# Commission to Investigate the Implementation of Next-Generation Nuclear Reactor Technology in New Hampshire


## Final Report

December 1, 2023

# Contents

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RSA 125-O:30 (HB 543, Chapter 253, Laws of 2022)

December 1, 2023

# Commission Overview

The Commission was established by the New Hampshire Legislature in 2022 to study and consider legislation or other actions related to potentially implementing next-generation nuclear reactor technology in New Hampshire. As outlined in the statute that created it, the Commission was tasked with investigating advances in nuclear technology, including generation IV reactor designs; safety, fuel consumption, and non-electric applications of new designs; potential siting options; partnerships; obstacles; and incentives. The Commission was also tasked to submit interim and final reports with findings and recommendations for proposed legislation. The purpose was to investigate the feasibility and options for next-generation nuclear technology in New Hampshire. See Appendix A.

# Commission Members

| **Member** | **Appointing Authority** |
|---|---:|
| Representative Michael Harrington, Vice Chair | Speaker of the House |
| Senator Howard Pearl | Senate President |
| Cathy Beahm | NH Dept. of Environmental Services |
| Marc Brown, Secretary | Governor, Member of the Public |
| Bart Fromuth | Governor |
| Daniel Goldner | PUC Chair |
| Matthew Levander | NextEra Energy/Seabrook Station |
| Christopher McLarnon | Governor |
| David Shulock | NH Dept. of Energy |
| Representative Keith Ammon, Chair | Speaker of the House |

# Executive Summary

The commission held meetings over the past year, hearing from experts on advanced nuclear technologies. Discussions covered existing nuclear plants, recent nuclear projects, advanced reactor designs, the nuclear fuel supply chain, non-electrical applications, and federal programs and policies.

Presentations highlighted nuclear power's reliability, efficiency, carbon-free generation, and role in climate strategies. Advanced designs emphasize passive safety, modular construction, load-following capabilities, and siting flexibility. Lessons from recent U.S. nuclear builds informed the commission on licensing, project management, and supply chain robustness. Several speakers emphasized nuclear's potential beyond electricity, including hydrogen production, desalination, district heating, powering data centers, and Bitcoin mining.

This report summarizes innovative reactor technologies at varying stages of commercialization, the evolving regulatory landscape, and some financial risks inhibiting deployment. It explores spent fuel recycling, consolidation of interim storage sites, and long-term waste management.

Federal initiatives aim to incentivize new nuclear plants, facilitate advanced reactor demonstrations, enhance domestic fuel production, and strengthen international cooperation and exports. Recent legislation with provisions supporting nuclear includes the Infrastructure Investment and Jobs Act, Inflation Reduction Act, CHIPS and Science Act, and the Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy (ADVANCE) Act.

This document offers state policy recommendations such as designating nuclear as "clean" energy, conducting feasibility studies for potential sites, streamlining regulation, appointing a nuclear development coordinator, and urging ISO New England to solicit advanced nuclear proposals.

Overall, the commission concluded advanced nuclear power generation is necessary for meaningfully reducing emissions and will likely see increasing deployments in the late 2020s and early 2030s, pending commercial demonstrations now underway. Nuclear plays a vital role in carbon-neutral energy generation while ensuring electricity remains reliable and affordable alongside renewables. The full report provides in-depth details for those interested in further exploration.

# Meetings Held Over the Course of the Commission

**1. October 11, 2022 – Organizational Meeting**

The commission organized and elected leadership roles. Rep. Keith Ammon was elected Chair, Rep. Michael Harrington as Vice Chair, and Marc Brown as Secretary.

See meeting minutes.

**2. November 21, 2022 – Presentations by Marc Nichol of NEI and Christopher Colbert of NuScale Power**

Marc Nichol of the Nuclear Energy Institute (NEI) discussed the advantages of advanced nuclear reactors. Nuclear power contributes 20% of US electricity and over 50% of carbon-free generation. More than 20 companies, including Westinghouse and GE, are developing advanced reactors for clean and affordable energy. Safety, waste management, job creation, and “environmental justice” were also discussed. The meeting covered licensing, funding, renewable energy backup, and spent fuel storage.

Mr. Colbert presented on NuScale's development of a small modular reactor. The reactor, approved by the Nuclear Regulatory Commission (NRC), offers an unlimited “coping period” as it can stay safe indefinitely without outside power, a smaller emergency planning zone, off-grid capability, and flexibility in power generation. NuScale aims to repurpose coal plants, reduce costs, and provide clean and reliable energy. The company has secured a project in Utah and plans for global deployment. The presentation addressed safety concerns, spent fuel storage, and cost viability.

See meeting minutes.

**3. December 12, 2022 – Presentations by Meredith Angwin and Jacqueline Siebens of Oklo**

Meredith Angwin, author of *Shorting the Grid* and a nuclear energy advocate, highlighted the importance of a reliable and sustainable electric grid. She emphasized the advantages of nuclear power and discussed the complexities of grid management, including the role of Regional Transmission Organizations (RTOs) and their impact on grid reliability. Angwin's insights provided valuable perspectives on the crucial role of nuclear energy in maintaining a solid grid.

Jacqueline Siebens introduced Oklo's Aurora, a small modular fast neutron reactor emphasizing safety, cost-efficiency, and fuel recycling, utilizing spent fuel and a compact, liquid sodium-cooled design for simplicity and flexibility. The Aurora reactors, with their small footprint, offer flexible siting options and can generate electricity and industrial process heat, promoting a sustainable nuclear fuel cycle by recycling spent fuel. Inspired by the EBR-II reactor, Oklo's design focuses on efficiency, reliability, and simplified construction, with significantly fewer parts than conventional reactors. Oklo adopts a "fission-as-a-service" model, reducing deployment costs and barriers, allowing customers to purchase reactor power without large initial investments.

See meeting minutes.

**4. January 23, 2023 – Presentations by Michael Wentzel of NRC and David Durham of Westinghouse**

Michael Wentzel of the Nuclear Regulatory Commission (NRC) discussed the NRC's efforts to become a modern, risk-informed regulator. He highlighted the past licensing work of the NRC's divisions and emphasized their vision of fostering innovation while maintaining regulatory principles. Wentzel provided insights into the licensing status of advanced reactors, engagement with industry stakeholders and showcased specific facility license applications under review. The NRC remains committed to ensuring nuclear technology's safe and efficient use through a robust regulatory framework and innovative approaches.

David Durham gave an overview of Westinghouse's role in the nuclear industry. He highlighted their global presence and extensive experience, with their technology used in over half of the world's reactors. Durham discussed their reactor technologies, including the AP1000, AP300 small modular reactor (SMR), and the eVinci microreactor. He emphasized Westinghouse's involvement in projects such as Vogtle in Georgia and the need for domestic enrichment capabilities. The eVinci microreactor gained interest from various industries, including NASA.

See meeting minutes.

**5. March 6, 2023 – Presentations by Jeff Navin of TerraPower and Dan Leistikow of Centrus Energy**

Jeff Navin presented on TerraPower's Natrium reactor project, a small advanced nuclear reactor using sodium coolant and a molten salt energy storage system. The Kemmerer, Wyoming project aims to create jobs and provide economic benefits to the community. Navin discussed financing, licensing, and the availability of High-Assay Low-Enriched Uranium (HALEU). TerraPower plans to load-follow and generate electricity through a steam turbine attached to a molten salt energy storage system. The cost is expected to be lower than previous projects, ranging from \$55 to \$60 per megawatt hour.

Dan Leistikow presented Centrus Energy's focus on high assay low enriched uranium (HALEU) production. Centrus aims to scale up HALEU production to meet the needs of advanced reactors while emphasizing the benefits of low-enriched uranium (LEU). Challenges such as whether HALEU production or demand would have to come first—the so-called "chicken and egg" problem—were discussed, and a public-private partnership was proposed to accelerate investments in enrichment capabilities. Centrus highlighted its technology readiness and timeline for HALEU production. Supply diversity and coordination within the industry were also emphasized.

See meeting minutes.

**6. April 7, 2023 – Presentations by Scott Nagley and Joshua Parker of BWX Technologies and Carol Lane of X-energy**

Scott Nagley and Joshua Parker detailed BWX Technologies' 65-year history in naval nuclear reactors, producing over 300 for U.S. submarines and aircraft carriers, and operating across 12 facilities with $2.1 billion revenue in 2021. They discussed BWXT's involvement in government and commercial sectors, including environmental cleanup, U.S. Department of Energy (DOE) labs, medical isotopes, and various partnerships. The presentation also touched on their work in space nuclear propulsion for NASA, microreactors for military use, and the enriched uranium supply chain. They covered reactor technology comparisons, supplier investment strategies, and non-electrical uses like producing Molybdenum-99 medical isotopes.

Carol Lane outlined X-energy's development of high-temperature gas reactors and TRISO fuel. She highlighted their Oak Ridge commercial-scale fuel facility, their 2020 selection for the DOE's Advanced Reactor Demonstration Program to construct the first Xe-100 plant, an 80 MWe modular reactor. X-Energy's reactor, adjustable between 100% and 40% power, complements renewables on the grid. They showcased its use for industrial process heat, including a project with Dow Chemical, and its smaller emergency zones due to passive safety. Discussions included TRISO fuel activation, heat management during load adjustment, retrofitting coal plants, and site requirements.

See meeting minutes.

**7. May 12, 2023 – Presentations by Craig Piercy of ANS and Gareth Thomas of Holtec**

Craig Piercy of the American Nuclear Society (ANS) presented a detailed overview of his organization and the nuclear industry's current and future prospects. He highlighted the growing interest in nuclear energy, discussed significant investments and advanced reactor designs, addressed fuel supply and workforce development challenges, and emphasized the importance of public engagement and education programs. Piercy analyzed the industry's landscape and its transition to innovative nuclear technologies.

Gareth Thomas from Holtec International outlined the company's evolution from specializing in spent nuclear fuel storage to expanding into nuclear plant decommissioning and developing the SMR160, a 160MW small modular reactor (SMR) designed for inherent safety and flexibility in deployment. Holtec is advancing the SMR160 under a DOE grant, targeting a Construction Permit Application submission to the NRC by late 2023, with the decommissioning Oyster Creek plant site in New Jersey as a potential deployment location. Thomas addressed challenges in securing power purchase agreements, managing construction costs for this novel SMR, and leveraging federal incentives, while highlighting Holtec's proficiency in the nuclear fuel cycle's backend.

See meeting minutes.

**8. June 19, 2023 – Presentations by Seth Grae of Lightbridge and Matt Wald, journalist**

Seth Grae discussed Lightbridge's advanced fuel designs for existing and small modular reactors

(SMRs). Lightbridge claims its fuel offers economic, safety, and proliferation resistance benefits. Partnerships with national laboratories were highlighted for fuel testing, and commercialization pathways were explored, including replacing the Russian fuel supply in Europe and targeting the SMR market. The discussion covered spent fuel, cost competitiveness, non-proliferation, and intellectual property protection. Lightbridge aims to contribute to the global energy transition with innovative fuel designs.

