on average [141]. A nuclear power plant's revenue is also assumed to be about 78% higher than a coal plant because nuclear plants have a higher capacity factor. In total, the economic output of a 300-500

MWe nuclear power plant was typically two times higher than the economic output of a coal plant of the same size in communities with more than 90,000 people.

The expected economic impacts for a 300 MWe and 500 MWe nuclear power plant in a community of 200,000 people or more are shown in Table 13. Although nuclear power plants are typically located in small communities to comply with federal regulations, the county size of 200,000+ is shown to approximate the economic impacts to the larger region (as opposed to just the local community), as that is more important for state considerations. It is worth considering that many of the coal sites analyzed in the site analysis are located along the Wabash or Ohio rivers that form borders with Illinois and Kentucky, respectively, and some of the regional economic impacts for those sites may go to those neighboring states.

Table 13. Nuclear Power Plant Operations Annual Economic Impact for Communities of 200,000+ [141]

		Employment (jobs)	Labor Income ($ Millions)	Value Added ($ Millions)	Total Output ($ Millions)
300 MWe plant	Direct Effect	100	$16.1	$53.5	$136.7
	Indirect Effect	161	$15.3	$30.9	$60.0
	Induced	91	$5.1	$9.2	$15.8
	Total	**352**	**$36.5**	**$93.7**	**$212.5**
500 MWe Plant	Direct Effect	140	$22.6	$84.9	$227.8
	Indirect Effect	269	$25.5	$51.6	$100.0
	Induced	139	$7.9	$14.1	$24.2
	Total	**548**	**$55.9**	**$150.6**	**$352.0**

One key input to the economic impact analysis is the assumptions about the direct and indirect jobs that would be created at a new nuclear power plant. The numbers used in the INL study were based on estimates from NuScale and TerraPower, primarily, each of which has estimated their technology's expected direct operational employee count. Other measures of direct employment requirements, based on historical data for nuclear power plants are higher, as shown in Table 14. The SMR technologies expect to need fewer employees and employees per MWe than traditional reactors due to their focus on design simplification and improved plant monitoring.

The total impact on local employment varies between estimates as well. Lightcast, an economic impact tool that measures the effects statewide and includes the effects of tax revenue increases, had a much larger jobs multiplier than the INL study. The jobs multipliers for NPP and fossil fuel power plants throughout the Midwest using the Lightcast model are shown in Figure 45. The jobs multiplier indicates how many total jobs (direct, indirect and induced jobs) would be created for each direct job created at a nuclear power plant. The Lightcast model only shows a nuclear jobs multiplier for states that have existing operating nuclear power plants, so Indiana did not have a known multiplier. However, it is evident from Figure 45 that the jobs multiplier for a NPP is similar to the job multiplier for a fossil fuel power plant in each state. The multiplier found in the

INL study which used IMPLANs economic model was 3.5 for a 300 MWe plant. The multiplier for the Lightcast model is larger (5.5-8.5, in various nearby states) and would be expected to be near 5.5 in Indiana, in line with Indiana's fossil fuel power plant multiplier. This would put the total employment impact of a new 300 MWe power plant at around 550 employees.

Table 14. Estimates for Direct Employment Requirements of SMRs

Source	Description	MWe (net)	Direct Jobs	Jobs/GW
DOE Liftoff Report [176]	Existing Fleet (GW-scale included)	Various		500
	SMR estimate	Various		237
INL 2024 [141]	SMR estimate	300	100	333
	SMR estimate	500	140	280
Univ. Idaho, 2019 Economic Impact [203]	12-pack of NuScale's US600	685	360	526
NuScale, 2021 Whitepaper [204]	12-pack of NuScale's Voygr Product	884	270	305
TerraPower, 2022 Press release [205]	1 - 345 MWe Natrium Reactor	345	250	725
Depart. Of Energy, AP-1000 [206]	Additional Jobs for Vogtle 3&4	2200	800	364
IEA Historical Data, Small Reactors (2001) [207]	A 1-unit plant with a 2-loop LWR	535	359	671
	A 1-unit plant with a 2-loop LWR	517	204	395
	A 2-unit plant with 2X 2-loop LWR	1048	479	457
	A 2-unit plant with 2X 2-loop LWR	1186	567	478
IEA Expected Employment (2001) [207]	AP-600 (not built)	625	282	451

These national estimates using generalized prices and employment estimates are a good start for understanding the potential economic impacts to Indiana for a new SMR. A full economic impact analysis for the operation of a new SMR in Indiana will be improved vastly once a specific site and technology are selected and the costs and jobs figures can be more carefully analyzed by working closely with that technology vendor.

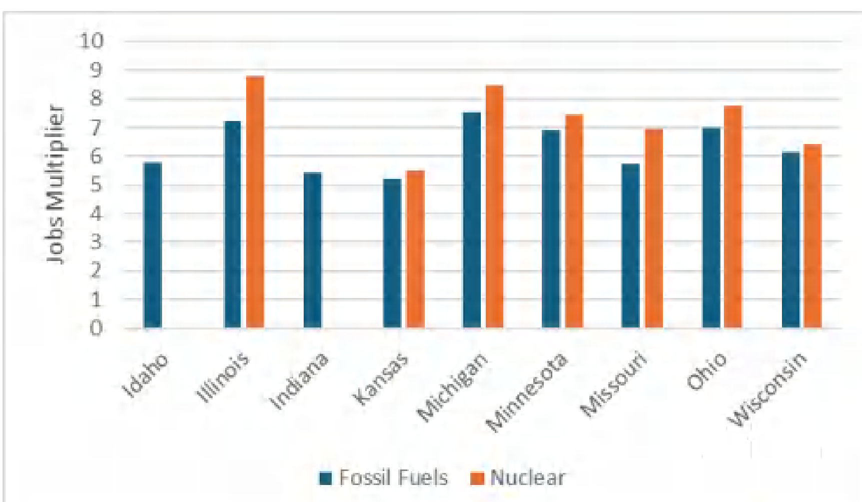

Figure 45. Jobs Multipliers for NPP and Fossil Fuel Plants in Midwest

3.3.3. Unaccounted Economic Impacts

Economic impacts measure the direct, indirect, and induced effects of the power plants. It treats the power plant much like a manufacturing facility. For example, examining the local goods and services that the plant and its employees will require and the goods and services that will be induced from that economic activity, and so on. Power plants are not typically seen as important in driving power consumption within the power plant's community because power plants connect to the wider transmission grid, and the supply and demand dynamics on the transmission grid are separate from the local supply and demand. However, it is possible that load growth throughout the grid will exceed the build-up of new capacity in general in which case behind-the-meter generation will be more common; in other words, the nuclear power plant may drive economic development around the local delivery of its output, electricity. As the supply of generation tightens nationwide, large energy consumers, like large manufacturing plants, may be choosing their site based on the grid that has the capacity to support them with local generation. If a utility cannot offer sufficient capacity for a new load, it may result in the loss of a new and seemingly unrelated economic development opportunity in that community.

3.3.4. Supply Chain Opportunities

While there are financial risks to being an early adopter of SMRs, the benefits of moving early presents the opportunity to have a role in developing the SMR supply chain ecosystem. SMRs are a new product, and as such, there are opportunities for suppliers to establish themselves throughout the supply chain. Early adopters may be able to explicitly negotiate with a technology vendor to site factories and other facilities within their borders, or a state may be able to craft the workforce development and supply chain programs in concert with the project to incentivize the new high-value and sustainable business opportunities to locate within the state. As SMR's market share grows, suppliers of specialized equipment, components, materials or services that have been established during early projects may be called upon in later projects.

In building a new SMR, many categories of expenditures are nearly all expended locally, including buildings, structures, sitework, and field supervision (see Table 11, for the expected local expenditures of the NuScale Project in Idaho). While these represent the largest portion of the economic impact during the construction phase, they would likely not be sustainable opportunities associated with being an early adopter. For example, when another SMR is built in another state, those elements would once again be sourced locally or regionally from that location. The largest elements of the construction economic impact that is mostly not locally sourced, and therefore the most likely to be a sustainable business opportunity, is reactor plant equipment, which for the NuScale project economic analysis, represented 48% of the total costs (at the time the economic impact analysis was conducted, see Table 11). Of those costs, only 27% were expected to be sourced locally within Idaho. Reactor plant equipment is also the most novel element of the SMR design, therefore representing the largest opportunity for early movers. If Indiana is an early mover in adopting SMRs, the state should seek opportunities to leverage their position to maximize the sustainable business opportunities in the reactor plant equipment category of costs, as either a supplier to those providers or a manufacturing site for assemblies and/or sub-assemblies of that equipment, as well as reactor components, which currently is non-existent in the U.S. for commercial nuclear power reactors.

That said, there is already one major nuclear manufacturing facility in Indiana, BWXT, which is located in Mount Vernon, IN. BWXT makes the large components of naval nuclear reactors including the reactor vessels and parts of the steam generator. They also complete the final assembly of the naval nuclear reactors on site and ship them out to the customer.

BWXT recently conducted a study to determine the feasibility of manufacturing the GE-Hitachi BWRX-300 SMR reactor vessels in their Indiana plant. They determined that manufacturing reactor vessels of that size would require them to build an entirely new 120,000 ft^2 facility due to the large size of the BWRX-300 vessels. The new facility would still benefit from much of the existing infrastructure, human resources, supply chain, and transportation facilities at their existing plant. They roughly estimated the cost of that facility at $80 million. In order to justify such a facility, they would have to have several orders on hand and a clear line of sight to 6-8 orders per year over the long term. They would also need orders with at least three years of lead time since building the facility and securing the supplies could take two years. While this study was specific to the final assembly of the GE-Hitachi BWRX-300 SMR, they speculate that a reactor vessel manufacturing facility of this size would be capable of making reactor vessels for other SMR designs as well, if the other designs were known upfront and the facility could be designed accordingly.

In order to manufacture nuclear components or final assemblies, manufacturers must obtain ASME certification. There are 79 companies throughout the country with one or more of these certifications though none is headquartered in Indiana. Besides BWXT, there are several other manufacturers with one of the ASME nuclear certifications that are headquartered elsewhere that have plants in Indiana, though the Indiana plants, in many cases, are not manufacturing the nuclear components. There are also manufacturing plants headquartered in Indiana that are capable of making nuclear reactor components but haven’t had a reason to obtain the ASME certification. To secure some of this economic impact and the possibility of Indiana becoming home to the go-to manufacturers for new SMR designs, the state may be able to create a broad-based program or incentive that drives component manufacturing in-state where possible and when the opportunity is significant and justified. This will require deep engagement with the technology provider, or a short-list of possible technology providers, as the project takes shape.

If the path to commercialization and liftoff proposed by the DOE comes to fruition, the U.S. will be deploying 13 GW/year from 2040 onward. If the NOAK costs are $3,600/kW, as the DOE predicts, the entire industry will be worth about $47 billion per year. [176]. If SMRs hold 30% of that market share and the reactor plant equipment category is 48% of project costs, the reactor plant equipment industry for SMRs could be worth $3.8 billion per year, a sizable opportunity to pursue.

The second largest non-local opportunity is the turbine plant equipment, which for the NuScale Project represented 11% of the total costs (at the time the Economic Impact analysis was conducted, see Table 11). Like the reactor plant equipment, the turbine equipment will not usually be sourced locally in an SMR project. The turbine plant equipment category, however, would be more difficult to build new sustainable business opportunities for Indiana manufacturers. The turbines used in nuclear reactors are similar to turbines used in other power plants, and this supply chain is better established and more difficult to enter. However, when it comes to existing manufacturing, Indiana has a leg up generally. Indiana has the fourth largest manufacturing output of any state at $289.5 billion, representing roughly 4.5% of all manufacturing. While Indiana may not be able to leverage their status as an early mover to negotiate new business opportunities in the turbine equipment side, the build will likely have an outsized in-state effect due to Indiana’s importance to U.S. manufacturing generally.

CHAPTER 4. POTENTIAL SITE EVALUATION AND CASE STUDIES

4.1 Site Analysis

A site analysis was performed on coal plant sites in Indiana for purpose of converting one to an SMR. Various factors such as population density, seismic activity, and retirement status were considered when narrowing down a potential site, and remaining sites were then prioritized to find sites hypothetically ideal for SMR development.

In this chapter, we explore and evaluate potential sites for the deployment of small modular reactors (SMRs) in Indiana, focusing on key criteria such as geographic suitability, infrastructure availability, environmental considerations, and regulatory requirements. By examining several case studies, this section highlights how various locations can be assessed for their viability in supporting SMR technology, ensuring both safety and economic feasibility. The insights from these analyses will guide the identification of optimal sites that align with Indiana's energy needs and broader development goals.

4.1.1. Site Selection

Due to the many benefits of coal-to-nuclear, all existing coal plants and coal plants retired within the last 10 years were included in the site analysis [208]. However, in order to include sites throughout the state, three suitable greenfield sites, and two other energy-related sites were added to the analysis as shown in Figure 46.

1. Greenfield sites selected for geographic diversity: The first greenfield site that was included in Cass County was selected because it is part of a DOE-designated energy community and, therefore, would be eligible for the 10% adder to the ITC, an important consideration in the cost of a nuclear power plant. The other two greenfield sites in North East Indiana are not in energy communities; none exist in that part of the state.
2. Other energy sites included: The abandoned Marble Hill nuclear site in Jefferson County and a gas plant that was retired in 2018 in Wabash County were also included in the analysis. This further expanded the geographic diversity of the sample.

Table 15. Generators and sites

	Operational Coal Plants	Retired Coal Plants	Greenfield Sites	Other Energy Sites
Generators	33	35		5
Sites	12	11 (4)*	3	2

* Four coal plants have some retired units and some operational units. For this study, they were classified as operational.

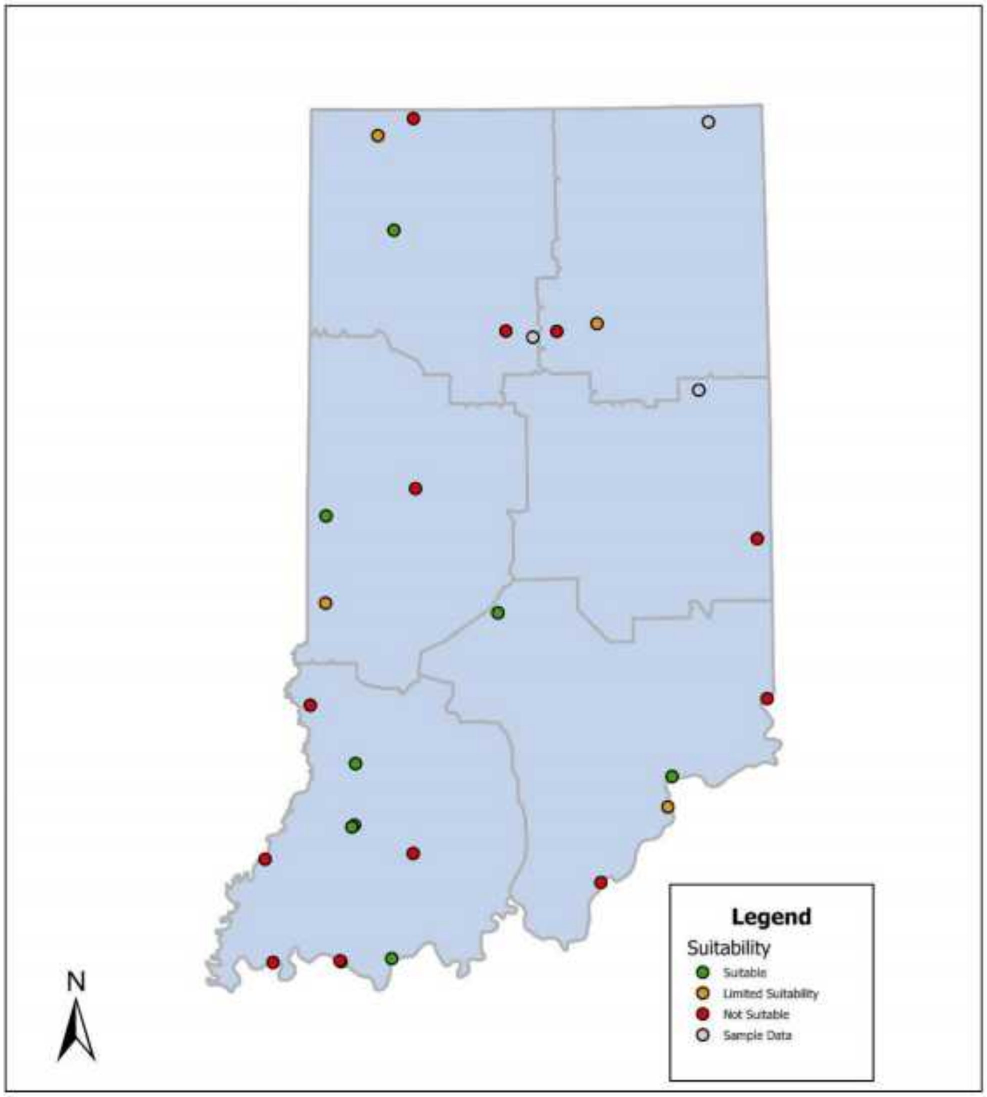

Figure 46. Sites Evaluated for Nuclear Suitability throughout Indiana. Here ‘*sample data*’ denotes greenfield sites selected for geographic diversity.

4.1.2. Analysis

The DOE’s publicly available tool STAND (Siting Tool for Advanced Nuclear Development) was used to conduct this siting analysis. STAND draws heavily from the Oak Ridge National Labs Siting Analysis tool for Power Generation Expansion (OR-SAGE) and from the EPRI nuclear power plant siting guidelines [209], two well-established siting resources. STAND incorporates a variety of screening factors, including geographical and technical factors, public sentiment, and political and economic factors that help determine how the site will perform on the 50 site criteria used by the NRC. Two factors missing from the STAND tool, but that would possibly lead to the decreased prioritization of a site if added into this siting analysis:

1. The applicability of the 10% adder in the ITC for being located in an energy community

2. The existence of a power plant now or in the past ten years with at least 200 MWe of capacity.

Together, the factors were used to eliminate some sites as unfeasible (Table 16, red) and deprioritize sites as unlikely for early development (Table 16, yellow).

4.1.2.1. Site Screening

Three factors were used to screen out sites that are not likely to be developed because of their geography. Sites that were eliminated by one or more of these screening criteria are highlighted in red in Table 16.

1. **High Population:** For population density near a large LWR station, the U.S. NRC RG 4.7 indicates "… a (nuclear) reactor should preferably be located such that … the population density, including weighted transient population, averaged over any radial distance out to 20 miles, does not exceed 500 persons per square mile (ppsm)." Since this work focuses on the deployment of small modular reactors that have smaller source terms and EPZs than the large LWR, the population density was evaluated within a 4-mile radius of the site [210]. The cap at 4 miles is based on vendors demonstrating small source terms that meet the U.S. NRC's 10 CFR 100 dose requirements at or near the NPP exclusion area boundary [211]. There are two general methodologies for verifying that the population density is less than 500 ppsm, which are listed below. For this analysis, both methods were used, and failing either test led to the designation of "too populated."
   a. There should be no population centers of 25,000 or more within 4 miles of the site.
   b. There should be no 100 m by 100 m cells with greater than 500 ppsm within 2 miles of the site.

   Six sites were screened out as too populated by one or both of these measures. In reality, SMRs may have a smaller radius than 4 miles depending upon the size of each reactor and the determination of the NRC. Still, those sites are not likely to be prioritized for early development due to the nearby population centers and the regulatory uncertainty/risk.

1. **High Seismic:** The 2002 EPRI siting guide suggests that large LWR technologies should be located on sites with a safe-shutdown earthquake (SSE) peak ground acceleration of less than 0.3g. Some SMRs are designed to withstand up to 0.5g of ground acceleration, and STAND can be adjusted to screen accordingly. For this initial screening, to be conservative, the level was left at 0.3g. Two coal plants in the southwestern part of the state were found to exceed that level and were eliminated as potential sites.
2. **100-yr Floodplain:** STAND identifies if the site is in the 100-year floodplain, which applied to three of the coal sites in this study. The NRC does not prohibit nuclear development on a 100-year floodplain though it will likely make construction and permitting more difficult. It may also make permitting with the local or state authorities more difficult.

4.1.2.2. Site prioritization

Certain criteria make a site less likely to be prioritized for early nuclear development. Sites that flagged one or more of these deprioritization criteria were highlighted in yellow in Table 16.

1. **Hazardous Facilities:** STAND identifies any hazards and protected sites within a 5-mile radius of the site that might be impacted by the site or present a hazard to the nuclear plant. Any of these have the potential to make permitting difficult, but given the prevalence of such sites, they are nearly impossible to completely avoid. Nearly all sites were near at least 1-3 hazardous facilities. Sites with 4-6 nearby hazardous sites were deemed non-priorities. Only one site had more than six hazardous facilities nearby (8). However, that site was already screened out as a high-population area.
2. **ITC Adder:** Sites located in DOE designated energy communities would qualify for an additional 10% adder to their ITC (see 3.1.3). This adder has a significant economic impact and unqualified sites are unlikely to be prioritized. Nearly all of the existing and former coal sites would qualify for this adder, and those that don't qualify now would most likely qualify once the coal plant retired since that is a determining factor in designating energy communities. There is one additional energy community in north central Indiana that does not have an operating or recently retired coal plant, and a site in that region was included in the analysis (Sample 1). The remaining two sites in northeastern Indiana that were included for geographic diversity, are not in energy communities and, therefore, would miss out on the 10% adder for the ITC.
3. **Coal-to-Nuclear Economic Benefits:** The coal sites that hosted coal plants with a small electrical capacity, e.g., less than 200 MW, would not benefit from many of the coal-to-nuclear economic savings outlined in Appendix A. Therefore, these sites would not be as likely to be prioritized and are designated as "small." The sites selected for geographical diversity that are not coal plant sites would also not be prioritized since they would not benefit from those economic advantages either, those designated as "greenfield."
4. **Heat Sink Availability:** The STAND tool also identifies whether a site has suitable water resources for cooling a nuclear power plant, with 50,000 gallons per minute being the suggested streamflow for a 300 MWe SMR. The tool flags any site without sufficient streamflow within a 20-mile radius, and they are designated in Table 16 as "low water." This affected two sites: one that had been eliminated as too populated and another that had already been deprioritized as a greenfield site. Some SMR technologies would not be affected by this criterion because they depend on dry cooling.

4.1.2.3. Other important criteria that had no impact on this site analysis

There were other aspects of the tool that did not have a substantial impact on the outcome because they weren't true for any of the sites analyzed or because they were the same across all the sites analyzed.

1. STAND did not find any of the selected sites to be on protected lands.
2. None of the sites had a landslide hazard.

3. None of the sites were located within 200 miles of a fault line.
4. None of the sites were found to be on a slope of greater than 12%.
5. While the STAND tool does have highly localized public sentiment data from a national nuclear survey, the variation throughout the state was too small to impact the nuclear site's suitability scores substantially.
6. STAND includes various screens that only vary from state to state and, therefore, could not impact this analysis since all of the sites were located in Indiana. These factors include state labor rates, state policies (such as moratoriums or legislature approval requirements, Climate Pollution Reductions Grant (CPRG) Program requirements, etc.), electricity market regulation, state electricity prices, and state electricity imports.

4.1.3. Results

Eight of the existing and former coal sites are suitable for SMR development, including six existing coal plant sites and two recently retired coal plant site (green boxes in Table 16). An additional eight sites pass the highest level of technical screening but have one or more factors that would make them unlikely to be prioritized (yellow boxes in Table 16)

4.1.4. Further Analysis

The sites were screened using the aforementioned technical, geological, and economic screening factors, which inform site selection at the highest level. True site selection would require engagement with the community, the existing site (and plant) owners, and the relevant government stakeholders. Also, the technical screening would be further refined before moving forward with site selection, including conducting a more detailed technical analysis of the geology, meteorology, and availability of cooling water to be used as a heat sink (if required).

Table 16. Site List and Screening or Prioritization Factors at Play

Name	Why Included	Capacity	Owner (Former owner)	County	Suitability for SMR
AES Petersburg	Existing Coal	2100 MWe	AES Indiana	Pike	Good
Cayuga	Existing Coal	1060 MWe	Duke	Vermillion	Good
Clifty Creek	Existing Coal	1300 MWe	Indiana-Kentucky Electric Corp	Jefferson	Good
Edwardsport	Existing Coal	800 MWe	Duke	Knox	Good
F B Cully	Existing Coal	370 MWe	So. Indiana G&E	Warrik	Too Populated (b)
Gibson	Existing Coal	3340 MWe	Duke	Gibson	High Seismic
Merom	Existing Coal	1080 MWe	Hallador	Sullivan	100 yr Flood
Michigan City	Existing Coal	540 MWe	NIPSCO	LaPorte	Too populated (a)
R M Schahfer	Existing Coal	1960 MWe	NIPSCO	Jasper	Good
Rockport	Existing Coal	2600 MWe	Indiana Michigan	Spencer	Good
Warrick	Existing Coal	820 MWe	AGC Div. of APGI	Warrick	Too Populated (b)
Whitewater Valley	Existing Coal	90 MWe	City of Richmond	Wayne	Too populated (a), small
AB Brown	Recent Retirement	530 MWe	So. Indiana G&E	Posey	High Seismic
Bailly	Recent Retirement	600 MWe	NIPSCO	Porter	4 Haz Fac.
Crawfordsville	Recent Retirement	23 MWe	Crawfordsville Energy	Montgomery	100 yr Flood
Eagle Valley (IN)	Recent Retirement	300 MWe	Indianapolis Power & Light (IPL)	Morgan	Good
Frank E Ratts	Recent Retirement	233 MWe	Hoosier	Pike	Good
Jasper	Recent Retirement	14 MWe	City of Jasper	Dubois	Small, Too Populated (b)
Logansport	Recent Retirement	61 MWe	Logansport	Cass	Small, Too Populated (b)
Peru (IN)	Recent Retirement	34 MWe	Peru	Miami	100 yr Flood, small
R Gallagher	Recent Retirement	600 MWe	Duke	Floyd	Too Populated (a)
Tanners Creek	Recent Retirement	1000 MWe	Indiana Michigan	Dearborn	6 Haz. Fac.
Wabash River	Recent Retirement	860 MWe	Duke	Vigo	5 Haz. Fac.
Miami Wabash (Gas)	Recent Retirement (Gas)	85 MWe	Duke	Wabash	Small, No ITC adder
Marble Hill	Abandoned Nuclear Site	None	Pub Serv. Co Indiana	Jefferson	No ITC adder
Sample 1	Geographic Diversity	None	N/A	Cass	Greenfield, 4 Haz Fac.
Sample 2	Geographic Diversity	None	N/A	Steuben	Greenfield, No ITC adder
Sample 3	Geographic Diversity	None	N/A	Adams	Greenfield, No ITC adder

Legends for colors in the table

Suitable per screening criteria
Did not pass major screening criteria (high seismic, high population or 100 yr flood plain)
Deprioritized sites

4.2 Use-case Scenarios

There are several potential instances in which an SMR design may be useful to the state of Indiana depending on key metrics including operational reliability, affordability, and degree of decarbonization.

4.2.1. Utility-Based Generating Facility

In this use-case scenario, a retired coal plant is being considered for conversion into an SMR. Based on the previous analysis performed in Section 4.1.3, the Frank E Ratts was identified as a recently retired coal plant with the potential to be configured into an SMR, as shown in Table 16.

This means the site was found to have no population centers of 25,000 or more within four miles of the site, an SSE of less than 0.3g, and not located within the 100-year floodplain. It was prioritized due to a relatively low number of hazardous facilities nearby, its qualification for a 10% adder to its ITC, its size being large enough to benefit from the coal-to-nuclear benefits outlined in A, and the presence of a suitable heat sink within a 20-mile radius.

To save costs, the SMR would be built utilizing as much of the existing infrastructure as possible. The Frank E Ratts former coal site was rated at 233 MWe capacity. Most SMR designs operate near this range, but for the purpose of this use-case scenario, three modules of the VOGYR design were chosen. Each module is rated at a 77 MWe capacity, shown in Table 4 allowing three to reach a maximum capacity of 231 MWe. It is possible that the region may have developed since the plant was shut down; however, since SMR designs, including the VOYGR, are modular, more modules can be added or removed as power requirements change.

Metrics:

- Reliability of operation – The capacity factor of nuclear (92.7%) is larger than other types of energy, such as natural gas (54.4%), coal (49.3%), and solar (24.6%). [212] The VOYGR model has a capacity factor of 95%. [213]. This makes an SMR a very reliable source of energy, as it operates at maximum power nearly twice as often as the previously occupying coal plant.
- Affordability – A more in-depth analysis of the costs of developing an SMR can be found in CHAPTER 3. Nuclear in general tends to have a high capital cost, while a low operational cost. SMRs are smaller and can be built in factories, which may reduce cost compared to traditional nuclear. Contrarily, the process of licensing an SMR design is the same as a large reactor, making the licensing process a larger expense compared to the power.
- Decarbonization –SMR designs, like other forms of green energy, do not produce carbon during operation. Since the design is replacing an existing coal plant, a major producer of carbon, this would be a step forward in decarbonization efforts.

4.2.2. On-site Power Generation for Data Center

In this use-case scenario, a data center is considering developing an on-site power generation facility. Indiana has 38 data centers located throughout the state and is looking to construct more in the upcoming years [214]. Data centers typically consume large amounts of power from the local power grid to run and cool their servers. However, onsite power can provide stability and consistency to the day-to-day operations, allowing the data center to remain operable for longer. In this use-case scenario, a 50 MWe data center is looking to construct on-site power generation and is considering constructing an SMR to meet their needs. The center is also considering upgrading to 100 MWe to take advantage of the recent AI boom.

A singular module of the VOGYR design was chosen, rated at a 77 MWe capacity, shown in Table 4. This exceeds their initial power capacity, allowing for a potential initial expansion of the facility. As the data center looks to expand to accommodate new technologies, more modules could be built on the existing infrastructure. This allows for easy expansion.

Metrics:

- Reliability of operation – Data centers, especially ones utilized for artificial intelligence, require consistent power. Due to the infrequency of SMR refueling, an SMR would provide adequate, stable power for both current and new data centers.
- Affordability – A more in-depth analysis on the costs of developing an SMR can be found in CHAPTER 3.
- Decarbonization – The need for data centers is growing quickly, and a rising concern amongst the public and relevant governing bodies is this growing demand for power will impact green energy targets and decarbonization goals. An SMR is capable of providing the required power consistently while maintaining green energy initiatives.

4.2.3. On-site Power Generation for Manufacturing Plant

In this use-case scenario, a manufacturing plant is considering developing an on-site power generation facility. In addition to on-site power generation, the manufacturing plant wants to utilize cogeneration, concurrently producing process heat to be used in the manufacturing process. This relies on receiving both electricity and useful thermal energy from a single source [215]. Since the manufacturing plant needs an outlet temperature of at least 700° C, they need a power source capable of producing a large amount of heat while also meeting the facilities' electricity demands. As shown in Table 5, there are several HTGR SMR designs capable of producing the necessary outlet temperature required for operation. For this use-case scenario, an Xe-100 was selected. The Xe-100 is capable of producing 80 MWe of electricity, with an outlet temperature of 750° C.

Metrics:

- Reliability of operation - Since the process heat is vital to the manufacturing process, the heating system needs to deliver a reliable supply of energy while being operable for months to years without interruption. The previously mentioned capacity factor of nuclear allows for a longer, uninterrupted operation. This could potentially be coordinated with other shutdowns that occur to further reduce downtime of the plant.

- Affordability - A more in-depth analysis on the costs of developing an SMR can be found in CHAPTER 3. Specifically for industrial applications that use process heat, selecting a power source capable of producing the process heat required for the manufacturing means the construction of both a power and heating facility do not need to be financed separately.
- Decarbonization – In addition to requiring power for operation, the requirement of process heat poses a unique challenge for decarbonization efforts in the manufacturing industry. Other types of green energy, such as solar or wind, do not produce the heat required for industrial applications. SMRs are uniquely positioned to produce the power and process heat necessary and also help reduce carbon emissions [216].

CHAPTER 5. NUCLEAR WORKFORCE DEVELOPMENT & EMPLOYMENT

To meet the demands of the 21st-century nuclear workforce, it is crucial to have intentional coordination and collaboration between the academic and private sectors. This collaborative effort will need to focus on expanding and specializing in training related to nuclear energy, including areas such as nuclear engineering, nuclear engineering technology, electrical engineering, operator training, advanced manufacturing, chemistry, radiological technicians, data analytics, cybersecurity, and other skilled trades. Additional training in policy, diplomacy, licensing, nuclear law, security, environmental science, finance, construction management, education, and leadership should also be prioritized. In this Chapter, detailed information is outlined on nuclear engineering trends, positions, competency groups, and job families required for the safe operation of an SMR plant and supporting industries, along with information on reskilling for nuclear-powered facilities and workforce and talent development specific to needs in Indiana. Gaps in opportunities and training for curriculum development at Indiana educational entities are also highlighted.

5.1 Trends in Demand for Nuclear Engineering Education

To comprehensively analyze trends in the nuclear industry, an examination of degrees awarded in nuclear engineering was conducted. The trends in degree awards from 2017 to 2022 are illustrated in Figure 47. Notably, data for 2020 is unavailable due to ORSIE's non-collection. From 2017 to 2022, total degrees awarded decreased from 1,071 to 940, a decline of 12.2%. Specifically, bachelor’s degrees fell by 26.7%, while master’s degrees decreased by 2.5%. In contrast, Ph.D. degrees increased by 24.1% during the same period. Significant changes occurred between 2019 and 2021, with all degree levels experiencing substantial declines. Bachelor’s degrees dropped by 28.6%, master’s degrees by 27.8%, and Ph.D. degrees by 9.3%. However, from 2021 to 2022, there was an increase in the number of degrees awarded across all levels [217, 218].

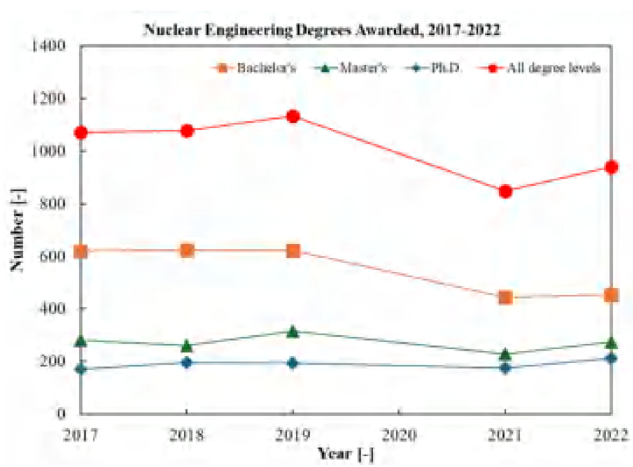

Figure 47. Five-year data for nuclear engineering degrees awarded from 2017 through 2022 [217, 218]

One reason for the drop in degrees around 2020 can be likely be attributed to the Coronavirus. The COVID-19 pandemic caused a nationwide 29% drop in college enrollment and a 22% decrease in high school graduates immediately attending college [219].

5.2 Employment or other post-graduation status

The employment or other post-graduation status is based on the career plans provided by the respondents in the surveys [217, 220, 218]. Based on the literature review, unlike the degree data, the employment or other post-graduation status is not a yearly survey. The 2017, 2020, and 2021 data are not publicly available. Data tables supporting the remaining years of 2018, 2019, and 2022 can be found in Appendix E.

Analysis of career plan data from 2018 to 2022 reveals distinct employment trends among graduates with B.S., M.S., and Ph.D. degrees in nuclear-related fields.

- For B.S. degree graduates, the predominant employment category was active duty in the U.S. military, with reported figures rising from 11.25% in 2018 to 22.54% in 2022. Other significant employment sectors included the nuclear utility sector, DOE contractors, other nuclear-related roles, and federal government positions.
- M.S. degree graduates primarily sought employment in DOE contracting, nuclear utilities, other nuclear-related sectors, federal government roles, and the U.S. military. Collectively, these categories represented over 40% of M.S. graduates' employment plans.
- Ph.D. degree graduates predominantly reported employment with DOE contractors and in other nuclear-related fields, alongside federal government positions. Specifically, the percentage of Ph.D. graduates employed by DOE contractors increased from approximately 21% in 2018 to around 27% in both 2019 and 2022. Over the same period, federal government and other nuclear-related employment for Ph.D. graduates fluctuated between 10% and 16%.