Journalist Matt Wald, an experienced nuclear industry writer, presented the emerging nuclear landscape and its potential for reducing carbon emissions. He discussed fusion and fission reactors, highlighting the progress and challenges of each. Wald focused on commercially available reactors like NuScale, GE Hitachi BWRX, Westinghouse AP 300, and second-wave reactors like X-energy XE 100 and TerraPower Natrium. He also mentioned other designs, such as Kairos, Moltex, and microreactors. Wald addressed topics including HALEU production, funding, and nuclear fuel resources.

See meeting minutes.

**9. August 7, 2023 – Presentations by Chris Lohse of the federal Gateway for Accelerated Innovation in Nuclear (GAIN) program, Julie Kozeracki, Senior Loan Program Advisor for the DOE Loan Programs Office, and Dr. Billy Valderrama from the DOE Office of Nuclear Energy.**

Chris Lohse, representing the GAIN program, highlighted its role in supporting stakeholders in advanced nuclear technology through outreach, industry tracking, and educational events. The GAIN voucher program, a key initiative, has allocated over $30 million to 50 companies for accessing DOE national lab expertise, assisting in areas like testing and licensing. Additionally, Lohse discussed GAIN's involvement in transforming retiring coal plants into nuclear sites, offering technical support and studies on reactor options and economic impacts.

Julie Kozeracki from the Department of Energy's Loan Programs Office (LPO) discussed its over $300 billion financing capacity, focusing on nuclear energy and new technology deployment. She emphasized the need for approximately 200 gigawatts of new nuclear power by 2050 for a clean energy transition in the U.S., acknowledging barriers like the lack of commercial plant orders and cost reduction challenges. Kozeracki proposed a consortium model for demand consolidation and cost overrun protection and noted promising discussions with developers about situating reactors at emerging large load centers like chip fabrication facilities.

Dr. Billy Valderrama from the Department of Energy's Office of Nuclear Energy outlined the office's priorities in maintaining the U.S. reactor fleet, developing advanced reactors, ensuring a domestic nuclear fuel supply, and expanding international nuclear cooperation. He highlighted the increase in Congressional funding for DOE nuclear programs, now over $1.7 billion, supporting research and partnerships, and showcased initiatives like hydrogen production at nuclear plants and microreactor test bed projects. Valderrama also discussed efforts to reduce reliance on Russian uranium, develop a domestic uranium supply chain, and enhance state outreach for incorporating new nuclear technologies into energy planning.

See meeting minutes.

**10. September 5, 2023 – Site visit to Seabrook Nuclear Power Plant**

On September 5, 2023, Seabrook Station Nuclear Power Plant in Seabrook, New Hampshire, welcomed commission members and interested guests for an informative tour. The plant, which began operations in 1990 and has an extended operating license until 2050, stands as a significant contributor to New England's power grid. The tour encompassed an interactive session with a control room simulator, providing insights into the training and licensing of plant operators. Site Vice President Brian Booth led a presentation, highlighting NextEra Energy Resources' stewardship of Seabrook Station and discussing initiatives for operational safety, including responses to a past siren activation incident. Participants explored various facility sections, including the steam turbines and reactor areas, gaining a comprehensive view of the plant's operations, its substantial environmental contributions, and its pivotal role in supplying power to approximately 1.4 million homes, while significantly reducing emissions. The event underscored Seabrook Station's importance in regional energy infrastructure and environmental sustainability.

**11. September 18, 2023 – Presentations by Ryan Duncan of Last Energy and Ryan Umstattd of fusion developer Zap Energy**

Ryan Duncan from Last Energy detailed their micro modular nuclear reactor technology, emphasizing rapid onsite assembly of factory-built modules and the goal to address challenges of large-scale nuclear plants. He discussed securing 25 billion in power purchase agreements across Europe for 51 units, with a focus on using existing supply chains and proven technology to achieve a 24-month delivery timeline post-regulatory approval. Duncan also highlighted their design's advantages like underground spent fuel storage and air cooling, allowing for more flexible plant siting.

Ryan Umstattd of Zap Energy detailed their fusion energy technology development, emphasizing its safety and minimal waste compared to fission, using a novel Z-pinch plasma confinement method. He discussed proprietary advancements in stabilizing plasma, noting that while experimental results are promising, they are yet to reach the break-even point for self-sustaining fusion. Umstattd outlined plans for a pilot fusion plant in Centralia, Washington in the early 2030s, aiming to provide grid electricity and scale up the technology. He estimated levelized cost of fusion power electricity may approach $30-60 per MWh, acknowledging uncertainties in commercialization timelines.

See meeting minutes.

**12. October 2, 2023 – Presentations by Eric Johnson of ISO New England, Tristan Jackson of Moltex Energy Canada, and Donald Gustavson of Ultra Safe Nuclear Corporation.**

Eric Johnson from ISO New England discussed the organization's roles in grid operations, market administration, and transmission planning, noting the shift in New England's energy mix towards natural gas and renewables. He detailed the interconnection queue process for new generation resources, highlighting over 38,000 megawatts of proposals, primarily in wind, solar, and battery storage. Johnson emphasized ISO New England's focus on reliability and neutrality regarding generation technologies, explaining how variable renewable resources are balanced and indicating the need for other energy sources during reduced renewable output.

Tristan Jackson from Moltex Energy Canada described the company's waste-burning nuclear reactor and fuel recycling technology, which separates previously used fuel into three streams for use in their molten salt reactor design. He outlined the benefits of this approach, including reduced nuclear waste liabilities and additional clean power generation, and discussed the challenges and economic aspects of licensing, regulations, and centralized versus distributed recycling facilities. Jackson also addressed waste management from Moltex reactors, noting the shorter half-life of output waste and ongoing work with Canadian authorities on containment criteria for long-term storage.

Donald "Gus" Gustavson from Ultra Safe Nuclear Corporation (USNC) presented their Micro Modular Reactor (MMR) and advanced TRISO fuel technology, highlighting the MMR's 1-15 MW power output and potential 40+ year lifespan, aimed primarily at remote communities and mining operations. He discussed USNC's efforts to establish their own fuel supply chain, including a pilot facility in Oak Ridge, TN, and a joint venture with Framatome for commercial-scale TRISO fuel production, while addressing the industry's challenges in obtaining High Assay Low Enriched Uranium (HALEU). Gustavson also noted that successful microreactor demonstrations outside New England’s merchant market structure are likely necessary for regional adoption, emphasizing the logistical benefits and lower risk of USNC's smaller, factory-fabricated reactor modules and the importance of completing their first public demonstration reactors.

See meeting minutes.

**13. November 6, 2023 – Presentations by Ryan McLeod of Canadian Nuclear Laboratories, James Walker of NANO Nuclear Energy, and Evan Cummings of Kairos Power.**

Ryan McLeod from Canadian Nuclear Laboratories (CNL) explored the concept of using nuclear reactors, specifically small modular reactors (SMRs), to power Bitcoin mining, highlighting the potential economic benefits of this pairing. He suggested that Bitcoin mining, with its high energy consumption and flexibility, could serve as a built-in customer for new reactor projects, providing a reliable electricity demand and enhancing investor confidence in advanced reactor deployment, even before a project receives its grid interconnection. McLeod cited existing examples of Bitcoin mining co-locating with nuclear plants and emphasized its role in improving electricity system economics as an interruptible load that adapts to real-time grid conditions and pricing.

James Walker, CEO of NANO Nuclear Energy, presented their microreactor technology, designed for remote sites like mines and industrial facilities, to replace diesel generation. He discussed two microreactor concepts: the solid-cored heat pipe reactor "ZEUS" from UC Berkeley, featuring passive cooling and suitability for high-temperature applications, and a Cambridge design "ODIN" using molten salt coolant for high output with passive safety. Walker emphasized the reactors' automated operation, long off-grid operational capability, and NANO's business model of retaining ownership to alleviate customer's operational and decommissioning concerns, underscoring the increased safety and deployment potential of these small-footprint reactors.

Evan Cummings, Director of Business Development at Kairos Power, introduced their Kairos Power Fluoride-salt Cooled High Temperature Reactor (KP-FHR), a 140MW molten salt cooled small modular reactor, emphasizing its cost competitiveness and commercialization strategy. He outlined Kairos' parallel development streams in reactor engineering, testing, regulatory licensing, fuel design, and supply chain, highlighting recent achievements such as significant progress in their Nuclear Regulatory Commission construction permit application and the development of the HERMES test reactor. Cummings stressed Kairos' mission to provide affordable, reliable, carbon-free energy, viewing nuclear power as crucial for economy-wide decarbonization and highlighting their reactor's potential in emission-free industrial heat applications, with a goal to enable SMR construction by 2030.

See meeting minutes.

# Introduction

## Overview of Advanced Nuclear Technologies

Advanced nuclear technologies mark a significant leap forward in nuclear energy, combining enhanced safety, efficiency, and versatility. These contemporary innovations encompass new reactor designs like Small Modular Reactors (SMRs) and High-Temperature Gas-cooled Reactors (HTGRs), each offering unique benefits. SMRs stand out for their compactness, ease of manufacturing, transportability, and scalability, catering to diverse power generation requirements. HTGRs operate at elevated temperatures compared to traditional reactors, thus improving thermal efficiency, and broadening their application in industrial sectors such as hydrogen production and process heat generation.

These advanced technologies are distinguished by their robust safety features. Many modern reactors are equipped with passive safety systems, relying on natural principles such as gravity and convection, reducing the reliance on active mechanical components. This approach significantly minimizes accident risks, making these reactors inherently safer. Additionally, strides in nuclear fuel technology, exemplified by TRISO (TRi-structural ISOtropic) fuel, provide increased resistance to radiation damage and higher melting points, further fortifying reactor resilience. These advancements align with global sustainability objectives, notably in reducing greenhouse gas emissions, a stark contrast to fossil fuel-based power generation. The modular design of SMRs enhances their compatibility with renewable energy sources, facilitating more adaptable and responsive power grids. This adaptability extends to repurposing existing infrastructures, like decommissioned coal plant sites, for new nuclear installations, underlining their critical role in the transition to cleaner energy sources.

## Importance of Nuclear Energy in Modern Power Generation

The role of nuclear energy in modern power generation is indispensable, offering a reliable and efficient electricity source while playing a pivotal role in reducing greenhouse gas emissions. As a low-carbon alternative to fossil fuels, nuclear power is instrumental in achieving carbon neutrality and addressing climate change concerns. These advanced reactors provide consistent and predictable energy, crucial for meeting baseload demands in contrast to the intermittency of renewable sources like solar and wind. SMRs and HTGRs have enhanced nuclear energy's adaptability and safety, enabling deployment in varied locales and potentially lowering construction costs, thus broadening its reach. Beyond electricity generation, nuclear energy's potential in industrial heat production, desalination, hydrogen production, and large-scale data center deployments positions it as a critical player in a comprehensive energy strategy. Advanced nuclear reactors open new paths for decarbonizing industrial processes by offering high-temperature heat, a challenging emission reduction sector. In a global energy landscape increasingly centered on sustainability and energy security, nuclear energy bolsters the reliability and diversity of power systems. It contributes significantly to environmental and economic goals, reaffirming its critical role in modern power generation.

# Existing Nuclear Power in ISO New England

ISO New England, the regional transmission organization (RTO) responsible for managing the electric power grid across six states in New England (Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut), operates with the aid of two nuclear power stations. Together, these stations contribute to roughly 20% of the region's electricity, and both utilize pressurized water reactors (PWRs), the prevalent type of nuclear reactor in the U.S.

In Connecticut, the Millstone Nuclear Power Plant is the largest in New England. Built in the 1970s and 1980s, it consists of two reactors that can generate 2,100 megawatts of electricity. The Seabrook Nuclear Power Plant in New Hampshire follows as the second largest, boasting one reactor capable of producing 1,250 megawatts of electricity, and was constructed in 1990. A second reactor site at Seabrook was not completed primarily due to financial difficulties and public opposition related to concerns about nuclear power.

New England once was the home of two additional nuclear power plants, the Vermont Yankee Power Plant in Vermont, and the Pilgrim Nuclear Power Station in Massachusetts. However, these were shut down in 2014 and 2019, respectively.

# Recent Nuclear Energy Projects in the U.S.

## Tennessee Valley Authority, Watts Bar 2

Watts Bar Nuclear Plant in East Tennessee achieved commercial operation with Unit 2 in October 2016, marking the first new nuclear generation of the 21st century in the USA. The unit produces 1,150 megawatts of continuous electricity, enough for 650,000 homes, without carbon emissions. The completion represents a significant investment in nuclear power as a clean, safe, and low-cost energy source and supports about 1,000 full-time jobs.

In October 2015, Watts Bar Unit 2 received a 40-year operating license from the NRC, the first such authorization since Watts Bar 1 in 1996. The license allows operation until October 2055, following a comprehensive review that took over 200,000 hours and eight years. The site was the first to comply with the NRC's Fukushima-related orders, and the decision to issue the license brings the total number of commercial nuclear reactors licensed in the USA to 100. The licensing of Watts Bar 2 is seen as a "historic milestone" in the history of Tennessee and TVA.

## Georgia Power, Vogtle 3 & 4

The Unit 3 reactor at the Alvin W. Vogtle Electric Generating Plant near Waynesboro, Georgia, has commenced commercial operation, marking the first time a new nuclear reactor has begun delivering power to the U.S. electric grid in nearly seven years. Owned primarily by Georgia Power, this Westinghouse AP1000 reactor will generate approximately 1,110 megawatts of energy, sufficient to power an estimated 500,000 homes and businesses without generating greenhouse gases. Unit 4 is anticipated to begin service in late 2023 or early 2024.

The construction at Vogtle has not been without challenges. Construction on Vogtle's Units 3 and 4 began in 2009, facing delays and cost overruns with the budget ballooning from $14 billion to $30 billion. Westinghouse identified the main contributing factors as issues with an inexperienced construction company, an incomplete design, and supply chain problems.

Despite these setbacks, valuable lessons have been learned and integrated into strategies to enhance quality control, modular construction, and supply chain management for future AP1000 projects. Notably, the AP1000 units at Vogtle have been granted a 60-year operating license initially, as opposed to the standard 40-year license, with Westinghouse expressing confidence that the units have the potential to last up to 100 years.

The successful deployment of Vogtle Unit 3 has been hailed as a milestone for the nuclear industry, reflecting a renewed interest in nuclear energy as a response to climate change. Nuclear energy contributed to 47% of America's carbon-free electricity in 2022, with expectations that Vogtle's operational reactors will further advance clean energy solutions. The experiences at Vogtle highlight both the complexities and potential long-term value of advanced reactor construction.

## Project Pele

BWX Technologies is participating in Project Pele, an initiative demonstrating a microreactor for the U.S. Department of Defense at Idaho National Laboratory. The project aims to construct and operate a transportable microreactor to supply power to military bases and operations based on BWXT's BANR (BWX Advanced Nuclear Reactor) design.

This design utilizes TRISO (TRi-structural ISOtropic) fuel, with the fuel for Project Pele sourced from the strategic uranium stockpile designated by the U.S. government for national security applications.

Project Pele is one of the early real-world demonstration projects for advanced microreactor technology, aiming to validate modular construction and operational capabilities. During discussions, BWXT cited experience with fuel supply chains and an application area for their reactor technology.

Overall, Project Pele is a significant development in the advanced nuclear industry, showcasing the potential of small modular reactors for military and remote power requirements. The success of this project can contribute to the validation of the technology and guide commercial applications in the future. Complete power testing of the Pele reactor is feasible by the end of 2023, with outdoor mobile testing at a DOE installation in 2024.

## MARVEL Project

The MARVEL (Microreactor Applications in a Versatile Environment for Research and Learning) project marks a significant step forward in nuclear energy development, focusing on microreactors. The Department of Energy's Office of Nuclear Energy oversees this initiative, which involves deploying a 100-kilowatt microreactor at Idaho National Laboratory (INL) by the end of 2024. The project aims to drive research and development in nuclear technology, particularly exploring microreactors' practical uses and operational efficiencies in a controlled setting.

One of the microreactor's notable features in the MARVEL project is its ability to follow loads. This capability enables the reactor to adjust its power output to meet the varying electricity demands, a vital attribute for integrating nuclear power into modern, increasingly renewable energy grids like those dependent on solar and wind power. The MARVEL microreactor's load-following adaptability positions it as a critical tool for studying the dynamic integration of nuclear energy into various energy systems, ensuring a stable and reliable energy supply, especially in grids with a significant renewable energy presence.

Moreover, the MARVEL project investigates how to integrate nuclear energy with other energy systems, including hydrogen production. The microreactor's potential to efficiently produce hydrogen opens up exciting possibilities for clean energy applications. Hydrogen serves many purposes, notably in transportation and industry, and producing it cleanly and efficiently with nuclear power could revolutionize sustainable energy solutions. Thus, the MARVEL project not only advances nuclear reactor technology but also broadens its impact across various energy applications, heralding a significant advancement in the utility and sustainability of nuclear energy.

## Dow Chemical and X-energy Joint Venture

Dow, a leader in materials science, and X-Energy Reactor Company, LLC (“X-energy”), an expert in nuclear reactors and fuel technology, are joining forces to build the first large-scale advanced nuclear reactor in North America. This project is part of the U.S. Department of Energy's Advanced Reactor Demonstration Program and aims to set up X-energy's Xe-100 high-temperature gas-cooled reactor at a Dow site on the U.S. Gulf Coast. Their goal is to supply safe, low-carbon power and steam to the site before the end of this decade. The plan includes up to $50 million for engineering work, with funding contributions expected from the DOE and Dow. They are also preparing to apply for a U.S. Nuclear Regulatory Commission construction permit.

In this project, X-energy's small modular reactor (SMR) and specialized fuel technology will play a crucial role. Their high-temperature reactor is suitable for various industrial applications, providing high-temperature heat and steam. The Xe-100 plant at Dow's site will offer cost-effective, low-carbon heat and power to support essential consumer and business product production. X-energy has received up to $1.2

billion in funding from the DOE to develop this advanced reactor and fuel facility. The company is actively working on the reactor's design and constructing a fuel facility in Oak Ridge, Tennessee. They are preparing to apply for licensure from the U.S. Nuclear Regulatory Commission.

## TerraPower’s Natrium Demonstration Project

Bill Gates-backed, TerraPower is constructing a first-of-its-kind demonstration plant for their Natrium advanced nuclear reactor design in Kemmerer, Wyoming. The company selected this small town of 2,700 residents due to an aging coal power plant slated for retirement in 2025 by local utility Rocky Mountain Power.

The coal plant closure raised fears in Kemmerer, as its associated mine provides most of the town's employment. TerraPower's arrival has drastically improved prospects. The 345-megawatt Natrium plant will create 200-250 high-quality, full-time jobs when operational. Rocky Mountain Power has also committed to rehiring the nuclear facility's 109 displaced coal plant workers. An additional 1,500 construction personnel will be needed on-site at peak building activity, providing a significant economic boost for the community.

On the technical side, the demonstration intends to prove the viability of TerraPower's innovative sodium-cooled, molten salt reactor concept. Sodium offers key safety advantages as a coolant, while the integrated molten salt storage acts as a large thermal battery, allowing flexible output. Together, these features enable Natrium plants to provide steady, low-carbon electricity to complement surging renewable generation on the grid.

Wind capacity has massively expanded in Wyoming recently, straining utilities when supply intermittently falls short of demand. TerraPower aims to show how its technology can help bridge these gaps. The company will reuse infrastructure like transmission lines and water rights from the retiring coal plant to cut costs and speed deployment.

Going beyond the initial demonstration, TerraPower has signed an agreement with Rocky Mountain Power to develop five additional Natrium units across Wyoming and Utah on fossil fuel sites slated for closure.

## NuScale and UAMPS Part Ways

In November 2022, NuScale Power gave a presentation to the Commission highlighting the Carbon Free Power Project (CFPP), a small modular reactor (SMR) project, in collaboration with Utah Associated Municipal Power Systems (UAMPS), representing over 50 municipal power systems in the western United States. However, in a setback on November 8, 2023, NuScale and UAMPS mutually terminated the CFPP due to financial challenges, including a substantial increase in projected power costs.

Following the CFPP's cancellation due to rising costs and concerns about economic feasibility, NuScale's CEO, John Hopkins, emphasized the company's ongoing commitment to SMR technology development with other partners. The U.S. Department of Energy (DOE) viewed the termination as unfortunate but believed the project's advancements could inform future nuclear projects. NuScale's unique position is underscored by its SMR design being the only one approved by the U.S. Nuclear Regulatory Commission, showcasing its potential for various applications like replacing closed coal plants and serving remote communities.

In a positive development, NuScale announced on November 20, 2023, that they have partnered with Oak Ridge National Laboratory for a techno-economic assessment of its SMR technology in decarbonizing a U.S. chemical facility. This new venture, supported by the DOE's GAIN initiative and expected to be completed within a year, focuses on steam heat augmentation. It could represent a significant step in using NuScale's technology for clean energy solutions in commercial chemical plants.