The data presented highlights a notable trend in the increasing importance of military and government-related employment for graduates across all degree levels in the nuclear sector. This trend is particularly relevant as the implementation of small modular reactors (SMRs) gains momentum.

As SMR technology is adopted more widely, the demand for skilled professionals in the nuclear energy sector is anticipated to rise due to the unique operational and regulatory requirements associated with SMRs. Specialized construction and liaising with the state regulatory bodies will require training. Consequently, states like Indiana, who are actively considering the implementation of SMR technology, are poised to become leaders in nuclear training and education. This positioning could enhance Indiana's role in shaping the future workforce for the nuclear industry, thereby contributing to local and national energy goals.

5.2.1. Integrating Industries into the SMR Workforce

The nuclear industry requires highly skilled roles that can be tapped from preexisting sectors with translatable skillsets such as construction, utilities, and automation. During the construction of an NPP, thousands of jobs can be created and last for years before declining and reaching an equilibrium with a mix of permanent personnel and varying degrees of contracted work. A significant job influx is created when construction of the plant begins, all the way through operational phases of the plant with contracted work [221]. Whether it's reinforced concrete works or the large-scale nature of NPP projects that require construction firm expertise [222], these highly skilled roles are vital to the construction phase of a nuclear plant. The U.S. labor movement has historically supported nuclear power to create well-paying jobs in the unionized sector [223], and they should not be overlooked as workforce needs are assessed. Current, previous, and aging utilities workers such as engineering, management, and technicians familiar with utility work in fossil-fueled plants also provide a ready workforce with transferable skills to operate and maintain the plant [224]. Automation is commonplace in manufacturing, a large source of jobs in Indiana, and the integration of automation technologies within nuclear plants shows another avenue for the workforce.

5.2.2. Challenges of Integration

While it was previously shown that there is an existing highly trained workforce ready or near-ready for nuclear power plant integration, the workplace culture in fossil fuel plants is vastly different from that in nuclear plants. The culture within nuclear power plants is governed and shaped by the safety protocols, organizational dynamics, and historical context associated with the industry. The implicit safety culture influences how safety is perceived and acted upon by personnel [225]. Much of this influence can be attributed to the historical nuclear events, which led to changes in safety protocols that increased awareness and behaviors related to the implementation and upholding of safety within the plant [226]. While fossil fuel plants can be characterized by the quick and flexible decision-making needed to meet fluctuating demands, nuclear plants follow carefully structured, governed practices where minor deviations can have significant consequences. The historical context and current practices in nuclear plants create a distinct culture from that of a typical fossil fuel plant, with continuous evaluation and adaptation of safety practices shown through the priority placed on initial and continual retraining as processes evolve. Previous utility workers, while having most of the necessary and relevant skill set required, would need a program that emphasized these culture changes to provide the best workforce for a nuclear SMR landscape.

5.3 Required Workforce Needs (Organizational Structure: Individual and Shared)

Organizational charts for various power plants from across the country were analyzed, focusing on generation capacity, required expertise, and facility locations [227] [228] [229] [230]. Figure 48 illustrates the organizational structure of standalone SMR plants and shared personnel SMR plants within a 100-mile radius. The analysis highlights opportunities and challenges in retraining workers from the fossil fuel industry and skilled trades for the nuclear sector. The model is based on staffing requirements from commercial nuclear power plants in the U.S. and Europe, noting that SMRs account for approximately 20% of existing nuclear generation capacity. Adjustments to the organizational charts reflect necessary personnel, training, and ongoing professional development. SMR plants built to the same specifications can share key positions, such as safety, licensing, and director of engineering, to optimize resources. Additionally, sharing maintenance crews for routine tasks could reduce costs and enhance efficiency, while centralizing operations for engineering roles may further streamline processes and improve cost-effectiveness.

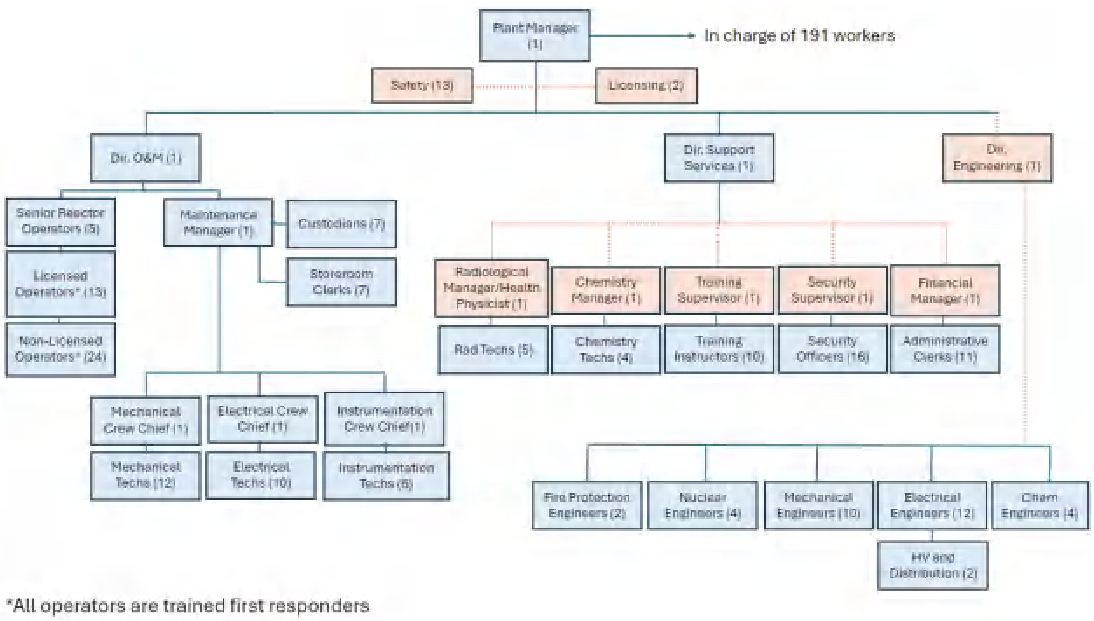

Figure 48. Organizational Chart for Standalone/Shared (Within 100 mi. - Orange) SMR Personnel

Each position outlined above is followed by the recommended number of personnel in that role, specific information regarding each position can be found in Appendix G. These values were chosen by utilizing information provided in workforce analysis in Europe and nuclear plants in the United States. Further detailed examination of more considerable commercial nuclear and fossil power generating stations in the United States confirmed these recommendations. Positions such as the plant manager, director of operations and maintenance, support services, and maintenance should initially be assigned to each plant as an individual facility. Positions such as licensing, radiation manager, chemistry manager, training manager, and financial manager may be shared between facilities within a reasonable distance throughout the state.

The idea of shared personnel is not new to nuclear power plants and has been referenced in multiple publications for financial, technical maintenance, engineering, licensing, safety, and other personnel. Westinghouse and General Electric share personnel between plants, which benefits the processes and organization of a plant due to the expertise and experience of the personnel; contracted personnel are then used to provide assistance during demand surges [231].

5.4 Statewide Workforce Needs Based on Organizational Model

While some Indiana residents receive electricity generated by Cook Nuclear Plant, as noted in previous sections, Indiana does not have commercial nuclear power generating stations. Two basic concerns regarding the development of nuclear power generation skill sets are related to those directly involved with the design, construction, operation, and maintenance of such facilities and the interface of state agencies with the Nuclear Regulatory Commission.

5.4.1. Skill Development for Nuclear Power Generation Workers

The interim report authored by Purdue University and Duke Energy in 2023 focused on the feasibility of developing a small modular reactor in Indiana, specifically to power the university's West Lafayette campus and surrounding community [1]. The report found that the plant's construction could create between 1,000-2,000 temporary jobs over 6-10 years, depending on the required infrastructure and reactor design. The number of temporary jobs is dependent on factors such as the size of the surrounding community, the local economy, and the existing workforce's willingness to undergo nuclear retraining.

The report indicates that a single plant would require 100-250 permanent employees. This staffing estimate was derived from a new SMR model and the proportional percentages of various job roles within current nuclear plants [232].

In addition, the report highlights certain skilled workers who could receive specialized training for SMRs. These workers include Heating, Ventilation, and Air Conditioning (HVAC) technicians, welders, electricians, instrumentation technicians, health specialists, cybersecurity professionals, and chemistry technicians. The workforce will require ongoing specialized training to stay up to date with the latest technology and industry requirements.

5.4.2. Specialized Training for Those Interested in Working at/on an SMR

Specialized training is essential for personnel in nuclear power generating stations to ensure safe and efficient operations within this highly regulated environment. Key training components include emergency preparedness for situations like station blackouts, where programs educate critical staff on response protocols and emphasize regular drills to maintain readiness. Operators and maintenance staff undergo extensive training on specific technologies and systems, utilizing full scope replica simulators for realistic practice in monitoring and controlling plant operations. Training must also focus on technology acceptance and adaptation to ensure familiarity with modern systems as the workforce transitions to include younger employees. Additionally, specialized training is necessary to maintain critical equipment, such as pumps and valves, to ensure operational reliability. The specialized training for nuclear workers—broken out into generalized training and specific equipment training—encompasses emergency preparedness, operational training with simulators, technology integration, and equipment maintenance.

Generalized Training Requirements

Generalized training for individuals working in SMRs or traditional nuclear power plants encompasses essential competencies for safety and operational efficiency. Key components of this training include:

1. Radiation Protection: Educates workers on minimizing exposure to ionizing radiation and understanding its biological effects.
2. Emergency Response: Prepares personnel to manage incidents effectively, ensuring the safety of workers and the surrounding community.
3. Security Training: Focuses on protocols to protect nuclear facilities from unauthorized access and threats.
4. Environmental Protection: Emphasizes safeguarding the environment from nuclear operations, including radioactive waste management.
5. Safety Culture: Strives to instill a safety-first mindset among employees to prioritize safety in daily operations.
6. Regulatory Compliance: Familiarizes workers with legal frameworks governing nuclear operations, including U.S. Nuclear Regulatory Commission (NRC) requirements.

Specialized training addresses technical and operational aspects, including:

1. Lock Out Tag Out (LOTO): Ensures safe equipment shutdown before maintenance.
2. Control Room Operations: Equips operators to monitor and manage plant systems.
3. Reactor Theory: Provides foundational knowledge of nuclear fission and reactor dynamics.
4. Decontamination: Trains workers in safely handling and disposing of radioactive materials.
5. Preventative Maintenance: Focuses on proactive measures to maintain equipment reliability.
6. Digital Systems: Prepares workers to operate and troubleshoot advanced digital control systems.
7. Chemical Handling: Ensures safe management of chemicals used in nuclear operations.
8. Fire Hazard Training: Prepares personnel to respond to fire risks.
9. Armed and Tactical Response: Essential for security personnel protecting the facility.

This comprehensive training framework is crucial for ensuring a competent and safety-conscious workforce in the nuclear industry.

5.4.3. Specific Equipment and System Training

Employees at nuclear power generation facilities receive ongoing training from equipment vendors and specialized organizations, which is crucial for familiarizing them with the latest technologies and ensuring safe, efficient operations. Equipment vendors provide specialized instruction on operating and maintaining their products through hands-on workshops, simulations, and technical support. For example, training sessions may focus on advancements in digital control systems or safety equipment, empowering employees to troubleshoot issues and perform maintenance effectively.

Trade unions also play a vital role in the continuing education of nuclear workers by collaborating with employers and training organizations to develop comprehensive programs that address workforce needs. These programs cover safety protocols, regulatory compliance, and technical skills relevant to nuclear operations. By facilitating access to training resources, unions ensure their members are well-prepared to meet job challenges and maintain high safety standards. Additionally, unions advocate for continuous learning, enhancing job security, and career advancement opportunities. This commitment to education benefits individual workers and contributes to the overall safety and efficiency of nuclear operations, fostering a competent and confident workforce capable of navigating the complexities of modern nuclear power generation.

5.4.4. Specific Positions that Provide Varying Levels of Interface with Nuclear Regulatory Commission (NRC)

The regulatory relationship between states and the U.S. NRC is intricate, focusing on safety, environmental considerations, and technological advancements. States engage with the NRC primarily through the licensing process, submitting environmental assessments that contribute to the required Environmental Impact Statements (EIS) for reactor licensing [233]. These assessments evaluate ecological impacts and public health risks before plant construction and operation. The NRC collaborates with state governments to uphold regulatory requirements and safety standards, incorporating insights from international safety reviews to enhance its regulatory role [234]. Additionally, the NRC works on modernizing instrumentation and control systems in the industry, addressing public concerns and technological innovations while emphasizing human factors engineering to maintain safety and operational efficiency [235]. The relationship with the NRC is vital for governing nuclear power generation and balancing oversight, innovation, and public safety.

Beyond the site director or plant manager, several positions facilitate the interface between nuclear power plants and the NRC. The regulatory affairs manager ensures compliance with regulatory requirements and communicates with the NRC, preparing necessary documentation such as license applications and safety reports [236]. The safety manager oversees safety protocol implementation, liaising between operational practices and regulatory expectations [237]. The environmental compliance officer monitors environmental impacts and ensures adherence to regulations, particularly during the licensing process [238]. The human factors engineer focuses on the design of control rooms and human-system interfaces to meet NRC safety guidelines [239]. Lastly, the emergency preparedness coordinator develops emergency response plans in compliance with NRC regulations, ensuring readiness for potential incidents [240]. Collectively, these roles contribute to a robust framework for regulatory compliance and safety assurance in nuclear power generation, fostering effective communication and collaboration with the NRC.

5.4.5. Refuel Outages and Contracted Workforce

Refueling outages, occurring every 18 to 24 months in conventional light-water based nuclear power plants, are crucial for replacing reactor fuel and performing maintenance and modification tasks that cannot be done during operation. These outages require a workforce of 600 to 1000 additional personnel at a traditional plant. Much of these additional personnel are unrelated to the nuclear side of the plant, including contractors and union workers skilled in nuclear operations and safety protocols. While contractors offer flexibility and specialized skills, overreliance on them can lead to increased costs and safety oversight issues. Effective integration of contractor personnel necessitates rigorous training to meet safety standards and can complicate outage management. Key roles needed include:

1. Nuclear Engineers
2. Safety Inspectors
3. Technicians
4. Skilled Tradespeople
5. Project Managers
6. Administrative Support Staff

Additionally, specialized personnel from equipment suppliers contribute expertise and ensure compliance with operational standards. This comprehensive workforce is essential for the safe and efficient execution of refueling outages in small modular reactors, addressing workforce challenges, and ensuring operational readiness.

5.5 Re-skilling and Re-training opportunities

As the energy sector shifts from fossil fuel-based power generation to nuclear energy, it is essential to recognize that workers trained in various fields will require reskilling and retraining to adapt to the new employment environment. This is particularly true for workers with experience in power generation facilities utilizing alternative heat sources. This transition to nuclear energy necessitates a comprehensive evaluation of existing educational programs to identify relevant opportunities for workforce development. In this context, programs at Ivy Tech Community College of Indiana (in the future referred to as Ivy Tech Community College or Ivy Tech) and Purdue University have been assessed to serve as examples[6]. This evaluation has led to identifying specific training initiatives and educational pathways that can effectively support workforce reskilling, ensuring that individuals are equipped with the necessary knowledge and skills to thrive in nuclear energy facilities. By focusing on developing targeted training programs, these institutions can play a pivotal role in facilitating the transition of workers from fossil fuel environments to the nuclear sector, thereby contributing to a sustainable energy future for Indiana.

A review of educational programs in states with established nuclear power generation facilities was conducted to pinpoint the opportunities that institutions within Indiana must address as they

[6] Assessment on programs that may be available in other in-state institutions are not included in the present study.

prepare to reskill and retrain the current workforce. Furthermore, additional opportunities have been identified through collaboration with industrial partners and other affiliated organizations that can provide essential training to support Indiana residents' workforce development needs fully.

5.5.1. Resources Available to Support Training Needs

Several resources are available to provide essential training for the design, construction, start-up, operations, maintenance, and modification of small modular reactors (SMRs) in Indiana. Key institutions include Ivy Tech Community College and Purdue University, specifically the Purdue Polytechnic Institute and the School of Nuclear Engineering. Each of these institutions plays a unique and supportive role to one another, as detailed in the following sections.

5.5.1.1. Ivy Tech Community College of Indiana

Ivy Tech Community College, the largest singly accredited community college in the nation [241], serves nearly 200,000 students annually [241], including more than 91,000 dual credit high school students [242] across nineteen campuses and twenty-six sites [243]. The college plays a significant role in educating Indiana’s industrial workforce at the certificate, technical certificate, and associate degree levels. It has extensive experience in training technicians and facilitating transfers to four-year institutions, including the Purdue University College of Engineering and the Purdue Polytechnic Institute. Ivy Tech maintains a strong partnership with Purdue, providing information on initial education, ongoing technical and safety training, and continuing education as technology evolves. The campuses shown in Figure 49 are categorized by size, with C1 being the largest and C3 being the smallest. Full-service campuses run specialized sites, which are similarly categorized with the S1 and S2 designations.

As a statewide institution with local campuses reporting to a centralized systems office, Ivy Tech can tailor programs to meet the specific demands of the communities they serve. Each program receives feedback from an advisory board of local industry and academic stakeholders. Since most community college students remain within a sixty-mile radius of their home campus, it is essential to offer training for jobs available in their service area. Ivy Tech provides various training programs for industrial partners, including those related to nuclear power generation. The college, at present, offers four credentials relevant to the nuclear workforce: certificate (CT), technical certificate (TC), Associate of Applied Science (AAS), and Associate of Science (AS) [244]. The CT is a short-term credential requiring 9–27 credit hours, often completed in six months. The TC is a long-term certificate requiring 30–40 credit hours, typically earned within one year. The AAS is a two-year terminal degree for direct workforce entry, while the AS is a transfer degree for students planning to continue to a four-year institution, though some AS degrees also prepare students for immediate employment. Ivy Tech is well-equipped to enhance existing programs and develop new ones in nuclear operations and engineering technology, addressing emerging workforce demands in Indiana. More information is available in Appendix I.

Figure 49. Service Area Map of Ivy Tech Community College of Indiana Campuses.

Ivy Tech has a long history of training employees for both union and non-union shops through U.S. Department of Labor (USDOL) registered apprenticeships, many of which are union-based [245]. In union programs, apprentices are hired by the union and participate in a curriculum that includes Ivy Tech-run and union-run courses, along with on-the-job training (OJT). Non-Ivy Tech courses are recognized and overseen by Ivy Tech, which awards an Associate of Applied Science (AAS) degree and often a Technical Certificate (TC) upon completion. Apprentices also receive a USDOL Office of Apprenticeship certificate. Relevant apprenticeship programs are offered through Ivy Tech’s School of Advanced Manufacturing, Engineering, & Applied Science [246], particularly in the Apprenticeship Technology—Building Trades program [247]. A notable example is the Apprenticeship Technology—Electrician, AAS program [248], which is highly relevant to the nuclear industry. Most Ivy Tech training is for non-union employees and students training independently of an employer. Relevant transfer and direct workforce entry programs are as follows:

- Engineering, AS
- Freshman Engineering, CT
- Engineering, TC
- Engineering—Mechanical Engineering, AS
- Mechanical Engineering Technology, AS
- Industrial Technology, AAS
- Industrial Electrical, CT

- Industrial Electrical Technology, TC
- Industrial Mechanical, CT
- Industrial Mechanical Technology, TC
- Materials Technology, CT
- Structural Welding, CT
- Interdisciplinary Industrial Workforce Certificate, CT
- Interdisciplinary Industrial Workforce Technical Certificate, TC
- Advanced Automation & Robotics Technology, AAS
- Heating, Ventilation, and Air Conditioning Technology, AAS
- Heating, Ventilation, and Air Conditioning, CT, TC
- Building and Property Maintenance Technician, CT

Ivy Tech Community College offers two programs to prepare students for careers in engineering: the engineering program and the engineering technology program. The engineering program provides an Associate of Science (AS) degree that facilitates transfer to four-year engineering programs, including to Purdue University's West Lafayette campus [249]. This program is part of the Transfer Single Articulation Pathways (TSAP), allowing students to transfer to any Indiana state-funded institution with junior status upon completion [250]. Students can fulfill Purdue's first-year engineering requirements and earn both a certificate (CT) and a technical certificate (TC). Those in articulated pathways, such as Civil, Environmental & Ecological and Mechanical Engineering, complete specified coursework to earn their AS in engineering. To better prepare for SMR development in Indiana, an articulation agreement with Purdue's Nuclear Engineering department is recommended to recruit students for nuclear engineering. The engineering technology program also offers an AS degree designed for transfer into a four-year Mechanical Engineering Technology program, following the TSAP framework for junior-level transfer [251]. This program emphasizes hands-on training relevant to the nuclear industry, preparing students for both further academic pursuits and immediate workforce entry. In summary, both programs at Ivy Tech are designed to facilitate transfers to four-year institutions while providing practical training for careers in nuclear engineering and technology.

Other programs related and relevant to the nuclear industry that are designed to prepare students for direct entry into the workforce and for upskilling current employees include Industrial Technology (INDT), Advanced Automation & Robotics Technology (AART), and HVAC. These programs offer CTs, TCs, and AAS degrees as previously noted. INDT and AART are industrial maintenance programs, and HVAC includes both maintenance and new construction aspects. Each of these programs trains students with the base skill required by the nuclear industry to work effectively during the construction phase and operation phase of an SMR. However, additional courses would need to be developed by Ivy Tech such as health physics, specialized inspections, and further welding implementations to fully meet specific job requirements of maintenance technicians within the nuclear sector, and examples of courses to develop are shown in Appendix I.

5.5.1.2. Purdue Polytechnic Institute

In addition to these, engineering technology programs have been offered at Purdue University since the 1960s. The School of Engineering Technology at Purdue Polytechnic Institute currently provides ABET-accredited undergraduate, MS, and PhD programs. The faculty includes 50 tenure or tenure-track members and 30 professors of practice. Purdue Polytechnic Institute, formerly Purdue University's College of Technology, serves 2,000 students statewide. The college offers programs to enhance workforce development, including energy-focused courses on nuclear power generation taught by a former nuclear utility engineer. The current courses and programs offered through the institute can be found in Appendix H. The college provides various levels of degree and certificates including Bachelor of Science (BS), which takes 4 years or 8 semesters to complete, and Master of Science (MS), which varies in time to complete depending on the specific program and previous courses taken but can be completed in as little as one extra year up to three years. Doctor of Philosophy (PhD) takes three to seven years dependent on previous schooling, undergraduate certificates gained while obtaining a bachelor's degree, and graduate certificates that can take between a few months to 2 years. Purdue Polytechnic can easily accommodate changes or additions to programs as it has done previously based on industry demands. Adding a Nuclear Engineering Technology program or specialized training certificate to Purdue Polytechnic could benefit the institute and the nuclear industry. There are many courses and certifications that could be added, developed, and modified to create a nuclear program within Purdue Polytechnic to jumpstart a career in the nuclear industry.

The Purdue Polyethnic Institute has produced more than 45,000 industry-ready professionals through schooling at 10 locations across Indiana, including Indianapolis, Kokomo, and South Bend. Each site offers a variety of degree programs. These sites are shown in Figure 50.

The college focuses on providing real world applications and experience through practical lab-based learning, research, and industry partnerships. With a multitude of previous alumni connections, industry partnership-based research projects, and ABET accredited programs, the Purdue Polytechnic Institute creates workforce ready graduates immediately after, upon, and before graduation with a job placement of 88.4% for 2023 grads. The current relevant programs offered that are directly transferrable to a nuclear workforce include:

- Cybersecurity
- Computer and Information Technology
- Engineering Technologies (BS)
- Automation and Systems Integration
- Computer Infrastructure and Network
- Electrical
- Energy
- Mechatronics
- Robotics

Figure 50. Purdue Polytechnic Institute Locations Across Indiana

The relevant certificates within Purdue Polytechnic and at Purdue University at large include:

- Constructions Site Supervision (C.S.S.C)
- Executive Construction Management
- Business Essentials
- Certified Financial Planner (CFP)
- Certified Information Systems Security Professional (CISSP)
- Google Cybersecurity Certificate
- Systems Engineering

The programs enable graduates to apply their skills in various roles within a SMR environment, including positions such as instrumentation technicians, electrical engineers, and financial managers. Certificates facilitate the advancement of current technicians into roles like crew chief or management, supported by new courses designed to enhance the nuclear workforce. While Purdue Polytechnic currently offers a limited number of certificates, Purdue provides a wide array, and the framework for developing additional nuclear-specific certificates exists within the college's engineering department. Thus, adapting existing programs at Purdue Polytechnic or introducing new nuclear-focused certificates is feasible. The courses within the program would enable other technology disciplines to take nuclear-related courses, fostering the ability to work in a nuclear environment with their degree in the future. This would apply to multiple technology programs; the construction management degree, for example, could then be used during the initial construction phases of an SMR, knowing the safety practices and protocols were instilled.

Detailed information regarding current Purdue Polytechnic programs can be found in Appendix H and applicable Purdue University certificates are listed in Appendix J.

The Purdue Polytechnic Institute does not currently support a Nuclear Engineering Technology program, the creation of such is feasible with its history of adaptation from skilled trades. Fostering a program that drives the incoming workforce towards a nuclear future in Indiana, particularly advanced reactors such as the proposed SMR, would provide a direct influx of skilled professionals for positions within the plant that are harder to cultivate/maintain. These positions include NLOs, LOs, engineering/technician management, etc. Multiple proposed courses, including radiation detection through nuclear instrumentation or simulation training for such a program, can be adapted and tuned to fill specific desirable roles within the plant. Specific descriptions can be found in Appendix K.

5.5.1.3. Purdue School of Nuclear Engineering

Established in 1960, the School of Nuclear Engineering at Purdue University is currently supported by 14 tenured or tenure-track faculty, including 9 full professors (3 of whom are named professors), 3 associate professors, 2 assistant professors, and 1 research faculty member. Additionally, 5 adjunct faculty members contribute to the school's academic tasks.

The school provides a comprehensive range of degree programs, including a Bachelor of Science in Nuclear Engineering (BSNE), Master of Science in Nuclear Engineering (MSNE), Doctor of Philosophy (PhD), and an online Master of Nuclear Engineering (MNE), accommodating both residential and remote learners. Currently, there are over 210 residential students, comprised of approximately 150 undergraduates and 60 graduate students, along with more than 20 online MNE graduate students, reflecting Purdue's commitment to flexible, high-quality education for professionals.

The school’s technical expertise spans comprehensive areas of nuclear engineering. The school also houses Purdue University Reactor Number 1 (PUR-1) research reactor, the only nuclear reactor in Indiana, which is being used for research, training and education. PUR-1 is considered a unique asset to the nuclear engineering community, as it is the first and only nuclear reactor that is licensed by U.S. NRC for its 100% digital instrumentation and control system. The school is also equipped with Purdue University Multi-dimensional integral test Assembly (PUMA), which is the only existing scaled integral test facility for advanced light water reactor designs, featuring up to 300 kW_{th} simulated nuclear heating, reactor control logic, more than 500 instruments, emergency core cooling system, and several passive safety systems, currently under consideration by several SMR vendors.

The school’s expertise in nuclear power includes thermal-hydraulics and reactor safety, reactor physics, core design, advanced reactor technology, reactor system analysis codes, verification, uncertainty quantification, and nuclear hybrid and storage. In instrumentation and control, the school specializes in nuclear security, nuclear forensics and non-proliferation, nuclear sensors, artificial intelligence and machine learning, and quantum technology. Expertise in nuclear fusion includes plasma-material interactions, magnetic confinement, inertial confinement fusion, and plasma physics. The school demonstrates expertise in radiation science and technology in radiation detection and measurement, radiation transport, biomedical applications, and medical isotope production. Purdue also leads in nuclear materials research, including advanced manufacturing, covering materials under extreme environments, advanced nuclear fuel, advanced nuclear manufacturing for medium and large components, and nuclear waste management.

Supporting its diverse research initiatives, the School of Nuclear Engineering houses several advanced research laboratories, such as the Advanced Reactor Thermal-hydraulics (ART) Laboratory, Applied Intelligence Systems Laboratory (AISL), Bio-Electric and Electro-Physics (BEEP) Lab, and Cybersecurity and Analytics for Industrial Control Systems (CYNICS) Lab. Other key labs include the Manufacturing & Materials for Extremes Lab, Metastable Fluid Research Lab (MFRL), Multiphase & Fuel Cell Research Lab, Nuclear Energy Systems Transport (NuEST) Lab, Nuclear Reactor Design and Simulation Lab, Radiation Imaging and Nuclear Sensing (RADIaNS) Lab, and the Thermal-hydraulics and Reactor Safety Lab (TRSL).

Figure 51 and Figure 52 present the recent data on student enrollment and degree conferred data by the School of Nuclear Engineering, Purdue University, respectively. The figures show a continuous increase in student enrollment from 2020 to 2024, with a 60% rise over this period. Similarly, the total number of degrees conferred grew by 30% from the 2020-2021 academic year to the 2023-2024 academic year.

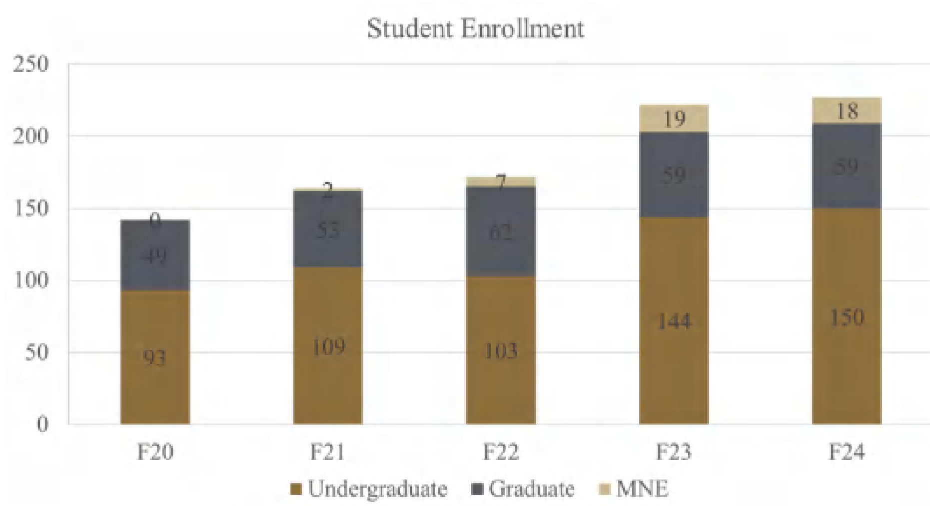

Figure 51. School of Nuclear Engineering, Purdue University student enrollment data from 2020-2023

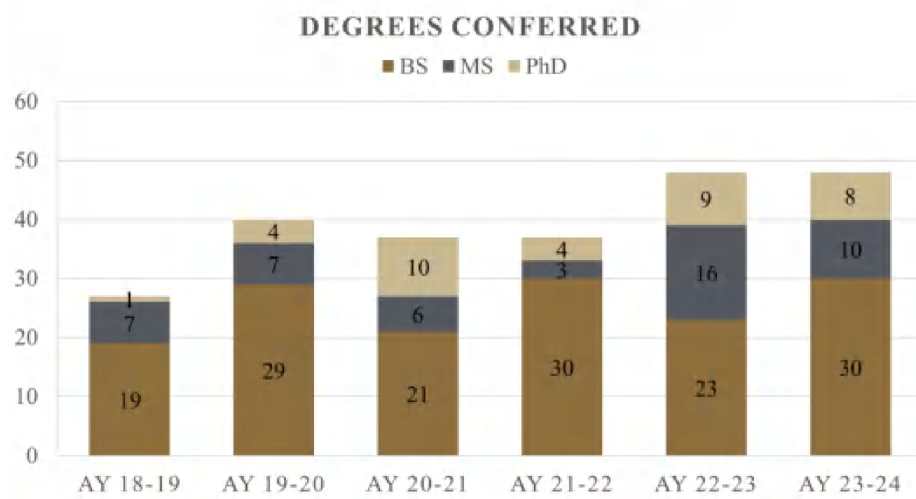

Figure 52. School of Nuclear Engineering, Purdue University degrees conferred data from 2018-2024

5.5.2. Synergistic Collaboration Opportunities

The planned synergy between and within Ivy Tech Community College, Purdue Polytechnic Institute, and Purdue Nuclear Engineering are designed to deliver comprehensive nuclear training for Indiana's workforce across all levels.

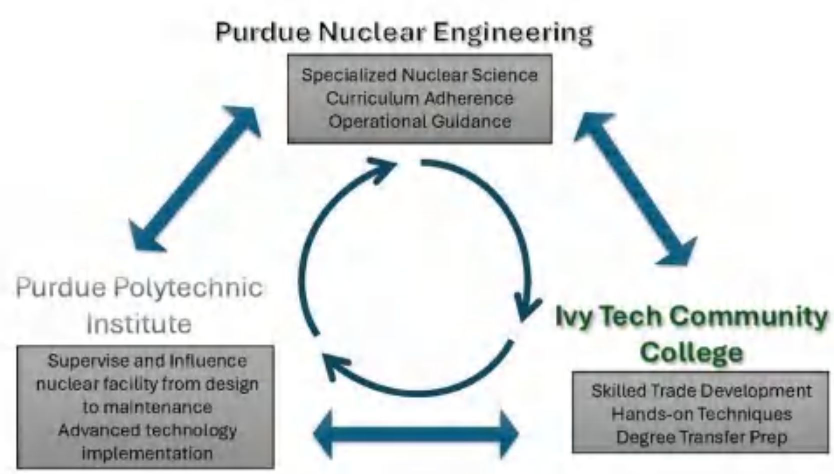

Figure 53. Collaboration Plan

This synergistic partnership focuses on developing tailored educational programs that seamlessly integrate theoretical knowledge with practical skills essential for the nuclear industry.

- Ivy Tech Community College is a foundational institution that provides accessible training and skill development opportunities for diverse learners. Its training offerings range from specialized welding techniques to preparation for four-year degrees in collaboration with partner institutions.

- Purdue Polytechnic Institute Engineering Technology enhances this framework by emphasizing advanced technological applications and innovative teaching methodologies. It equips graduates with the skills to supervise, translate, and provide guidance in the design, construction, operation, and maintenance of nuclear facilities.
- Purdue Nuclear Engineering contributes its specialized expertise in nuclear engineering, science, and technology ensuring that the curriculum adheres to industry standards and safety regulations. Graduates from this program are well-prepared to provide needed technical expertise for both conventional and emerging advanced reactor technologies.

Collectively, these institutions create a robust ecosystem that prepares students for immediate employment in the nuclear sector and fosters continuous professional development. Students could get certificates to cover first-year engineering requirements for nuclear engineering or associate with specialized skills training before transferring into the nuclear engineering technology (NET) program. The NET program then would foster skills within the chosen discipline of nuclear science, operator training, or continuous technician skills. Operator training would heavily emphasize simulator training, which is core to the role, with 5 weeks of on- and off-simulator training required in current nuclear power plants per NRC regulations. This effectively addresses the evolving needs of the workforce and bolsters the state's economic growth in the nuclear energy field. To ensure the long-term success of these efforts, it is essential to consider how to develop the nuclear energy talent pipeline.

Developing the Nuclear Energy Talent Pipeline

The recommendations for developing the nuclear energy talent pipeline take a comprehensive approach, from early education initiatives for middle and high school students to specialized training programs for technicians at associate and bachelor's degree levels. This strategy is essential to cultivate and continually provide a skilled workforce capable of meeting the energy sector's needs [252], [253]. Organizations like IN MaC can play a pivotal role by providing resources and support to enhance students engaged in STEM fields such as nuclear science and engineering [254], [255].

Structured training programs must emphasize technical competencies and safety and operational standards. Competency training in the Occupational Safety and Health Administration (OSHA) has been crucial to improving worker practices in technical fields, suggesting a similar benefit could be achieved in the nuclear sector [256], [257]. By integrating OSHA practices into the proposed curriculum, educational institutions can ensure future technicians are well-versed in maintaining safety protocols paramount to operations in a nuclear power plant.