# “Nuclear Enlightenment” Period

During his presentation to the Commission on May 12, 2023, Craig Piercy from the American Nuclear Society (ANS) distinguished between today's "Nuclear Enlightenment" and the "Nuclear Renaissance" from 15-20 years ago. The Nuclear Renaissance refers to the period in the early 2000s when there were plans to build many new large nuclear reactors in the U.S., but only a couple of projects came to fruition. On the other hand, the Enlightenment reflects more of an awakening to nuclear power's potential role in deeply decarbonizing the electricity system while maintaining reliability. Unlike a top-down push for large, costly new nuclear plants, the Enlightenment involves more grassroots interest in next-generation nuclear technologies like small modular reactors that can overcome past challenges. There is more recognition today that achieving ambitious climate goals requires a combination of renewables plus a firm low-carbon energy source like nuclear. So while the Renaissance fizzled, the Enlightenment suggests a durable shift in considering nuclear’s advantages as a carbon-free resource that can complement intermittent renewables.

## Nuclear Power in Recent Popular Culture

Nuclear energy has received renewed attention in recent popular culture, with two major films released in 2023 exploring the issue from different angles.

Oliver Stone's "Nuclear Now" makes the case that nuclear energy is essential to the solution to climate change. Stone travels to France, Russia, and the United States in the film, meeting with nuclear scientists, engineers, and policymakers to underscore his argument that nuclear power can generate electricity cleanly, safely, and efficiently. The film starts with a montage depicting climate change through images of melting glaciers, rising sea levels, and wildfires, then moves on to Stone's interviews with experts in various countries. These professionals agree with Stone, emphasizing nuclear power's role in meeting the world's expanding energy demands. As the film concludes, Stone calls for a renewed commitment to nuclear power as a key means to combat climate change.

Christopher Nolan's "Oppenheimer" presents a biopic about J. Robert Oppenheimer, the scientist who headed the Manhattan Project to create the first atomic bomb during World War II. The film delves into Oppenheimer's intricate relationship with nuclear weapons and his moral struggle with the destruction his creation wrought. From his early days as a scientist to his leadership of the Manhattan Project, the story portrays Oppenheimer as both a brilliant and dedicated scientist and a man deeply troubled by the atomic bomb's destructive power.

Along with "Nuclear Now," "Oppenheimer" offers a distinct perspective on nuclear energy and raises vital questions about this technology's future.

# Regional Energy Market and Changing Resource Mixes

The transformation of New England's electricity industry during the 1990s and the establishment of competitive wholesale power markets under ISO New England's administration has led to a significant evolution in the region's energy landscape. New England has transitioned from a historical reliance on vertically integrated utilities to a more diverse mix of merchant power generators. Presently, the region's primary sources of electricity generation are natural gas and, increasingly, renewable energy, reflecting a commitment to cleaner and more sustainable energy sources by regional states.

Below is a table of New Hampshire's energy generation mix as compared to the entirety of ISO New England.

| For 2022 | New Hampshire | | ISO New England | |
|---|---|---|---|---|
| **Generation** | **GWh** | **% of Total** | **GWh** | **% of Total** |
| **Nuclear** | 10,922 | 58% | 27,386 | 26% |
| **Natural gas** | 4,502 | 24% | 55,917 | 53% |
| **Hydroelectric** | 1,201 | 6% | 6,602 | 6% |
| **Wood** | 711 | 4% | 2,960 | 3% |
| **Wind** | 482 | 3% | 4,046 | 4% |
| **Petroleum** | 445 | 2% | 1,855 | 2% |
| **Coal** | 305 | 2% | 348 | 0% |
| **Other biomass** | 141 | 1% | 1,797 | 2% |
| **Other** | 50 | 0% | 1,762 | 2% |
| **Solar** | 4 | 0% | 3,346 | 3% |
| **Battery** | - | 0% | (8) | 0% |
| **Pumped storage** | - | 0% | (398) | 0% |
| **Grand Total** | **(18%) 18,764** | **100%** | **105,612** | **100%** |

Source: U.S. Energy Information Administration (eia.gov)

A critical aspect discussed in the presentation by ISO New England on October 2, 2023, was the change in New England's electricity resource mix from 2000 to the present, with projections extending to 2040 in line with participant state decarbonization goals. Notably, coal and oil-based generation have experienced a substantial decline, reducing from 40% of the regional energy mix to a minimal fraction today. Natural gas has emerged as the dominant energy source. However, renewable resources would have to significantly increase their share of overall electricity generation by 2040 to achieve ambitious regional state policy targets.

ISO New England maintains a policy of neutrality and technology-agnosticism towards advanced nuclear energy. They prioritize integrating diverse resources based on economics and reliability, refraining from taking a stance in favor of or against any specific technology. ISO-NE does not set targets for advanced nuclear's share in energy generation but focuses on assessing reliability impacts. Economic and state-level factors drive the evolution of New England's resource mix rather than ISO-NE's influence. Their core mission is grid reliability and electricity market administration, providing a platform for resources without explicit support or opposition to advanced nuclear technologies.

# Potential Benefits of Advanced Nuclear Technology

Several presentations to the commission highlighted the advantages of advanced nuclear reactor designs over traditional large reactors. One key advantage is their smaller, more flexible size, allowing incremental capacity additions and versatile siting options. This adaptability makes them suitable for microgrids and diverse environments, including retired fossil fuel plants, industrial facilities, and remote areas. Additionally, these reactors have reduced reliance on water, enhancing their sustainability and suitability for regions with water scarcity.

Advanced reactors also feature intrinsic passive safety measures that significantly reduce accident risks. Their lower radioactive inventories and reduced emergency planning zones contribute to improved public safety. These reactors benefit from modularized construction, streamlining factory production, standardizing licensing procedures, and reducing costs through large-scale manufacturing. These efficiencies in construction and operation are essential for making nuclear energy more accessible and economically viable.

Several advanced nuclear designs offer load-following capabilities, seamlessly integrating with renewable energy sources and providing grid-balancing services. High-temperature reactors, in particular, enable non-electric applications such as thermochemical hydrogen production and desalination and provide process heat for energy-intensive industries like metallurgy, chemicals, and cement production. Some developers are exploring innovative business models, such as nuclear power-as-a-service through power purchase agreements. Furthermore, advancements in nuclear fuels and fuel cycles hold the potential to extract carbon-free energy resources from existing nuclear waste stockpiles. These multifaceted benefits position advanced nuclear reactors as a promising solution to sustainably meet future energy demands.

## Modular Construction and Transportability

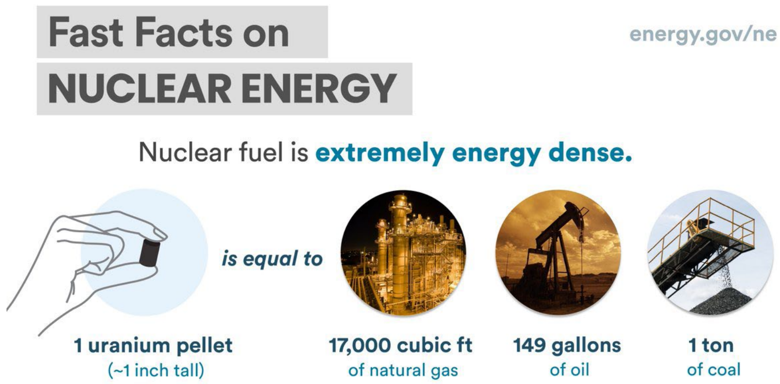
Modular construction is a groundbreaking innovation in advanced reactor technologies, offering numerous advantages over traditional large, on-site-built reactors. Many new advanced reactors are designed as micro or small modular units, with a significant portion of their assembly taking place off-site in factory locations, followed by on-site assembly at the reactor site. This modular approach enhances quality control and standardization while facilitating cost reductions through continuous improvements in mass production processes. These reactors' compact, modular sizes enable incremental capacity expansion and flexible siting options, including repurposing retired fossil fuel plant locations. Innovative business models like nuclear power-as-a-service through power purchase agreements are becoming increasingly viable.

Analogously, the conventional method of building nuclear plants is likened to constructing unique airports, often resulting in cost overruns and delays. In contrast, the new generation of small modular reactors (SMRs) embraces a more efficient approach, akin to aircraft production in a factory setting. This approach ensures superior quality control, economies of scale, and the ability to benefit from the experience gained during each reactor's construction. The modular design fosters economies of scale and allows for stacking reactor units and sharing civil structures, optimizing space and resource utilization. By adopting this "airplane" model, SMRs hold the promise of reducing costs and expediting deployment, departing from the traditional "airport" model of nuclear reactor construction.

Modular design can significantly reduce project risks, making deployments faster and more cost-effective. Manufacturing reactors in factories and transporting them to sites worldwide will change the deployment model for nuclear power, reminiscent of the efficient production of military aircraft during World War II. This opportunity to fully utilize advanced reactors depends on replication, standardization, and factory-based production, ensuring a more robust, flexible, and economically viable future for nuclear energy.

## High Energy Density

Nuclear power plants provide copious amounts of reliable, carbon-free electricity from a small amount of fuel. A conventional nuclear reactor can produce over 1,000 megawatts of power for around 1 million homes. This massive energy output comes from a few hundred fuel assemblies that must only be replaced every 1-2 years. Nuclear fuel has an extremely high energy density, meaning a small quantity releases immense heat energy during fission. For example, one uranium fuel pellet the size of an adult's fingertip contains as much energy as over a ton of coal. The high energy density of nuclear fuel, millions of times greater than fossil fuels, enables nuclear plants to generate enormous amounts of electricity from compact reactor cores constantly undergoing controlled nuclear chain reactions. This allows nuclear power plants to provide always-on, weather-independent, baseload power with minimal fuel requirements and land use footprint.




## Continuous Energy Supply

Unlike intermittent sources of power like wind and solar, nuclear energy supplies steady and dependable electricity throughout the day, every day of the week, regardless of weather conditions. Operating consistently at over 90% of their capacity, conventional nuclear plants rarely shut down, pausing only briefly every 18-24 months for refueling processes. They generate steady power by utilizing the intense heat emitted from continuous nuclear fission reactions within the fuel rods. With the capability to store over a year's worth of fuel on-site, nuclear plants enjoy an edge in fuel security compared to fossil-fuel-dependent plants that require regular deliveries. With its high availability and continuous generation profile, nuclear energy supplements intermittent renewable sources, playing an essential role in maintaining grid reliability. Its constant capacity and unvarying energy production provide vital baseload power and mitigate difficulties in integrating an increased percentage of renewable sources into the power generation mix.

## Ability to Load-Follow

Modern nuclear reactor designs offer substantial load-following capabilities, including Oklo's Aurora reactor, Westinghouse's AP1000, TerraPower's Natrium reactor, and X-energy's Xe-100. Westinghouse's AP1000, for instance, can operate within a 60-100% power range to effectively balance the grid. The smaller size of advanced Small Modular Reactors (SMRs) enhances their load-following performance, with NuScale's SMR technology able to rapidly adjust output to complement intermittent renewable generation.