Establishing clear career pathways through technician certification programs can enhance the professional development of personnel in the nuclear energy field [258], [259]. Evidence from pharmacy training highlights the importance of accreditation and structured training programs to foster competent workforces [253], [260]. The nuclear industry can adopt similar models to promote continuous learning and professional growth, improving job satisfaction and retention among technicians [258], [259]. Collaboration between educational institutions and industry stakeholders is crucial to ensure training remains relevant and informed with current technological advancements [256], [257]. This partnership can foster innovative training methods to cater to diverse learning preferences, thereby enhancing the effectiveness of the educational pipeline [253], [255]. Implementing these strategies encourages immediate workforce needs with a sustainable competency and safety pipeline for future energy production challenges.

Further consideration should include expanding partnerships with the U.S DOE through various programs, including the Nuclear Energy University Program (NEUP) administered by the Office of Nuclear Energy. This program engages with universities and colleges to facilitate research and development, enhance infrastructure, and support student education. By administering research grants, NEUP aims to attract talented students to various nuclear professions and create new opportunities for prospective students to enter the nuclear field. A collaborative effort between the DOE and academic institutions could also lead to establishing career centers dedicated to the long-term training and workforce development of nuclear personnel. These centers would work with nuclear reactor companies, utilities, private sector partners, and other stakeholders to ensure a well-prepared workforce for the nuclear energy sector. The recommendations will cover the full spectrum of the nuclear energy talent pipeline, from educating middle and high school students to training technicians at the associate through bachelor’s degree levels.

Development of Nuclear Co-op and Internship Programs for Eventual Job Placement.

Establishing nuclear power internship programs for job placement requires a comprehensive understanding of job stress factors, organizational personality types, and job performance within nuclear power plants. Collaboration between educational institutions and industries is essential for planning, executing, and evaluating internship programs to meet workforce development needs. Internship programs are crucial for connecting academic knowledge with practical industrial requirements, highlighting the importance of a proper setup and support for successful outcomes. Internship programs can improve students' skills and industry relevance by aligning curricula with industry demands, leading to successful job placements. Continuous evaluation and improvement of internship programs are crucial to meet the evolving demands of the nuclear power industry and ensure students' successful transition into the workforce.

Development of Nuclear Education Camp for Secondary Students

Informing and exposing middle and high school students to nuclear power generation through camps and education programs is crucial for fostering interest and understanding in this field. By implementing both model schools and short-term educational programs, it is possible to enhance the acceptability of nuclear power among students in these age groups [261]. In view of this, opportunities like camps and programs to engage students in STEM fields including nuclear power, becomes even more important when the federal government funding for middle and high school education has led to reduced exposure to hands-on science education [262]. Longitudinal analyses have shown that early academic enrichment programs play a significant role in preparing students for specialized high school admissions, emphasizing the importance of early exposure to educational resources [263]. Programs that expose students to various STEM careers, such as healthcare professions, can help increase interest and serve as a pipeline for future career choices [264].

In view of these, starting from summer of 2023, the School of Nuclear Engineering at Purdue University has been offering the *Atoms At Work* nuclear summer camp, which is a five-day nuclear summer education program for high school students that blends interactive lectures with hands-on experiments, including utilizing the facilities at Purdue University. Additionally, hands-on programs like robotics software initiatives have proven effective in engaging middle school students and sparking their interest in STEM fields [265].

By expanding research and design opportunities for underrepresented high school students, programs can effectively expose students to computer science and mathematics, broadening their horizons [266]. Collaborative initiatives like the BioEnergy Academy for Teachers aim to educate middle and high school teachers on sustainable bio-energy, highlighting the importance of integrating complex topics into educational curricula [267]. Enrichment programs have successfully met the unique needs of students with talents and gifts, providing exploratory activities that enhance cognitive abilities and creativity [268]. Enrichment programs provide exploratory activities that enhance cognitive abilities and creativity among gifted students, and the flexibility and variety of enrichment programs, designed to cultivate curiosity and capabilities, effectively addresses the needs of talented learners. By engaging high school students in basic research through structured instructional interventions, programs like the NeuroLab Research Experiences can bridge the gap between academic knowledge and practical applications in STEM fields [269]. Virtual programs like the Nuclear Power Summer Institute and Day of Science offer students' hands-on activities and educational tools to learn about the nuclear industry, fostering interest and understanding in nuclear power [270]. Such initiatives play a vital role in inspiring the next generation of scientists and engineers, preparing them for future careers in nuclear power generation.

Timeline for Workforce Development in Indiana's Nuclear Industry

The development of a skilled workforce for the nuclear industry in Indiana can be structured into three critical phases: identifying interested individuals, training these individuals, and maintaining a sustainable program for ongoing professional development. Each phase is essential for ensuring that Indiana can effectively support the growth of its nuclear power generation capabilities, particularly with the advent of SMRs.

Phase 1: Identifying Interested Individuals and Program Development

The first phase involves outreach and identifying individuals interested in pursuing careers in nuclear power generation. This can include high school students, college students, and professionals seeking to transition into the nuclear field. All the universities in Indiana, including Purdue University (Engineering Technology and Engineering) and Ivy Tech Community College, play a pivotal role in this phase by developing new programs tailored to meet the needs of the nuclear industry. This includes creating curricula that cover essential topics such as nuclear engineering principles, safety protocols, and operational training specific to SMRs. The collaboration between educational institutions and industry stakeholders is crucial to ensure the programs are relevant and aligned with current technological advancements and workforce needs.

Outreach initiatives focused on each unique group identified above can be implemented to raise awareness about the opportunities within the nuclear sector, emphasizing the importance of safety culture and technical skills required for various roles. This phase may also involve partnerships with local high schools and community colleges to introduce students to nuclear science and engineering concepts, fostering early interest in the field.

Phase 2: Training Individuals

Once individuals are identified, the next phase focuses on training as many interested candidates as possible. This training should encompass theoretical knowledge and practical skills necessary for employment in the nuclear power generation industry. Training programs can be structured to include a combination of classroom instruction, hands-on laboratory experiences, and internships/apprenticeship at various institutions, nuclear facilities and industry partners. The curriculum should accommodate various learning styles and backgrounds, ensuring that new students and professionals seeking certification can benefit from the program. This approach not only prepares individuals for immediate employment but also equips them with the skills necessary for future advancements in their careers. Furthermore, the training programs should be adaptable to incorporate emerging technologies and practices in the nuclear sector, mainly as the industry evolves with the introduction of SMRs.

Phase 3: Maintaining a Sustainable Program

The final phase is dedicated to maintaining a sustainable workforce development program that provides continuous professional development and training for employees at SMR facilities. This involves establishing a framework for ongoing skill-focused education, including refresher courses, specialized training sessions, and workshops that address new technologies and regulatory changes in the nuclear industry. Collaboration with industry partners is essential to ensure that the training remains relevant and that employees are equipped with the latest skills and knowledge.

Creating a feedback loop between employers and educational institutions can help identify skills gaps and inform curriculum updates, ensuring that the workforce remains competitive and capable of meeting the demands of the nuclear sector. Establishing mentorship programs and career advancement pathways can encourage employee retention and professional growth, fostering a culture of continuous learning and improvement within the nuclear workforce.

The timeline for developing a workforce for Indiana's nuclear industry involves a strategic approach that encompasses identifying interested individuals, providing comprehensive training, and maintaining a sustainable program for ongoing professional development. By focusing on these three phases, Indiana can effectively prepare a skilled workforce capable of supporting the growth and safety of its nuclear power generation capabilities.

CHAPTER 6. SAFETY REVIEW

Safety topics associated with SMRs, which can differ from conventional nuclear power reactor, are related to design and new fuel forms, cyber security, potential environmental concerns, and spent fuel management.

6.1 Best Practices and Safety Features

Best practices and safety features in SMRs include inherent safety features, advanced control systems, modularity, redundancy and resilience. In addition, significant changes from earlier conventional nuclear power reactors include emergency preparedness and response, fuel design, and cybersecurity. Each safety feature is discussed in more detail below.

- **Inherent safety features:** SMRs rely on natural circulation systems, air-cooling systems, and passive shutdown systems to eliminate the need for active pumps or other machinery to shut down the reactor and remove the decay heat. In addition, inherent safety systems reduce maintenance and operation costs, allowing for a simpler design without the need for complex piping layouts and configurations [271]. Notable passive shutdown system designs include lithium expansion modules (LEM), lithium injection modules (LIM), electromagnets, and thermostatic switches. For example, LEM systems act similarly to an analog thermometer that is placed inside the core. The LEM consists of a Lithium-6 reservoir above the core and an inert gas which occupies the space in core during normal operation. However, if the temperature rises above the allowable limit, the lithium-6 will expand and displace the inert gas, thereby inserting negative reactivity [272]. These systems can act in milliseconds to shut down the reactor automatically with no operator action.

- **Advanced control systems:** The advanced control systems in SMRs represent a significant evolution in instrumentation and control (I&C) technology, aimed at enhancing safety, security, and operational flexibility. SMRs, typically operating at 300 MWe or less, leverage modular, factory-fabricated designs, and their I&C systems are focused on improving safety and security, streamlining installation logistics, enhancing plant adaptability, increasing operational flexibility, and ensuring affordability. These systems offer faster response times, secure data transmission, and more legible displays, allowing operators to respond more effectively while reducing the potential for human error—critical lessons learned from incidents like Three Mile Island, Chernobyl, and Fukushima. SMRs also incorporate higher levels of automation, using advanced control methods suited to their smaller size, which enhance control precision and operational impact. These advancements in I&C systems contribute significantly to making SMRs safer, more adaptable, and better equipped to meet modern energy needs [273].

- **Modularity, redundancy, and resilience:** The three main consistent economic savings measures due to modularization include ease of transport, standardization, and shorter build schedules. The reduced size and weight of SMRs allow for transportation on existing roads and bridges. This dramatically decreases logistical difficulty and allows 80% of the plant to be built off-site. Standardization allows for plants to be built on an assembly line-style format, which will dramatically decrease fabrication costs as supply chains and expertise can be localized. Some SMRs, notably HTGRs, can utilize extraordinarily resilient TRISO fuel. The first advantage of TRISO fuel is its ability to contain fission products as observed in a containment directly surrounding each particle. This is illustrated in the image in Figure 54 [97]. Typical reactors use cladding to hold the fuel pellets in place and contain the gases released from the fission reaction. In a catastrophic event, if the cladding is punctured and released into the air, the radioactive fission products may leak into the atmosphere. However, TRISO fuel can contain these fission products within a pebble that is approximately 750-830 micrometers in size [97]. Another advantage of TRISO fuel is the ability to withstand heat. ORNL tested TRISO fuel and found that a pebble can withstand 1800° C (over 3,000° F) for more than 300 hours without failing or compromising the containment. [97]. This means in a scenario that would typically cause reactor meltdown, TRISO fuel can withstand the environment for more than 300 hours. The large thermal inertia of liquid metal also allows for slow temperature changes, giving operators more time to respond to unforeseen transient scenarios. Thermal inertia means that it is difficult to change the temperature of the volume. While this makes it challenging to bring the reactor up to temperature, it also means that if the core temperature dramatically increases, the working fluid will not rapidly change in temperature, giving operators time to manage the situation [75]. The Defense in Depth (DiD) is a concept used to implement multiple levels of protection and barriers between radioactive material and the public. This strategy serves to firstly, prevent accidents and secondly, limit the consequences of any accidents. The DiD consists of five different levels of protection and control. The levels of DiD can be seen in Appendix B. Each level of the DiD should be completely independent from the next and each level must exist regardless of the design of the reactor [274]. For SMRs, this means that although they possess a multi module design, each level of DiD must remain independent. The emergency preparedness and response (EPR) should be observed as the fifth level of DiD and operate reliably regardless of the design. This means the EPR should include all appropriate arrangements for unexpected events during emergency situations. The fifth level covers the incident if the radioactive materials were released into the environment and public already. The attempt to mitigate the offsite consequences is the role of the EPR [275].

- **Fuel design:** A typical uranium oxide (UO_2) pellet is approximately 3/8-inch in diameter and 5/8-inch in length [276]. The pellet is a “thimble-sized” ceramic cylinder that can produce heat after undergoing fission reactions. To encourage fission, the uranium is “enriched” by increasing the concentration of Uranium 235. UO_2 pellets are used in most currently operational reactors, so the regulation and supply chains are well established. A typical PWR or BWR can contain “up to 10 million pellets,” which are organized into stacks called “fuel rods,” then the fuel rods are organized into “fuel assemblies” [276]. TRISO fuel is designed to be used in HTGRs and molten salt-cooled reactors. Comprised of poppy seed-sized robust particles, TRISO fuel is made from uranium, carbon, and oxygen. Each particle is composed of a center made of uranium, a carbon layer, a silicon carbide (SiC) layer, and a carbon outer shell [277, 278], as shown in Figure 54. TRISO pellet regions and fuel particle layers are outlined in Appendix C. When compared to traditional fuels, such as typical UO_2 pellets, TRISO pebbles perform better in resisting against various reactor conditions, such as irradiation, corrosion, or high temperatures. In December 2022, Kairos signed an agreement to manufacture TRISO fuel for Los Alamos National Laboratory demonstration reactor Hermes [279]. BWXT has manufactured TRISO fuel for the "U.S. Office of Nuclear Energy's Next Generation Nuclear Plant" as well as the DOE's Advanced Gas Reactor (AGR) program. USNC manufactures their own fuel that contains TRISO particles, called FCM fuel, without relying on the government or any commercial entity due to their ownership over the manufacturing chain. The X-Energy in-house developed TRISO-X fuel is a fuel element design specifically developed for the Xe-100 HTGR [280]. An X-Energy TRISO-X Fuel Fabrication plant is currently undergoing the licensing application phase (Category II) according to the U.S. NRC [281].

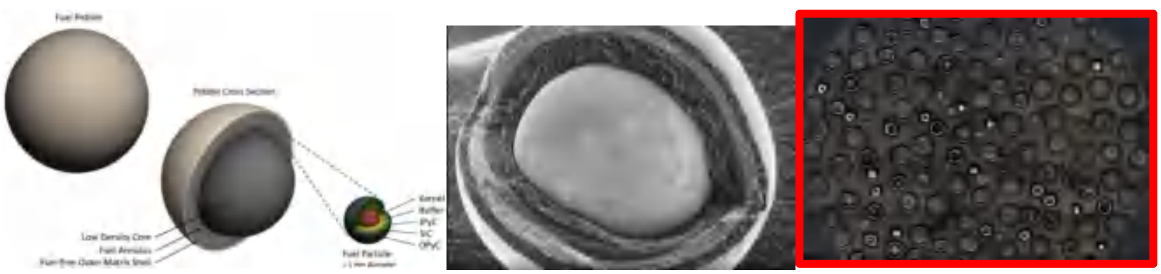

Figure 54. KP-FHR TRISO Pellet Design [282]. TRISO Fuel [97]. TRISO Fuel in Fuel Pellet [97]

- **Cybersecurity Measures:** The general requirements of a cybersecurity system would have to be consistent with 10 CFR 73.54 [283]. It stipulates that a licensee of any NPP must provide full confidence that digital systems integral to the operation of such NPPs are sufficiently protected against any form of cyber-attacks, including design basis threats (DBT) [284]. The establishment and implementation of a cybersecurity program by a licensee in accordance to 10 CFR 73.54 and 10 CFR 74.55 [285], must protect and maintain any digital system, network, or communication system affiliated with the safety, security, emergency preparedness (SSEP) functions of all nuclear-related facilities also known as critical digital assets (CDAs) [286]. Adhering to the NRC Regulatory Guide 5.71 [286], a procedure to establish a cybersecurity program within a nuclear-related facility should include analyzing all digital systems (computers, communication systems, and networks), reviewing CDAs, deploying a defensive architecture, addressing all potential cyber-related risks to CDAs, and implementing security life-cycle activities in accordance with program maintenance, as shown in Figure 55 below

[286]. If the system supports or protects critical systems, it is considered a critical system (CS). If it does not, it is considered a "noncritical system." If the CS also supports or protects critical assets, the licensee's system is a CDA; otherwise, the CS is classified as a digital asset. According to the U.S. NRC, a security defensive architecture includes five concentric cybersecurity defensive levels, bounded by security measures such as, but not limited to, firewalls and diodes. These five levels, from 4 to 0, are vital, protected, owner-controlled, corporate, and public systems/information. Levels 4 and 3 use unidirectional, non-software-based links to ensure the safety of vital, protected, and owner-controlled systems.

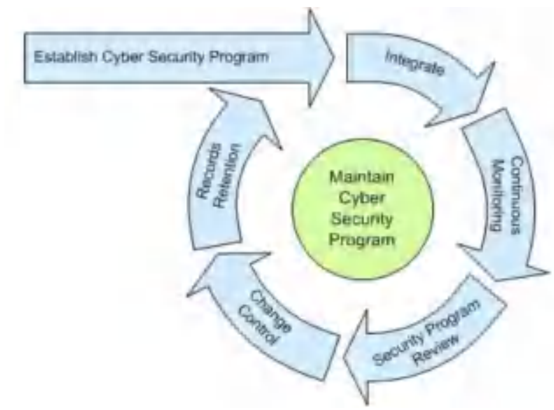

Figure 55. Process of establishing, implementing, and maintaining the cyber security program of a Nuclear Facility

6.2 Environmental Impact and Nuclear Waste

- **Air Emissions:** The consumption of fossil fuels releases carbon dioxide into the atmosphere, which can have harmful effects on the environment. Indiana relies most on coal for electricity generation followed by natural gas [162]. SMRs, like traditional nuclear reactors, do not produce air pollutants such as carbon dioxide during normal operation, though emissions are associated with the construction of these plants. While SMRs do not emit greenhouse gases during operation, emissions are produced during the decommissioning of old plants and the construction of new SMRs. When considering the emissions from the initial construction of SMRs and the fuel manufacturing process, there is an overall reduction in predicted emissions compared to the projected emissions of the U.S.'s current energy portfolio. The total emissions avoided, relative to energy generation, are shown in Figure 56. Although emission levels depend on the individual design of SMRs, the overall concept is estimated to significantly reduce CO_2 emissions. For example, a study by the NEA showed that the SMR market could potentially reach 21 GW by 2035. If this expansion of SMRs occurred and a build rate of 75 GW was maintained annually, it could result in avoiding 15 gigatons of CO_2 emissions. The NEA further suggested that if SMRs were utilized along with existing nuclear plants, nuclear hybrid energy systems, and hydrogen technologies, approximately 87 gigatons of CO_2 could be avoided—equivalent to over two years' worth of global CO_2 emissions at 2020 levels [287].

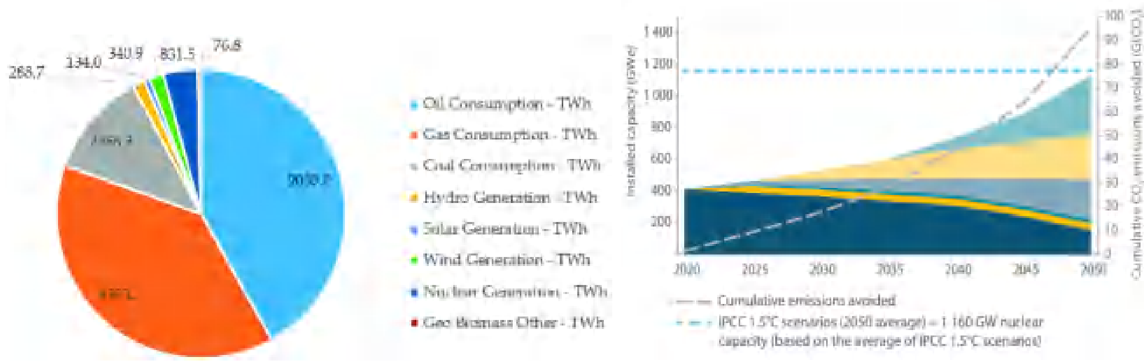

Figure 56. Left: Distribution of energy consumption in USA in 2020 [288] Right: Projection of CO_2 emissions that could be avoided using a combination of nuclear energies [287]

- **Water Usage/Thermal Pollution:** Most SMR designs use light water as a coolant and neutron moderator. While some reactor designs rely on other coolants, e.g., molten salts, light water remains a common coolant for NPPs and SMRs alike. When power plants use cooling water from nearby bodies of water, anthropogenic heat emissions can impact water temperature and quality after being discharged. Typically, this involves releasing warm water (from steam used to spin turbines) into cooler water, gradually raising the overall temperature of the body of water. This issue also occurs in fossil fuel plants. This heat discharge could pose a threat to aquatic life in the bodies of water from which the coolant is drawn. Several fish species are highly sensitive to temperature changes, and thermal pollution can negatively affect their vital functions. In fact, between 1962 and 1967, the Federal Water Pollution Control Administration documented ten instances of fish being killed by thermal pollution from nearby fossil fuel plants. There have been more severe cases, such as waste heat from the Indian Point Nuclear Station indirectly causing the deaths of tens of thousands of bass in the Hudson River. Although this wasn't a direct cause and effect, the warmer water attracted the bass toward the plant, where they became trapped in equipment or the water intake system. Furthermore, if thermal pollution persists and the water temperature increases over time, it can have lasting effects on the ecosystem, impacting various forms of aquatic life beyond just fish [289]. To reduce thermal pollution, SMRs adopt alternative cooling methods such as recirculating tower cooling and dry cooling. In recirculating tower cooling, two closed loops handle heat dissipation, but water loss due to evaporation is higher than in once-through systems. Dry cooling, which uses air to cool steam, nearly eliminates water use and thermal pollution but is less efficient and more costly than wet cooling methods [290].Thermal efficiency, the ratio of energy output to input, dictates a plant's cooling and water consumption. SMRs have similar thermal efficiency to conventional NPPs but can improve it by up to 10% with certain enhancements, as shown in Figure 57. However, increased efficiency requires more water. Wet cooling systems are more efficient than dry systems, and SMR designs function similarly to NPPs, using water to cool reactors, generate steam, and condense it back before discharge, leading to comparable thermal pollution.

- **Land Use:** Land use includes not only the siting of a facility but also activities such as agriculture, residential, industrial, and recreational uses. It also encompasses impacts on air, water, wildlife habitats, and human health. The EPA monitors land use to minimize negative effects, though some activities, such as habitat restoration, can be beneficial. SMR construction and operation must consider effects on water, agriculture, suburbanization, and human health. While SMRs typically require significantly less land than traditional NPPs, their size and impact on the surrounding area can vary depending on the design. Table 17 compares the footprints and land use impacts of various SMR designs.

- **Nuclear Waste Production:** According to the Nuclear Energy Institute (NEI), nuclear waste is "fuel that's been used in a reactor once" [291]. In a standard nuclear reactor, the fuel is solid and contained within long metal tubes called fuel rods. Any fuel rod removed from the reactor is considered nuclear waste. Because nuclear fuel is highly energy-dense, it can generate a large amount of power using very little fuel and produces minimal waste. A standard nuclear reactor with a 1,000 MWe output produces approximately 3 cubic meters of waste per year [292]. In industry-standard PWRs, fuel rods are composed of assemblies of cylindrical UO_2 pellets stacked inside the rod's casing [293]. These pellets contain uranium, enriched to a level usable by the reactor. As the fuel rods are used, the by-products of atomic fission remain safely contained within them. Once the uranium concentration drops below a usable level, the spent fuel rods are removed from the reactor core and placed into an on-site storage pool, where they remain until their reduction in decay heat over time is low enough for dry-cask storage. After 2-5 years, the spent fuel rods can be transferred to large storage casks for indefinite storage [291].

- **Storage Solutions:** Spent fuel is typically stored to manage its radioactivity. Nuclear fuel storage has two phases: short-term and long-term. Short-term storage involves keeping spent fuel on-site in pools of water to cool for 2-5 years before transferring it to dry cask storage. These casks remain on-site until the fuel is moved to long-term storage. Long-term deep geological storage involves placing waste in indefinite storage, either on-site or at designated repositories. A planned permanent site at Yucca Mountain, Nevada, has been halted under various administrations [294]. The DOE now focuses on federal consolidated interim storage, engaging communities to site a federally owned intermediate storage facility [295] [296]. Although no SMRs are currently built, plans for their fuel storage exist. Of the seven evaluated SMR designs, only four using standard UO_2 pellets have publicly available storage plans. The remaining three designs, using non-standard fuel formats, have not disclosed their storage plans. Table 18 outlines the storage plans for these SMR designs.

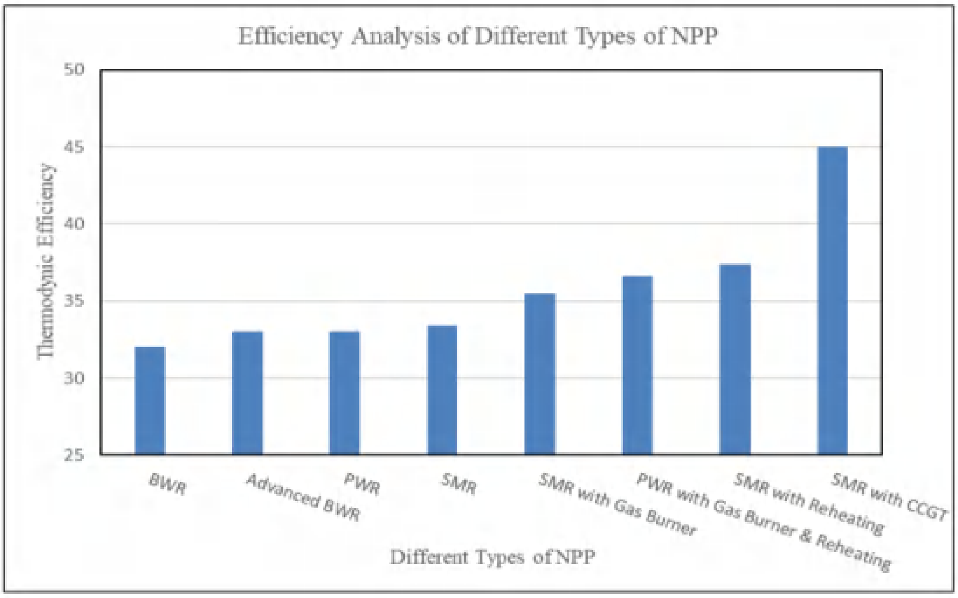

Figure 57. Varying Thermal Efficiencies of Different Nuclear Power [297]

Table 17. Overall SMR Design Land Use Summary [298, 299, 300, 301, 302, 303, 304, 305, 298, 306]

SMR Design (1 unit)	Approximate Plant Footprint (m^2)	Approximate Site Footprint (m^2)	Specific Locational Land Use
SMR-300 (Holtec International)	30,000	141,640	Threatened and Endangered
BWRX-300 (GE-Vernova)	8,400	26,300	Corrosion
VOYGR (NuScale Power)	4,877	140,000	Snow Load
RR SMR (Rolls-Royce)	Not Established	40,000	Residential Use and Impact
Xe-100 (X-Energy)	32,725	53,000	Multitude of Applications
Natrium Reactor (TerraPower-GE-Vernova)	65,000	180,000	Volcanic Impact
KP-FHR (Kairos)	Not Established	750,000	Proximity to ORNL

Table 18. SMR Storage Plans

SMR Name and Company	Fuel Type	Short Term Storage Method	Short Term Storage Capacity	Long Term Storage Method
SMR-300 (Holtec)	UO_2 Pellets	Spent Fuel Pool	150 Fuel cell Locations	MPC37 Storage Casks
BWRX-300 (Hitachi)	UO_2 Pellets	Spent Fuel Pool	620 Fuel storage slots, or 300% of core capacity	Dry Storage Casks on On-site Fuel Storage Installation
VOYGR (NuScale)	UO_2 Pellets	Proprietary/Not Public	Proprietary/Not Public	Dry Storage Casks on On-site Dry Cask Storage Site
Rolls Royce SMR	UO_2 Pellets	-	-	Eventually Transported to Off-Site Geologic Repository
Xe-100 (X-Energy)	TRISO-X	-	-	-
KP-FHR (Kairos)	TRISO	-	-	-
Natrium (TerraPower)	Molten Uranium-Zirconium Alloy	-	-	-

6.3 Project Siting

Selecting a suitable site for SMR deployment requires careful evaluation of multiple environmental and regulatory factors to ensure operational safety and long-term viability. Key criteria for site selection include seismic and geological stability, proximity to existing infrastructure, and environmental impact considerations, all of which are essential to meeting regulatory requirements and supporting safe, efficient operations.

Additionally, responsible site planning involves considering the full lifecycle of the facility, including decommissioning requirements. Appendix F outlines NRC standards for financial assurances and site cleanup, which require SMR projects to incorporate plans for safe and effective decommissioning from the outset. Factoring these long-term obligations into site evaluations helps ensure that potential SMR sites can meet both operational and regulatory standards throughout their lifespan.

This comprehensive approach to site assessment allows groups to carefully weigh the suitability of various locations for SMR deployment, taking into account both environmental and regulatory requirements.

6.3.1. Seismic and Geological Stability

When siting a nuclear power plant, it is important to keep in mind that different locations have different hazards of varying magnitudes. The NRC requires that all components in a reactor can operate without issue during natural phenomena at levels as most severe as historically reported for a particular area [307]. In this study, natural hazards are broken up into three categories: earthquakes, sinkholes & landslides, and floods.

Earthquakes: While Indiana is not located on a tectonic plate boundary, intraplate faults can induce earthquakes in some counties. Earthquakes in stable continental regions occur less frequently than earthquakes on plate boundaries, but they can still be disastrous. There are five seismically active zones that are of relevance to the state of Indiana: the Anna Seismic Zone (ASZ), the Wabash Valley Seismic Zone (WVSZ), the St. Genevieve Seismic Zone (SGSZ), the New Madrid Seismic Zone (NMSZ), and the Eastern Tennessee Seismic Zone (ETSZ). Of these, the NMSZ is the most active. These seismic zones are shown in Figure 58, which depicts major cities as red dots and felt earthquakes between the years 1811 and 1975 as black open circles [308]. Another potential threat to nuclear reactors is liquefaction. When certain soils are exposed to the vibrations of an earthquake, they can behave similarly to a liquid. According to the Indiana Geological Survey, “This could result in the structural failure of buildings, bridges, and other structures,” as shown in Figure 58. [309]

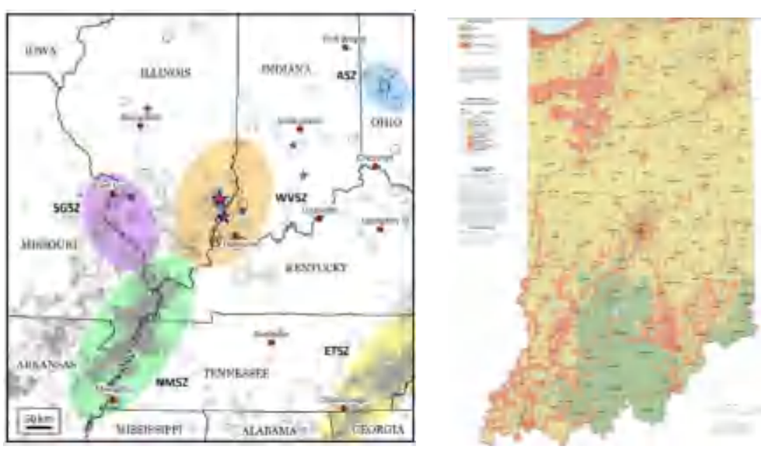

Figure 58. Regional Seismicity Map [308] (left) and Map of Liquefaction Potential (right) [310]

Sinkholes & Landslides: Much of southern Indiana sits on a karst geologic structure. The limestone is perforated with caves and small passages that occasionally collapse, causing sinkholes. Reactors sited in southern Indiana may have to contend with the possibility of unstable karst, as shown in Figure 59. While karst and sinkholes complicate reactor construction, neither pose insurmountable challenges. Power plants have been built on karst and in areas where sinkholes are common. To ensure structural stability, the power plant's foundation can be built on piles anchored deep into the bedrock to minimize the effects of karst movement or sinkholes [78]. Landslides pose a danger to all buildings located near an unstable slope. Landslide risk can be mitigated by providing adequate drainage, planting stabilizing grasses, excavating to create a lower slope, and installing artificial anchors and retaining walls. As shown in Figure 59, landslides are most common in southern Indiana, and near bodies of water [310].

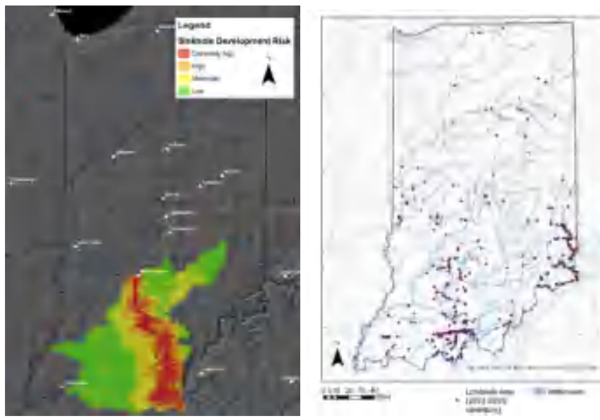

Figure 59. Risk of Sinkhole Development in Southern Indiana [309] (left) and map of Landslides Found on Highways (right) [310]

Floods: Floods are particularly problematic because power plants are often located near rivers or lakes. Floods can be caused naturally, or by the failure of a dam or levee. Natural floods are far more common and can occur in more places than floods caused by failing infrastructure. The threats presented by dam or levee failures could range from minor hazards to extensive damage. Both types are extremely site-specific, but generally, natural floods are more common in narrow valleys, floodplains, and directly upstream of reservoirs. Dam and levee failures only present a hazard to downstream areas. Plant designers must be able to guarantee the successful operation of safety systems during the largest flood that the site has experienced. This includes studying how seismic hazards can affect floods and determining if flooding could compromise the plant's ability to dissipate heat.

6.3.2. Proximity to Population Centers and Emergency Planning Zones (EPZs)

Before a nuclear plant can be licensed, an EPZ must be developed. The EPZ is broadly defined to be the area in which any type of emergency planning would be necessary in the case of a major accident. EPZs are broken down into several overlapping zones that represent areas where particular actions may be necessary. The exclusion area (EA) refers to land in the immediate vicinity of the reactor. According to the NRC, "This area may be traversed by a highway, railroad, or waterway, provided arrangements are made to control traffic on the highway, railroad, or waterway in case of emergency," [311]. For a typical nuclear power plant, an evacuation zone may

encompass an area within a 2-mile radius of the plant in all directions and a 5-mile swath of land downwind of the plant. Extending beyond that is the plume exposure pathway that extends 10 miles away from the plant. A food sampling area extends 50 miles from the plant to monitor if food or water supplies have been contaminated. An illustration of this example is shown in Figure 60. The NRC states that “The choice of the size of the EPZs represents a judgment on the extent of the detailed planning that must be performed to ensure an adequate response base,” [312]. This means that a smaller reactor with less serious design basis accidents may require a smaller EPZ.
The NRC also requires the creation of a low population zone (LPZ) around the reactor to minimize the number of people affected were an accident to occur. The NRC defines the size of the LPZ to be “such that the distance to the boundary of the nearest densely populated center containing more than about 25,000 residents must be at least one-and-one-third times the distance from the reactor to the outer boundary of the LPZ,” [313]. NRC regulation RG 4.7 Rev 4 poses further restrictions on power plants citing near population centers. This restriction limits the siting of nuclear reactors near areas with high population densities. The population density is calculated by drawing a circle centered at the reactor and dividing the 5-year projected population (including transient populations) within that circle by the area of the circle. The population density of all such circles with a radius of less than or equal to 20 miles should be less than or close to 500 persons per square mile [314]. Due to the notable power difference between a traditional nuclear power plant and an SMR, the NRC developed new rules regarding emergency plans for SMRS, 10 CFR 50.160, that includes a scalable approach to developing an EPZ. An example of a scalable EPZ is shown in Table 19.

Table 19. Potential EPZ Scalable EPZ [275]

<table>
<tr><td colspan="2">Conditions to determine EPZ</td><td colspan="3">EPZ Qualification for given conditions</td><td>Ingestion exposure EPZ</td><td colspan="3">Off-site EP Plan</td></tr>
<tr><td>Location with an expected dose of ≥ 10 mSv</td><td>Location with an expected dose of < 10 mSv</td><td>Site boundary</td><td>2 miles</td><td colspan="2">5 miles</td><td>10 miles</td><td></td><td></td></tr>
<tr><td></td><td>Site boundary</td><td>EPZ Border</td><td>Outside EPZ</td><td colspan="2">Outside EPZ</td><td>Outside EPZ</td><td>Not Required</td><td>May be Required</td></tr>
<tr><td>Site boundary</td><td>2 miles</td><td>Inside EPZ</td><td>EPZ Border</td><td colspan="2">Outside EPZ</td><td>Outside EPZ</td><td>Required</td><td>Required</td></tr>
<tr><td>2 miles</td><td>5 miles</td><td>Inside EPZ</td><td>Inside EPZ</td><td>EPZ Border</td><td>Outside EPZ</td><td colspan="2">Required</td><td>Required</td></tr>
<tr><td>5 miles</td><td>10 miles</td><td>Inside EPZ</td><td>Inside EPZ</td><td colspan="2">Inside EPZ</td><td>EPZ Border</td><td>Required</td><td>Required</td></tr>
</table>

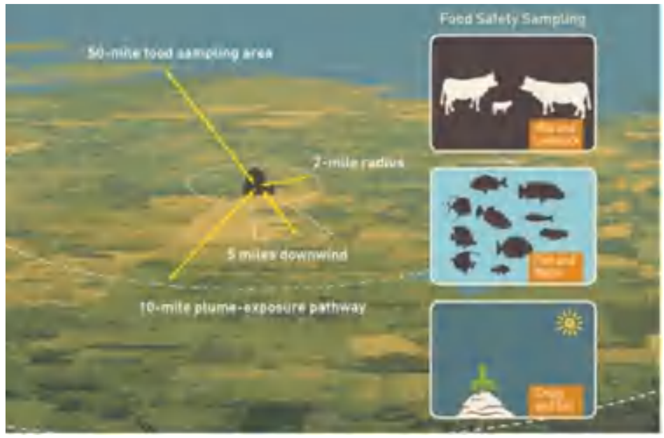

Figure 60. Emergency Planning Zones [315]

6.3.3. Transportation Safety

Transporting nuclear materials involves a list of federal and state regulations. Federal regulations differentiate and ascertain allowable quantities and levels of radioactivity of given materials and have specific regulations for transporting them either through road, rail, air, or sea. The state of Indiana also has laws in place regarding the transportation of nuclear materials, including waste and spent fuels. Indiana has put into place laws 10-14-8 and 10-14-9 that regulate the shipping of nuclear materials [310]. NRC Regulation Physical Protection of Category 1 and Category 2 Quantities of Radioactive Material in Transit (10 CFR 37, Part D) outlines requirements for transferring certain quantities of radioactive material. The quantity category is calculated using the ratio of the radionuclide's activity and the given category's threshold [316]. Appendix D describes the category thresholds for various materials in terabecquerels (TBq) and curies (Ci).

The NRC regulation on Packaging and Transportation of Radioactive Material 10 CFR 71 requires that licensees transporting licensed material and utilizing public highways for transport must comply with DOT regulations in areas of packaging, marking and labeling, placarding, accident reporting, shipping papers and emergency information, hazardous material training and shipper or carrier registration, and security plans. The licensee must comply with DOT regulations for transportation by rail, air, vessel, and public highway. The NRC can grant various exemptions from the regulation requirements. For a package to be approved, the application for approval must include a package description so that the package can be accurately identified and evaluated. The description must have information with respect to packaging and the contents inside, including the model number, containment system identification, radioactivity identification, maximum decay heat amount, and other information to sufficiently identify the package [317].

The surface of the package must also not exceed a radiation level of 2 mSv/h or 200 mrem/h. A package exceeding this threshold is required to be transported only through exclusive use shipment [318]. A package design evaluated under normal transporting conditions must go through a series of tests to determine the effect of normal conditions on the design. These tests include heat and cold tests, pressure tests, a vibration test, a water spray test, a free drop test, a corner drop test, a compression test, and a penetration test [319]. Alongside these conditions, a package also undergoes tests for the conditions for hypothetical accidents. These tests include a free drop test, a crush test, a puncture test, a thermal test, an immersion test for the fissile material, and an immersion test for the package [320]. There are also tests for the accident conditions for plutonium air transport. These tests include an impact test, a compression test, direct impact tests, a luminous flame exposure test, an immersion test, an individual free-fall test, and an individual submersion test [321]. The NRC provides operating controls and procedures for a licensee transporting licensed material and/or delivers the material to a carrier. First, there must be no defects, such as cracks, that may reduce the packaging's effectiveness. The containment system must also maintain structural integrity at pressures exceeding the maximum operating pressure, and the package must be marked with identifying information, specifically the model and serial numbers, the gross weight, and the NRC assigned package identification number [322].

The state of Indiana defines high level radioactive waste (HLRW) as either: (i) Reactor fuel that has been irradiated, (ii) Liquid waste from a first or subsequent cycle solvent extraction system in an irradiated fuel reprocessing facility, (iii) Solid waste that the liquid waste from an irradiated fuel reprocessing facility has been converted into, or (iv) Spent fuel that can be disposed or waste that remains after the reprocessing of spent fuel. Indiana also defines low level radioactive waste (LLRW) as any radioactive material from an NRC licensed facility except for: (i) HLRW, (ii) Spent fuel, (iii), Transuranic waste, (iv) Byproducts. "Spent nuclear fuel" is defined by fuel that has either been withdrawn from a reactor after irradiation or has not been separated through reprocessing. To be permitted to ship HLRW or LLRW through Indiana, the shipper must apply and pay a fee to the department of homeland security. The permit is required to state its purpose and an expiration date. Before transporting HLRW through Indiana, a shipper must submit the issued permit and fees for trucking shipments and/or rail shipments where applicable. For both HLRW and LLRW transportation, the permits and fees are to be submitted to the director, who consults the commissioners of the state department of health, transportation, and environmental management, the department of natural resources director, the state police department superintendent, representatives of the NRC, Federal Emergency Management Agency, DOE, and DOT, and a local emergency management agency representative. The DOT has Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials, but there may be alternative routes that the director deems safer under 49 CFR 172.80. Those who ship HLRW or LLRW through Indiana must reimburse the government if shipment security has been provided and incurred expenses. If the state police department determines that a motor vehicle violates any part of this regulation, it is allowed to detain, seize, or impound the vehicle and the cargo it carries. The state police department, its agents, motor carrier inspectors of the state police department, and other law enforcement officers can conduct motor vehicle and cargo inspections to determine [323].

The state of Indiana defines highway route-controlled quantity (HRCQ) radioactive material as a single package quantity exceeding the least of either: (i) 3000 times the A_1 value of radionuclides for special form Class 7 material, (ii) 3000 times the A_2 value of radionuclides for normal form Class 7 material, or (iii) 1000 TBq or 27,000 Ci. It is important to note that the values of A_1 and A_2 are listed in 49 CFR 173.435 and a radionuclide is an unstable isotope of a radiation-emitting element. To be permitted to ship HRCQ materials through Indiana, the shipper must submit an application to the department of homeland security. The permit is required to state its purpose and an expiration date. Before transporting HRCQ materials through Indiana, a shipper must submit the issued permit and fees for trucking shipments and/or rail shipments where applicable.

6.3.4. Infrastructure Needs

Nuclear power plants require infrastructure to be built and to operate. Electrical transmission lines, railways, roadways, emergency services, and water sources are examples of necessary infrastructure to create and maintain nuclear power plants.

6.3.4.1. *Electric Transmission Lines*

Electric power lines are a necessity for distributing the generated energy from the plant to the rest of the grid. The power plant connects to the grid using high-voltage long-distance transmission lines, allowing newly built power plants to be easily added to the electric grid. Unlike regulations for sitting, the NRC does not have any distance requirements for the plant's proximity to established power lines [324]. Although the NRC does not impose distance requirements for transmission lines, constructing new transmission lines, especially in rural areas where eminent domain is frequently invoked, presents significant challenges. From a financial perspective, repurposing a retired coal plant is more economically advantageous and likely more politically acceptable, as these sites already have substations connected to the existing transmission infrastructure.

6.3.4.2. *Railway Lines*

Railway lines are important to the transportation of fuel and materials for nuclear power plants. Nuclear power plants consume, on average, 27 tons of fuel per year at an average power of 1000 Mwe [325]. This fuel can be carried into the power plant through railways. In addition to fuel, modules of a power plant or SMR can be developed then transported to the plant site by railway lines and assembled on site [326]. Internationally, the IAEA considers land and railway routes with sufficient bridge and tunnel clearance for large loads as basic infrastructure for a nuclear power project but is less specific about railway line requirements [327].

6.3.4.3. *Roadways and Emergency Services*

Roadways to power plants allow access for both workers and emergency services and are constructed or upgraded as needed for new plants. Due to their flexibility, the NRC's Reactor Site

Criteria does not include any requirements for a plant's proximity to existing roadways. However, 10 CFR Part 100.2.e states, "Potential hazards associated with nearby transportation routes, industrial and military facilities must be evaluated, and site characteristics established such that potential hazards from such routes and facilities will pose no undue risk to the type of facility proposed to be located at the site." In the case of a fire emergency, nuclear plants are required to have their own on-site fire emergency services. This eliminates the need for regulations relating to the proximity of nearby fire stations. However, if necessary, additional fire safety and security services would be contacted. Access to existing off-site emergency services is an important infrastructure need to maintain the safety of nuclear power plants.

6.3.4.4. *Water Infrastructure*

Nuclear power plants and SMRs use water to generate electricity. Water is heated into steam and used to turn a turbine connected to a generator, creating electricity. This process requires the power plant have a constant water source. This can be achieved by siting the power plant near a large body of water and using a pumping system to transport it to the reactor. Besides, the steam cycle operates as a closed-loop system that requires a makeup water source. In most commercial reactors currently in operation, this makeup water is typically supplied through onsite wells. A large body of water is primarily necessary for the main condenser and service water system, which cool the closed cooling water systems within the plant. These systems, in turn, provide cooling for essential plant equipment such as pumps, motors, and heat exchangers.

6.4 Safety Comparison to Traditional Nuclear

6.4.1. Risk of Severe Accident

Small modular reactors are generally presumed to decrease the risk of severe accident potential by building on existing safeguards and security requirements [328]. Most SMRs can be built below ground to enhance protection from possible incidents involving "sabotage and natural phenomena hazard scenarios" [328]. SMRs can be fabricated and fueled in a factory decreasing the chance of potential severe accident scenarios during the "transportation and handling of nuclear fuel" [328]. In cases where the reactor is designed to be refueled at the factory, the module is sealed, transported back to the manufacturing facility, and a new, pre-fueled reactor core is installed at the site. For PWR SMRs, a decreased power density, number of fuel rods, and total fuel mass decreases the typical PWR concerns including but not limited to containment, heating, over pressurization, hydrogen production, and interactions between the fuel and coolant [329]. For HTGRs, TRISO fuel dramatically decreases the risk of severe accidents by creating fuel particles that can survive at 1800° Celsius for over 300 hours while containing fission products. This effectively prevents meltdowns in TRISO fueled reactors [330]. Economically viable molten salt rectors will allow SMRs to take advantage of the increased safety that comes with low operating pressures, reducing the risk of a loss of coolant accident [331]. Conversely, some organizations believe SMRs may decrease in safety due to passive safety systems which are not infallible, less robust containment systems, underground siting which increases risk of flooding, and the fact that more SMRs are required to meet the same energy needs [332].

6.4.2. EPZ Requirements

Current regulation for a traditional reactor requires a ten-mile EPZ for plume exposure and a fifty-mile EPZ for ingestion exposure. However, due to their smaller size and additional safety features, EPZs for SMRs are expected to be smaller than those of traditional nuclear power plants, and may not be required to extend beyond the plant's site boundary [333]. In the NuScale design, approved by the NRC, the EPZ was limited to the site boundary. Some EPZs may be scalable based on the projected accident offsite dose. [334] An example of a scalable EPZ setup can be observed in Table 20. Established EPZs for existing SMR designs are outlined in Table 21, noting that their EPZs are significantly smaller than EPZs for traditional reactors.

Table 20. Scalable EPZ

If projected accident offsite doses are greater than 1 roentgen equivalent man (REM) at *LOCATION* (mi)	EPZ would be *DISTANCE* (mi) from the site boundary
0	2
2	5
5	10
Less than 1 REM at site boundary	0

Table 21. EPZ Requirements Comparison

SMR Design	Manufacturer	Comparison to traditional nuclear
SMR-300	Holtec International	A NPP requires an EPZ of at least 10 miles from the site boundary, whereas Holtec claims there is no EPZ "required outside of the fence-line" [335] .
BWRX-300	GE-Vernova	The BWRX-300 claims to have an EPZ of 1000 meters or 0.62 miles [336] . This is much smaller than the 10-mile requirement for most TRs.
VOYGR	NuScale Power	NuScale's proposed EPZ of "the site boundary of the power plant" was accepted by the NRC. [334]
RR SMR	Rolls-Royce	In the most recent (March 19, 2024) stakeholder briefing, Rolls Royce stated they will publish findings and EPZ information in "late summer 2025" [337].
Xe-100	X-Energy	The Xe-100 uses a TRISO-X Fuel which reduces the safety perimeter from 10 miles to 400 meters.
Natrium Reactor	TerraPower-GE Vernova	Natrium published a related EPZ document, but it focused on seismic activity. No official EPZ was outlined [338].
KP-FHR	Kairos Power	Due to the use of TRISO fuel, "The radioactive consequences of [KP-FHR] accidents are anticipated to be low enough to enable an EPZ to be located at a site boundary that is substantially smaller than established for typical large LWR facilities." [339]

CHAPTER 7. COMMUNITY ENGAGEMENT

Community response is analyzed through feedback from focus groups and surveys, providing clear insights into public input. Insights about public interest and awareness are also gained through detailed analysis using data from surveys and focus groups. Lastly, community surveys are thoroughly implemented in Sections 7.2 and 7.3.

7.1 Introduction and Background

Considerations for the viability of nuclear energy, including SMRs, depend on stability, cost, governance, safety, security, and public perception [340]. Further considerations, such as public opposition to nuclear power, are based on historical incidents such as Chernobyl, Fukushima Daiichi, and Three Mile Island, as well as societal perceptions of risk and safety [341]. Addressing barriers to SMRs as a new energy technology implementation, such as public opposition and knowledge gaps, requires involving the public, government and regulatory decision-makers, developers, and utility operators in community-level deliberation and education processes [342].

As with other land use planning considerations, several siting criteria must be considered for SMRs, such as geographical, water resources, geological, exclusion zones, transportation routes, and socio-economic and environmental risks [343]. As a home rule state, local government entities oversee siting and development processes guided by local land use regulations. Indiana State Code outlines the authority of four types of plan commissions to guide the local planning process and authorizes land use regulation through standards and processes in the zoning ordinance [344]. Planning and zoning are voluntary in Indiana, with 82 of 92 counties adopting both planning and zoning.

This research on nuclear energy community considerations was conducted as part of the 2024 Indiana-Focused Small Modular Nuclear Reactor Study. Data was collected via four focus group sessions and a state-wide electronic survey to understand Indiana decision-makers' and residents' perceptions of nuclear technology, specifically of SMRs. The study focused on four thematic concepts, including opinions and perceptions about nuclear energy, nuclear energy siting, electricity production, and technical resources. Through these concepts, the study sought to explore the following questions:

1. What types of knowledge and opinions do decision-makers and residents currently possess about nuclear technology, specifically small modular reactors?
2. How do decision-makers and residents perceive land use siting for small modular reactors?
3. What are decision-makers' and residents' considerations for electricity production?
4. What types of technical resources do decision-makers and residents need for small modular reactors?

The results of this study are intended to be used as a baseline to better understand Indiana decision-makers' and residents' perceptions of SMRs and to guide future technical assistance and education resources for these audiences.

7.2 Methods

7.2.1. Focus groups

The focus group study included four sessions held virtually via Zoom in August 2024, with 18 participants from across the state. These participants represented four areas of expertise, including a) planners and emergency managers, b) local economic development officials and economic developers, c) local elected officials, and d) utility professionals. Participants were selected based on a constructed database that included county information, geographic identifiers from Indiana's population breakdown (metropolitan, micropolitan, and noncore areas), county plan commission type (advisory, area, metropolitan), and participant roles, ensuring a balanced representation of geography and office locations across the state [345], [346]. Each one-hour session was organized by area of expertise, with two to seven representatives attending each focus group.

The semi-structured focus groups followed the moderator guidelines of Krueger and Casey [347]. A lead researcher was the facilitator, guiding the conversation, asking questions, and listening to the participants, while a second researcher recorded notes and occasionally asked clarifying questions. Both researchers leading the focus groups were professionals in university extension and engagement community development with land use expertise. The focus group guide (Appendix L) was designed around four thematic concepts. The discussion began with general questions about the participants' opinions, perceptions, and knowledge about nuclear energy, including small modular reactor technology. The conversation shifted to nuclear energy siting, including local planning tools and considerations. The electricity generation discussion focused on current and future energy considerations, which were coded to include the state of Indiana's codified electricity policy (reliability, resilience, stability, affordability, and environmental sustainability). Each focus group session discussed the types of technical resources the participants needed to support nuclear energy decision-making.

The University Institutional Review Board approved the study under protocol number IRB-2024-850. Researchers collected responses through handwritten notes and audio recordings, with participant consent. The audio discussions were transcribed and reviewed against the notes for accuracy. A codebook was developed to ensure consistency between the two researchers during the coding process [348]. The codebook was created deductively, focusing on the four themes of opinions and perceptions about nuclear energy, nuclear energy siting, electricity production, and technical resources. After both researchers coded one transcript, the framework was updated inductively to collapse overlapping sub-themes in electricity production and eliminate child codes in technical resources to capture more resources (Appendix M). The two researchers coded the same transcript using the revised codebook, discussed the findings to ensure consistency, and made final adjustments to the framework. The remaining transcripts were split between the researchers and analyzed using NVivo 14 software. Intercoder reliability was established using Cohen's Kappa coefficient, with a score of 0.7 achieved after the third round of coding. Representative quotes were included in the results to highlight key themes. While data was anonymized to prevent identifying specific individuals or locations, quotes were attributed to general geographic areas or professional affiliations.

7.2.2. Survey

The project team developed a survey informed by a review of national and international nuclear energy public opinion surveys within the four research themes of opinions and perceptions about nuclear energy, nuclear energy siting, electricity production, and technical resources [349], [350], [351], [352], [353] (Appendix N). The University Institutional Review Board approved the study under protocol number IRB-2024-849.

The survey was designed as a 15-minute online survey using the Qualtrics® company platform. The survey sample was based on quota sampling. Sampling rates of selected characteristics were determined within Indiana or at the national level. Multiple quotas were used to improve the representation of particular respondent types and to ensure that certain types of respondents were not over-represented. Gender and age quotas were set by the Qualtrics® company using the U.S. Census demographic targets, while the residential location targets were set by Purdue using Indiana's population breakdown [345], [346]. The survey was limited to Indiana full-time residents above the age of 18 years. The quotas for gender were 48% male, 52% female, and non-binary, natural fallout. The quotas for age ranges were 30% for 18-34 years, 32% for 35-54 years, and 38% for ages 55+. The quotas for residential locations were 60% urban, 20% suburban, and 20% rural, with a population breakdown of metropolitan, 78.4%, micropolitan, 14.9%, and noncore, 6.6%. The additional consideration that small modular reactor technology may likely be installed in rural areas due to potential restrictions in zoning in micropolitan and metropolitan regions necessitated an oversampling of rural respondents.

Data were collected by the Qualtrics® company between July 2 and July 20, 2024, resulting in 1,012 complete and usable surveys. On average, the survey took respondents 12.7 minutes to complete (median was 8.9 minutes). The target number of surveys to be completed was one thousand.

The relationship between the quotas and the final sample is summarized in Table 22.

The survey quotas were generally satisfied, given the resources and timeframe available to conduct the survey, and a total of 1,012 valid and complete surveys were collected. Regarding gender, the sample contained slightly fewer males and more females. In terms of age, fewer respondents under the age of thirty-five responded to the survey than anticipated (264 versus 300), while more respondents were fifty-five or older (422 versus 380). Lastly, the quotas for suburban and rural respondents were met, while urban respondents were slightly underrepresented compared to the quota (547 versus 600).

Table 22. Comparison between Survey Quota and Survey Sample

Quota Variable	Quota	Percent of Survey Sample	Number of Survey Respondents
Gender:			
Male	48%	45.0%	455
Female	52%	53.9%	545
Non-binary	Natural Fallout	0.9%	9
Other	N/A	0.1%	1
Prefer Not to Answer	N/A	0.2%	2
Total	*100%*	*100%*	*1012*
Age:			
Age 18-34	30%	26.1%	264
Age 35-54	32%	32.2%	326
Age 55+	38%	41.7%	422
Total	*100%*	*100%*	*1012*
Residential Location:			
Urban	60%	54.1%	547
Suburban	20%	22.4%	227
Rural	20%	22.1%	224
Prefer Not to Answer	N/A	1.4%	14
Total	*100%*	*100%*	*1012*

While the county of residence was not part of the study, it should be noted that eighty-six of the ninety-two Indiana counties were the source of at least one response (Table 23). The proportion of responses by county generally followed the population, with Marion County being the most populated and the source of the largest number of surveys.

Survey responses were not recorded from the following counties: Carroll, Martin, Pike, Switzerland, Tipton, and Union. The U.S. Census classifies all of these counties as Noncore.

Table 23. Survey Respondent Residence by County

County	N	Percent
Adams	7	0.69%
Allen	77	7.61%
Bartholomew	14	1.38%
Benton	1	0.10%
Blackford	5	0.49%
Boone	12	1.19%
Brown	3	0.30%
Cass	6	0.59%
Clark	22	2.17%
Clay	5	0.49%
Clinton	3	0.30%
Crawford	1	0.10%
Daviess	3	0.30%
Dearborn	4	0.40%
Decatur	6	0.59%
DeKalb	3	0.30%
Delaware	22	2.17%
Dubois	3	0.30%
Elkhart	25	2.47%
Fayette	4	0.40%
Floyd	13	1.28%
Fountain	4	0.40%
Franklin	4	0.40%
Fulton	2	0.20%
Gibson	5	0.49%
Grant	6	0.59%
Greene	4	0.40%
Hamilton	29	2.87%
Hancock	11	1.09%
Harrison	6	0.59%
Hendricks	11	1.09%
Henry	3	0.30%
Howard	21	2.08%
Huntington	5	0.49%

Jackson	12	1.19%
Jasper	5	0.49%
Jay	2	0.20%
Jefferson	8	0.79%
Jennings	3	0.30%
Johnson	14	1.38%
Knox	7	0.69%
Kosciusko	8	0.79%
LaGrange	3	0.30%
Lake	63	6.23%
LaPorte	25	2.47%
Lawrence	4	0.40%
Madison	24	2.37%
Marion	191	18.87%
Marshall	7	0.69%
Miami	2	0.20%
Monroe	14	1.38%
Montgomery	2	0.20%
Morgan	6	0.59%
Newton	3	0.30%
Noble	10	0.99%
Ohio	2	0.20%
Orange	2	0.20%
Owen	3	0.30%
Parke	3	0.30%
Perry	6	0.59%
Porter	21	2.08%
Posey	2	0.20%
Pulaski	1	0.10%
Putnam	5	0.49%
Randolph	3	0.30%
Ripley	3	0.30%
Rush	1	0.10%
Scott	6	0.59%
Shelby	8	0.79%
Spencer	2	0.20%
St. Joseph	50	4.94%

Starke	2	0.20%
Steuben	6	0.59%
Sullivan	2	0.20%
Tippecanoe	20	1.98%
Vanderburgh	43	4.25%
Vermillion	1	0.10%
Vigo	22	2.17%
Wabash	5	0.49%
Warren	1	0.10%
Warrick	4	0.40%
Washington	4	0.40%
Wayne	11	1.09%
Wells	3	0.30%
White	4	0.40%
Whitley	3	0.30%
Total	1012	100.00%

7.3 Results and Discussion

7.3.1. Focus groups

7.3.1.1. Opinions and perceptions about nuclear energy

Focus group participants were asked to describe how well-informed they were about nuclear energy used to produce electricity, specifically SMRs, which led to more focused discussions about concerns, advantages, and trusted sources of information. The utility focus group and local economic development participants expressed that they possessed some knowledge about nuclear and SMR technologies, with local elected officials, planners, and emergency manager participants expressing a lack of knowledge. References to public acceptance concerns, especially due to high-profile historical disasters, were frequently mentioned in each focus group discussion.

> "…there is history with nuclear and already formed opinions… it is not about what are the perceptions, it is rather, how do you stack new information to offset changing those perceptions. People know two things about nuclear. One, we dropped the bomb during World War II…and then we had nuclear power, and it did not go well." – Local economic developer

Perceptions of safety and adequate emergency response were two predominant themes of concern in all focus group discussions. Specifically, in discussions with local government officials, economic development, planners, and emergency responders, the concern about the lack of knowledge and the ability of local government and emergency responders to be able to adequately address nuclear considerations, especially in counties that are underfunded for emergency responses and have limited or no hospital and medical access.

> "What are the safety implications of having them…I just do not know enough to even have that conversation…let alone with nine members of a planning commission." – County plan director

The utility providers' concerns also expanded into the feasibility of implementing nuclear technology related to cost, timelines, and regulatory requirements.

> "…concerned about the ability to execute on something like this…(nuclear) has this long construction and planning timeframe, some more than ten years, probably from start to finish. Over that time, you have to invest significant amounts of dollars along the way…and ensure that there are regulatory processes and procedures in place where commissions can ensure that utilities, as long as they are moving prudently and checking points along the way, the commission will approve cost recovery from customers…and utility shareholders are not at risk of losing out when there are things like cost overruns." – Utility representative

Utility participants also mentioned concerns from a national security standpoint when procuring uranium in the supply chain.

> A major concern is "the lack of diversity in the supply chain around uranium, and how that works…Russian-sponsored companies essentially control a good portion of that market, and you cannot avoid ever dealing with them because they are the cheapest offer on the market, or at least they have been historically…the dependency on a foreign source of energy or that perception is also going to be tough to deal with." – Utility representative

Each focus group mentioned the advantages of nuclear energy, such as being more efficient in operation and land use, more reliable, and a cleaner energy source than natural gas. Nuclear power was also compared as an alternative to solar power, with the advantage of a smaller footprint.

> The advantages of nuclear are that it is "…more efficient…if you are a business or an industry looking at something when you need power, you need it now…you cannot wait on solar... it is a shock absorber in the system that we do not have now." – Local elected official

> "…when you think about clean energy, and you are getting to net zero, carbon emissions, it sort of has to be on the table. Not only the existing nuclear that we have but new nuclear. I do not think a grid effectively works, probably without it. So that is a pretty good argument to try to find a way to make it work within that United States grid." – Utility representative

> "…the smaller footprint…we have that huge solar farm here, and the biggest argument that we hear is losing the farm ground." – County plan director

All focus groups additionally mentioned economic development and job creation as advantages of nuclear.

> "There is a lot of job creation that goes along with that, a lot of economic benefit to the area that would receive it, in addition to the entire supply chain that it takes to fabricate." – Utility representative

> "I imagine there are really high, skilled, high paid good jobs. I would imagine that comes along with SMRs." – Local economic developer

Trusted sources of information mentioned in all focus groups included universities with expertise in nuclear energy and land use, such as Purdue and Purdue Extension as a technical assistance provider, federal government offices and laboratories researching nuclear energy, the U.S. military through its long history with nuclear energy, and nuclear industry experts. All focus group conversations additionally listed concerns about conveying information through trusted sources of information and how to conduct education programs with the public.

> "It is not always easy to know who I would say the good actors and the bad actors are, but you know, just sourcing good information that you have confidence in….it goes back to…education and trying to really sift through what is real facts, or what is prospective confidence." – Local economic developer

> "…understanding what advancements have taken place, so we understand it from a safety standpoint but also being able to describe that not only to our boards of citizen planners, but to the members of the public, that may be the ones living next to something like this, and understanding what that is going to look like, how can it be mitigated." – County plan director

7.3.1.2. Nuclear energy siting

Focus group participants were asked about siting considerations for SMRs. This discussion often included what was needed for the SMR technology as well as potential land use conflicts. All four focus groups also discussed community engagement in the siting process.

Seven of the 13 community-based participants shared that they had engaged in at least preliminary discussions about nuclear or SMR technology, specifically in their communities or organizations. This ranged from mentioning that it should be included in a future comprehensive plan to engaging in research and learning about nuclear technology. All four focus groups discussed technical considerations for siting, including proximity to transmission lines and substations, geological needs, and water access.

> "It would be as close to the grid as they can….close to a large substation to move the power out as it is produced." - Local elected official

> "It is maybe even a little more finicky than other generation sources because it obviously needs water access and transmission availability... Seismic activity is something you want

to try to avoid. So it is a little more particular, and to try to find the right kind of location ... not everywhere, is going to be a great location for them" - Utility representative

Focus participants also expressed looking at demand when considering siting SMRs.

> (SMRs need to be) "close to ...our big industries that need that power." - County plan director

> "Where is it very hard to get that kilowatt? Are there deserts? If we look at maps in terms of our infrastructure... are there areas and gaps in the infrastructure to where it would make sense to put a small modular reactor." - Local economic developer

The planners and emergency management focus group discussed transportation and decommissioning.

> "...during the construction phase, and then during your operational phases and then, if there is any routine maintenance or emergency operations... you do not want something to go wrong, and you are going down a county road to get to this thing (you want to know) that the roads are wide enough to handle, and designed to handle the heavier equipment that's going to be running on them." - Emergency management director

> "I think you would have to look at the decommissioning plans." - County plan director

Utility participants mentioned the need for a workforce throughout the different phases of an SMR.

> "You are also going to need not just construction resources but also operating and maintenance, as well as your personnel. So, a trained, educated workforce, or at least a location where folks like that are willing to relocate to." - Utility representative

Three of the focus groups brought up safety standards or considerations in siting.

> "Because of the heightened public perception of this as a threat. I wonder if some people might drive some sort of, you know, early warning detection." - Local economic developer

> "Something else to throw on the radar interconnected to this is that emergency services plan. Obviously, an operation like this would need a very unique response mechanism." - Local economic developer.

Focus participants also discussed potential land use conflicts between SMRs and other land uses and possible tools to mitigate. Most of these discussions centered around residential. Utility representatives, planners, and local elected officials all mentioned setbacks or buffers as tools to reduce land use conflict.

> "There has to be a certain separation from homes or distance between a city and one of these..." - Utility representative

Planners also brought up possible unintended consequences of buffer yards or landscape screening.

> “One of the possibilities is putting up a buffer yard of sorts, which provides a lot of nesting opportunities for different animals and birds, but sometimes that can create secondary issues with the electrical system. That you do not necessarily want to promote bird and rodent housing immediately next to something that's going to compromise the system.” - County plan director

From a viewshed perspective, planners discussed how scale and aesthetics affect how well an SMR blends into the surrounding area.

> “Understanding what that scale will look like will change the character around it and so on if it blends in…I have seen a substation of sorts for, I think, a water pump station, and they built it to look like a house nobody ever pulls in for the most part. But you would not know if you drove by.” - County plan director

Other factors that participants named could contribute to land use conflict, including noise level, property values, and possible emissions. Participants in the planning and emergency management focus group recognized that current and past development regulations could affect where SMRs can be sited, mainly residential sprawl.

> “We allow single-family homes in our Ag areas a lot. ... requiring only two acres for a new single-family home in any Ag area. So should we be limiting those (in) areas that these nuclear SMRs should be sited?” - County plan director

Focus group participants also discussed general locations for SMRs. Both local economic developers and elected officials mentioned repurposing coal fire plants that have retired or are retiring.

> “And if they plan to shut down these coal fire (plants)...that would be a question for Duke and NIPSCO. Could they put it back into that same footprint as the coal fire (plant) was? To be able to use still the main lines and the substation that's already there.” - Local elected official

> “I have always been thinking about closing all these coal plants. How could they be repurposed? They have all the transmission sort of infrastructure there, and many of them are very remote and already sort of viewed as a high-intensity use.” - Local economic developer

Several focus participants discussed siting in rural versus urban areas. There was some agreement that rural areas are likely more accessible to site in due to lower population density. However, there is some concern about resources and support in rural areas and consideration for where the energy is needed.

> “For rural locations away from populations, you are going to have an easier time to pass that than you will if you put it around some of these towns.” - Local elected official

> "The whole idea is to put it where you need it. Well, I need it right down the street. I think that is going to be a bit of a challenge, convincing people that it is okay to have it two and a half miles outside your city gate." - Utility representative

> "So just maybe some compounding site dynamics,...the more rural you go, the less infrastructure and support, and capacity may be that smaller, more rural community might have for those (emergency) responses as well." - Local economic developer

All four focus groups discussed community engagement in siting SMRs. A theme that emerged was the importance of informing and educating participants, citing the newness of SMR technology and the lack of conventional nuclear energy production in Indiana as primary reasons. Participants listed the general public, decision-makers, and youth as three distinct audiences for education.

> "So understanding what advancements have taken place, so we understand it from a safety standpoint but also being able to describe that not only to our boards of citizen planners, but to the members of the public, that may be the ones living next to something like this, and understanding what that is going to look like, how can it be mitigated." - County plan director

> "So I mean, you probably start talking to junior high and high school kids if you want to get this to pass in ten years." - Local elected official

Participants in the planning and utility focus groups discussed the need for public discourse in the siting process.

> "…getting locals involved, getting decision-makers at that area to be supportive, or talk about its importance... these developers or anybody else that they need to come in early and spend the time at the local level." - Utility representative

> "If something like this moves forward, we will start discussing it... how do our standards, UDOs, and zoning ordinances reflect this?" - County plan director

Three of the four groups mentioned conflict in communities over land use planning and concerns about shifting policies, particularly a perceived increase in the use of moratoriums. Participants drew parallels between SMR siting and solar and battery storage siting.

> "It is just those "what ifs" that people lay in bed thinking about at night, to then bring up to a county's meeting that the county commissioners then want to pull a moratorium on whatever we are discussing. They want to put a moratorium on it. That seems to be the clickbait for the county commissioners these days is moratorium everything." - County plan director

> "It is frustrating sometimes, and as I said, I could draw parallels to solar because, at the end of the day, the state of Indiana operates that you own your property, and for the most

> part, you can do what you want on it with some limitations, but solar projects I mean you have got counties that have done full moratoriums on solar. Who is to say a county, a region, or state will not do full moratoriums on SMRs." - Local economic developer

> "You are going to have the typical sort of bipolar... social media fighting that drives so many, so much of public opinion these days. I think so whoever does the Facebook game [best], I guess, would win" - Utility representative

7.3.1.3. Electricity production

Participants were asked to share some considerations for how electricity is produced now and in the future that are important to their communities and areas of expertise. Follow-up questions clarified responses to follow the state of Indiana's codified electricity policy: reliability, resilience, stability, affordability, and environmental sustainability. Another category was added to address planning for longer term technology development that did not fit one of the five pillars.

Reliability consists of adequacy, the ability of the electric system to supply the electrical demand and energy requirements for end-use consumers at all times, and operating reliability, the ability of the electrical system to withstand sudden disturbances. This pillar was mentioned the most frequently across all focus groups. Participants mentioned the need for a consistent electricity supply and the need to use electricity whenever needed, especially in light of coal plant retirements and the expanded development of data centers and artificial intelligence technologies that will increase electricity demand.

> "Only because we have been dealing with natural gas or lack thereof issue which has forced us for the last five years to look at our capacity…just in the last year, we have had two large data centers…which is going to suck much electricity out of capacity, meaning out of the region regardless of where they are getting it from." - Local economic developer

> "One of the RFIs that came through the State was about 30% more than the whole county's current usage of electricity. And if you do look at trends, most of these projects that are coming to us, which is only a fraction of all the projects, we see the requirements, and the demands for electricity continue to go up." – Local economic developer

> "But a lot of it comes down to. I do not want to look at it or have it affect my property values. I still, at whatever cost, want to be able to turn my stuff on." – County plan director

Resilience is the ability of a system or its components to adapt to changing conditions and to withstand and rapidly recover from disruptions or off-nominal events. This pillar was mentioned the least and was discussed in the three focus groups of local economic developers, planners and emergency managers, and utilities. The themes included updating infrastructure so that the grid can withstand security breaches and natural disasters.