Furthermore, several advanced reactor developers have optimized their engineering designs for load-following capabilities. TerraPower's Natrium reactor incorporates molten salt energy storage, providing the ability to sustain output during periods of low electricity demand. Holtec's SMR design is similarly capable of substantial load-following, aligning with peak and off-peak cycles.

These load-following attributes of modern nuclear generation significantly enhance grid flexibility and reliability, addressing the challenges posed by rising renewable intermittency. This flexibility improves the economics of nuclear power and positions it as a valuable asset for balancing electricity grids as the generation mix evolves. These advancements underscore the untapped potential of modern nuclear reactors in serving crucial roles in maintaining grid stability.

## Passive Safety Systems

The presentations on advanced reactors showcased a prominent emphasis on safety innovations, particularly through the incorporation of passive systems that rely on natural forces such as gravity, convection, and conduction. The NuScale presentation highlighted their small modular reactor's passive safety features, such as cooling via natural circulation, that require no operator action. Similarly, Oklo's microreactor design capitalizes on inherent safety characteristics, eliminating the need for operator intervention. Westinghouse stressed the significant advantage of the AP1000 reactor's passive safety systems. Several advanced reactor designs were even described as having "walk-away" safety, meaning the reactor can passively shut down and cool itself safely without human or electrical intervention.

Additionally, high-temperature gas reactors were praised for their excellent safety performance, largely attributable to the inert helium coolant and robust TRISO fuel particles. These technological advancements illustrate a concerted effort in the nuclear industry to simplify and enhance safety by leveraging natural mechanisms to automatically cool reactors during abnormal conditions or accidents, reducing risks and human dependency.

## Small Emergency Planning Zones

Multiple presentations highlighted the safety advancements in modern nuclear reactors, particularly in reducing emergency planning zones (EPZs). NuScale Power's Small Modular Reactor, licensed by the Nuclear Regulatory Commission, features inherent safety measures that eliminate the need for external emergency support. This design restricts the EPZ to the reactor's site boundary, which is significantly smaller than the traditional 10-mile radius for conventional reactors. Similarly, Oklo's microreactor design requires no off-site EPZ, reflecting these technologies' lowered risk and environmental impact. If situated at former coal plant sites, these advanced reactors can also benefit from existing infrastructure and skilled labor.

The Nuclear Regulatory Commission (NRC) is updating its emergency preparedness regulations to align with the lower risks of advanced reactor designs. These updates make the regulations more scalable and performance based. This change significantly reduces or eliminates the necessity for off-site emergency planning, a significant advancement credited to the passive safety features of modern reactors.

The potential to install advanced microreactors in populated areas, thanks to the dramatic reduction or elimination of EPZs, stood out as a critical benefit. This development could address many public safety concerns and ease the challenges of siting nuclear reactors.

## Carbon-Free Energy Generation

Nuclear energy significantly contributes to carbon-free electricity generation in the United States, constituting more than 50% of the nation's carbon-free power and contributing to 20% of its total electricity production. Carbon reduction models heavily rely on nuclear energy, often using it for up to 43% of electricity generation, thus highlighting its potential as a dependable and dispatchable energy source. When nuclear energy is limited in such scenarios, it can substantially increase the cost of achieving a clean energy system, emphasizing the economic value of nuclear power in low-carbon energy planning.

Regarding its carbon footprint, nuclear energy is on par with wind power, placing it among the energy sector's technologies with the lowest carbon footprint. Advanced reactors, exemplified by companies like Oklo, exhibit lifecycle $CO_2$ emissions similar to wind power and significantly lower emissions than solar power, aligning nuclear power with green energy objectives. These advanced reactors also boast small carbon footprints, roughly equivalent to that of a single-family home, and they incorporate inherently safe and robust safety systems, providing flexibility in selecting their operational locations.

Nuclear energy extends its utility beyond electricity generation, which plays a vital role in industrial processes and transportation and contributes to further decarbonization through hydrogen production. Innovative designs like the Natrium reactor can collaborate with renewables, creating a zero-carbon grid and reinforcing nuclear power's pivotal role in a carbon-free future. Its high energy density requires less land than wind and solar power and features like on-site fuel storage enhance reliability. Advanced designs facilitate seamless integration with renewables, positioning nuclear power as a critical player in achieving a stable, resilient, and carbon-free grid.

Furthermore, there is growing public support for nuclear energy, particularly among younger generations concerned about climate change. This support strengthens nuclear energy's position as an indispensable tool for carbon reduction, a trend likely to persist as the demand for reliable, round-the-clock clean energy continues to rise, especially to complement variable renewable sources.

## Potential Benefits to New Hampshire's Economy

Attracting advanced nuclear projects to our state could offer significant economic benefits. Constructing new plants would bring a surge of high-paying jobs during construction and create lasting operation and maintenance positions. This influx of employment would raise employment rates and spur local economic growth.

The state could strengthen its economic position by leveraging its nuclear supply chain manufacturing capabilities and sourcing components like reactor vessels to American manufacturers, as is already being done by Westinghouse at their plant in Newington, NH. This move could tap into the $50+ billion nuclear industry, potentially creating numerous skilled manufacturing jobs, boosting the state's technological advancement, and enhancing its economic landscape.

Deploying advanced reactors in locations of retired fossil fuel or biomass plants could ease workforce transitions, offering stable, long-term local employment. Moltex, for example, plans to build its first reactor in New Brunswick, projecting a levelized cost of electricity competitive with fossil fuels and cheaper than renewables with storage. This economic viability, supported by tax credits from the US Inflation Reduction Act, could position states like New Hampshire and New England to attract investments from Moltex and similar companies, addressing our state's need for new firm power generation.

Journalist Matt Wald envisions advanced nuclear reactors creating localized "industrial power zones" reminiscent of the 19th-century hydropower canals that powered New England's manufacturing. Manufacturing historically clustered around hydropower sources, a pattern that could repeat with modern reactors like X-energy's Xe-100. Placing these reactors near industrial areas can directly supply electricity and high-temperature heat for various processes, potentially leading to "energy parks." This model, offering more than just electricity, could amplify a reactor's value and productivity. Wald's vision suggests reviving the early hydropower era's co-located power and industry model, promoting nuclear-powered industrial clusters.

## National Security Implications

Centrus Energy, a leading nuclear fuel manufacturer, highlighted the importance of establishing robust domestic production capabilities, focusing on high-assay, low-enriched uranium (HALEU). This strategic endeavor is essential for addressing commercial demands and enhancing national security. Developing a self-sustaining American supply chain for critical nuclear fuels like HALEU is pivotal for revitalizing U.S. leadership in the global nuclear industry and securing the nation's interests.

Several of presentations to the Commission underscored the fact that the United States heavily relies on imported nuclear fuel and enrichment services, often sourced from foreign state-owned companies, leaving the country vulnerable to geopolitical disruptions.

National security concerns center on Russia's significant role in the global nuclear fuel supply, highlighting the need to reduce dependence on foreign nations for critical fuel and related services. The strategic move to establish a self-reliant domestic nuclear supply chain aligns with national security imperatives.

The HALEU fuel program, authorized by the Energy Act of 2020 with approximately $600 million in funding, addresses the challenge of HALEU production and matching it with customer demand, often referred to as the "chicken and egg" problem in advanced nuclear reactor technologies.

Centrus Energy's ramping up production of small quantities of HALEU in Piketon, Ohio, in collaboration with the Department of Energy, marks a significant milestone in this effort, signifying tangible progress toward achieving commercial and national security objectives.

# Advanced Nuclear Reactor Technologies

The commission received detailed presentations on nearly a dozen individual advanced reactor technologies at various stages of design, licensing, and commercialization.

Below is a table summarizing the advanced fission reactor manufacturer's designs.

| Manufacturer | Design Name | Technology | Fuel Type | Cooling Medium | Power Output (MWe) | Cost per MWh |
|---|---|---|---|---|---|---|
| **BWXT** | BANR | High Temperature Gas Reactor | TRISO | Helium | 50 MWth | NA |
| **BWXT/GE Hitachi** | BWRX-300 | Boiling Water Reactor | LEU | Light Water | 300 | NA |
| **Holtec** | SMR-160 | Light Water | LEU | Light Water | 160 | NA |
| **Kairos Power** | KP-FHR | Fluoride Salt-Cooled, High Temperature | TRISO | Molten Salt | 140 | NA |
| **Last Energy** | PWR-20 | Pressurized Water | LEU | Air | 20 | $50 - 60 |
| **Moltex Energy** | SSR-W | Molten Salt | Recycled Fuel | Molten Salt | 300 - 600 | $60 |
| **NANO Nuclear** | ZEUS & ODIN | Micro-SMR | HALEU | Air & Molten Salt | NA | NA |
| **NuScale Power** | VOYGR SMR | Light Water | LEU | Light Water | Up to 924 (77 per module) | 'Cost competitive' |
| **Oklo** | Aurora | Fast Neutron | HALEU | Molten Salt | 1.5 - 15 | 'Market competitive' |

| | | | | | | |
|---|---|---|---|---|---|---|
| **TerraPower** | Natrium | Sodium-Cooled Fast Reactor | HALEU | Molten Salt | 345 (boost to 500 for 5.5 hours) | $80 - 120 |
| **Ultra Safe Nuclear** | MMR | Micro Modular Reactor | TRISO | Helium w/ secondary molten salt loop | 1 - 15 | $70 - 80 |
| **Westinghouse** | AP300 | Light Water | LEU | Light Water | 300 | $80 - 120 |
| **Westinghouse** | eVinci | Heat Pipe Technology | TRISO | Passive | 5 | 'Competitive w/ natural gas' |
| **X-energy** | Xe-100 | High Temperature Gas Reactor | TRISO | Helium | 80 (Single) 320 (Four-pack) | $200 (competitive w/ diesel) |

## *Light Water SMRs*

Light water small modular reactors (SMRs) apply conventional light water reactor technology using pressurized or boiling water at smaller individual module sizes. Rather than the 900-1600 MW output of traditional large light water reactors, SMRs range from around 50-300 MW per module. Critical advantages of smaller capacities are reduced financing needs, suitability to serve smaller electricity grids, flexibility for incremental capacity expansion, and enhanced siting options.

The presenters emphasized passive safety systems, modularization, and construction lessons learned as key advantages of their light water SMR designs compared to today's large reactors. Most target regulatory approval and commercial operation within 5-10 years.