> "…the age and condition of it, the resistance to any hazards out there to include earthquakes, floods, extreme weather…And the company's response and recovery capabilities. How long does it take to restore power when it is out, and as well as the repair and maintenance that they go through." – County emergency manager

Stability refers to the ability of an electric system to maintain a state of equilibrium during normal and abnormal conditions or disturbances. Local economic developers, planners, and emergency managers discussed stability regarding concerns over potential disruptions through companies changing hands, especially large entities with parent companies outside of the United States.

> "We should be having and creating our own power, and not having it owned by whatever other foreign group is out there, so that is a big thing… who is going to end up owning that power?" – County plan director

> "trying to make electricity more and more local as possible to help stabilize the grid infrastructure for us." – County emergency manager

Affordability refers to retail electric service that is affordable across the residential, commercial, and industrial customer classes. Although all focus groups discussed affordability, the utility focus group discussed it most frequently from the perspectives of operating costs and affordable consumer rates.

> "…I look at my so charges right now, and you know it is the single fastest increase I see on our cost to serve. That is not even my fuel charges, not my PPA. It is MISO pass through charges are the single fastest rising price I have right now, grid reliability and upgrade. Think of the money you can spend on putting that into a reactor at your back door." – Utility representative
>
> "…just give us the cheapest, cleanest stuff that you can…those are kind of the two major customer groups or advocacy groups." – Utility representative

Environmental sustainability includes decisions regarding Indiana's generation mix that take into account both environmental regulations and consumers' demands for sustainable sources of generation. Similar to affordability, environmental sustainability was mentioned in all focus groups, with greater emphasis from utility representatives. The theme of combining clean energy with clear regulatory requirements and affordable cost was present across focus groups.

> "the general direction seems to be cleaner energy sources. But how fast will we have to get there because of different environmental regulations that will come down on us?...you don't want to be in a position necessarily where you have all of your eggs in one basket, so kind of diversity of some renewables as well as some storage, as well as some natural gas in the

near term, and the midterm. And then really looking towards SMRs and advanced nuclear towards the end of the planning period. Timeframe seems to be a pretty decent strategy given the fact that nobody can predict the future." – Utility representative

The utilities focus group participants further addressed all five pillars as striving for a balance to meet customer needs.

> "Trying to balance all of those things at once and come up with the right mix of generation for utilities is what we strive to do." – Utility representative
> "…there are different customer groups that have different concerns that at least we are always trying to balance." – Utility representative

Other considerations for electricity generation that the focus groups addressed included adding nuclear to long-term plans of 20 years or more, especially considering SMRs are a new technology and development and construction require long timelines. All groups also mentioned the need for a balanced approach of multiple energy sources, including nuclear.

> "We are looking at our 20-year plan for resources for energy right now…in our prior plan things like small modular nuclear or advanced nuclear was showing up sort of in the back half of half of the 20 year plan…given the timeframe that it takes to get it developed to the place where it's commercially available...and then actually get a plant, sited and operating." – Utility representative

> "We need to update our comprehensive plan. Ours is pretty boilerplate about 25 years ago, to start with…none of that was considered…understanding where electricity is going to be playing a part is important from a planning side. Now, whether or not it gets to the policy, and a part of that document is going to be a whole another thing." – County plan director

> "I think we were shortsighted in dismantling coal soon, and now our baseload suffers for it…we should have fought harder as the utility sector to keep those online longer. Let's see how people are when it comes time to dismantle the windmills when they are at the end of their life cycle, which is going to be soon. And what is going to go in their place?... hopefully, will have small nuclear to go in that slot…it's all of those things. – Utility representative

> "Twenty years from now, instead of redoing the (wind) towers, or redoing solar, they will just come down…this technology might cost more upfront, but the maintenance probably will not be what it is on wind or solar…they will actually run their timeframe, and then we won't revisit them." – Local elected official

7.3.1.4. Technical resources

All four focus groups shared technical resources, or assistance they felt was needed to site SMRs. Participants in each group talked about general education. This included SMR technology, electricity generation, and future energy demands. Planners specifically felt that understanding the scale and characteristics of SMRs was crucial to being able to discuss siting regulations and that education needed to be backed by research.

> "But the understanding the size. I just can't wrap my mind around what size they would be to you know make sure your regulations for the SMRs would be accurate." - County plan director

> "I need good educational materials. I have seen brochures. I have not seen videos, films. I have not had cases presented. I need to be able to have this firehose effect of information and education push out. I need a big pipe of information." - Local economic developer

Technical assistance was mentioned a couple of times. One local economic developer felt communities would need help with emergency response planning and elected officials discussed the need for risk assessments for potential sites.

> "I think that any community that did this would probably look for some state or federal support on how do they skill up or professionalize... [a] response mechanism." - Local economic developer

Planners, local economic developers, and local elected officials all discussed the need for clear policies, regulations, and guidelines.

> "Getting the state to come in and be like, 'Hey, this is kind of what we're looking at'... or understanding that the IURC may step in and make this regulation." - County plan director

> "I do not think any community is going to want the feds or the state to tell them what they can and cannot do and get rid of our local rule. However, at the same time, there needs to be some kind of guidelines, or even standards or minimums." - Local elected official

> "I will share that the Indiana legislature seems to lead. If it is a political hot potato, they do not want to touch it, and nothing is going to happen." - Local economic developer

One of the local elected officials and a utility representative stressed that setting up a new technology like this is a collaborative effort.

> "If there was some effort to bring those voices together in a message that you know hit places where people are looking, not just technical magazines or trade magazines, that type of thing," - Utility representative

> "I just think it is going to have to be a group effort by the universities, electric companies, MISO... and at state and federal levels.... Everybody is going to have to get down to the table and figure out." - Local elected official

7.3.2. Survey

The following analysis of survey data employs the survey instrument for structure and uses the full sample of respondents (N = 1,012) unless noted otherwise. Table titles reflect the questions asked in the survey.

7.3.2.1. Opinions and perceptions about nuclear energy

Only 6.3%, or 64 out of 1,012 respondents, felt that they were well informed about nuclear energy used to produce electricity (Table 24). Nearly two-thirds (62.5%) thought they were either moderately or slightly informed, with almost 40% of respondents indicating they were "slightly informed," whereas 23% replied as moderately informed about nuclear energy used to produce electricity. The remaining nearly one-third (31.1%) of respondents replied that they were "not at all informed" about the use of nuclear energy to produce electricity.

Table 24. How informed do you feel about nuclear energy used to produce electricity?

How much informed?	**N**	**%**
Not at all informed	315	31.1%
Slightly informed	403	39.8%
Moderately informed	230	22.7%
Well informed	64	6.3%
Total	*1,012*	*100.0%*

Slightly more than sixty percent (61.3% or 620 out of 1,012 respondents) of respondents mentioned that they had not heard about the advanced-design nuclear power plants and SMRs (Table 25). This is equivalent to three out of five respondents mentioning that they had not heard about advanced-design nuclear power plants or SMRs. Slightly more than a quarter (26.3% or 266 respondents) reported that they had heard about the advanced-design nuclear power plants and SMRs. Around 13% or 126 out of 1,012 respondents mentioned that they were not sure if they had heard about the advanced-design nuclear power plants and SMRs.

Table 25. Have you heard about advanced-design nuclear power plants called Small Modular Reactors (SMRs)?

Heard about SMR?	N	%
No	620	61.3%
Not sure	126	12.5%
Yes	266	26.3%
Total	*1,012*	*100.0%*

Nearly 12% (11.8%, or 120 out of 1,012 respondents) of respondents either strongly oppose or oppose the idea of using SMR nuclear technology for electricity generation (Table 26). On the opposite end of the spectrum, 46% of respondents (465 out of 1,012 respondents) either favor or strongly favor the idea of using SMR technology as one of the ways to produce electricity in the U.S., with nearly 13% (12.7%) of all respondents strongly in favor. Slightly more than 42%, or two in five respondents, were neutral, neither opposing nor in favor of using SMR technology for electricity generation.

Table 26. How much do you oppose or favor the use of SMR nuclear technology as one of the ways to produce electricity in the United States?

Oppose or favor SMR	N	%
Strongly oppose	45	4.4%
Oppose	75	7.4%
Neither oppose or favor	427	42.2%
Favor	336	33.2%
Strongly Favor	129	12.7%
Total	*1,012*	*100.0%*

Respondents were asked to select their three greatest concerns about the SMR nuclear technology from a given set of concerns (Table 27). Risk of accident (63.4%) and Production of radioactive water (55.7) were the greatest concerns as both concerned more than half of all respondents. Onsite waste storage (41.3%) was a concern of about two-fifths of the respondents. Cost of nuclear power (24.1%) and Lack of understanding of the technology (23.1%) concerned almost a quarter of respondents. Respondents were least concerned with Lack of transparency in regulatory or development process (17.8%), Time it takes to build a power plant (11.8%), Competition with investment in renewable energy (9.5%), and Fuel reliance from foreign adversaries (9.3%). Approximately one in ten respondents (10.5%) responded that “I do not have concerns about nuclear power.”

Table 27. Select your three greatest concerns related to SMR nuclear technology (ordered by percent of respondents choosing a specific concern from highest to lowest concern)

Description of Concern	Frequency	Percent of Respondents
Risk of accident	642	63.4%
Production of radioactive water	564	55.7%
Onsite waste storage	418	41.3%
Cost of nuclear power	244	24.1%
Lack of understanding of the technology	234	23.1%
Lack of transparency in regulatory or development process	180	17.8%
Time it takes to build a power plant	119	11.8%
I do not have concerns about nuclear power	106	10.5%
Competition with investment in renewable energy	96	9.5%
Fuel reliance from foreign adversaries	94	9.3%
Other	23	2.3%

Respondents were asked to select three strongest arguments for using the SMR nuclear technology (Table 28). The top three arguments for SMR nuclear technology were Low cost of electricity (48.1%), Energy independence (40.7%), and Reduction of greenhouse gases (38.2%), followed by Preservation of natural resources (35.8%), Good paying jobs (28.5%), Reliability of electricity (28.1%) and Safety of nuclear facilities (17.1%). The least strong argument for SMR was the Battery storage capability for other energy production, with only 7.6% of respondents citing it as one of their top three. Meanwhile, nearly one in six (15.4%) respondents indicated that they do not have a strong argument for nuclear power.

Table 28. Select your three strongest arguments for SMR nuclear technology (ordered by percent of respondents choosing a specific argument from highest to lowest)

Description of Argument	Frequency	Percent of Respondents
Low cost of electricity	487	48.1%
Energy independence	412	40.7%
Reduction of greenhouse gases	387	38.2%
Preservation of natural resources	362	35.8%
Good paying jobs	288	28.5%
Reliability of electricity	284	28.1%
Safety of nuclear facilities	173	17.1%
I do not have a strong argument for nuclear power	156	15.4%
Battery storage capability for other energy production	77	7.6%
Other	14	1.4%

Respondents weighed in on the perceived trustworthiness of various sources of information on nuclear technology (Figure 61). The twelve options included elected officials, governmental agencies, organizations, businesses, science journals and scientists. Of the 1,012 valid responses, respondents selected Federal Elected Officials as the least trustworthy amongst the twelve sources of information for nuclear technology (Yes = 28.3%), followed by State and Local elected officials (Yes = 34.1% and 37.2%, respectively). In contrast, the most trustworthy resource was Scientists (Yes = 82.7%).

While elected officials had the lowest level of trustworthiness, government agencies performed better with State Government agencies being the most trustworthy sources of information amongst the three (Yes = 48.1%) and Local the least (44.5%). In comparison, 62.6% and 64.1% of respondents selected public regulatory authorities and science journalists as trustworthy sources of information about nuclear technology. Meanwhile, utilities, nonprofits, and nuclear plant manufacturers received 59.3%, 57.9%, and 54.1% affirmative responses, respectively.

The gap between affirmative response between Scientists, the top-ranked option, and science journalists, the second-ranked option, is almost 19 percentage points. An impressive eight in ten respondents in the Hoosier state selected scientists as trustworthy sources of information.

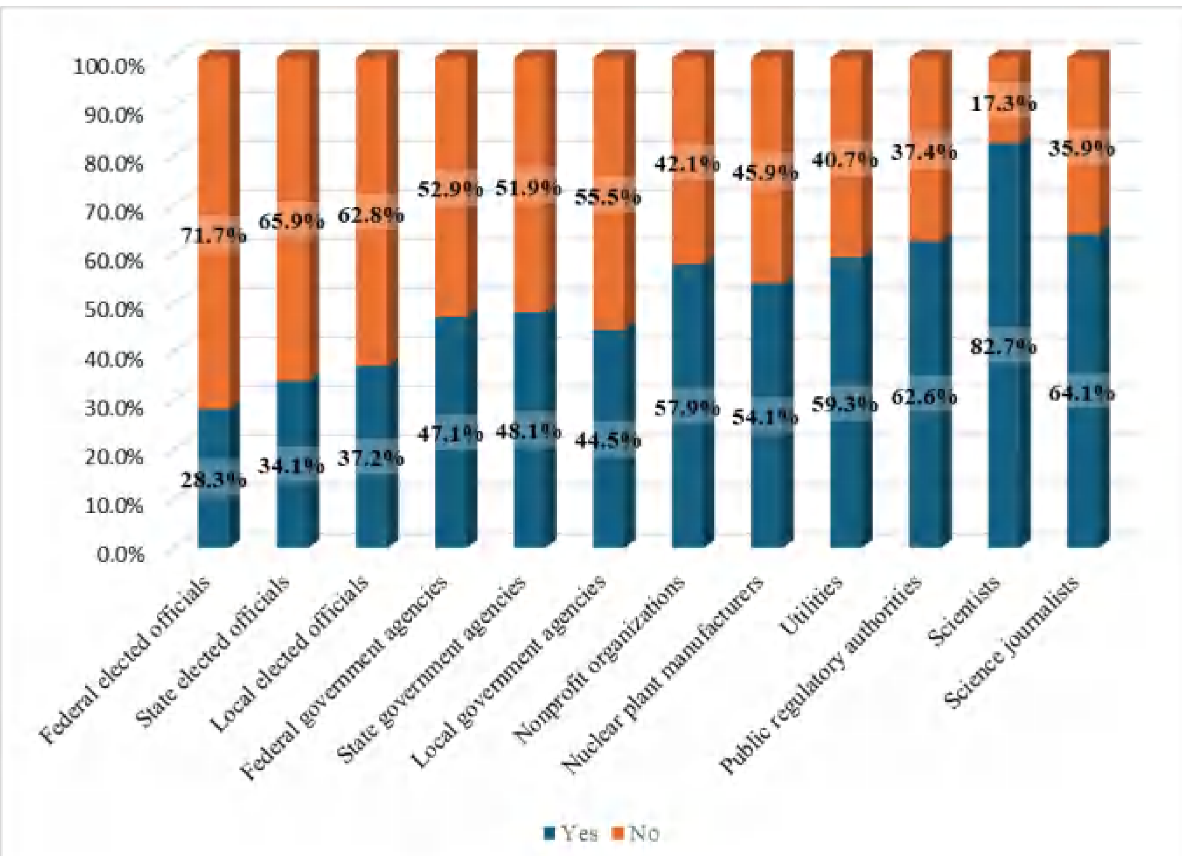

Figure 61. Which of the following do you think are trustworthy sources of information on nuclear technology? Yes or No?

Respondents were asked about their level of confidence regarding the safety of conventional and SMR nuclear power plants (Figure 62 and Figure 63).

For conventional nuclear power plants, 20% of 1,012 respondents considered the conventional nuclear power plant a very safe option. Of 1,012 respondents, 44% considered conventional nuclear power plants moderately safe. This means that almost three out of five respondents were confident that conventional nuclear power plants were either very safe or moderately safe. Eighteen percent of respondents considered conventional power plants as “Not Safe” and another 18% of respondents did not know the safety aspects of conventional nuclear power plants.

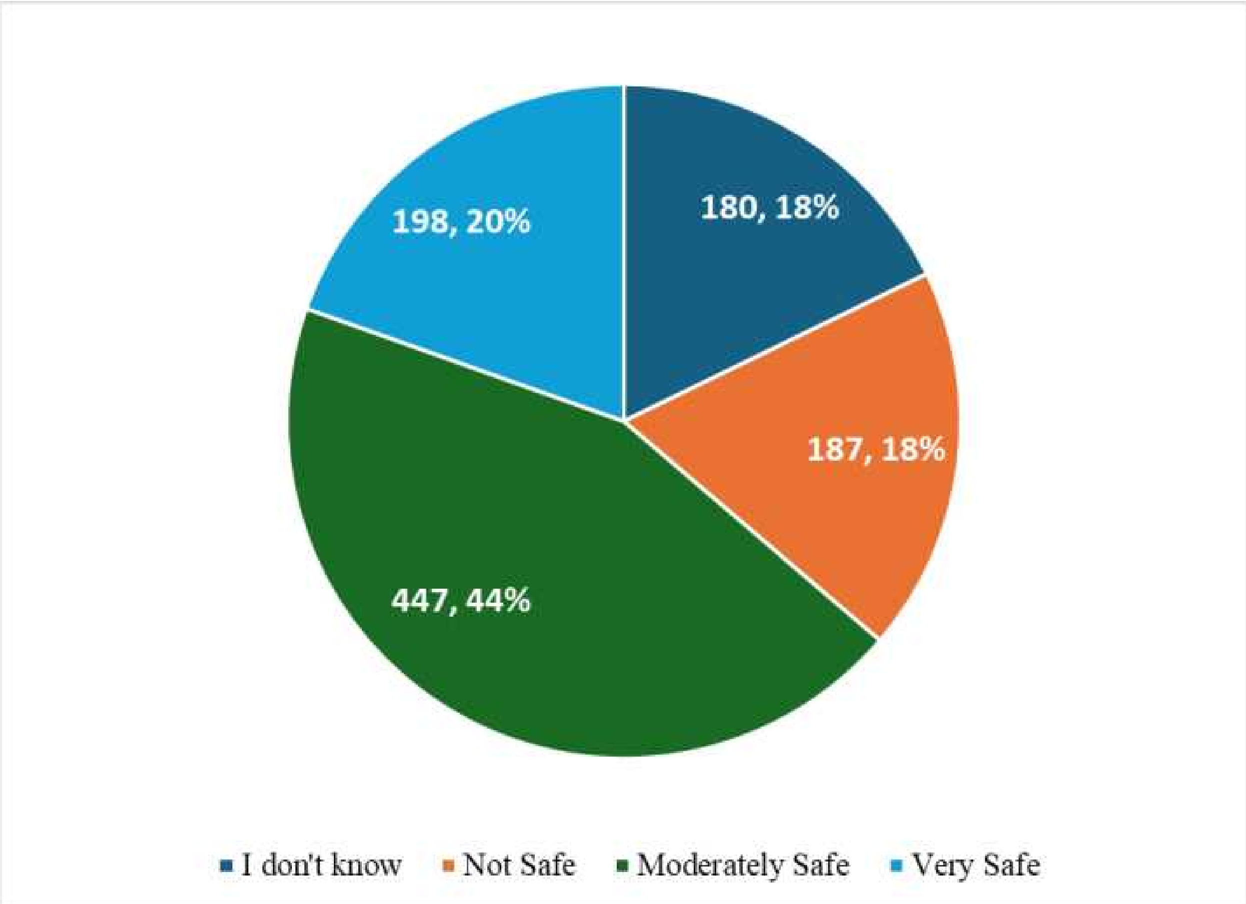

Figure 62. What is your level of confidence in the operational safety of nuclear power plants – Conventional nuclear power plants

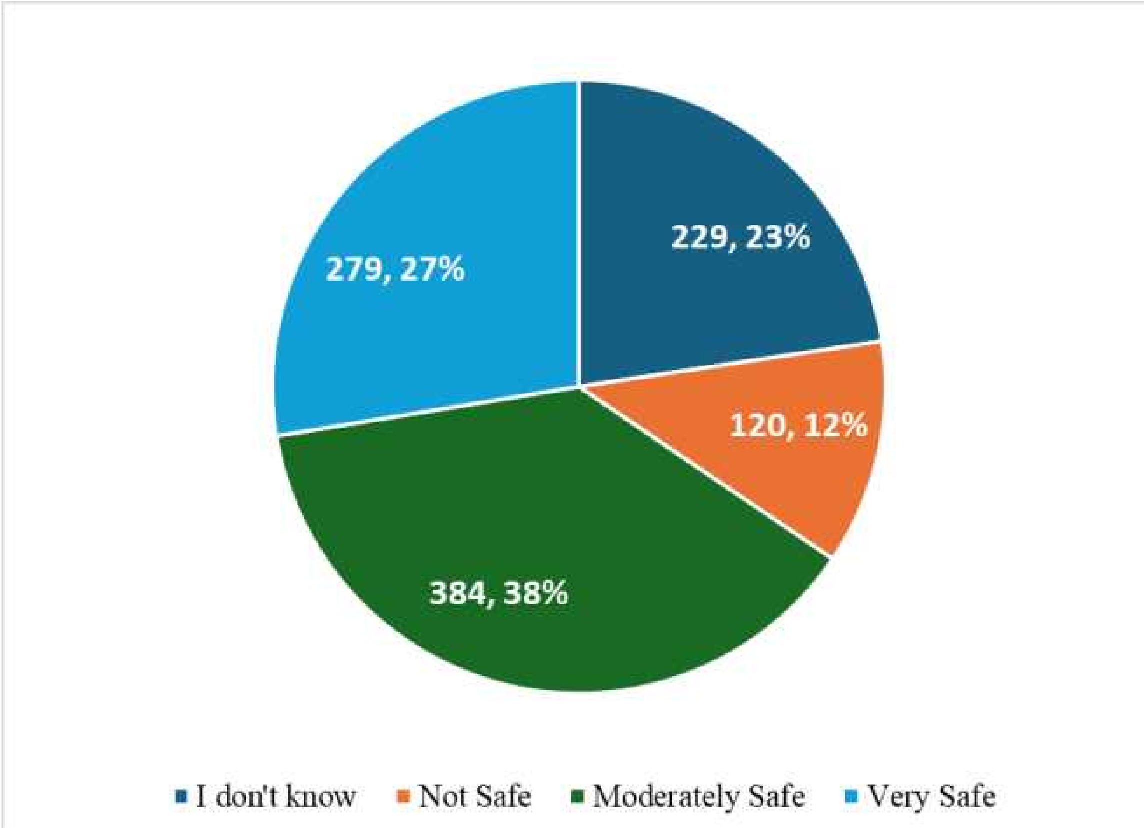

Figure 63. What is your level of confidence in the operational safety of nuclear power plants – SMR nuclear power plants

In contrast to conventional nuclear power, 27% of respondents were confident that SMR nuclear power plants are very safe, and 38% were confident that SMR nuclear power plants are moderately safe. This means that 65% of respondents, or three in five respondents, considered SMR nuclear power plants as either very safe or moderately safe. Nearly one in four (23%) respondents reported that they didn't know about the safety aspects of the SMR nuclear power plants. Twelve percent of respondents replied that the SMR nuclear power plants were not safe.

For comparison, if safety ratings are scored from zero to two (Not Safe = 0, Moderately Safe = 1 and Very Safe = 2), the conventional nuclear energy safety score was 1.01 versus 1.2 for SMR. Both are in the moderately safe range.

In addition to the level of confidence in the operational safety of nuclear power generation, respondents were also asked about the safety related to the radioactive waste generated from nuclear energy production (Figure 64). Out of 1,012 respondents, only 13% selected onsite storage of nuclear waste as very safe, and 45% selected onsite storage of nuclear waste as moderately safe. This means that 58% of respondents, or almost three in five respondents, considered the storage of nuclear waste onsite as either a very safe or moderately safe option. 19% of respondents, or nearly one in five respondents, selected that they didn't know about the safety aspects of onsite nuclear waste storage. Twenty three percent, or nearly one in four respondents replied that onsite storage of nuclear waste was not safe.

Similar to the analysis for the operational safety of nuclear energy production, if safety ratings are scored from zero to two (Not Safe = 0, Moderately Safe = 1 and Very Safe = 2), the nuclear waste storage score was 0.876, or between not safe and moderately safe.

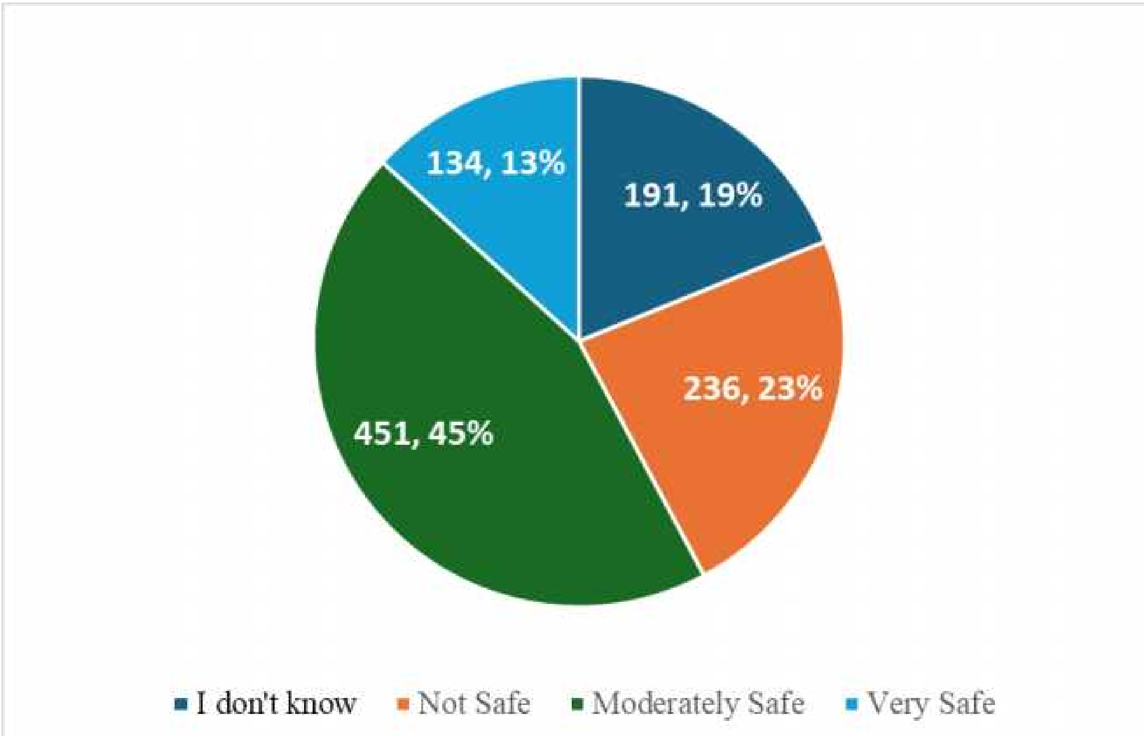

Figure 64. What is your level of confidence in the safety of onsite nuclear waste storage?

The final safety question in this survey section was related to the likelihood of various technological activities causing a serious accident or disaster (Table 29). For simplicity, the lowest and highest levels of likelihood were combined with their 'somewhat' counterparts to analyze which technological activities were perceived to have the highest (or lowest) likelihood of causing a serious accident or disaster. Nearly three-quarters of respondents (73.5%) regarded the Transport of hazardous material as the most likely to cause a serious accident or a disaster, with Chemical facilities (65.3%) and Virus research laboratories (57.3%) rounding out the top three. Air transport (31.4%), SMRs (28.3%) and Natural gas distribution (27.1%) were deemed to be relatively safe, with between a quarter and a third of respondents reporting that a serious accident or a disaster caused by these activities was Not at all likely or Somewhat unlikely.

Table 29. Which of the following industrial or technological activities do you think is likely to cause a serious accident or a disaster? (Not at all likely, Somewhat unlikely, Neither likely nor unlikely, Somewhat likely, Very likely) Ordered by likelihood.

Activity	Not at all likely/Somewhat Unlikely	Neither likely nor unlikely	Somewhat likely/Very likely
Transport of hazardous material	11.6%	14.9%	73.5%
Chemical facilities	14.6%	20.1%	65.3%
Virus research laboratories	18.9%	23.8%	57.3%
Nuclear power plants - conventional	20.0%	27.5%	52.6%
Natural gas distribution	27.1%	30.7%	42.2%
Nuclear power plants - SMR	28.3%	31.3%	40.4%
Air transport	31.4%	29.1%	39.5%

7.3.2.2. Nuclear energy siting

The following survey results provide insights into the public's willingness to live near a variety of facilities that may be comparable to a small modular nuclear reactor. The facilities include (as listed in the survey):

a) Biogas/biomass energy generation facility
b) Co2 storage site
c) High voltage power line
d) Household waste incinerator
e) Landfill
f) Large airport
g) Major chemical facility
h) Mobile phone relay antenna
i) Nuclear power plant-conventional
j) Nuclear power plant- SMR
k) Radioactive waste disposal

A total of 1,012 respondents participated in responding to the question: “How likely would you be willing to live near the following?” Their responses were categorized into five levels of likelihood. Here, like the previous question, the lowest and highest levels of likelihood were combined with their ‘somewhat’ counterparts. In addition, each level was assigned a score from “Not at All Likely” equaling zero to “Very Likely” equaling four.

When asked “How Likely would you be willing to live near the following?” all of the facilities ranked below (without rounding) the neutral “Neither” score of two (Table 30). Overall, only one facility type, “Mobile phone relay antenna” has a majority of respondents indicate some likelihood that they would be willing live near a facility.

For example, the facility type scoring the lowest on the willingness scale was “Radioactive Waste Disposal, where the largest proportion of respondents, 622 individuals or 61.5%, indicated that they were "Not at all likely" to be willing to live near such a facility. Following this, 186 respondents, representing 18.4% of the total, stated that they were "Somewhat unlikely" to live near a radioactive waste disposal facility. Combined with the "Not at all likely" group, more than three-quarters of the respondents (79.9%) have reservations about living near such a facility. This suggests discomfort or opposition among a substantial population toward residing close to a radioactive waste disposal facility.

In contrast, 10.3% (105 respondents) were willing to live near a radioactive waste disposal facility. The relatively small neutral group (“Neither likely nor unlikely,” 9.8%) suggests little opportunity for further education or engagement to shift opinions.

Table 30. Likelihood of Being Willing to Live Near Different Types of Facilities Sorted by Least Willing to Most Willing

Facility Type	**Not at all likely/ Somewhat Unlikely**	**Neither likely nor unlikely**	**Somewhat likely/ Very likely**	**Willingness Score (Not at All Likely (0) to Very Likely (4))**
Radioactive waste disposal	79.9%	9.8%	10.3%	0.74
Major chemical facility	74.3%	13.1%	12.6%	0.96
Landfill	72.2%	12.9%	14.8%	0.99
Household Waste Incinerator	64.6%	19.4%	16.0%	1.16
Nuclear power plant-conventional	63.3%	20.8%	15.9%	1.17
Biogas/Biomass	57.6%	26.4%	16.0%	1.28
CO2 (carbon) storage site	56.7%	24.5%	18.7%	1.33
Large airport	59.3%	19.1%	21.6%	1.33
Nuclear power plant-SMR	54.5%	23.5%	22.0%	1.39
High Voltage Power Line	51.0%	22.3%	26.7%	1.52
Utility-scale solar development	39.6%	28.6%	31.8%	1.78
Utility-scale wind development	37.4%	28.0%	34.6%	1.85
Mobile phone relay antenna	34.6%	29.3%	36.1%	1.93

Question 10: “How Likely would you be willing to live near the following?”

While radioactive waste disposal is required as a by-product of energy production, these survey data also present a detailed comparison of respondents' willingness to live near different types of energy production facilities, including a conventional nuclear power plant, a SMR nuclear power plant, utility-scale solar development, and utility-scale wind development. We can observe differences in public perception and acceptance of these facilities by examining these results.

Table 31 shows respondents' preferences for the siting of small modular reactors (SMRs), highlighting their flexibility in location, smaller footprint compared to traditional nuclear plants, and potential for underground installation. The majority of respondents (53.4%) prefer SMRs to be located in rural areas, while 16.0% favor urban areas, and 12.7% opt for suburban locations. A portion of respondents (13.6%) expressed no preference, and a smaller group (4.2%) suggested other options.

Table 31. Given that SMR allows for flexibility in siting and requires a much smaller footprint compared to a traditional nuclear power plant, and is often installed underground, where should SMRs be located? Urban area, Suburban area, Rural area, I have no preference, or Other.

Geographic Preference	N	%
I have no preference.	138	13.6%
Rural area	540	53.4%
Suburban area	129	12.7%
Urban area	162	16.0%
Other (please specify)	43	4.2%
Total	**1012**	**100.0%**

*NOTE: Rural area: open and/or sparsely populated countryside, not within commuting distance to urban or suburban areas; Suburban area: outskirts of city or town, outlying area economically tied to an urban area, within commuting distance; Urban area: urbanized area, -city or town, metropolitan area

Table 32 and Table 33 explore the respondents' preference for the location of SMRs by the respondents' current residential location. Preferences were recorded from respondents in rural, suburban, urban, and unspecified residential locations.

Overall, rural areas are the most favored for SMR siting, with 53.4% of all respondents choosing this option. Rural residents showed a particularly strong preference, with 54.9% selecting rural locations. Suburban residents demonstrated an even higher preference for rural siting, with 60.4% favoring this option, while urban residents were slightly lower at 51.2%.

Urban siting is the second most preferred choice overall, selected by 16.0% of respondents. Notably, 24.5% of urban residents favored urban locations for SMRs, compared to just 7.6% of rural residents and 4.0% of suburban residents.

Suburban areas were chosen by 12.7% of all respondents as a preferred location for SMRs, with suburban residents (16.7%) favoring this option more than rural (11.6%) and urban (11.9%) respondents.

A portion of respondents expressed no strong preference for SMR siting, with 13.6% selecting "I have no preference." Urban residents had the highest rate of indifference (9.9%), while rural and suburban respondents were more decisive.

Finally, 4.2% of all respondents selected "Other" as their preferred location, with 7.1% of rural and suburban residents falling into this category, while 2.6% of urban respondents did the same.

Table 32. Respondents' Preference for SMR Location by Respondents' Residential Location in Levels

Given that SMR allows for flexibility in siting and requires a much smaller footprint compared to a traditional nuclear power plant, and is often installed underground, where should SMRs be located?	**How would you describe your current residential location?**				Total
	Prefer not to answer	*Rural area*	*Suburban*	*Urban area*	
I have no preference	11	42	31	54	138
Other	1	16	12	14	43
Rural area	0	123	137	280	540
Suburban area	0	26	38	65	129
Urban area	2	17	9	134	162
Total	**14**	**224**	**227**	**547**	**1012**

Table 33. Respondents' Preference for SMR Location by Respondents' Residential Location in Percentages

Given that SMR allows for flexibility in siting and requires a much smaller footprint compared to a traditional nuclear power plant, and is often installed underground, where should SMRs be located?	**How would you describe your current residential location?**				Total
	Prefer not to answer	*Rural area*	*Suburban*	*Urban area*	
I have no preference	78.6%	18.8%	13.7%	9.9%	13.6%
Other	7.1%	7.1%	5.3%	2.6%	4.2%
Rural area	0.0%	54.9%	60.4%	51.2%	53.4%
Suburban area	0.0%	11.6%	16.7%	11.9%	12.7%
Urban area	14.3%	7.6%	4.0%	24.5%	16.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Related to preferences for SMR siting location is a respondents' willingness to live in some proximity to the SMR facility (Table 34). The largest group of respondents are open to living near an SMR (58.8%), though preferences vary based on proximity. In comparison, 41.2% (417 respondents) indicated they are not willing to live next to an SMR at any distance.

Overall, 26.1% (264 respondents) are willing to live 10-20 miles away from an SMR, making this the most popular distance for those open to living nearby. Another 16.0% (162 respondents) prefer a range of 5-9.99 miles from the SMR.

Smaller percentages of respondents were willing to live closer: 8.8% (89 respondents) would live 1-4.99 miles away, while 7.9% (80 respondents) are comfortable living less than a mile from an SMR.

Table 34. How close would you be willing to live next to an SMR nuclear power plant?

Distance	**N**	**%**
0-.99 miles	80	7.9%
1.00-4.99 miles	89	8.8%
5.00-9.99 miles	162	16.0%
10.00-20 miles	264	26.1%
I am not willing to live next to an SMR	417	41.2%
Total	**1012**	**100%**

7.3.2.3. Opinions and perceptions about the environment and energy sources

This survey section explored respondents' opinions and perceptions about the environment and energy sources.

Table 35 presents respondents' satisfaction levels with the place or community where they currently live. The majority of respondents express positive feelings about their communities, with 39.6% (401 respondents) indicating they are "Satisfied" and 26.9% (272 respondents) reporting they are "Very satisfied." Together, these groups account for over two-thirds (66.5%) of all respondents.

Meanwhile, 22.8% (231 respondents), feel neutral about their current living situation, neither satisfied nor unsatisfied. And on the other end of the spectrum, 10.7% of respondents report dissatisfaction with their current community, with 6.6% (67 respondents) reporting being "Unsatisfied" and 4.1% (41 respondents) "Very unsatisfied."

Interestingly, a crosstabulation between respondents' willingness to live near an SMR and their corresponding satisfaction with their community shows that respondents that are Neutral about their community are the least willing to live near an SMR (51.1%) and those that are Satisfied with their community the most willing (64.6% or 35.4% not willing).

Table 35. In general, how satisfied are you with the place/community where you currently live?

Satisfaction Level	N	%
Very unsatisfied	41	4.1%
Unsatisfied	67	6.6%
Neutral	231	22.8%
Satisfied	401	39.6%
Very satisfied	272	26.9%
Total	**1012**	**100%**

Table 36 shows respondents' concerns about different types of pollution on a day-to-day basis. Air pollution is the most commonly cited concern, with 45.0% (455 respondents) identifying it as the pollution that bothers them the most. This suggests that air quality is a significant issue for nearly half of the respondents.

Water pollution is the second most concerning, with 20.6% (208 respondents) of respondents expressing worry about the contamination of water resources. Land pollution follows, with 15.6% (158 respondents) indicating it as their primary concern.

Interestingly, 18.9% (191 respondents) report that they are not concerned about any form of pollution in their daily lives.

Table 36. What kind of pollution bothers you **most** on a day-to-day basis?

Pollution Type	N	%
Air pollution	455	45.0%
Land pollution	158	15.6%
Water pollution	208	20.6%
I am not concerned about pollution.	191	18.9%
Total	**1012**	**100%**

Table 37 presents respondents' concerns about climate change. The majority of respondents viewed climate change as a significant issue, with 28.4% (287 respondents) believing it is an issue to a “Very great extent” and 23.6% (239 respondents) to a “Great extent.” Together, these groups represent 52% of respondents being highly concerned about climate change.

Additionally, 27.1% (274 respondents) believed climate change is an issue to “Some extent”" reflecting moderate concern among a large portion of respondents.

On the other hand, 21% of respondents expressed little concern about climate change with 12.2% (123 respondents) seeing it as a concern to a "Little extent," while 8.8% (89 respondents) responded "Very little extent."

Table 37. To what extent do you think climate change is an issue to be concerned about?

Extent of Concern about Climate Change	**N**	**%**
Very little extent	89	8.8%
Little extent	123	12.2%
Some extent	274	27.1%
Great extent	239	23.6%
Very great extent	287	28.4%
Total	**1012**	**100%**

Table 38 presents the top considerations for respondents regarding electricity production, ranked by the frequency of selection. The most important factor for the majority of respondents was **affordable electricity**, selected by 69.2% (700 respondents), indicating that cost plays a crucial role in public preferences for energy production.

Energy independence was the second most selected consideration, chosen by 30.7% (311 respondents), reflecting the desire for reduced reliance on foreign energy sources. The **preservation of natural resources** was a priority for 26.2% (265 respondents), emphasizing the importance of sustainable energy production methods.

Concerns about resilience were significant, with 23.4% (237 respondents) selecting **resiliency to withstand catastrophic events and natural disasters** as a key factor. This was closely followed by the **reduction of carbon emissions**, selected by 22.3% (226 respondents), highlighting environmental concerns about energy production.

The ability of the **electrical system to withstand sudden disturbances** was important to 21.4% (217 respondents), and **energy security** was a consideration for 20.0% (202 respondents), reflecting concerns about reliability and protection against energy threats.

Stable systems that match electrical supply to demand were prioritized by 17.8% (180 respondents), while **economic growth** (15.8%) and **job opportunities** (14.9%) showed that respondents also value economic factors related to energy production.

Other factors, such as **adequate fuel resources for electricity** (14.3%), and a **small footprint** (less land use) (10.7%), were less frequently selected. Only 1.7% (17 respondents) chose "Other" considerations not listed in the survey.

Table 38. Select the top three considerations for the way electricity is produced that are the most important to you. Sorted by Most Selected

Electricity Production Considerations	Frequency	Percent of Respondents
Affordable electricity	700	69.2
Energy independence	311	30.7
Preservation of natural resources	265	26.2
Resiliency to withstand catastrophic events and natural disasters	237	23.4
Reduction of carbon emissions	226	22.3
Electrical system can withstand sudden disturbances	217	21.4
Energy security	202	20.0
Stable system that matches electrical supply to demand	180	17.8
Economic growth	160	15.8
Job opportunities	151	14.9
Adequate fuel resources for electricity	145	14.3
Small footprint (less land use)	108	10.7
Other	17	1.7
Total	**2919**	

The following tables (Table 39 and Table 40) summarize respondents' attitudes toward expanding various energy sources, reflecting a range of support or opposition depending on the source.

Coal mining receives mixed reactions. The largest proportion of respondents (37.9%) neither oppose nor favor its expansion. However, opposition is notable, with 16.9% strongly opposing and 18.9% opposing, making a combined 35.8%. On the other hand, 18.3% favor and 8.0% strongly favor coal mining expansion.

Hydraulic fracking had similar levels of opposition as coal mining, with 16.5% strongly opposing and 17.7% opposing (34.2% combined). Nearly half of the respondents (48.1%) remain neutral. Support is lower for hydraulic fracking than coal. (17.7% versus 26.3%), with 12.7% favoring and 4.9% strongly favoring fracking.

Conventional nuclear power had a more divided response. While 43.9% of respondents were neutral, 20.7% favor and 7.3% strongly favor nuclear power (28% total). Opposition to conventional nuclear power range from 17.4% reporting Oppose and 10.8% reporting Strongly oppose, totaling 28.2%.

Small Modular Reactors (SMRs) receive more support than conventional nuclear power, with 29.9% favoring and 11.7% strongly favoring them (41.6% combined). Opposition was lower with

10.6% of respondents reporting Oppose and 8.3% reporting Strongly oppose (18.9%), while 39.5% were neutral.

Offshore oil and gas drilling received a relatively high level of opposition, with 12.5% strongly opposing and 21.1% opposing (33.6% combined, or the third highest level of opposition). However, neutral respondents made up 33.3%, and those in favor account for 23.6%, with 9.5% strongly favoring (33.1% total in favor) offshore drilling, resulting in the most even split of support across all eight energy sources.

Natural gas expansion garnered the most support among the traditional energy sources. A majority either favor (39.0%) or strongly favor (13.7%), or 52.7% total in favor. Only 12.4% oppose or strongly oppose its expansion, while 34.9% were neutral.

Utility-scale solar had the highest support, with 37.0% favoring and 20.4% strongly favoring solar expansion (57.4% combined). Opposition was minimal, with only 3.5% strongly opposing and 6.5% opposing or 10% in total.

Utility-scale wind also enjoyed strong support, with 38.7% favoring and 22.8% strongly favoring (61.5% combined). Opposition was slightly higher than solar but still low, with 4.1% strongly opposing and 7.9% opposing wind energy expansion.

Table 39. To what extent do you favor or oppose expanding the following energy sources? (Percentages)

Energy Source	Strongly oppose	Oppose	Neither oppose or favor	Favor	Strongly favor
Coal mining	16.9%	18.9%	37.9%	18.3%	8.0%
Hydraulic fracking	16.5%	17.7%	48.1%	12.7%	4.9%
Conventional Nuclear power	10.8%	17.4%	43.9%	20.7%	7.3%
SMR Nuclear power	8.3%	10.6%	39.5%	29.9%	11.7%
Offshore oil and gas drilling	12.5%	21.1%	33.3%	23.6%	9.5%
Natural gas	3.3%	9.1%	34.9%	39.0%	13.7%
Utility-scale solar	3.5%	6.5%	32.7%	37.0%	20.4%
Utility-scale wind	4.1%	7.9%	26.5%	38.7%	22.8%
N	*1012*	*1012*	*1012*	*1012*	*1012*

Another way to explore the comparison in support for expanding energy sources is through an index. Here, in Table 40, the level of favorability is calculated through an average score – ranging from Strongly oppose = 0 and Strongly Favor = 4 – weighted by the number of favorability responses for each energy source. Table 40 shows that utility-scale wind and solar received the highest favorability scores, (2.68 and 2.64, respectively), followed by natural gas (2.51) and SMR nuclear power (2.26).

In contrast, the energy sources that were least favorable included hydraulic fracking (1.72), coal mining (1.82) and conventional nuclear power (1.96).

Table 40. To what extent do you favor or oppose expanding the following energy sources? - Overall Level of Favorability

Type of Energy Source	Level of Favorability (Strongly oppose = 0 and Strongly Favor = 4)
Utility-scale wind	2.68
Utility-scale solar	2.64
Natural gas	2.51
SMR nuclear power	2.26
Offshore oil and gas drilling	1.97
Conventional nuclear power	1.96
Coal mining	1.82
Hydraulic fracking	1.72

7.3.2.4. Demographics

The following tables highlight the demographics of respondents, including information on gender, race, ethnicity, residential location, education, income, employment, political views, and preferred sources of information.

Table 41 presents respondents' gender identities. The majority identified as women (53.9%, 545 respondents), followed by men (45.0%, 455 respondents). A small percentage identified as non-binary (0.9%, 9 respondents), and only 0.1% (1 respondent) selected other. Additionally, 0.2% (2 respondents) chose to prefer not to answer.

Table 41. What is your gender identity?

Gender Identity	N	%
Woman	545	53.9%
Man	455	45.0%
Non-binary	9	0.9%
Other	1	0.1%
Prefer not to answer	2	0.2%

Table 42 shows respondents' racial identities, allowing multiple selections. The majority identified as White (78.6%, 795 respondents). Black or African American follows at 14.7% (149 respondents). Fewer respondents were Asian (0.6%, 6 respondents), American Indian or Alaska Native (0.2%, 2 respondents), and Native Hawaiian and Other Pacific Islanders (0.2%, 2 respondents). Additionally, 4.1% (41 respondents) identified as Two or more races, while 0.8% (8 respondents) selected other races. A small percentage, 0.9% (9 respondents), preferred not to answer.

Table 42. What do you usually identify as your race (Please check all that apply).

Race	N	%
American Indian or Alaska Native	2	0.2%
Asian	6	0.6%
Black or African American	149	14.7%
Native Hawaiian and Other Pacific Islanders	2	0.2%
Two or more races (selected or identified specifically)	41	4.1%
White	795	78.6%
Other races	8	0.8%
Prefer not to answer	9	0.9%
Total	**1012**	**100%**

Table 43 presents respondents' ethnicities. A majority of respondents identified as Not Hispanic or Latino (94.1%, 952 respondents). A smaller group identified as Hispanic or Latino (4.1%, 41 respondents), while 1.9% (19 respondents) preferred not to answer.

Table 43. What is your ethnicity?

Ethnicity	N	%
Hispanic or Latino	41	4.1%
Not Hispanic or Latino	952	94.1%
Prefer not to answer	19	1.9%

Table 44. How would you describe your current residential location?

Location	N	%
Urban area	547	54.1
Suburban area	227	22.4
Rural area	224	22.1
Prefer not to answer	14	1.4
Total	**1012**	**100.0**

Table 44 categorizes respondents' descriptions of their current residential locations. As described earlier, residential location was part of the sampling quota. The majority resided in an urban area (54.1%, 547 respondents). suburban areas accounted for 22.4% (227 respondents), while rural areas comprise 22.1% (224 respondents). A small portion of respondents, 1.4% (14 respondents), preferred not to answer the question.

Table 45 outlines respondents' highest level of education completed. The largest group, 29.1% (294 respondents), held a high school diploma or GED, followed by 23.6% (239 respondents) who completed some college, but no degree.

Some high school or less accounted for 4.6% (47 respondents), while 13.9% (141 respondents) possessed an associate's or technical degree. A total of 18.2% (184 respondents) obtained a bachelor's degree, and 10.2% (103 respondents) hold a graduate or professional degree.

Only 0.4% (4 respondents) preferred not to disclose their educational attainment.

Table 45. What is the highest level of education you have completed?

Educational Attainment	**N**	**%**
Some high school or less	47	4.6
High school diploma or GED	294	29.1
Some college, but no degree	239	23.6
Associates or technical degree	141	13.9
Bachelor's degree	184	18.2
Graduate or professional degree (MA, MS, MBA, PhD, JD, MD, DDS etc.)	103	10.2
Prefer not to answer	4	0.4
Total	**1012**	**100**

Table 46. Please choose the category in which the combined total income of your household fell in 2023 (yourself and any household member you live with).

Income Level	**N**	**%**
Less than $25,000	213	21.0
$25,000 - $49,999	292	28.9
$50,000 - $74,999	206	20.4
$75,000 - $99,999	114	11.3
$100,000 - $149,999	101	10.0
$150,000 - $199,999	27	2.7
$200,000 - $299,000	17	1.7
$300,000 and above	3	0.3
I do not know	8	0.8
Prefer not to answer	31	3.1
Total	**1012**	**100**

Table 46 presents the distribution of household income levels among respondents for the year 2023. The largest group fell into the $25,000 - $49,999 income range, comprising 28.9% (292 respondents). The second most common income bracket was less than $25,000, with 21.0% (213 respondents) followed by 20.4% (206 respondents) in the $50,000 - $74,999 range and the $75,000 - $99,999 category accounted for 11.3% (114 respondents).

The remaining income levels show decreasing frequencies: $100,000 - $149,999 at 10.0% (101 respondents), $150,000 - $199,999 at 2.7% (27 respondents), and $200,000 - $299,000 at 1.7% (17 respondents). Only 0.3% (3 respondents) reported earning $300,000 or more. A small portion of respondents, 0.8% (8 respondents), indicated they did not know their household income, and 3.1% (31 respondents) preferred not to answer the question.

Table 47. Which of the following categories best describes the industry you primarily work in (regardless of your actual position)? Sorted by proportion sample.

Industry Sector	N	%
Other Services (except Public Administration)	193	19.1
Prefer not to answer	187	18.5
Manufacturing	94	9.3
Health Care and Social Assistance	86	8.5
Retail Trade	75	7.4
Educational Services	62	6.1
Construction	47	4.6
Public Services	40	4
Transportation and Warehousing	33	3.3
Accommodation and Food Services	32	3.2
Information	31	3.1
Professional, Scientific, and Technical Services	24	2.4
Arts, Entertainment, and Recreation	23	2.3
Finance and Insurance	23	2.3
Wholesale Trade	12	1.2
Utilities	11	1.1
Management of Companies and Enterprises	10	1
Agriculture, Forestry, Fishing and Hunting	9	0.9
Administrative and Support and Waste Management and Remediation Services	8	0.8
Real Estate and Rental and Leasing	8	0.8
Mining, Quarrying, and Oil and Gas Extraction	4	0.4
Total	**1012**	**100**

Table 47 categorizes respondents based on the industry sector in which they primarily work, regardless of their actual job position. The most frequently selected sector was Other Services (except Public Administration), representing 19.1% (193 respondents). This category was followed closely by those who prefer not to answer, accounting for 18.5% (187 respondents).

The Manufacturing sector included 9.3% (94 respondents), while Health Care and Social Assistance comprised 8.5% (86 respondents) of the sample. The Retail Trade sector accounted for 7.4% (75 respondents) of respondents, and Educational Services was chosen by 6.1% (62 respondents) of respondents.

Further down the list, Construction had 4.6% (47 respondents) share of respondents, followed by Public Services at 4.0% (40 respondents). Other sectors included Transportation and Warehousing (3.3%, 33 respondents), Accommodation and Food Services (3.2%, 32 respondents), and Information (3.1%, 31 respondents).

The Professional, Scientific, and Technical Services sector was reported by 2.4% (24 respondents) of respondents, and both Arts, Entertainment, and Recreation and Finance and Insurance each represented 2.3% (23 respondents) of the sample.

The remaining sectors included Wholesale Trade (1.2%), Utilities (1.1%), Management of Companies and Enterprises (1.0%), Agriculture, Forestry, Fishing and Hunting (0.9%), Administrative and Support and Waste Management and Remediation Services (0.8%), Real Estate and Rental and Leasing (0.8%), and Mining, Quarrying, and Oil and Gas Extraction (0.4%).

Table 48. How would you describe your political views?

Political Views	**N**	**%**
Very liberal	65	6.4
Liberal	159	15.7
Moderate	330	32.6
Conservative	192	19.0
Very conservative	106	10.5
No opinion	126	12.5
Prefer not to answer	34	3.4
Total	**1012**	**100**

Table 48 presents respondents' descriptions of their political views. The largest group identified as Moderate (32.6%, 330 respondents), potentially reflecting balanced political perspectives.

Liberal views were held by 15.7% (159 respondents), while Very liberal respondents represent 6.4% (65 respondents), totaling 22.1% of the sample. In contrast, Conservative views accounted for 19.0% (192 respondents), and Very conservative respondents made up 10.5% (106 respondents), for a total of 29.5% of respondents.

Additionally, 12.5% (126 respondents) of respondents expressed No opinion regarding their political stance. A small percentage, 3.4% (34 respondents), prefer not to disclose their political views.

Table 49 summarizes respondents' preferred sources for news and information. The most popular source was Television, which was utilized by 67.4% (682 respondents) of respondents. Following closely, Internet sources were preferred by 57.2% (579 respondents), providing evidence for the reliance on online platforms for information. In addition, Social Media was chosen by 35.5% (359 respondents) of respondents.

While electronic forms of information dissemination were most frequent, Local newspapers remained relevant for 29.7% (301 respondents) of respondents, while Radio was favored by 25.0% (253 respondents), indicating traditional media still holds importance.

Podcasts were an important source of information for 16.4% (166 respondents) of respondents, while national/regional newspapers were listed by 16.1% (163 respondents) of respondents.

A smaller portion of respondents, 7.9% (80 respondents), relied on other sources not specified in the options, and 2.5% (25 respondents) preferred not to disclose their news preferences.

Table 49. What are your preferred sources for news and information? (Select all that apply)

Information Source	**Frequency**	**Percent of Respondents**
Television	682	67.4%
Internet	579	57.2%
Social Media	359	35.5%
Local newspaper	301	29.7%
Radio	253	25.0%
Podcasts	166	16.4%
National/regional newspaper	163	16.1%
Other sources	80	7.9%
Prefer not to answer	25	2.5%
Total	**2608**	

With 2608 total responses and 1012 respondents, Table 50 suggests that many people use multiple sources to find news and information. Table 50 shows that 70.6% of respondents use multiple sources, with 44% using three or more.

Of those respondents (n=296) that use a single source for news and information, Television (42.9%) was the most common source, followed by online (internet and social media) with 29.4%,

Table 50. What are your preferred sources for news and information? (Total Number of Sources)

Number of Information Sources	N	Percent of Respondents
1	296	29.2
2	269	26.6
3	216	21.3
4 or more	230	22.7
Total	**1011**	**99.8**

NOTE: One respondent chose not to answer

Table 51. What are your preferred sources for news and information? Respondents listing one source only.

Sole Information Source	N	Percent of Respondents
Television	127	42.9%
Internet	58	19.6%
Social Media	29	9.8%
Other sources	27	9.1%
Prefer not to answer	24	8.1%
Radio	11	3.7%
Local newspaper	10	3.4%
National/regional newspaper	6	2.0%
Podcasts	4	1.4%
Total	**296**	**29.2**

7.4 Community Engagement Recommendations

Several opportunities exist to support nuclear energy and SMR education and technical assistance for critical stakeholders. Indiana residents trust scientists, public regulatory authorities, and science journalists for nuclear energy education. Utilizing these groups to communicate timely science-based education and framing information by the audience on electricity generation, future demands, safety, siting, technology, and construction processes can help alleviate misconceptions [354]. A combination of accessible education pathways is needed to address these issues to meet stakeholder needs, including news articles, in-person opportunities for question-and-answer discussion, short videos, and education bulletins.

Local decision-makers also need education and technical assistance resources to educate themselves and their constituents about nuclear energy and ensure they are crafting policies in alignment with the most updated regulatory and technology guidelines. State agencies must collaborate with trusted experts from industry, federal agencies, and university researchers to develop policy guidance for emergency response plans, risk assessments, and planning and zoning for siting SMR facilities [355]. This policy guidance should be crafted in collaboration with and shared through the intended audiences of professional associations for planners, county and municipal associations, and emergency responders. Without this expert guidance, communities will be hindered in decision-making as local nuclear energy knowledge and experience are limited across the state. Intentionally partnering with trusted associations and groups will further enhance information-sharing. Communities need to know where and how to site SMRs and how to prepare for and manage emergencies. The size of emergency planning zones may influence local siting acceptance. For example, if developers, operators, and regulatory agencies can shrink the size of emergency planning zones with guidance and training, there may be more potential for siting SMRs [343].

In addition to providing education and technical assistance for policy and plan development, community engagement processes should be designed and implemented as a format to share information and engage residents and interested parties through facilitated dialogue, which is especially relevant for a controversial issue such as nuclear [354].This format provides a pathway for trust-building and decision-making at the local level [356]. As with all land use planning and siting efforts, clear expectations about outcomes and the purpose of a community engagement process should be a central focus. A partnership between state agencies and engagement experts in community development, land use, and facilitation to develop processes and training will be needed to support this type of effort.

As Indiana communities are introduced to new nuclear energy generation technologies, such as SMRs, their residents and decision-makers need ready-to-access education, technical assistance, and community engagement process training to expand knowledge and build expertise in local policy development and implementation. Planning for siting, building, and managing SMRs will be a long-term commitment. Therefore, a robust plan to educate and engage residents, local decision-makers, and other interested parties will be needed to set the stage for long-term communication.

CHAPTER 8. SUMMARY AND RECOMMENDATIONS

The report explores the potential deployment of small modular reactors (SMRs) in Indiana as part of the state's future energy strategy, aligning with Indiana Senate Bills 271 and 176. SMRs, which have power capacities under 470 MWe, offer flexibility and scalability compared to traditional nuclear reactors, making them a key option for Indiana's energy future. Indiana currently depends on coal, natural gas, wind, and solar for its energy needs, but lacks nuclear power infrastructure. With the increasing emphasis on clean, reliable energy sources, SMRs provide an opportunity to diversify the state's energy portfolio.

The report reviews nuclear feasibility studies conducted in states like Michigan, Kentucky, and Maryland, which demonstrate the benefits of nuclear energy, such as reduced carbon emissions, energy reliability, and economic development. However, these studies also emphasize the regulatory and technological challenges that need to be addressed, particularly in workforce development. The report also examines both domestic and international advancements in SMR technology, such as ongoing projects and regulatory approvals, providing Indiana with a pathway to follow.

SMRs have key advantages over traditional nuclear reactors. Their smaller size and modular construction can reduce costs and shorten construction times. SMRs can also be more flexible in siting and offer potential repurposing of Indiana's coal plants, which have suitable infrastructure for conversion. In terms of safety, SMRs are equipped with advanced passive systems, including natural circulation cooling and passive shutdown mechanisms, which reduce the need for human intervention and enhance operational safety. Additionally, SMRs have a smaller environmental footprint, though they still produce nuclear waste and thermal pollution, requiring careful management.

The report emphasizes that while SMRs hold substantial promise, their deployment is not without risks. Any entity that intends to deploy an SMR in Indiana would need to secure federal and state funding to offset the costs associated with SMR development, particularly in the early stages. Regulatory challenges also loom large, requiring Indiana to align its state regulations with federal nuclear safety standards and develop clear licensing and approval processes. The report notes that Indiana is well-positioned for SMR development, ranking second only to Texas in the number of coal plants suitable for conversion to nuclear. MISO, which is the primary RTO that manages Indiana's grid, has projected future capacity shortfalls, highlighting the urgent need for new energy sources like SMRs to maintain grid stability.

SMRs offer significant economic benefits, particularly in terms of job creation and local economic growth. The construction of an SMR could employ thousands of people and can present long-term economic impacts for the state far exceeding those of traditional coal plants. However, the financial risks, regulatory hurdles, and public perception challenges associated with SMRs must be carefully managed. Indiana would benefit from learning from other states' experiences, engaging stakeholders early, and conducting comprehensive safety and environmental assessments to ensure that SMRs are deployed safely and sustainably.

Furthermore, workforce development is critical to the successful deployment of SMRs. Not only Indiana, but the entire nation currently lacks the nuclear expertise necessary to support SMR development, construction and operation. A coordinated effort between the academic institutions including technical colleges and nuclear industry will be essential in developing a skilled workforce capable of supporting the state's nuclear energy development. Public engagement and education initiatives are also key to fostering community support for SMR projects, as public perception of nuclear energy can often be mixed. Providing clear, science-based information about SMRs will help dispel misconceptions and build trust within local communities.

In conclusion, SMRs represent a significant opportunity for Indiana's energy future, but their deployment requires careful planning, a balanced approach and collaboration between all of Indiana's energy stakeholders. Comprehensive feasibility studies, regulatory alignment, workforce development, and robust community engagement are necessary components to ensure that SMRs can be safely and successfully integrated into Indiana's energy landscape. By addressing the financial, regulatory, and technological challenges, Indiana can position itself as a leader in adopting this emerging technology while creating economic opportunities and ensuring energy security.

In view of these, the following recommendations are made based on the findings of the present study.

- **Conduct Further Feasibility Studies and Secure Funding**: Indiana's energy stakeholders should initiate detailed feasibility studies focused on SMR deployment and actively seek federal and state funding to mitigate financial risks, especially for early-stage projects.
- **Address Regulatory and Technological Challenges**: The state must develop strategies to navigate the regulatory and technological challenges of SMRs, aligning state regulations with federal standards and preparing for licensing and safety approval processes specific to SMRs.
- **Evaluate SMR Design Suitability**: The state, in coordination with the potential off-taker and the utility group, should carefully evaluate which SMR designs would best fit the state's energy needs, considering factors such as flexibility, scalability, and regulatory readiness.

- **Prepare for Regulatory and Licensing Processes**: The state must develop clear processes for SMR licensing, ensuring that regulations are aligned with federal nuclear safety standards.
- **Continue Safety and Environmental Impact Assessments**: Indiana's energy providers should prioritize comprehensive safety assessments of SMR designs, focusing on seismic stability, environmental impacts, and long-term waste management solutions.
- **De-risk SMR Development**: Indiana's energy stakeholders should attract private investors and secure federal grants to minimize the financial risks associated with SMR projects, ensuring that cost and schedule risks are not passed on to utilities or ratepayers.
- **Foster Local Economic Development**: The state should incentivize local suppliers and workforce development initiatives to maximize the economic benefits of SMR projects, ensuring that local workers and suppliers are well-positioned to support SMR deployment.
- **Establish Educational and Training Pathways**: Indiana's energy stakeholders should develop educational pathways from high school to bachelor's degrees focused on nuclear-related fields. Partnering with in-state institutions like Purdue University and Ivy Tech will ensure the development of a skilled workforce capable of supporting SMR projects.
- **Address Workforce Shortages through Targeted Programs**: Indiana's energy stakeholders should create specialized programs to bridge workforce gaps caused by retirements in the nuclear sector, including retraining current workers and preparing students for careers in nuclear energy, as well as repurposing trained workers in retiring fossil-fuel plants.
- **Enhance Education and Technical Assistance for Stakeholders**: Indiana's energy stakeholders should prioritize science-based education for local residents and decision-makers, providing accessible formats such as Q&A sessions, videos, and educational bulletins to build public trust and support for SMRs.
- **Develop Robust Community Engagement Programs**: Indiana's energy stakeholders must design and implement community engagement initiatives that foster transparent dialogue with stakeholders, ensuring long-term public acceptance of SMR technologies through trust-building and informed decision-making.

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APPENDICES

A. Cost Savings through C2N Transition

If an operating or recently retired coal site has not been transformed for other purposes (for instance, a gas plant) and the connection to the grid is still in place, deploying an SMR at that site will be able to reuse some of the components from the coal plant and reduce the plant's overnight capital cost (OCC) by 7-26%.

The 2022 INL C2N report [357] outlined the total costs of construction of a new nuclear power plant for three general technology types including direct costs and indirect costs as described in the Energy Economic Data Base (EBDB) [358] and owner's costs as described in the 2017 Advanced Fuel cycle Cost Basis Report (CBR) [359]. The cost estimates for the three technology types shown in Table 52 were taken directly from the 2022 INL report. The estimated savings for a C2N project were mostly taken from the same report with some exceptions described herein:

1. Land and Land rights: The INL report assumes that the owner of the nuclear plant is the same as the owner of the coal plant, and therefore, the land will not cost them anything. However, this study contemplates new owners and shows savings of 0-100%.
2. Structure and Improvements: The INL study supposes that up to 24% savings can be achieved by reducing the cost of yard work, the construction of administration and service buildings, and the construction of electric switchyard buildings. This study includes the same assumption.
3. Turbine Plant: There are several code of accounts (COAs) that appear in both coal plants and nuclear plants because both use steam generators. Although reusing some of the steam-cycle system components would give an opportunity to reduce the OCC through the C2N transition, it is challenging. Due to the radioactive materials (both activation of the coolant system and release of the radioactive isotopes through defective points of the reactor coolant pressure boundary), the nuclear plant has stringent requirements on the steam-cycle components. Thus, reusing some of these components causes licensing challenges. In this work, the reuse of the steam-cycle components is not recommended in the C2N transitions. As such, no possible cost savings were assumed (0%), even though the INL study did show some potential savings.
4. Electrical Plant: This includes all of the equipment required to deliver electricity to the transmission grid and provide auxiliary power to the plant itself. The cost savings of 42-78%, taken from the INL study, assumes that the nuclear power plant has an electrical capacity less than or equal to the capacity of the coal plant it is replacing [357].
5. Main Condenser and Heat Rejection System: A large nuclear power plant requires an ultimate heat sink, which can be a large cold-water source such as a lake, river, or ocean to dump the excess heat from the power conversion cycle. 2-3% of the total OCC costs include the equipment and associated structures and piping that dispose of the heat rejected by the

power plant and provide make-up water to the power plant. These costs include the cooling towers and the structures, equipment and interconnecting piping systems to get and treat the plant make-up water. Some SMR technologies are dry-cooled and do not require water, such designs would see no savings from the existence of a heat sink on site. For those that do require water cooling, the heat rejection system of the coal plant may be partially or totally reused as long as the heat rejected by the nuclear power plant is less than or equal to the heat rejection of the coal plant. While the INL report assumed a maximum savings of 100%, the 100% savings case included the assumption that the steam generator would be reused. Since this study does not consider that feasible, the maximum savings potential was reduced to 90% to consider the cost to rebuild the piping and structures to connect to the new generator.

6. Initial Fuel Inventory: The fuel inventory account does not contain cost savings because coal and nuclear plants use different fuel types.
7. Indirect costs typically include the cost of the architect/engineer services, including construction services, engineering, construction management, quality assurance, field supervision, startup, and testing [357]. Table 52 shows indirect costs as 21-25% of total costs as was used in the INL 2022 study, though the 2017 CBR noted that indirect costs typically accounted for 31% of total costs according to the EEDB in the 1970s and 42% of total costs in the 1980s [359]. The INL study assumed that the indirect cost savings would mirror the direct cost savings. Since the direct cost savings were adjusted, per the above points, when taking the same approach, the indirect cost savings change commensurately.
8. Owners' Costs: Several costs not listed with the EEDB are listed in the CBR. These include owners' costs, startup commissioning costs, and contingency costs. Owners' costs include land, substation, transmission facilities, generator step-up transformer, nuclear insurance, taxes, fees, permits, owner's engineering, supervision and quality assurance, roads, ancillary buildings (e.g. visitor's centers, cafeterias, parking lots), training of operations staff, owner's general and administrative overhead, and licensing with all the local regulatory agencies [359, 357]. The CBR estimates that the owners' costs and contingency costs will account for 10% of the total OCC. However, there is no clear breakdown of each of these subcosts. The INL study assumed that all owners' costs, startup costs and contingency costs would be eliminated in a coal-to-nuclear transition. However this seems unlikely since the insurance, taxes, fees, owners' engineering, supervision and quality assurance, local licensing, training of operations staff, general administration and overhead, startup costs, and contingency costs would not be zero during the construction of a new nuclear power plant even if it were replacing a coal plant. Ancillary buildings, land, step-up transformers, substations, transmission facilities, and roads would be reusable, however. Absent a detailed breakdown of the owner's costs in either resource, for this study, the savings were reduced from 100% to 50-90%.

Table 52. Cost savings from Reusing a coal plant site to develop an SMR (% of OCC)

COA title (Number)	**PWR**	**SFR**	**NHTR**	**Min Savings**	**Max Savings**
Land and land rights (20)	0.3%	0.2%	0.3%	0%	100%
Structure and Improvements (21)	15%	12%	10%	0%	24%
Reactor Plant Equipment (22)	18%	29%	30%	0%	0%
Turbine Plant Equipment (23)	15%	10%	14%	0%	0%
Electric Plant Equipment (24)	5%	4%	5%	42%	78%
Miscellaneous Plant Equipment (25)	2%	1%	1%	6%	91%
Main Condenser and Heat rejection system (26)	3%	2%	2%	0%	90%
Initial Fuels Inventory	7%	11%	6%	0%	0%
Indirect Costs (9)	25%	21%	21%	3%	19%
Owner's Costs and Contingencies	10%	10%	10%	50%	90%
TOTAL	**8%-26%**	**7%-22%**	**8%-22%**		

B. Levels of Defense in Depth

Table 53. The levels of DiD [275]

DiD Level	Objective	Essential Means	Radiological Consequences/Impact
1	Prevention of abnormal operation, breakdowns, and failures	Conservative design and strong quality in construction and operation, along with control of main plant parameters inside defined boundaries	No off-site radiological impacts or consequences
2	Control of abnormal operation, breakdowns, and failures	Control, regulation, and limiting systems along with other surveillance features	
3	Control and manage accidents to limit radiological emissions and prevent core meltdown conditions	Reactor Protection System (RPS), safety systems/protocol, and accidents procedures as well as additional safety features	No off-site radiological impacts or just minor radiological consequences
4	Control and management of accidents with core melt to limit off-site releases and emissions	Complementary safety features to control core melt; management and handling of accidents with core melt	Off-site radiological impact may necessitate temporary and local protective measures
5	Mitigation of radiological consequences stemming from the releases of radioactive material	Emergency response beyond site premises along with levels of intervention.	Off-site radiological impact will necessitate protective measures

C. TRISO Particle Layers

Table 54. Tabulated Description of each TRISO Particle Layer

TRISO Layer	Description
Kernel	• Spherical fissionable fuel at center of particle • Fuels utilized consist of a range of types UO2, (U, Th)O2, UC2, (U,Th)C, PuO2, and UCO
Buffer	• Porous carbon buffer attenuates fission recoils and provides void space to accommodate fission gas release. • Porosity of buffer is described as low density ~50% porous pyrolytic carbon (PyC). • Purpose is to absorb kinetic energy of fission fragments ejected from fuel kernel surface (fission product recoil) to provide space for accumulation of gaseous fission products and carbon monoxide. • Mechanically, it decouples the kernel from the IPyC layer to accommodate swelling.
IPyC	• Dense layer of carbon with ~85% porosity. • Protects the kernel from corrosive gases (hydrochloride and chlorine) liberated during the SiC coating process. • First load-bearing layer from fission products and carbon monoxide during operation. • Retains fission gas products.
SiC	• High density, high-strength layer of SiC. • Primary objective is for structural strength of the particle. • Provides the TRISO pressure vessel support for internal fission gasses and impermeability to metallic fission products.
OPyC	• High density carbon layer. • Protects the fuel particle during formation of the spherical fuel compact. • Acts as additional barrier to release of gaseous fission products in event of SiC layer failure. • Necessary to provide a bonding surface between TRISO particles and carbonaceous matric material of fuel compact.