### BWX Technologies BWRX-300

Joshua Parker of BWX Technologies presented on his company's joint development with GE Hitachi of the BWRX-300 small modular reactor design, leveraging their boiling water reactor experience into a 300-megawatt capacity project. Based on GE Hitachi's ESBWR reactor, the design includes safety features like natural circulation emergency cooling and emphasizes constructability within 24 months through modularization and factory fabrication. Marketed as a simple, safe, and small boiling water reactor, the BWRX-300 aims to provide affordable carbon-free energy with flexible siting. The commercialization target is the mid-2020s, and several U.S. utilities have expressed interest. BWX Technologies highlighted its wide-ranging nuclear innovation capabilities, from manufacturing naval nuclear reactors and commercial components to international research reactor fuel delivery. Engaging in projects like microreactor design and medical isotope production, BWXT is eyeing emerging applications, including space nuclear propulsion, and developing the BANR microreactor being developed in the aforementioned, Project Pele, targeting commercial production by 2028. The focus remains on using proven experience and innovation to enable advanced reactor deployments.

### Holtec International SMR-160

Gareth Thomas, Senior Vice President at Holtec International, presented the company's light water SMR-160 design, with a capacity of 160 MW and an aim to utilize retiring nuclear plant infrastructure. Holtec completed the design certification process with the Canadian regulator and plans to apply to the U.S. Nuclear Regulatory Commission by late 2023. Lessons from recent construction projects, including those from the AP1000, have informed the design, and Holtec targets commercial operation by 2030. The company identified the former Oyster Creek nuclear site in New Jersey, which it is decommissioning, as the likely location for the first project. Although financing the first plant and attracting a customer poses challenges, Holtec believes new tax credits will enhance SMR economics. Supply chain readiness and the availability of skilled trades workers also present critical challenges. Holtec's 160 MW design offers extensive load-following capabilities, and the company anticipates strong global demand for SMRs to help meet urgent decarbonization needs. The benefits of factory manufacturing and serial project replication from modular construction further strengthen the case. Holtec aims to become an early mover in commercializing light water SMR technology.

### Last Energy PWR-20

Ryan Duncan, Director of Government Relations at Last Energy, explained how their modular reactor design , the PWR-20, aims to overcome perennial difficulties with large, gigawatt-scale nuclear plants by taking a modular construction approach. Their self-contained reactor units are built in a factory setting and consist of approximately 40 pressurized water reactor modules, each the size and shape of a standard 18-wheeler trailer. These modules are shipped via conventional transport to the plant site and rapidly assembled in around 90 days. Each module contains essential reactor components, including steam generators, control rod drive mechanisms, coolant pumps, pressurizers, and instrumentation. Once fully assembled, the plant footprint spans about half an acre. Its underground retention pools also store spent fuel onsite for the 42-year lifespan before final disposal, minimizing transportation. The plant utilizes conventional light water reactor technology, not novel designs, for licensing ease. However, it incorporates extensive passive safety features for decay heat removal, avoiding human intervention. Air cooling enables flexible siting and is not restricted to large water bodies. Last Energy will privately finance and operate the plants, selling power directly to industrial buyers seeking clean energy via long-term contracts. They plan to deploy modular fleets tailored to each customer’s demand profile. With agreements worth billions already signed for over 50 units in Europe, Last Energy aims to pioneer the feasible commercialization of advanced nuclear technology through simplicity, restraint of scope, and innovations in modular manufacturing and ownership.

### NuScale Power VOYGR

Chris Colbert of NuScale Power presented the company's light water Small Modular Reactor (SMR) technology, the VOYGR, featuring modules that are 77 Mwe (gross) each, with the capability to host up to 12 modules per plant for a total capacity of 924 Mwe (gross). This design emphasizes passive safety systems, natural circulation cooling, and black start capability, contributing to its safety and resilience. The modular approach offers benefits like simplicity, efficient factory-based manufacturing, flexible siting options, versatile applications such as desalination and hydrogen production, and load-following capabilities to complement renewables. NuScale’s focus on safety, modular manufacturing, and operational flexibility attracted Utah Associated Municipal Power Systems (UAMPS) as their first customer, who ordered a 12-module plant which was expected to be online in 2029. Unfortunately, this project has since been cancelled as of November 2023, in part due to undersubscribing of potential customers.

### Westinghouse AP300

David Durham from Westinghouse provided an overview of their 225 MW light water Small Modular Reactor (SMR), the AP300, utilizing their successful AP1000 technology on a more compact scale. Westinghouse aims to condense the AP1000's technology into a smaller, more versatile package, taking advantage of the knowledge acquired from building and operating the larger model. Mr. Durham emphasized that this is not a first-of-a-kind technology and highlighted the passive safety features, modular construction, and projected 60+ year license term that characterize the design. Westinghouse is targeting design certification of the AP300 by 2027 with full commercialization likely in the early 2030s. Additionally, Westinghouse's presentation touched on their extensive nuclear energy experience as an industry leader, with technology in over half of the world's operating nuclear reactors. They also discussed their eVinci microreactor for remote sites and their facility in Newington, New Hampshire, which manufactures critical reactor components. Through these initiatives, Westinghouse intends to use its decades of experience to spearhead deploying next-generation nuclear technologies.

## *High-Temperature Gas Reactors*

High-temperature gas reactors (HTGRs) use helium as a coolant and carbon in the form of graphite as a moderator. Helium is a very good coolant because it has a high specific heat capacity, which means that it can absorb a lot of heat without significantly increasing its temperature. Graphite is a good moderator because it slows down neutrons without absorbing too many of them, which allows the reactor to operate at a higher temperature. The high-temperature output enables electricity production via gas turbines and process heat applications like hydrogen generation. TRISO (tri-structural isotropic) particle fuel provides robust fission product retention at high temperatures.

### BWX Technologies BANR

BWXT is developing an advanced nuclear microreactor called the BWXT Advanced Nuclear Reactor (BANR). BANR utilizes high-temperature gas reactor (HTGR) technology with TRISO fuel in a modular, factory-built design rated at 50MW thermal output per module. It leverages BWXT's expertise in nuclear fuel and reactor manufacturing as well as decades of HTGR research and operations experience. BANR aims for transportability by fitting each reactor module within standard shipping containers. It has a long 5+ year refueling cycle enabled by the high-density BWXT-fabricated TRISO fuel elements with uranium oxycarbide kernels. Safety is enhanced through passive systems and inherent features. BANR offers flexibility in power conversion modes for process heat, electricity generation or cogeneration. Applications for the reactor include remote and off-grid applications for communities, mining, oil extraction, and industrial process needs. BANR is currently in the risk reduction and demonstration phase, progressing toward an initial production decision and ultimate commercial deployment.

### X-energy Xe-100

Carol Lane of X-energy explained how the company is developing the Xe-100, an 80 MWe high-temperature gas-cooled pebble bed modular reactor. The core comprises approximately 220,000 billiard ball-sized graphite pebbles containing the TRISO fuel particles. Helium flows over the pebbles, heating up to 565°C to produce steam for electricity generation or industrial process heat applications. The reactor offers inherent safety features and can load follow between 100% and 40% power in 15 minutes, providing grid flexibility. The modular design enables road-shippable factory fabrication of components and rapid on-site assembly. X-energy aims to prove the economics of the Xe-100 and deploy the first unit through the Department of Energy's Advanced Reactor Demonstration Program at a Dow Chemical facility in the Gulf Coast region, with commercial operation targeted around 2028. The reactor's compact size, passive safety, and flexibility make it well-suited for integration with industrial facilities and retiring coal plants.

## *Molten Salt Reactors*

Molten salt reactors (MSRs) operate by dissolving fissile fuel in a molten salt mixture that serves as the coolant and chemical processing fluid. This enables high operating temperatures at low pressures, passive safety features, continuous refueling capabilities, and reduced waste generation. However, some molten salt designs have corrosion resistance and remote maintenance challenges. Molten salt reactors were discussed by several of the expert presenters at the commission meetings.

### TerraPower Natrium

Jeff Navin, Director of External Affairs at TerraPower, provided insights into TerraPower's innovative molten chloride fast reactor design, emphasizing its use of liquid sodium chloride salt instead of solid fuel rods. This unique approach enables walk-away safety, load-following features, and multiple power conversion options like electricity or hydrogen production. TerraPower's Natrium reactor couples a sodium-cooled fast reactor with a molten salt energy storage system, allowing continuous variable output to integrate seamlessly with renewables. The high boiling point of sodium, used as a coolant, provides inherent safety benefits, with the reactor core immersed in a pool of liquid sodium that rises and transfers heat through a loop system. The cooled sodium then recirculates into the core, eliminating the need for mechanical pumps. Natrium's heat loop connects to a molten salt energy storage system, separating the nuclear plant from power generation and enabling flexible electricity output. With a storage capacity of 500 megawatts for 5.5 hours, the plant can vary its output between 40-500 megawatts to balance grid demand, combining steady baseload capacity with storage to complement intermittent wind and solar generation. TerraPower projects that this sodium-cooled, salt-storage design can generate electricity at $55-60/MWh when deployed at scale, competitive with other energy sources. The first commercial Natrium plant is slated for 2030 in Kemmerer, Wyoming, pending licensing and fuel supply. With Natrium's advanced design, TerraPower aims to offer clean, flexible, and cost-effective nuclear energy to contribute to decarbonization efforts.

### Moltex Energy SSR-W

During a commission meeting on October 2, 2023, Tristan Jackson, representing Moltex Energy, presented a detailed overview of their innovative approach to nuclear energy. Their primary focus centers on developing a waste-burning reactor, marking a significant departure from conventional nuclear reactor designs. This reactor belongs to the Generation IV category, differing in fuel configuration and coolant system from Generation II reactors, such as the one located in Seabrook, New Hampshire. Moltex's reactor uniquely harnesses used nuclear fuel for its operation, effectively recycling it to generate additional energy. This approach relies on the presence of conventional reactors that have completed the once-through fuel cycle, as the Moltex reactor depends on the fuel used by these reactors.

Moltex Energy's waste-burning reactor is designed to complement existing nuclear power plants rather than function independently. For instance, in a 1.2-gigawatt plant like Seabrook, Moltex could integrate a 600-megawatt waste-burning reactor capable of operating for approximately 60 years using the available spent fuel supply stored onsite at the Seabrook facility. This strategic approach would situate the reactor within the established nuclear boundaries of existing plants. It aims to reduce fuel waste liabilities and contribute substantial clean, consistent, and dispatchable power to the grid.

Additionally, Moltex Energy directs its attention to innovative energy storage solutions, exploring the application of molten salt technology initially developed for the concentrating solar power sector. This approach proves considerably more cost-effective than lithium-ion batteries, offering a mere fraction of the cost and the ability to store energy for approximately three days. In practical terms, a 500-megawatt reactor could charge up to a gigawatt of thermal energy storage for about two-thirds of the day, subsequently providing dispatchable peaking power equivalent to one and a half gigawatts. This method of storing energy as heat could be particularly effective when directly linked to an operational reactor, showcasing Moltex's focus on enhancing the efficiency and adaptability of nuclear power generation.