D. Quantity Category Thresholds of Radioactive Materials

Table 55. Quantity Category Thresholds of Radioactive Materials [360]

Radioactive Material	Category 1		Category 2	
	(TBq)	(Ci)	(TBq)	(Ci)
Americium-241	60	1,620	0.6	16.2
Americium-241/Be	60	1,620	0.6	16.2
Californium-252	20	540	0.2	5.4
Cobalt-60	30	810	0.3	8.1
Curium-244	50	1,350	0.5	13.5
Cesium-137	100	2,700	1	27
Gadolinium-153	1,000	27,000	10	270
Iridium-192	80	2,160	0.8	21.6
Plutonium-238	60	1,620	0.6	16.2
Plutonium-239/Be	60	1,620	0.6	16.2
Promethium-147	40,000	1,080,000	400	10,800
Radium-226	40	1,080	0.4	10.8
Selenium-75	200	5,400	2	54
Strontium-90	1,000	27,000	10	270
Thulium-170	20,000	540,000	200	5,400
Ytterbium-169	300	8,100	3	81

E. Employment or Other Post-Graduation Status

Table 56. Employment data of 2018 [220]

Year 2018	B.S.	M.S.	Ph.D.	Total
Continued Study/Postdoctoral Appointment	143	88	33	264
Academic Employment	1	1	12	14
Federal Government Employment	15	10	19	44
DOE Contractor Employment	13	20	34	67
State and Local Government Employment	1	0	0	1
Nuclear Utility Employment	41	13	5	59
Other Nuclear-Related Employment	49	13	16	78
Other Business Employment	25	9	16	50
Foreign (non-U.S.) Employment	3	5	8	16
U.S. Military, Active Duty	44	24	7	75
Other Employment	11	2	0	13
Still Seeking Employment	45	13	12	70
Unknown/Not Reported	232	62	33	327

Table 57. Employment data of 2019 [217]

Year 2019	B.S.	M.S.	Ph.D.	Total
Continued Study/Postdoctoral Appointment	144	90	10	244
Academic Employment	3	3	19	25
Federal Government Employment	11	9	21	41
DOE Contractor Employment	25	36	37	98
State and Local Government Employment	3	0	0	3
Medical Facilities	1	6	3	10
Nuclear Utility Employment	46	19	1	66
Other Nuclear-Related Employment	35	31	14	80
Other Business Employment	18	6	14	38
Foreign (non-U.S.) Employment	4	2	10	16
U.S. Military, Active Duty	65	16	5	86
Other Employment	10	10	2	22
Still Seeking Employment	28	4	4	36
Unknown/Not Reported	229	84	54	367

Table 58. Employment data of 2022 [218]

Year 2022	B.S.	M.S.	Ph.D.	Total
Continued Study/Postdoctoral Appointment	91	52	19	162
Academic Employment	0	5	10	15
Federal Government Employment	8	17	16	41
DOE Contractor Employment	14	21	33	68
State and Local Government Employment	0	<3	0	3
Nuclear Utility Employment	35	21	9	65
Other Nuclear-Related Employment	9	19	20	48
Other Business Employment	5	4	5	14
Foreign (non-U.S.) Employment	3	4	4	11
U.S. Military, Active Duty	48	12	8	68
Other Employment	<3	<3	<3	9
Still Seeking Employment	<3	<3	<3	9
Unknown/Not Reported	241	117	85	443
total	454	272	209	956

F. Long-Term Decommissioning

Safely decommissioning a nuclear power plant site is necessary to ensure the health and safety of employees and the public. The NRC has processes and regulations for the decommissioning and termination of licenses that an applicant wanting authorization to possess and use nuclear materials must abide by. These regulations are divided into the following sections: release criteria requirements, final status survey requirements, termination of licenses and decommissioning, financial assurance requirements, completeness and accuracy of radiation safety records, and criteria for decommissioning. With the intention to decommission, the applicant or licensee must be able to have its license terminated, complete a final radiation survey, and include financial assurance that decommissioning will be completed in a safe, timely, and practicable manner.

Release Criteria Requirements

If the net radioactivity results in a dosage less than 25 mrem per year for individuals expected to receive the most radiation exposure and is at a level as low as reasonably achievable (ALARA), the NRC can accept the site for unrestricted use. Determining the qualifying radiation level that is ALARA for a site to be accepted for unrestricted use must consider detriments, such as transportation accident casualties, that may be caused by decontamination and radioactive waste disposal. [361, 362]. The NRC can accept a site to terminate licenses described in Title 10 of CFR, including but not limited to licenses for operation, producing nuclear material, disposal of nuclear material, and transportation of nuclear material. These licenses can be accepted for termination with restrictions if specific conditions are satisfied. The licensee must demonstrate that all reductions in residual radioactivity levels are either achieving levels ALARA while considering detriments or cannot be reduced further without harming the environment or the public, as well as that the dosage from residual radioactivity does not exceed 25 mrem per year for individuals expected to receive the most exposure. They must provide financial assurance that can sufficiently enable an independent third party to be responsible for site control and maintenance and submit a decommissioning plan or License Termination Plan (LTP) that specifies their intent to restrict site use and decommission in accordance with NRC regulations. The plan should incorporate advice from the community affected by decommissioning. If the institutional controls at a site were stopped, there is assurance that the dosage from residual radioactivity is ALARA and does not exceed 100 mrem per year for individuals expected to receive the most exposure to the radioactivity. However, the NRC allows the limit for residual activity to be 500 mrem per year instead of 100 mrem only if the licensee demonstrates that further reductions are not achievable, are too expensive, or would harm the environment or public. This limit will also be adjusted if they provide institutional controls that are durable, provides financial assurance that can sufficiently enable a government entity or independent third party to be responsible for control and maintenance of the institutional controls and conduct periodic site rechecks at least every 5 years [363, 362].

The NRC can accept a site to terminate its license using alternate criteria for a dosage if the licensee assures the protection of public health and safety and submits an analysis for possible exposure sources to show the unlikeliness of it exceeding 100 mrem per year, employs practical site restrictions to minimize onsite exposures, and lowers dose levels to ALARA with consideration to detriments. Other requirements include submitting a decommissioning plan or LTP that specifies their intent to restrict site use and decommission in accordance with NRC regulations and providing financial assurance through a trust fund that can sufficiently enable an independent third party to be responsible for site control and maintenance. The decommissioning plan should specify their plans to decommission using alternate criteria and should incorporate advice from the community affected by decommissioning. Using alternate criteria requires NRC approval and recommendations based on comments from the EPA [364].

The NRC can accept a site to terminate its license using alternate criteria for a dosage if the licensee assures the protection of public health and safety and submits an analysis for possible exposure sources to show the unlikeliness of it exceeding 100 mrem per year, employs practical site restrictions to minimize onsite exposures, and lowers dose levels to ALARA with consideration to detriments. Other requirements include submitting a decommissioning plan or LTP that specifies their intent to restrict site use and decommission in accordance with NRC regulations and providing financial assurance through a trust fund that can sufficiently enable an independent third party to be responsible for site control and maintenance. The decommissioning plan should specify their plans to decommission using alternate criteria and should incorporate advice from the community affected by decommissioning. Using alternate criteria requires NRC approval and recommendations based on comments from the EPA [364].

Final Status Survey Requirements

Licensees must survey areas and subsurfaces to evaluate radiation level magnitudes, residual radioactivity quantities, and potential hazards from the detected radiation levels and residual radioactivity. Surveying and monitoring the areas and subsurfaces may be necessary for a licensee to abide by the regulations in 10 CFR Part 20 [365].

Licensees must survey areas and subsurfaces to evaluate radiation level magnitudes, residual radioactivity quantities, and potential hazards from the detected radiation levels and residual radioactivity. Surveying and monitoring the areas and subsurfaces may be necessary for a licensee to abide by the regulations in 10 CFR Part 20 [365].

Termination of Licenses and Decommissioning

Unless the licensee applies for a license renewal at least 30 days prior to the license expiration date, a specific license will expire at the end of the license expiration day. If a specific license was revoked by the NRC, the license expires at the end of the day the NRC determines as the expiration date. A specific license will continue, even after the expiration date if needed, until the NRC notifies the licensee of the termination. At this time, the licensee should control entry to areas that are restricted and limit the use of byproduct material when decommissioning. A licensee must notify the NRC within 60 days if the license expires, if activities authorized by the license are not conducted or 24 months, or if areas containing residual radioactivity are suitable to be released based on NRC requirements, resulting in activities authorized by the license to be stopped. If these occur, the licensee must start decommissioning or submit a decommissioning plan to the NRC to be approved. The licensee can request to extend the 60-day period if the NRC deems the extension safe and in the public interest. If the license conditions require, or the decommissioning procedures are not yet NRC approved, the licensee must submit a decommissioning plan. If the proposed procedures affect health and safety, they must get approval before beginning. The plan must include a description of the site conditions, procedures, protection measures being taken, and a final survey of radiation, as well as an estimated decommissioning cost, a comparison of the cost with the amount saved for decommissioning, a financial assurance plan, and a justification for delay if the plans states decommissioning will be complete after 24 months after the plan is approved. The NRC will approve the decommissioning plan if it demonstrates a practical completion time as well as that the workers and public will be safe due to adequate protection. Licensees should complete decommissioning within 24 months of the start of the process unless approved by the NRC. If the plan involves the decommissioning of the whole site, the licensee should request to terminate the license within 24 months of the start of decommissioning unless approved by the NRC. The NRC can approve an alternative decommissioning completion schedule if necessary. To complete decommissioning, the licensee should submit a Certificate of Disposition of Materials (Form 314), survey the entire area where licensed activities occurred, and submit the results of the survey. Once the NRC determines there has been proper disposal of material, residual radioactive contamination has been eliminated with effort, the radiation survey demonstrates suitability for release, any other information that demonstrates suitability for release has been submitted, and required records are received, the license will be terminated [366, 367, 368].

Financial Assurance Requirements

For a licensed unsealed byproduct material with a half-life more than 120 days and in amounts greater than 10^5 times the amounts listed in Appendix B of 10 CFR 30: The licensee should submit a certification that it can provide financial assurance in the amount shown in Table 59 based on the quantity of material.

Table 59. Financial Assurance Amount per Amount of Material [369]

Greater than 10^4 but less than or equal to 10^5 times the applicable quantities of appendix B to part 30 in unsealed form. (For a combination of isotopes, if R, as defined in § 30.35(a)(1), divided by 10^4 is greater than 1 but R divided by 10^5 is less than or equal to 1.)	$1,125,000
Greater than 10^3 but less than or equal to 10^4 times the applicable quantities of appendix B to part 30 in unsealed form. (For a combination of isotopes, if R, as defined in § 30.35(a)(1), divided by 10^3 is greater than 1 but R divided by 10^4 is less than or equal to 1.)	225,000
Greater than 10^{10} but less than or equal to 10^{12} times the applicable quantities of appendix B to part 30 in sealed sources or plated foils. (For a combination of isotopes, if R, as defined in § 30.35(a)(1), divided by 10^{10} is greater than, 1, but R divided by 10^{12} is less than or equal to 1)	113,000

If the certification states that financial assurance would be obtained after the NRC approves the application and issues the license and prior to receiving the material, the applicant (soon to be licensee) must submit the signed monetary contract that satisfies the amounts. If the applicant chooses to defer executing the monetary contract until after the NRC issues the license, the applicant must submit the signed monetary contract that satisfies the amounts prior to receiving the material. Funding plans for decommissioning to be reviewed and approved are required to have:

1. A detailed decommissioning cost estimate
2. Reasons for using assumptions from the DCE
3. A description of the financial assurance method
4. A certification that provides the financial assurance will fulfill the cost estimate
5. A signed monetary contract that satisfies whichever financial assurance method chosen

The decommissioning funding plan is required to be resubmitted when the license is renewed and at least every 3 years. The plan should be adjusted to consider cost changes and changes in the amount of contamination. Cost changes may be affected by radioactive material spills, changes in waste inventory and cost of disposal, changes in the facility, changes in the authorized limits for possession, costs that exceed the estimated cost, onsite disposal, and settling pond use.

Until a site is released, the licensee should keep its decommissioning information as records. These records should be transferred to the new licensee if licensed activities are transferred. Here the responsibility for maintaining the records before license termination falls to the new licensee. The licensee is required to use financial assurance funds for decommissioning only and is responsible for replenishing the funds. The licensee must report replenishing activity to the NRC within 30 days of the actions taken, stating the new fund balance [369].

A licensee notifying the NRC that it will begin decommissioning due to any of the 4 occurrences for the NRC to be notified within 60 days must include financial assurance of the estimated decommissioning cost. After the decommissioning plan is approved, the financial assurance amount can be reduced with NRC approval as decommissioning commences and contamination is reduced [366]. For licensed materials other than material used for uranium or thorium milling, an applicant applying for authorization to possess and use either between 10 and 100 mCi or greater than 100 mCi of source material must provide financial assurance for decommissioning. For all financial assurance requirements, refer to 10 CFR 30.35 [370]. For decommissioning plans for facilities removing spent fuel, HLRW and LLRW exceeding radionuclide concentration limits are classified as Class C waste in 10 CFR 61 (GTCC waste) [371]. An applicant applying for a license, or a holder of a license must include financial assurance in its decommissioning funding plan. For decommissioning funding plan adjustments, financial assurance methods, records requirements, and fund replenishment requirements, refer to 10 CFR 30.35 [372].

A licensee notifying the NRC that it will begin decommissioning due to any of the 4 occurrences for the NRC to be notified within 60 days must include financial assurance of the estimated decommissioning cost. After the decommissioning plan is approved, the financial assurance amount can be reduced with NRC approval as decommissioning commences and contamination is reduced [366]. For licensed materials other than material used for uranium or thorium milling, an applicant applying for authorization to possess and use either between 10 and 100 mCi or greater than 100 mCi of source material must provide financial assurance for decommissioning. For all financial assurance requirements, refer to 10 CFR 30.35 [370]. For decommissioning plans for facilities removing spent fuel, HLRW and LLRW exceeding radionuclide concentration limits are classified as Class C waste in 10 CFR 61 (GTCC waste) [371]. An applicant applying for a license, or a holder of a license must include financial assurance in its decommissioning funding plan. For decommissioning funding plan adjustments, financial assurance methods, records requirements, and fund replenishment requirements, refer to 10 CFR 30.35 [372].

Completeness and Accuracy of Radiation Safety Records

Information from an applicant or licensee provided to the NRC and information required for the applicant or licensee to maintain should be complete and accurate. The applicant or licensee should notify the NRC within 2 business days of any implications for public health, safety, and/or security [373].

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Criteria for Decommissioning

The independent spent fuel storage installation or monitored retrievable storage installation at a site is required to be designed with consideration to decommissioning. There must be provisions made for decontamination, minimizing the amount of waste and equipment that is contaminated, and facilitating waste and contaminated material removal when the ISFSI or MRS is decommissioned [374, 371].NRC Licensing Costs

NRC Licensing Costs

The total cost of getting a plant licensed to construct and operate is roughly $150 to $300 million, regardless of the reactor size.

1. ESP (Optional): $50-$100 million over a 5-year period, which includes the following [188]:
    a. $1 million over the first 2 years to select the site, plan, and build the team.
    b. A team of 5-10 skilled people throughout the 5-year period at a total cost of $5-$10 million to manage the work, plans, and communications and to answer requests from the NRC.
    c. Technical studies as required by the NRC: meteorology, geology, hydrology, ecology, socioeconomics, land use, demography, archaeology, noise, visual, and emergency planning.
    d. Public communications and public outreach activities.
2. Reactor Licensing: The cost of obtaining both the construction and operating license is estimated to be $100-$200 million on top of the cost of developing the site permit studies [188].
    a. Construction license costs depend heavily on whether or not the owner has previously obtained an ESP. This cost estimate assumes the ESP is already completed. For a construction license for a site without an ESP, the cost would be increased by about $50-$100 million, as the cost of those technical studies wouldn't change dramatically based on the timing of their completion.
    b. Operation license costs depend on whether the design has previously been certified. The above estimate assumes that the design has not yet been certified, as most designs have not been certified before the owners applied for the operating license. Bloomberg estimated that NuScale spent between $500-$600 million to become a certified design so most technologies would not pay to certify their design before their first deployment [375].

G. Position Role Information

Plant Manager

Role: The plant manager will oversee all operations performed at the plant and is the bridge between the plant and corporation. They implement all state and federal laws on site and are accountable for all activities through the primary directors.

Qualifications/Experience: Minimum bachelor's degree in related field (engineering, business, etc.) and will have moved horizontally through previous management roles.

Licensing

Role: The licensing group reports functionally to the plant manager but is the onsite coordinator with the NRC and INPO. They interpret and implement the regulatory standards set by the NRC and IAEA by setting standards, scheduling audits, preparing reports and documents for management/NRC as needed, and maintaining all up-to-date licensure on site.

Qualifications/Experience: Minimum bachelor's degree in engineering/engineering tech, related science degree, or legal/paralegal studies. Previous NPP licensing, knowledge of or specific training regarding nuclear engineering codes, standards, and licensing desired.

Safety:

Role: Ensure compliance with NRC, INPO, and OSHA standards on site for all personnel to ensure safety to workers, environment, and surrounding population to plant. Work closely with the licensing and training team. Consistently evaluate and update safety procedures on site, perform hazard and safety analyses with compliance testing, and implement/maintain safety documentation for plant.

Qualifications/Experience: Minimum associate's but bachelor's degree preferred in safety engineering, nuclear safety analysis, or other related technical discipline, experience with implementation of NRC nuclear safety rules and regulations including 10 CFR 830, 10 CFR 21, 51-52, etc.

Dir. O&M:

Role: Oversee and direct all O&M on site including various operators, maintenance crews, clerks, etc. They coordinate and schedule daily, weekly, quarterly, and yearly maintenance reviews. The dir. O&M coordinates with all O&M personnel as well as interface with the other directors to keep the site functioning up to standards during normal and abnormal runtime.

Qualifications/Experience: Bachelor's or master's degree in engineering, engineering technology, construction management, or related field. Minimum 5 years nuclear experience within plant or similar previous role.

Dir. Support Services:

Role: The dir. support services is responsible for all support activities on site including finances, radiological testing, chemistry, etc. They will plan out scheduling of support service activities daily, weekly, quarterly, and yearly by working with various management on site. They provide guidance, prepare reports as needed, and fulfill the plant managers will through various tech and managers underneath their leadership.

Qualifications/Experience: Minimum bachelor's degree in radiological science/health physics, chemistry, finance, business, or related degree. Minimum 5 years in nuclear plant with previous management position preferred.

Dir. Engineering:

Role: Responsible for the direction and control of all engineering activity on site with plant needs and regulatory requirements in mind. Provide technical and expertise for identification, RCA, and problem resolution with extensive prior experience. Work closely with dir. O&M and safety team for future corrections/suggestions to improve efficiency and safety on site from direct experience with plant equipment.

Qualifications/Experience: Minimum bachelor's degree in engineering discipline or equivalent nuclear navy experience. Minimum 5 years nuclear industry experience including plant side. At least 2 years previous supervisor/management experience within plant or similar previous role, and working towards or already qualified PE.

Maintenance Manager:

Role: The maintenance manager is the principal oversight under dir. O&M to implement O&M operations through plant. They direct and implement the dir. O&M scheduled maintenance through the use of the crews and techs to keep plant running efficiently with safety in mind for personnel. They track progress after distributing tasks, coordinate with other departments, and create reports for management on site. Maintain workforce ALARA implementation, schedule and coordinate for refuel/outage periods, and oversee storeroom clerks for shipment/equipment logging.

Qualifications/Experience: Minimum associate's degree in technology field with prior tech/crew chief or operator experience

Radiological Manager/Health Physicist:

Role: Work closely with safety team and ensure utmost safe handling of radioactive materials, metals, and chemicals for all plant personnel, environment, and surrounding communities. Provide direction and supervision to radiation techs for possessing/transporting nuclear materials on/offsite, evaluating and creating new safety procedures as necessary by performing health/risk analyses, selecting radiation protection equipment for workforce and plant, and tracking/trending all radiological data from plant monitors.

Qualifications/Experience: Bachelor’s in engineering, health physics, chemistry, related science/technology degree, or equivalent nuclear navy experience. 2-5 years previous health physics work in nuclear desired and familiarity with NRC rules and regulations regarding safe usage of a protection of radioactive materials.

Chemistry Manager:

Role: Directly responsible for planning and administering chemical performances on and off site through the coordination of chemistry technicians. Develop and coordinate chemical treatment/analysis at facility, guide through complex chemical tasks, and ensure compliance to NRC, state, and federal standard. Work closely with health physicist for environmental metrics, waste storage or shipment, and provide reports/presentations to upper management as needed.

Qualifications/Experience: Minimum bachelor’s degree in chemistry, chemical engineering, or chemical eng. tech. 3-5 years previous chemistry experience especially in nuclear environment and 1-2 years management role desired.

Training Supervisor:

Role: Develop, store, implement, and maintain all related training videos, courses, simulations, and materials to incoming and current employees on site. Prepare and reevaluate training programs and materials from direct reports from management on site and organizational standards from INPO, NRC, etc.

Qualifications/Experience: Minimum associate’s but bachelor’s degree preferred in STEM or tech related field. Min. 2-year history designing, implement, and executing training to new and current hires, excellent multitask and coordination skills, and knowledge of NRC and INPO accreditation criteria.

Security Supervisor:

Role: Design, support, and implement all physical and digital security systems on site to train and enforce proper security protocols in accordance to plant, NRC, INPO, WANO, and national security standards. Engage with each organization during plant safety and security audits. Train and retrain security officers onsite to keep adequate physical and mental facilities to prepare for hazardous incidences onsite. Track and maintain the confidential usage of all documents and materials in the plant based on appropriate security clearances.

Qualifications/Experience: Minimum bachelor’s degree, 5-10 years designing and implementing proven security programs within industrial setting, but nuclear site preferred. Knowledge of and compliance with NRC 10 CFR security regulations. Previous NRC or governmental agency interface role.

Financial Manager:

Role: Lead and advise a team of financial and administrative clerks for the purchasing and logging of all onsite activity through close work with management. Effectively establish budget for purchasing and documentation of necessary equipment, components, and all needs for the plant. Develop budget reports, value analyses, and reports as needed for plant managers.

Qualifications/Experience: Bachelor's degree in business, finance, accounting, or other related financial discipline. 1-3 years previous management.

SRO:

Role: SROs are ultimately in charge of all functions and decisions on how to run the plant safely in accordance with established rules, laws, and regulations. Manage plant's operations through LO and NLO from control room. Work closely with safety and licensing to ensure the plant is safe and up to code. Regularly test and train operators for normal and abnormal plant conditions. Perform 10 CFR 50.59 and SQR reviews.

Qualifications/Experience: Bachelor's degree in engineering, engineering tech, or related science degree. Current or previous LO with 1-5 years of experience. Qualified RO and must pass POSS and BMST. Pass security screening and background check and have previous managerial or supervisor experience within plant or comparable outside of plant.

Mechanical Crew Chief:

Role: Directly supervises and oversee daily mechanical maintenance, installation, and repair through the use of maintenance techs. Optimize maintenance schedules for plant after coordination with dir. O&M. Ensure all mechanical systems perform in perfect condition and uphold the safety requirements necessary for site through diagnostics, meter information, trending, and tracking data from mechanical systems.

Qualifications/Experience: Bachelor's degree in mechanical engineering or mechanical engineering technology. Excellent schematic interpretation and implementation, equipment manual knowledge, mechanical and industrial practice experience within power generation. Knowledge of NRC, INPO, and OSHA regulations

Electrical Crew Chief:

Role: Responsible for overseeing the maintenance, repair, testing, diagnosing, and analyses of electrical systems on site through electrical technicians. Implement maintenance manager's maintenance schedule while also ensuring the safe and efficient use of electrical systems on site in accordance with the rules and regulations of the plant. Work closely with the other maintenance crew chiefs for maintenance scheduling and repair. Prepare reports and presentations for upper management as required.

Qualifications/Experience: Minimum associate's degree in electrical engineering, electrical engineering tech, or similar degree but bachelor's degree preferred. Prior management/supervisor experience. Valid electrician's license/certification, Extensive knowledge of turbines, generators, transformers, switches, etc.

Instrumentation Crew Chief:

Role: Responsible for all calibration, coding, implementation, diagnosing, troubleshooting, and repair of all systems, sensors, and software for plant through leadership of instrumentation technicians. Ensure the safe operations of machinery and equipment through providing technical expertise in line with maintenance manager's scheduling. Work closely with other crew chief for upkeep of maintenance performed in plant. Retain and monitor all I&C documentation for review.

Qualifications/Experience: Minimum associate's degree in electrical engineering, electrical engineering technology, mechanical engineering technology, automation tech, robotics tech, or related field but bachelor's degree preferred. Prior instrumentation technician experience. Knowledge of NRC, INPO, and OSHA regulations.

LO:

Role: Responsible for manual decisions to operate plant within limits according to SROs wishes and use of NLOs. Routinely test equipment for functionality and report any failures to maintenance for fix. Start, stop, control, turbines, generators, auxiliary equipment, pumps, fans, valves, etc. for normal and abnormal operations. Follow all NRC administrative procedures for regular and irregular occasions. Initiate emergency procedures as required.

Qualifications/Experience: engineering, engineering tech, science degree, or equivalent navy experience, previous in-plant experience as NLO or engineer.

NLO:

Role: Monitor, trend, and review all equipment for LO and SRO as needed. Take control of all auxiliary equipment to perform necessary plant function as required. Run calculations and report findings to upper management per protocol. Assist in coordinating other disciplines within facility per procedure. First responder on site to all crises and hazards.

Qualifications/Experience: Bachelor's degree in engineering, engineering tech, related science degree, or equivalent nuclear navy experience. Must pass POSS and BSMT, undergo year-long training and pass tests at appropriate times, willing to pursue licensure to become LO.

Fire Protection Engineers:

Role: Responsible for guidance, expertise, and administering fire safety, hazard analyses, guiding personnel according to safety codes, and overseeing fire protection systems/protocols on site. Design and implement fire protection processes closely with the safety team. Inspect equipment in the plant for vulnerabilities followed by troubleshooting as needed. Perform fire calculations, post-fire investigations, and develop new guidelines based on results.

Qualifications/Experience: Bachelor's degree in fire protection, fire protection engineering, or engineering with specific certifications

Nuclear Engineers:

Role: Responsible for daily, weekly, quarterly, and yearly nuclear scheduling and maintenance such as startup physics tests, fuel transportation, reactor monitoring, and nuclear calculations. Perform fuel and waste studies working with chemistry and radiologic department. Research and implement nuclear storage, movement, handling, etc. In all plant processes for improvements to efficiency and safety on site.

Qualifications/Experience: Bachelor's in nuclear engineering, engineering technology, or related science degree such as physics, chemistry, math with additional nuclear or power experience. Equivalent nuclear navy experience accepted. Willing to go through rigorous training regarding safety procedures, state/federal regulations, core processes, etc.

Mechanical Engineers:

Role: Responsible for performing daily analyses, diagnostics, and overseeing project implementation for mechanical systems on site. Provide mechanical expertise through research, consultation, design, and coordination with other disciplines. Design and implement valves, pipes, tanks, pumps, etc. in accordance with rules and regulations from OSHA, INPO, and NRC. Lead projects, modify systems, and evaluate mechanical systems using knowledge in thermodynamics, statics, fluid mechanics, etc. Work closely with mechanical maintenance as necessary.

Qualifications/Experience: Bachelor's degree in mechanical engineering or mechanical engineering technology, proficiency in CAD software, knowledge of practical applications of mechanical systems in power plant setting.

Electrical Engineers:

Role: Responsible for designing, testing, calculation, and monitoring of electrical systems, devices, and equipment in the plant. Perform tests using arc flash analyses, short circuit, load flow calculations, AC/DC power tests, motor performance, and programming. Implement schematic, Programmable Logic Controller (PLC) programming, BAS system monitoring, and more for the plant. Work closely with electrical technicians as needed.

Qualifications/Experience: Bachelor's degree in electrical engineering, electrical engineering technology, energy engineering tech, or other related degree. Knowledge in designing and implementing low-high voltage. Willing to go through LOTO training.

Chemical Engineers:

Role: Evaluate and optimize chemical processes on plant with close collaboration of dir. of support services and chemistry department. Troubleshot chemical equipment using data input from technicians. Analyze water and cooling systems, wastewater, and emission control while informing management on quality issues.

Qualifications/Experience: Bachelor's degree in chemical engineering or chemical engineering technology.

High Voltage (HV) and Distribution:

Role: Responsible for design, analysis, and maintenance of HV systems including transformers, relay stations, switch gears, circuit breakers, and HV technology on site. Oversee installation of HV while ensuring they interface with the plant's power generation and load distribution equipment. Troubleshoot system issues, optimize load, maintain PLC with HV systems, and follow all NRC/OSHA guidelines.

Qualifications/Experience: 2-5 years in design and distribution of HV systems, specialized work in power system desires, LOTO training, IEEE and IEC code knowledge.

Mechanical Techs:

Role: Perform routine maintenance, repairs, inspections, and cleaning of all mechanical systems on site. Assist with installation and upkeep, report and diagnose irregularities, and inform upper management. Support other personnel on site with tools and materials needed while keeping up necessary technical documentation.

Qualifications/Experience: Minimum Associate's degree in mechanical engineering or mechanical engineering technology. 0-2 years related experience, working knowledge of power tools, physically fit to perform tasks at plant, and passable grade in EEI Mass test preferred.

Electrical Techs:

Role: Work closely with electrical crew chief and engineers to monitor and perform daily maintenance routines for electrical systems. Use benchtop lap skills to test and fix electrical components. Conduct maintenance on computer systems, solenoids, motors, switches, etc. Respond to abnormal electrical malfunctions and report as needed. Calibrate, clean, and repair electrical systems/

Qualifications/Experience: Minimum associate's degree in electrical engineering or electrical engineering technology.

Instrumentation Techs:

Role: Help install, inspect, test, repair, and calibrate electrical devices, components, and equipment on site. Troubleshoot PLC devices and implement patches as needed. Perform routine maintenance on control devices and systems. Abide by all safety requirements during routine duties.

Qualifications/Experience: Minimum Associate's degree in industrial instrumentation technology, electrical engineering technology, robotics, automation/controls or related field.

Rad Techs:

Role: Perform day-to-day monitoring of radiation levels within plant to ensure safe operation for personnel, environment, NRC/INPO standards, etc. Monitor, measure, and record radiation using Geiger counters, dosimeters, and scintillation detectors. Test and monitor radiation protection for defects and work with financial clerks as needed. Provide recommendations to protocol for safety. Immediately alert for evacuation for radiation outbreak and initiate containment procedures. Aid with fuel transportation in and out of plant.

Qualifications/Experience: Minimum associate's degree in radiation technology, nuclear science, nuclear technician, or equivalent. Prior radioactive experience preferred.

Chemistry Techs:

Role: Perform routine analysis on chemical processes in the plant such as sampling, testing, monitoring, and documentation as necessary. Maintain strict safety procedures in the handling and processing of materials and fluids from plant, OSHA, and NFRA requirements. Create graphical analyses of trends from plant equipment and empirical evidence.

Qualifications/Experience: Minimum Associate's degree in chemistry, chemical technology, biology, or related STEM degree. 1+ years working in laboratory setting.

Training Instructors:

Role: Provide training and technical expertise/lessons to incoming and current job force. Cover all generalized training such as rad safety, ALARA, etc. or specialized training like electrical LOTO. Maintain all training materials while consistently evaluating for new procedures. Establish monthly simulation training for operators.

Qualifications/Experience: Minimum Bachelor's degree in engineering, technology, HR with specialized training, or related science degree. 1-3 years relevant experience.

Security Officers:

Role: Protect the health and safety of the public by defending the plant from all internal and external threats by maintaining perimeter, routine patrols, and directly controlling who comes into and out of facility physically and digitally. Monitor and test all security/communications systems following NRC requirements. Train and stay physically fit for the job as necessary. Learn and apply nuclear defense strategies to keep the plant and surrounding communities safe. Maintain security reports for NRC and INPO usage.

Qualifications/Experience: Background check, pass psychological and physical exam, adherence to NRC CFR Part 50, 52, and 73. Licensed to use weapons as necessary.

Administrative Clerks:

Role: Effectively coordinate and perform all administrative and financial functions for plant operation. Perform financial analyses, budget calculations, etc. for financial manager to coordinate with plant leadership. Directly support individual managers on site as needed.

Qualifications/Experience: 2-5 years related clerk experience and proficiency in administrative tools/techniques.

Storeroom Clerks:

Role: Receive, inspect, process, log, and distribute incoming material, equipment, components, and tools for all plant personnel. Directly log and track all equipment on the plant. Audit storerooms as necessary. Interface with techs, chiefs, and engineering on site for all nuclear materials to run facility. Investigate any inventory differences and conduct investigation to eliminate discrepancies.

Qualifications/Experience: Minimum high school diploma or GED, 1-3 years in administrative role, clerk position, or inventory experience, excellent communication and written skills.

Custodians:

Role: Responsible for cleaning and maintaining premises for safe operation according to plant requirements from NRC guidelines. Keep plant in clean condition through sweeping, scrubbing, utilizing chemical solutions, maintaining cleaning supplies, drives industrial cleaning vehicles, etc.

Qualifications/Experience: Minimum high school diploma, knowledge of cleaning materials, tools, and chemicals in an industrial context preferred, willing to go through standard mandatory classes to work within nuclear environment.

H. Current Ivy Tech and Purdue Polytechnic Programs to Support SMR Workforce

Business Administration (AAS, AAS, AAS, AAS, AS, TC)

Position: Admin Clerk/Licensing

Depending on the specific job duties assigned to admin clerks/licensing, the Business Administration courses would be used to learn management, marketing, economics, accounting, finance, business communications, and more. It is accredited by ACBSP and those obtaining degrees keep the administrative functions under control and in top condition for the plant to run smoothly during normal and abnormal conditions.

Chemistry (AS)

Position: Chemistry Technician/Chemistry Manager

Those with an AS in chemistry learn foundational skills on lab equipment utilization along with gaining knowledge in topics such as o-chem, atomic structures, physical chemistry, and quantitative analysis. Graduates could then become a chemistry technician collecting and analyzing sample within the plant's primary systems for radiation, acids, etc. For optimal plant running conditions. They could also switch to a 4-year degree to pursue a higher level in the plant such as chemistry manager or dir. of support services.

Cybersecurity/Information Assurance (AAS, Accelerated AAS, AS, TC)

Position: Cybersecurity

Students learn how to defend systems, networks, data, etc. To protect the plant from cyber-attacks that would be intended to harm, alter, or destroy data/systems for the plant with the goal of harming those on site or the public. They learn the ethics of controlling data for the plant along with gaining the tools to identify and neutralize the threats before coming up with a solution to prevent future attacks.

Electrical Engineering Technology (AS)

Position: Electrical Technician/Crew Chief, Instrumentation Technician/Crew Chief

Students pursuing the electrical engineering technology Associate's gain knowledge in routine electrical maintenance of building systems and equipment. Graduates gain foundational knowledge and skills in electrical theory, AC and DC systems, analog and digital applications, C++ programming, filter design, circuit simulations, benchtop equipment, and testing methodology. They can become an electrical maintenance technician or transfer to a 4-year degree to become crew chief or electrical engineer within the plant.

Electronics & Computer Technology (AAS, TC, TC)

Position: Instrumentation Technician/Crew Chief

Like the previous degree, the electronics and computer technology graduates learn core electrical concepts but dive more into specifics such as op-amp and RLC circuit designing, power supplies, JFETs and MOSFETs, etc. They learn system diagnostics and how to maintain/troubleshoot electrical systems with more of a computer focus than previous. They can fill either electrical technician or instrumentation technician role or can pursue higher education for crew chief or engineering roles.

Homeland Security/Public Safety (AAS, AAS, AAS, AS)

Position: Security, Safety, Radiological Technician, Fire Engineer

Graduates of the homeland security program(s) can learn a wide variety of skills for public safety to protect those in and around the plant. Depending on the program chosen, students learn code standards, fire hazard and safety training, lab skills, emergency management skills, hazmat and radiological training, water treatment, etc. Dependent on program and skills learned, they could fill multiple roles in plant from security to fire engineering (with extra certs) to radiological technician.