### Kairos Power KP-FHR

Kairos Power is actively developing its Fluoride-salt Cooled High-Temperature Reactor (KP-FHR), a 140MW small modular reactor. This project aims to leverage modern technologies to enhance the economics, safety, waste reduction, and reliability of nuclear power generation compared to conventional light and heavy water reactors.

The KP-FHR employs a high-temperature molten fluoride salt as its coolant, achieving an electrical conversion efficiency of 45-50%, comparable to advanced light water reactors. It utilizes Tristructural Isotropic (TRISO) fuel compacts, recognized for their durability by the Department of Energy. These fuel particles feature silicon carbide containment layers, adding an extra layer of protection against fission product release. The reactor's design enables passive safety, with decay heat driving convection cooling without requiring pumps or external power. Moreover, it's engineered for 30-year operation between refuelings, minimizing maintenance requirements.

Kairos Power is pursuing a strategic approach to bring this technology to the commercial energy sector. They are actively working on licensing the Nuclear Regulatory Commission (NRC), conducting a comprehensive testing program with Engineering Test Units (ETUs), collaborating with suppliers to establish fuel production pipelines, and developing in-house manufacturing capabilities. This approach aims to reduce financial risks while accelerating the deployment of this advanced reactor technology to reduce reliance on fossil fuel-based electricity generation by 2030.

### *Fast Neutron Reactors*

Fast neutron reactors operate with high-energy neutrons, unlike conventional reactors that rely on slower-moving thermal neutrons to cause fission. This characteristic allows fast neutron reactors to run at higher temperatures, enhancing their efficiency over traditional nuclear reactors. In fast reactors, high-energy neutrons extract more energy from the fuel, increasing the overall energy output. One significant advantage of fast neutron reactors is that they can use spent fuel from traditional reactors as a fuel source. This approach improves fuel efficiency and offers a way to manage nuclear waste by reusing spent fuel. By combining higher efficiency with the ability to recycle spent fuel, fast neutron reactors stand out as a promising and innovative technology in nuclear energy.

#### Oklo Aurora

Jacqueline Siebens, Director of Policy and External Affairs at Oklo, explained her company's development of small modular fast neutron reactors called Aurora. These reactors cool with liquid sodium and use metallic fuel made from recycled, spent fuel. The small size of the reactor, ranging from 1.5 to 15 megawatts, enables flexible siting. The simplicity of the design, which has far fewer parts than conventional large reactors, aims to cut construction and operating costs. Oklo also leads a compact fuel recycling process to reuse spent fuel. Oklo's goals include providing reliable, affordable clean electricity through long refueling cycles, simple design, and recycling. The company anticipates NRC approval in the 2025-2026 timeframe and plans to sell "fission-as-a-service," providing heat or power directly to customers like companies and remote communities. The design allows for flexible siting, including in populated areas, and the compact size facilitates factory fabrication and truck transport.

### *Microreactors*

Microreactors are very small nuclear reactors with 1-20 Mwe power outputs, designed for remote communities, military bases, or industrial applications. Their small size provides inherent safety advantages and siting flexibility. Microreactors can enable affordable, reliable off-grid power and district heating and generally compete with diesel generators

#### BWX Technologies BANR

The BWXT BANR (BWX Advanced Nuclear Reactor) high-temperature gas reactor covered previously is considered a microreactor. As part of their efforts to showcase the technology, BWXT engages in Project Pele, which involves constructing and operating a BANR reactor to power a U.S. military base.

### Last Energy PWR-20

Last Energy PWR-20 discussed previously is considered a microreactor.

### NANO Nuclear Energy ZUES and ODIN

NANO Nuclear Energy is developing advanced microreactor designs with UC Berkeley and Cambridge University research teams. CEO James Walker explained that NANO aims to provide carbon-free nuclear energy to remote mining, industrial, and military sites currently reliant on polluting diesel generators. After surveying renewable options, they found that only microreactors - reactors sized to fit inside standard shipping containers - could provide the consistent, location-flexible energy these sites require.

Walker spotlighted two separate reactor concepts NANO is concurrently developing. UC Berkeley's "ZEUS" design utilizes conventional solid fuel rods and a solid heat transfer matrix to remove heat, eliminating the need for pumps or coolant fluids. The matrix passively conducts heat from the core-periphery to air turbines, generating electricity. Walker touted this approach's intrinsic safety advantages, citing that even a total systems failure would not impede safe passive cooling without any operator action. ZEUS also runs at higher temperatures, which makes it better suited for process heat applications like hydrogen production.

Alternatively, their "ODIN" design from Cambridge employs a molten salt coolant, which carries heat to a steam generator at lower core temperatures but higher output levels. Both designs are engineered for fully automated operation and sustained decade-long refueling cycles with minimal personnel. For example, Walker stated that ZEUS has no moving parts inside the core. NANO intends to retain ownership over the microreactors while leasing power to clients to eliminate their nuclear regulatory burdens. In closing, Walker emphasized that these microreactors represent a new paradigm of safe, simple, affordable nuclear energy access well-matched to many niche sites.

### Oklo Aurora

Oklo's 1.5 MWe Aurora project discussed above is considered a microreactor.

### Ultra Safe Nuclear Corporation MMR

Ultra Safe Nuclear Corporation (USNC) is developing a micro modular reactor (MMR) product they describe as a nuclear "battery" - able to provide variable power output between 1-15MW based on application needs, with an estimated 40+ year operating lifetime. The design utilizes TRISO fuel particles embedded in a dense silicon carbide matrix. This fully ceramic micro-encased fuel provides robust safety margins and inherent accident tolerance.

Director Business Operations, Donald "Gus" Gustavson explained that USNC's commercialization strategy currently targets remote communities, mining, and industrial sites that value reliability over cost sensitivity. He stated first-of-a-kind projections around 12 cents per KWh, dropping below 8 cents for subsequent units. USNC has two public pilot projects underway with the Department of Defense and Canadian nuclear authorities to demonstrate performance.

A key focus area covered was fuel manufacturing, given specialized TRISO fuels' much more substantial impact on opex versus traditional reactors. Mr. Gustavson elaborated on USNC's efforts to stand up a complete fuel supply chain. This includes a pilot fuel fabrication facility in Oak Ridge, a joint venture with Framatome to produce commercial-scale volumes and contracts with Urenco for initial low-enriched uranium supply.

Obtaining high-assay, low-enriched uranium (HALEU) to power small modular reactor designs is an ongoing challenge for most manufacturers. However, USNC's nearer-term ability to utilize lower enrichment levels provides a bridge until reliable HALEU availability matches projected demand. Mr. Gustavson further examined licensing, transport, and waste process needs at each fuel production step required to feed an advanced nuclear fleet.

USNC aims to leverage the modular simplicity and safety inherent in their microreactor design and vertical integration on specialized TRISO fuel manufacturing to drive regulatory acceptance and commercial expansion in applications that can utilize the technology's advantages.

#### Westinghouse eVinci

David Durham of Westinghouse discussed their eVinci microreactor design during his presentation. The eVinci is a small, transportable nuclear battery that uses heat pipe technology and TRISO fuel. It only requires minimal staffing and security and does not need any active cooling systems. The eVinci can operate for 8+ years before needing refueling. Its compact size allows it to be shipped in three standard shipping containers and installed with minimal site preparation. Durham noted that eVinci is targeted for remote sites, military bases, and the marine industry as an alternative to diesel generators. It can provide reliable, carbon-free energy off-grid. The eVinci's passive safety, lack of melting risk, and factory-assembled and transportable design are key features enabling this flexibility. Westinghouse believes the eVinci can be cost-competitive with diesel energy and provide emission-free 24/7 power for applications ill-suited to renewable sources.

### Other Comments on Microreactors

When discussing various advanced nuclear technologies, journalist Matt Wald offered a perspective on microreactors. He stated that he foresees a minor role for microreactors in New England under the best circumstances. In Wald's view, these tiny nuclear plants will most likely deploy in remote communities, mining sites, and military bases that need reliable power off the primary grid. He mentioned companies like Oklo, Westinghouse, Ultra Safe Nuclear, and X-energy as developers of microreactor designs. Wald explained that microreactors could also supply resilient backup power for critical infrastructure like data centers that process financial transactions. However, due to their small size and niche applications, he cautioned against expectations of widespread microreactor adoption in regions like New England that already have robust grid infrastructure. Wald sees them as filling targeted needs for reliable, off-grid power in remote locales rather than broadly transforming nuclear power generation.

## *Fusion Reactors*

Fusion power generation mimics the energy-producing reactions at the Sun's and other stars' core. Unlike fission, where atoms like uranium split to release energy, fusion combines light elements, typically isotopes of hydrogen such as deuterium and tritium, at extremely high temperatures and pressures. These nuclei collide at a sufficient velocity to overcome their natural repulsive forces and fuse, releasing a significant amount of energy as helium and a neutron. This process demands incredibly high temperatures, often in the tens of millions of degrees, to strip electrons from the atoms and create a plasma state where fusion occurs. Containing this hot plasma poses significant challenges, and scientists and engineers use magnetic confinement with devices like “tokamaks” or inertial confinement with lasers to address them. Fusion power offers a nearly inexhaustible and clean energy source with minimal radioactive waste and no carbon emissions. However, building commercial fusion power plants still represents a significant scientific and engineering challenge.

Michael Wentzel of the NRC briefly mentioned fusion when discussing the NRC's activities related to advanced reactors. He stated that the "advanced reactor" definition in the Nuclear Energy Innovation and Modernization Act includes fusion reactors. Therefore, the NRC must develop an associated regulatory framework for licensing fusion facilities. Wentzel noted that the NRC staff is currently working on options for regulating fusion reactors, which will be presented to their commission for a policy decision when ready. He acknowledged recent advances in fusion but did not provide specifics on the timeline for commercial fusion power. The NRC aims to have a regulatory framework in place so that fusion can be licensed once the technology matures. In summary, Wentzel indicated the NRC is laying the groundwork to support the future licensing of fusion reactors, but commercial viability is still some years away.

Craig Piercy of the American Nuclear Society stated in his presentation that while there has been recent excitement around fusion energy, including an experimental milestone at Lawrence Livermore National Laboratory in California and a fusion company, Helion Energy, announcing a power purchase agreement, Piercy cautioned against hype and unrealistic timelines. He believes large-scale commercial fusion is still likely decades away, comparing it to the slow adoption of jet engines from the 1930s to the 1950s. Experimental progress is encouraging but scaling up to an economical fusion reactor will take major technological leaps and likely not happen until at least 2035-2040. In the meantime, fission reactors offer proven carbon-free energy generation that can be deployed now. Rather than directly displacing fission in the short term, fusion will take many years to realize its potential and will co-exist with fission technology for the foreseeable future. Piercy advocates a measured approach to fusion that does not assume it will solve decarbonization needs in the next 10-20 years when fission options are available.