Industrial Technology (AAS, TC, TC, TC, TC, TC)

Position: Instrumentation Technician/Crew Chief, Electrical Technician/Crew Chief, Nuclear Welder

Graduate of the industrial technology program(s) learn basic and emerging principles/concepts/ and technology for an industrial environment. They learn how to troubleshoot and maintain electrical and mechanical systems on site to diagnose and maintenance service equipment. Depending on the program, they also learn multiple welding techniques and skills. They would be equipped for multiple roles including various technicians and chiefs with provided and additional training.

Legal and Paralegal Studies (AAS, AS)

Position: Licensing

Graduates of legal and paralegal studies learn governmental structures/organizations, sources of law, litigation processes, and learning to understand laws/regulations. They gain the skills to work as a legal assistant, administrative assistant, governmental agent, etc. or pursue higher education. They could fill the licensing role on site with specialized nuclear code training from DOE, etc.

Logistics and Supply Chain Management (AAS, AS, TC)

Position: Administrative Clerk, Financial Manager, Storeroom Clerk

Graduates of this program learn the logistics of transportation and storage of materials, process inventory, supply chain analyses, and tools for increasing efficiency. They could fill multiple roles including administrative clerk, storeroom clerk, or financial manager.

Mechanical Engineering Technology (AS)

Position: Mechanical Technician/Crew Chief

Graduates of the mechanical engineering technology program learn fundamental mechanical knowledge through hands-on experience with mechanical devices and software. They learn to fix multiple appliances, systems, and devices and design components in various CAD software. With further schooling/certifications, they would be ideal for becoming mechanical technicians or crew chiefs.

Network Infrastructure (AS, TC, TC)

Position: Security, Administrative Clerk

Graduates learn how to install, configure, maintain, troubleshoot, and secure networks. Learn core concepts networking including QOS, NAT, VPN, SDN, network automation, security, and more. They take courses in infrastructure, wireless technology, cybersecurity, installation, and network requirements. They would be a great fit for an administrative clerk or security position depending on how digital security job duties are distributed through the plant.

Smart Manufacturing (AAS, TC)

Position: Instrumentation Technician/Mechanical Technician Crew Chief

Students learn how to design, troubleshoot, and program digital devices such as computers, PLCs, robots, and other specialized industrial and manufacturing software. They use electrical and mechanical skills to diagnose, repair, and test components. They learn how to be safe and determine appropriate methodology to work around computer-controlled machinery, systems, and equipment. They would fill a technician role or chief depending on higher education.

Computer and Information Technology (BS)

Position: Cybersecurity or Administrative Clerk

Graduates learn how to design, implement, and administer local and wide networks. They learn to help fight cyber threats or keep a business running efficiently through digital applications, management information systems, computer networks and more. Easy to customize the degree from concentrations and minors along with specialized training in either software development, systems analysis, design and integration, data management, or wireless networking. Ideal for cybersecurity person or administrative clerk

Cybersecurity (BS)

Position: Cybersecurity or Administrative Clerk

Cybersecurity graduates learn the core principles to guard a business's digital assets and provide protection against internal and external threats. Skills such as secure coding, cryptography, digital forensics, and UNIX fundamentals are learned and applied to a wide variety of cybersystems and threats. There is potential for multiple campus internships to gain real world knowledge before entering the workforce. Ideal for whichever role covers the cybersecurity of the site.

Automation and Systems Integration Technology (BS)

Position

Learn skills that can interface between manufacturing, electrical, and mechanical systems in a primarily industrial environment. Learn automation, robotics, and systems with hands-on labs/coursework. Ideal to become instrumentation, mechanical, or electrical technicians/crew chiefs, electrical or mechanical engineers

Mechanical Engineering Technology (BS)

Position: Mechanical Engineer, Mechanical Technician, or Crew Chief

Graduates of the program focus on the methods, materials, and all the skills to operate manufacturing equipment and systems. They learn how to manage and distribute people, machines, and production resources for efficiency and safety. Emphasis on advanced materials, sustainable energy, and product realization. Ideal for mechanical engineer, technician, or crew chief.

Computer Engineering Technology (BS)

Position: Electrical Engineer, Instrumentation Technician/Crew Chief

Learn fundamentals of coding and PLC coding and interfacing with digital systems. They learn to understand microcomputers and systems in all input/output devices to design/implement computer and electronic devices.

Mechatronics Engineering Technology (BS)

Position: Instrumentation Technician, Crew Chief

Students in this program find the intersection between electrical, manufacturing, mechanical, and computing for industrial environments. They learn the fundamentals of programming, mechanics, design specifications, instrumentation and controls automation, statics, hydraulics, and more. They are a core group of individuals perfect for controlling and programming systems such as the instrumentation technician and crew chief within the plant.

Robotics Engineering Technology (BS)

Position: Instrumentation Technician/Crew Chief, Electrical Technician/Crew Chief

Graduates of the robotics engineering technology program learn the fundamentals of coding and apply their skills for robotic solutions in a wide variety of industries. They are equipped to design, repair, and maintain robotic systems in automobiles, manufacturing plants, and more. Classes include C programming, electronic systems, statics + dynamics, industrial controls, robotic kinematics, etc. They would be ideal for instrumentation technician/crew chief, but also have the skills for electrical technician.

Electrical Engineering Technology (BS)

Position: Electrical engineering technology students learn the intersection of analog and digital electronic systems in everyday life. Communications, controls, power electronics, and more allow them to pursue a wide variety of industries with knowledge from classes about DC/AC systems, data acquisition, electronic prototyping, embedded digital systems, etc. They would be ideal for electrical engineers, electrical technician/crew chief, instrumentation technician/crew chief, and dir. of engineering with experience.

Energy Engineering Technology (BS)

Position: Electrical Engineer, Electrical Technician/Crew Chief, HV and Distribution with training, Radiological Technician/Manager, or Licensing

Graduates in energy engineering technology choose the intersection between electrical devices, clean energy, climate change, and policy. They have broad knowledge of troubleshooting electrical circuits, evaluating renewable energy systems in industrial, residential, and commercial setting, and all processes of energy transmission, distribution, etc. They receive many of the same courses to electrical engineering students, but get more in power systems, renewable energy system design, smart grids, and green politics. They would be ideal as the electrical engineer, electrical technician/crew chief, HV and distribution engineer, radiological technician/manager, or potentially licensing with extra training.

Supply and Sales Engineering Technology (BS)

Position: Administrative Clerk/Financial Manager, Storeroom Clerk, Maintenance Manager

Graduates of this program learn a variety of skills from supply chain management, statistical quality control, warehouse and inventory management, operations planning, and more. They are experts in the administrative/financial analyses field while also learning the engineering process to mold a company into a more efficient version than previous. They could fill a variety of roles including administrative clerk/financial manager, storeroom clerk, or maintenance manager with experience.

I. **I**vy Tech Identified Courses and Program for SMR Workforce Support

Below are some example courses and programs identified that could be implemented at Ivy Tech Community College to train, re-train, and reinforce an SMR workforce.

Welding

Welding is a specialized skill within a nuclear sector that is required during both the construction and operation phases of an SMR. Ivy Tech is an ideal place to train and reinforce the specific training needed to become a certified in the nuclear-welding workforce. Currently, the college offers a CT in Structural Welding [376], and offers American Welding Society (AWS) certifications at AWS-accredited campuses. This certification, however, is missing specialized trainings/techniques such as additional volumetric inspection, pipe welding, and structural welding that is not currently covered to the necessary degree needed for nuclear welding. While it could be covered in this course, an additional course might be necessary to cover these specialized techniques. In either case, the result would be a TC in welding that meets the requirements of nuclear welder.

ASME, AWS, and Specialized Inspections

Beyond volumetric testing, radiographic inspection is used routinely within the nuclear industry, but maintaining the equipment would likely be untenable due to expense, regulation, and safety considerations. Theory would still be covered, and third-party testing services could still be utilized. Other common tests to be implemented within the course/program include visual inspection, magnetic particle inspection, eddy current testing, ultrasonic testing, and liquid/dye penetrant testing.

While radiographic inspection is used routinely within the nuclear industry, maintaining ionizing radiation producing equipment such as x-ray sources and gamma sources would likely be untenable due to expense, regulation, and safety considerations. However, theory would be covered and third-party testing services could be utilized. Other common tests could be covered and conducted on campus including visual inspection, magnetic particle inspection, eddy current testing, ultrasonic testing, and liquid/dye penetrant testing. Beyond inspection techniques, ASME Sections 3 and 9, along with AWS certification testing could be implemented into the course. While AWS accreditation and certifications are not recognized within the nuclear sector, the standards a similar enough that AWS certification testing would be beneficial for preparing students to perform well during interviews with competency tests. N-Stamps were also researched, but as they pertain to nuclear component certification and commercial part production, Ivy Tech would not need to pursue N-Stamps [377].

Radiological Safety/Health Physics

Lastly, Ivy Tech could benefit from a radiation safety/health physics degree, or courses ingrained within other degrees. Specific training is typically provided by the utility and companies contracted by the utility, but embedding radiation safety into the program or developing a specialized course would be highly recommended to prepare students for the necessary precautions in the nuclear field. Given the need for safety technicians to enforce OSHA policies, NRC regulations, EPA requirements, etc., health physics and other courses/degrees may need to be required.

J. Current Purdue Certificates for SMR Workforce Development

- **Constructions Site Supervision (C.S.S.C)**
  - 3 months
  - Learn field supervision for management of people, schedules, coordination, leadership, quality, budgets, safety, and project planning. Become a field supervisor in charge of managing the safety and work of those underneath them.
- **Executive Construction Management**
  - 12 credit course
  - Gain an understanding in construction accounting, finance, law, risk management, marketing, and strategy. Specifics include sustainable site development, construction leadership, construction accounting, financial management, quality, and more. Useful for immediate real-world application to manager roles.
- **Business Essentials**
  - Works as a mini-MBA experience for broad business functions including accounting, strategic management, financial management, and more.
- **Certified Financial Planner (CFP)**
  - 10 months
  - Developed by experts who served on the CFP Board of Examiners, the CFP certificate covers fundamentals of financial planning, insurance, investment planning, income tax planning, retirement planning, employee benefits, and more.
- **Certified Information Systems Security Professional (CISSP)**
  - 5-day bootcamp
  - Covers security and risk management, asset security, security architecture and engineering, communication and network security, identity and access management, security assessment and testing, security operations, and software development security. Ideal for those in a security or cybersecurity role and prepares professionals for CISSP certification exam by (ISC)^2
- **Google Cybersecurity Certificate**
  - As little as 6 months

- Fully prepared for a minimum, entry level cybersecurity job by learning data protection using various tools like Python, Linux, SQL, SIEM, and Intrusion Detection Systems (IDS). Learn programming for cybersecurity tasks, frameworks and controls, SIEM tools, detection and response, packet capture and analysis, and more.

- **Systems Engineering**

  - 12-18 months Learn the interconnections between social, biological, economic, political, and technological systems to design and improve systems designs. Excellent to learn to combine all aspects of a project/function into one cohesive unit to deliver the envisioned result.

K. Proposed Nuclear Engineering Technology Courses

This section delineates the proposed curriculum for the nuclear engineering technology program at Purdue University. The program is anticipated to align closely with existing plans of study in intent and content. The curriculum is designed to be integrated within the current four-year academic framework, with the primary objective of cultivating a workforce proficient in the nuclear power generation sector and deeply ingrained in the safety culture paramount to the industry.

The program encompasses core courses that establish a robust foundation for technical degrees. These foundational courses are strategically designed to equip students with essential competencies critical for various roles within the nuclear sector, including technician positions, operator training, and nuclear sciences. A synthesis of insights from a former nuclear utilities engineer who has transitioned into an engineering technology professor and contributions from the nuclear engineering program at Purdue University informs the development of this curriculum.

The suggested curriculum reflects the engineering technology pathways available at Purdue. It incorporates a comprehensive analysis of peer institutions across the United States that currently contribute to the nuclear workforce in the energy sector. The proposed nuclear engineering technology program at Purdue University aims to provide a rigorous educational experience that prepares students for successful careers in the nuclear power generation industry, emphasizing both technical proficiency and a commitment to safety culture critical to the field.

Year 1		Year 2		Year 3		Year 4	
Sem 1	Sem 2	Sem 1	Sem 2	Sem 1	Sem 2	Sem 1	Sem 2
MA 16010 Analytical Geometry and Calculus I	MA 16020 Applied Calculus II	MA 266 Ordinary Different Equations	NET XXX Standard Materials Engineering	NET XXX Engineering of Nuclear Power Systems	ECE 20001 Electrical Engineering Fundamentals I	NET XXX Engineering of Nuclear Power Systems	NET XXX Advanced Nuclear Reactor Design & Safety Analysis
CHM 115 General Chemistry	CHM 116 General Chemistry	NET XXX Sophomore Capstone	NET XXX Sophomore Capstone	NET XXX Junior Capstone	NET XXX Junior Capstone	NET XXX Introduction to Reactor Theory and Applications	NET XXX Senior Capstone
COM 114 Fundamentals of Speech Communication	ENGL 108 First Year Composition	Humanities Gen ed	NET XXX Standard Materials Engineering	NET XXX Nuclear Materials Laboratory	NET XXX Nuclear Thermalhydraulics Laboratory	NET XXX Project Management for Nuclear Projects	Humanities Gen ed
NET XXX Intro to Nuclear Engineering Technology	TECH 120 Design Thinking in Technology	NET XXX Radiation Protection and Health Physics	NET XXX Nuclear Regulatory Compliance & Safety Culture	NET XXX Nuclear Thermal-Hydraulics I	NET XXX Nuclear Plant Systems and Components	Technical Selective	Elective
PHYS 172 Modern Mechanics	NET XXX C++ Programming OR NET XXX Fortran Programming	PHYS 200 Level (221, 241, 272)	MET 200 Thermodynamics I	Technical Selective	NET XXX Operational Training for Small Modular Reactors	NET XXX Materials in Nuclear Industry	Technical Elective

Figure 65. Sample Nuclear Engineering Technology (NET) Plan of Study

Figure 65 serves as a comprehensive representation of the nuclear engineering technology program, highlighting its alignment with ABET ETAC accreditation standards and its dual function as a pathway for both degree-seeking students and professionals seeking to enhance their expertise in the nuclear field. It is important to note that all academic programs typically include three distinct categories of courses: core courses, degree-specific courses, and elective courses. In the context of the nuclear engineering technology degree, the curriculum is designed to not only fulfill the requirements for the degree but also to provide pathways for individuals who may already hold a bachelor's degree in engineering, engineering technology, or other related STEM fields. Specifically, the courses within this program can be utilized to obtain a nuclear certificate, thereby enhancing the qualifications of these individuals for careers in the nuclear sector. The core courses are foundational and are required for all students enrolled in the program, ensuring that they acquire essential knowledge and skills pertinent to engineering technology. Following the core courses, students will engage in degree-specific courses that delve deeper into nuclear engineering principles, practices, and applications. Finally, the elective courses provide students with the opportunity to tailor their education according to their interests and career aspirations, allowing for a more personalized academic experience.

Assessment of Workforce Training Needs for Small Modular Reactor (SMR) Project Planning

As project planning for small modular reactors (SMRs) commences, it is imperative to conduct a thorough assessment of the training needs of the workforce. This assessment should take place at the outset of the project to ensure that the necessary skills and competencies are identified and addressed promptly. A comprehensive review of the existing training programs and resources available in Indiana will be essential to pinpoint specific gaps in knowledge and skills critical for the successful operation of SMR facilities within the state.

During this assessment phase, it is crucial to engage with key stakeholders, including industry experts, educational institutions, and regulatory bodies, to gather insights on the specific requirements of SMR facilities. This collaborative approach will facilitate a nuanced understanding of the unique operational demands and safety protocols associated with SMRs, thereby informing the development of targeted training programs. The following courses have been identified as beneficial for the workforce development program, yet they are currently not offered in Indiana. These courses are essential to equip the workforce with the requisite knowledge and skills necessary for effective operation and maintenance of SMR facilities:

Advanced Nuclear Reactor Design and Safety Analysis: A course focused on the principles of advanced reactor technologies, including safety analysis methodologies specific to SMRs.

Nuclear Regulatory Compliance and Safety Culture: This course covers the regulatory framework governing nuclear operations and emphasizes the importance of safety culture in the nuclear industry.

Operational Training for Small Modular Reactors: A specialized training program designed to provide hands-on experience with the operational aspects of SMRs, including control room operations and emergency response protocols.

Nuclear Plant Systems and Components: An in-depth examination of the systems and components unique to SMRs, including cooling systems, containment structures, and instrumentation.

Radiation Protection and Health Physics: A course dedicated to the principles of radiation protection, including monitoring, assessment, and management of radiation exposure in a nuclear facility.

Project Management for Nuclear Projects: This course would focus on project management principles tailored to the nuclear sector, addressing the unique challenges and regulatory considerations inherent in SMR projects.

By addressing these identified training needs by developing new courses and programs, Indiana can ensure that its workforce is adequately prepared to meet the operational demands of SMR facilities. This proactive approach will not only enhance the skill set of the workforce but also contribute to the overall safety and efficiency of nuclear power generation in the state.

L. Focus Group Guide

Welcome and Introductions
Name, Affiliation

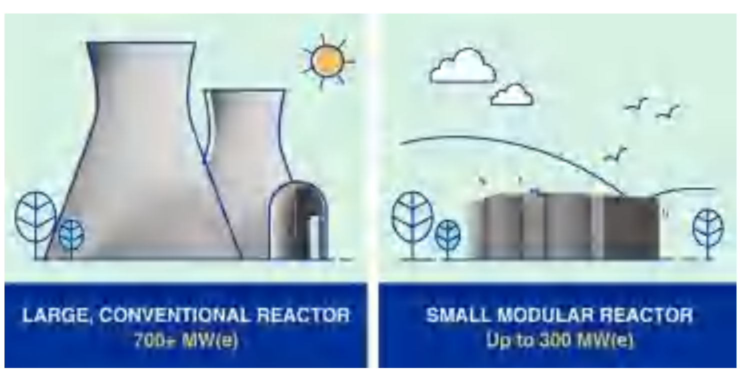
Purpose of Study

With the support of the Indiana Office of Energy Development, a multidisciplinary Purdue University team is conducting a focus group about perceptions of nuclear technology as part of the Indiana-Focused Small Modular Nuclear Reactor Study. The research team will conduct four focus groups with statewide stakeholder groups including planners and emergency managers, LEDOs / economic developers, local elected officials, and utilities. You are meeting as part of the [list name] stakeholder group. The team is also conducting an online survey of adults in Indiana 18 years and older about perceptions of nuclear technology. The research results will be shared as a report with the Indiana Office of Energy Development, in communication materials for stakeholder groups with summaries of key findings, and submitted for publication in academic journals.

The focus group data will be summarized so that specific names, offices, or locations cannot be attributed to individual responses. The researchers will not disclose anything that you have said as an individual. However, we cannot control participant conversations after we conclude the focus group. The meeting session will be recorded for transcription to maintain the accuracy of the conversation. The audio and transcript files and notes will be stored on a secure server accessible only to the research team.

Before we get started with the questions, we want to revisit the SMR description shared in the introductory letter.

Description of SMR: A Small Modular Reactors (SMR) is different from the conventional nuclear reactor in that it is Smaller in power generation and size with a smaller radioactive fuel inventory allowing for flexibility in siting, and Modular in design and assembly with enhanced safety features.



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Small Modular Reactor Nuclear Technology Focus Group Questions

How well-informed do you feel about nuclear energy used to produce electricity?

What do you know about advanced-design nuclear power plants called Small Modular Reactors (SMRs)?

Follow-up examples: status of technology for electricity generation, economic impacts, regulatory conditions, siting, workforce, safety, environmental impacts

What are your concerns related to nuclear power?

What are your arguments for nuclear power?

Who do you trust as sources for nuclear information?

What do you think some of the considerations should be in siting SMRs?

What are some considerations for the way electricity is produced that are important to you or your field?

Follow-up examples: The five pillars of electric service are reliability, resilience, stability, affordability, and environmental sustainability.

What should Indiana's future energy portfolio look like?

What additional information do you need to make decisions about SMRs in your community?

Wrap Up

Thank participants for their time.

For questions or follow up, please get in touch with Tamara Ogle (togle@purdue.edu) or Kara Salazar (salazark@purdue.edu)

M. Small Modular Reactor Nuclear Technology Focus Group Coding Framework Summary

Theme	Sub-themes	Description
Opinions and perceptions about nuclear energy	Information and knowledge Concerns Advantages Trust	Theme covers the amount of background information and knowledge participants currently do or do not possess about SMR and nuclear energy, including status of technology for electricity generation, economic impacts, regulatory conditions, siting, workforce, safety, and environmental impacts. Opinions and perceptions include concerns, advantages, and trusted sources of information about nuclear technology.
Nuclear energy siting	Land use planning Community engagement Land use conflicts	Theme addresses considerations of how decision makers may site SMRs in an urban area (urbanized area - city or town, metropolitan area), suburban area (outskirts of city or town, outlying area economically tied to an urban area, within commuting distance), or rural area (open and/or sparsely populated countryside, not within commuting distance to urban or suburban areas). Community engagement includes the processes decision-makers use to elicit feedback in the siting process. Land use conflict issues include buffers, setbacks, residences, not in my backyard (NIMBY) statements, farmland preservation, and/or renewable energy.
Electricity production	Current sources Future considerations Pillars of electric service	Theme covers considerations of current and future sources of electricity production and the pillars of electric service from the Indiana Office of Energy Development. Pillars of Electric Service: Reliability consists of adequacy, the ability of the electric system to supply the electrical demand and energy requirements for end-use consumers at all times, and operating reliability, the ability of the electrical system to withstand sudden disturbances. Resilience is the ability of a system or its components to adapt to changing conditions and to withstand and rapidly recover from disruptions or off-nominal events. Stability refers to the ability of an electric system to maintain a state of equilibrium during normal and abnormal conditions or disturbances.

		Affordability refers to retail electric service that is affordable across the residential, commercial, and industrial customer classes. Environmental sustainability includes decisions regarding Indiana's generation mix that take into account both environmental regulations and consumers' demands for sustainable sources of generation.
Technical resources		Theme captures the types of products and technical assistance providers decision makers need for nuclear energy planning.

N. Small Modular Reactor Nuclear Technology Survey

Purdue University, with the support of the Indiana Office of Energy Development, is conducting a survey on Indiana residents' perceptions of nuclear technology as part of the Indiana-Focused Small Modular Nuclear Reactor Study.

Your participation in this survey is voluntary and anonymous. The survey should take approximately 10-15 minutes to complete. Participants must be 18+ years of age.

For information regarding the survey, please contact Tamara Ogle (togle@purdue.edu) or Kara Salazar (salazark@purdue.edu). This survey research is referenced as IRB-2024-849.

Screening questions

What is your age?
- Below 18
- <drop down> 18-101

Are you a full-time resident of Indiana?
- Yes
- No

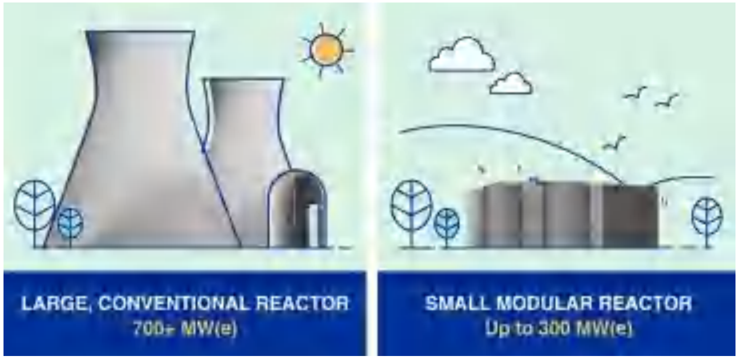
Which Indiana county do you live in?
- <drop down> 92 counties
- I don’t know

Opinions and perceptions about nuclear energy

1. How informed do you feel about nuclear energy used to produce electricity?
   a. Not at all informed
   b. Slightly informed
   c. Moderately informed
   d. Well informed

2. Have you heard about advanced-design nuclear technology called Small Modular Reactors (SMRs)?
   a. No
   b. Yes
   c. Not sure

Description of SMR: A Small Modular Reactors (SMR) is different from the conventional nuclear reactor in that it is **Smaller** in power generation and size with a smaller radioactive fuel inventory allowing for flexibility in siting, and **Modular** in design and assembly with enhanced safety features.



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3. How much do you oppose or favor the use of SMR nuclear technology as one of the ways to produce electricity in the United States?

   Strongly oppose, Oppose, Neither oppose or favor, Favor, Strongly favor

4. Select your three greatest concerns related to SMR nuclear technology.
   a. Production of radioactive water
   b. Risk of accident
   c. Cost of nuclear power
   d. Time it takes to build a power plant
   e. Competition with investment in renewable energy
   f. Lack of transparency in regulatory or development process
   g. Lack of understanding of the technology
   h. Onsite waste storage
   i. Fuel reliance from foreign adversaries
   j. I do not have concerns about nuclear power
   k. Other (please specify)

5. Select your three strongest arguments for SMR nuclear technology.
   a. Reduction of greenhouse gas
   b. Preservation of natural resources
   c. Energy independence
   d. Low cost of electricity
   e. Safety of nuclear facilities
   f. Good paying jobs
   g. Battery storage capability for other energy production
   h. Reliability of electricity
   i. I do not have a strong argument for nuclear power
   j. Other (please specify)

6. Which of the following do you think are trustworthy sources of information on nuclear technology?

	No	Yes
a. Federal elected officials		
b. State elected officials		

c. Local elected officials
d. Federal government agencies
e. State government agencies
f. Local government agencies
g. Nonprofit organizations
h. Nuclear plant manufacturers
i. Utilities
j. Public regulatory authorities
k. Scientists
l. Science journalists
m. Other (please specify)

7. What is your level of confidence in the operational safety of nuclear power plants?

	Not Safe	Moderately Safe	Very Safe	I don't know
a. Conventional nuclear power plants				
b. SMR nuclear power plants				

While various repository plans are being discussed at the Federal level, the radioactive waste from nuclear power plants in the U.S. is currently stored on site in dry casks.

8. What is your level of confidence in the safety of onsite nuclear storage?
   a. Not Safe
   b. Moderately Safe
   c. Very Safe
   d. I don't know

9. Which of the following industrial or technological activities do you think is likely to cause a serious accident or a disaster?
   Not at all likely, Somewhat unlikely, Neither likely nor unlikely, Somewhat likely, Very likely
   a. Air transport
   b. Chemical facilities
   c. Transport of hazardous material
   d. Natural gas distribution
   e. Nuclear power plants – conventional
   f. Nuclear power plants - SMR
   g. Virus research laboratories
   h. Other (please specify)

Nuclear energy siting questions

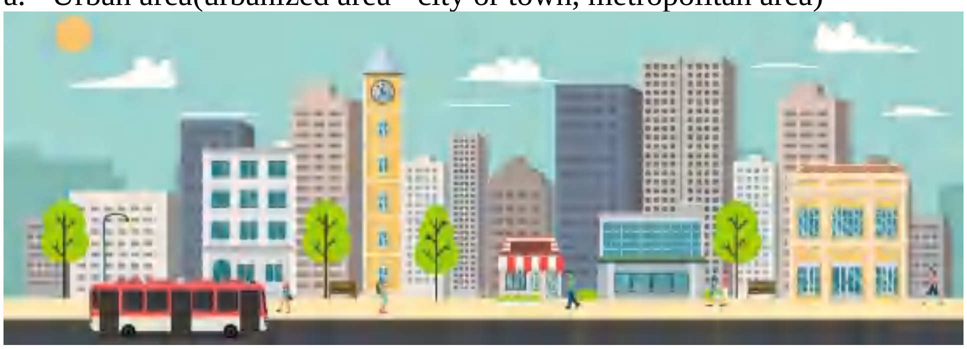
10. How likely would you be willing to live near the following?
    Not at all likely, Somewhat unlikely, Neither likely nor unlikely, Somewhat likely, Very likely

    a. Biogas/biomass energy generation facility

b. Co2 storage site
c. High voltage power line
d. Household waste incinerator
e. Landfill
f. Large airport
g. Major chemical facility
h. Mobile phone relay antenna
i. Nuclear power plant-conventional
j. Nuclear power plant- SMR
k. Radioactive waste disposal
l. Utility-scale solar development
m. Utility-scale wind development

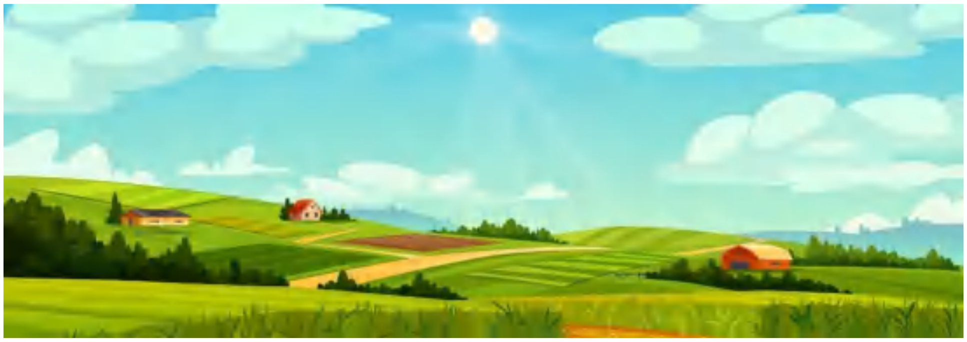
11. Given that SMR allows for flexibility in siting and requires a much smaller footprint compared to a traditional nuclear power plant, and is often installed underground, where should SMRs be located?

    a. Urban area(urbanized area - city or town, metropolitan area)



    b. Suburban area (outskirts of city or town, outlying area economically tied to an urban area, within commuting distance)

    c. Rural area (open and/or sparsely populated countryside, not within commuting distance to urban or suburban areas)



d. Other (please specify)

e. I have no preference

12. How close would you be willing to live next to an SMR nuclear power plant?
    a. 0-.99 mile
    b. 1-4.99 miles
    c. 5-9.99 miles
    d. 10-20 miles
    e. I am not willing to live next to an SMR

Opinions and perceptions about the environment and energy sources

13. In general, how satisfied are you with the place/community where you currently live?
    a. Very unsatisfied
    b. Unsatisfied
    c. Neutral
    d. Satisfied
    e. Very Satisfied

14. What kind of pollution bothers you most on a day-to-day basis?
    a. Air pollution
    b. Water pollution
    c. Land pollution
    d. I am not concerned about pollution.

15. To what extent do you think climate change is an issue to be concerned about?
    a. Very little extent
    b. Little extent
    c. Some extent
    d. Great extent
    e. Very great extent

16. Select the top three considerations for Indiana's electrical system that are most important to you.
    a. Adequate fuel resources for electricity
    b. Affordable electricity

c. Electrical system can withstand sudden disturbances
d. Economic growth
e. Energy independence
f. Energy security
g. Preservation of natural resources
h. Reduction of carbon emissions
i. Resiliency to withstand catastrophic events and natural disasters
j. Small footprint (less land use)
k. Stable system that matches electrical supply to demand
l. Job opportunities
m. Other

17. To what extent do you favor or oppose expanding the following energy sources?

Strongly oppose Oppose Neither oppose or favor Favor Strongly Favor

a. Coal mining
b. Hydraulic fracking
c. Conventional Nuclear power
d. SMR Nuclear power
e. Offshore oil and gas drilling
f. Natural gas
g. Utility-scale solar
h. Utility-scale wind

Demographics

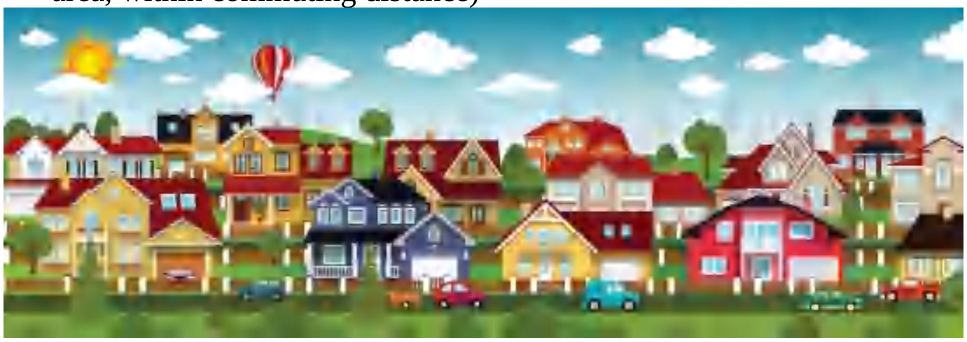
18. What is your gender identity?
a. Man
b. Woman
c. Non-binary
d. Other
e. Prefer not to answer

19. What do you usually identify as your race? Select all that apply.
a. American Indian or Alaska Native
b. Asian
c. Black or African American
d. White
e. Native Hawaiian and Other Pacific Islander
f. Two or more races
g. Other races
h. Prefer not to answer

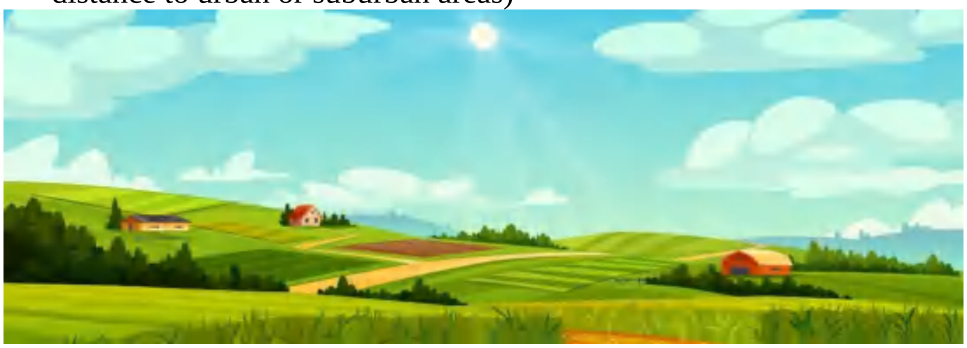
20. What is your ethnicity?
a. Not Hispanic or Latino
b. Hispanic or Latino
c. Prefer not to answer

21. How would you describe your current residential location?
    a. Urban (urbanized area - city or town, metropolitan area)

    b. Suburban (outskirts of city or town, outlying area economically tied to an urban area, within commuting distance)



    c. Rural (open and/or sparsely populated countryside, not within commuting distance to urban or suburban areas)



    d. Prefer not to answer

22. What is the highest level of education you have completed?
    a. Some high school or less
    b. High school diploma or GED
    c. Some college, but no degree
    d. Associates or technical degree
    e. Bachelor's degree
    f. Graduate or professional degree (MA, MS, MBA, PhD, JD, MD, DDS, etc.)

g. Prefer not to answer

23. Please choose the category in which the combined total income of your household fell in 2023 (yourself and any household member you live with).
    a. Less than $25,000
    b. $25,000 - $49,999
    c. $50,000 - $74,999
    d. $75,000 - $99,999
    e. $100,000 - $149,999
    f. $150,000 - $199,999
    g. $200,000 - $299,000
    h. $300,000 and above
    i. I do not know.
    j. Prefer not to answer

24. Which of the following categories best describes <u>the industry you primarily work in</u> (regardless of your actual position)?
    a. Agriculture, Forestry, Fishing and Hunting
    b. Mining, Quarrying, and Oil and Gas Extraction
    c. Utilities
    d. Construction
    e. Manufacturing
    f. Wholesale Trade
    g. Retail Trade
    h. Transportation and Warehousing
    i. Information
    j. Finance and Insurance
    k. Real Estate and Rental and Leasing
    l. Professional, Scientific, and Technical Services
    m. Management of Companies and Enterprises
    n. Administrative and Support and Waste Management and Remediation Services
    o. Educational Services
    p. Health Care and Social Assistance
    q. Arts, Entertainment, and Recreation
    r. Accommodation and Food Services
    s. Public Services
    t. Other Services (except Public Administration)
    u. I am not employed.
    v. Prefer not to answer

25. How would you describe your political views?
    a. Very conservative
    b. Conservative
    c. Moderate
    d. Liberal
    e. Very liberal

f. No opinion
g. Prefer not to answer

26. What are your preferred sources for news and information? Select all that apply.
    a. National/regional newspaper
    b. Local newspaper
    c. Television
    d. Radio
    e. Podcasts
    f. Internet
    g. Social Media
    h. Other sources
    i. Prefer not to answer