Journalist Matt Wald tempered expectations around fusion energy, stating that while fusion development is essential to fund and could become practical, he would not count on it becoming a significant contributor to power generation in the next few decades. Wald explained that the recent fusion experiment touted as a "breakthrough" by the Department of Energy barely produced more energy than it consumed. He emphasized that in a commercial fusion plant, the reaction would need to produce fusion reactions orders of magnitude faster. Additionally, Wald noted that fusion reactors create significant radioactive waste, with components becoming intensely radioactive from neutron exposure during operation. He highlighted fusion's fuel challenges, requiring scarce hydrogen-like deuterium and tritium forms. Ultimately, Wald cautioned against holding one's breath for fusion, assigning it to the "Don't Hold Your Breath" category of nuclear technologies decades away from practical deployment. He advised that other forms of nuclear fission should be relied upon for more near-term carbon-free energy production.

Fusion was noted to not be viable for commercial deployment in the near term, in contrast to the numerous advanced fission reactors covered. While fusion is a potential longer-term nuclear energy option, the commission is focused on commercially relevant advanced fission nuclear technologies in the 2020s-2030s timespan.

### Zap Energy

On September 18, 2023, the commission received a presentation from Ryan Umstattd of Zap Energy, a company dedicated to advancing nuclear fusion power as a sustainable energy source. Zap Energy's approach to fusion stands out for its utilization of a concept called Z-pinch, which involves the controlled induction of nuclear fusion reactions within a plasma of hydrogen isotopes through pulses of electricity. Their groundbreaking innovation employs sheared fluid flow within the plasma column to stabilize against intrinsic instabilities, enabling longer reaction durations. The latest experimental reactor, FuZE-Q, has demonstrated substantial performance improvements, achieving daily fusion reactions. However, it is essential to note that their current output remains below the breakeven levels required for electricity production, necessitating ongoing research and development efforts.

Zap Energy envisions the potential mass manufacturing of compact fusion modules by replacing conventional concrete containment structures with liquid metal walls. Their commercialization roadmap includes plans to operate a demonstration fusion pilot plant at a retiring coal facility in Centralia, Washington, by the early 2030s. While projected costs range from $30-60 per MWh, Zap acknowledges uncertainties given the technical maturity of fusion technology. Their private-funded approach, focused on efficient design and construction techniques, aims to expedite fusion's path to viability as a baseload generator with minimal environmental impacts. Zap Energy's exploration of fusion energy signifies notable progress towards environmentally friendly and sustainable energy solutions, presenting a possible means to address future energy requirements.

# Nuclear Fuel Supply Chain

## Supply Chain Outlook

A prominent concern in the nuclear industry is the U.S.'s dependence on foreign sources for nuclear fuel. With 40% of the supply originating from Russia or Russia-controlled countries, this reliance raises questions about national security and economic sustainability. The call for re-establishing domestic enrichment and fuel production capabilities is gaining momentum. Reviving domestic production could reduce foreign dependency and rejuvenate American leadership in the global nuclear landscape.

The nuclear fuel supply chain encompasses diverse and multifaceted challenges and opportunities, from sourcing to disposal. While progress is evident in many areas, the overarching narrative suggests that a more comprehensive and coordinated approach may be required to fully realize the potential of nuclear energy in the U.S. Reviving domestic production, innovating in refinement, and embracing responsible disposal strategies are vital to shaping a resilient and sustainable nuclear industry.

## Chicken-And-Egg Problem

The so-called "chicken-and-egg" problem is a central dilemma in developing advanced nuclear reactors that require high-assay low-enriched uranium (HALEU) fuel. Advanced reactor designs like TerraPower's Natrium require this specific type of fuel, but there is currently a limited commercial supply since enrichment companies are hesitant to invest without assured demand. At the same time, companies developing these advanced reactors need a reliable HALEU fuel supply before they can move forward, creating a deadlock where fuel suppliers are waiting for reactor demand and reactor developers are waiting for a reliable fuel supply.

The impact of this stalemate is far-reaching. The uncertainty in both HALEU production and reactor demand has slowed the progress of new nuclear technology, making it challenging for reactor developers to secure financing and customers. Utilities also hesitate to invest in new reactor technology if the fuel supply is uncertain. This deadlock has implications for advancing nuclear power, meeting decarbonization goals, and reestablishing U.S. leadership in nuclear technology.

Coordinated efforts and strategic planning are needed to overcome this "chicken-and-egg" problem. Proposed solutions include government involvement in providing initial HALEU supply, guaranteeing purchase contracts, and using national security needs to anchor demand. Public-private partnerships may also be a way to align incentives across the supply chain. These efforts would ensure the fuel supply infrastructure is established concurrently with reactor development and deployment, breaking the cycle, and advancing nuclear technology.

## HALEU Production for Advanced Reactors

High-assay, low-enriched Uranium (HALEU) has gained significant prominence in the United States due to its unique attributes. HALEU sets itself apart from conventional low-enriched uranium (LEU) primarily through its higher concentration of the U-235 isotope, typically ranging from 5% to 20%. This elevated U-235 content enables HALEU to deliver a greater energy output than standard LEU, which usually contains up to 5% U-235.

The distinctive characteristics of HALEU make it well-suited for advanced nuclear reactors, including small modular reactors (SMRs) and specific Gen IV reactor designs. These advanced reactors offer numerous advantages, such as compact size, reduced capital costs, improved safety features, and enhanced operational efficiency with higher burn-up rates. HALEU's higher energy density allows these reactors to operate for extended periods between refueling, a crucial feature, especially for SMRs designed for remote or decentralized locations. Furthermore, HALEU enables the deployment of reactors utilizing innovative fuel cycles to minimize nuclear waste production.

In response to the growing demand for advanced nuclear reactors, several U.S. companies are actively engaged in HALEU production. Centrus Energy, located in Piketon, Ohio, has received approval from the U.S. Nuclear Regulatory Commission (NRC) to become the sole licensed HALEU production facility in the United States. Urenco USA, operating a centrifuge facility in Eunice, New Mexico, has also expressed interest in contributing to U.S. HALEU requirements. Additionally, Dow Chemical, TerraPower, and the Nuclear Energy Institute (NEI) are founding members of the HALEU Consortium.

The HALEU Consortium, established by the U.S. Department of Energy (DOE), plays a pivotal role in securing a domestic supply of HALEU. Its objectives include:

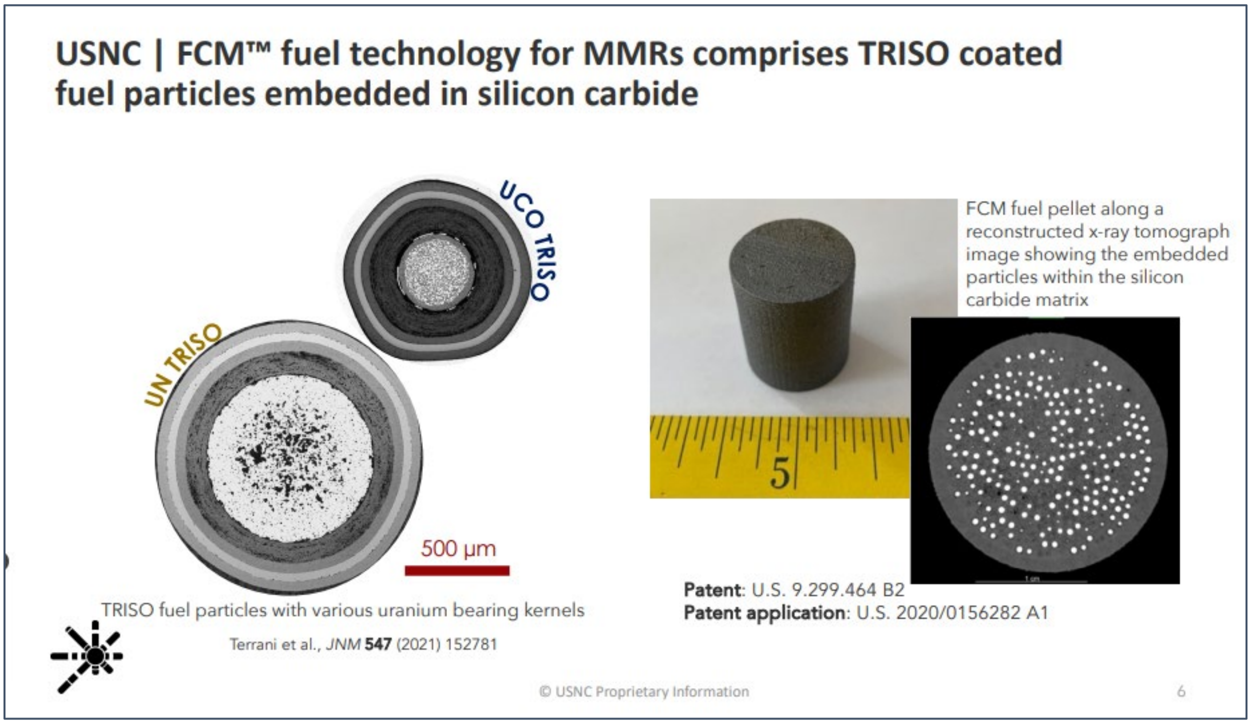
1. Estimating HALEU demand for domestic commercial use.
2. Procuring HALEU for commercial purposes.
3. Identifying opportunities to enhance the reliability of the HALEU supply chain.

This Consortium operates within the framework of the HALEU Availability Program, created under the Energy Act of 2020 to support HALEU's availability for civilian research, development, demonstration, and commercial applications, serving as a vital communication channel for the Office of Nuclear Energy (N.E.) and its consortium members.

Recognizing the pivotal role of HALEU in advancing nuclear energy technologies, the U.S. Department of Energy (DOE) is actively pursuing strategies to secure a domestic supply of HALEU. These collective efforts contribute to the availability and development of HALEU, which is crucial for advancing more efficient and sustainable nuclear energy solutions in the United States.

## TRISO Fuel Technology

TRISO (TRi-structural ISOtropic) fuel represents a superior category of nuclear fuel recognized for its exceptional durability. Each TRISO particle comprises a uranium, carbon, and oxygen core. Surrounding this core are three distinct layers of carbon and ceramic materials meticulously designed to contain and prevent the release of radioactive fission products effectively. Remarkably small, approximately equivalent to a poppy seed, these particles exhibit remarkable robustness. They can be shaped into cylindrical pellets or spherical structures akin to billiard balls, referred to as "pebbles," making them suitable for deployment in high-temperature gas or molten salt-cooled reactors.




*Slide from Ultra Safe Nuclear Corporation's presentation.*

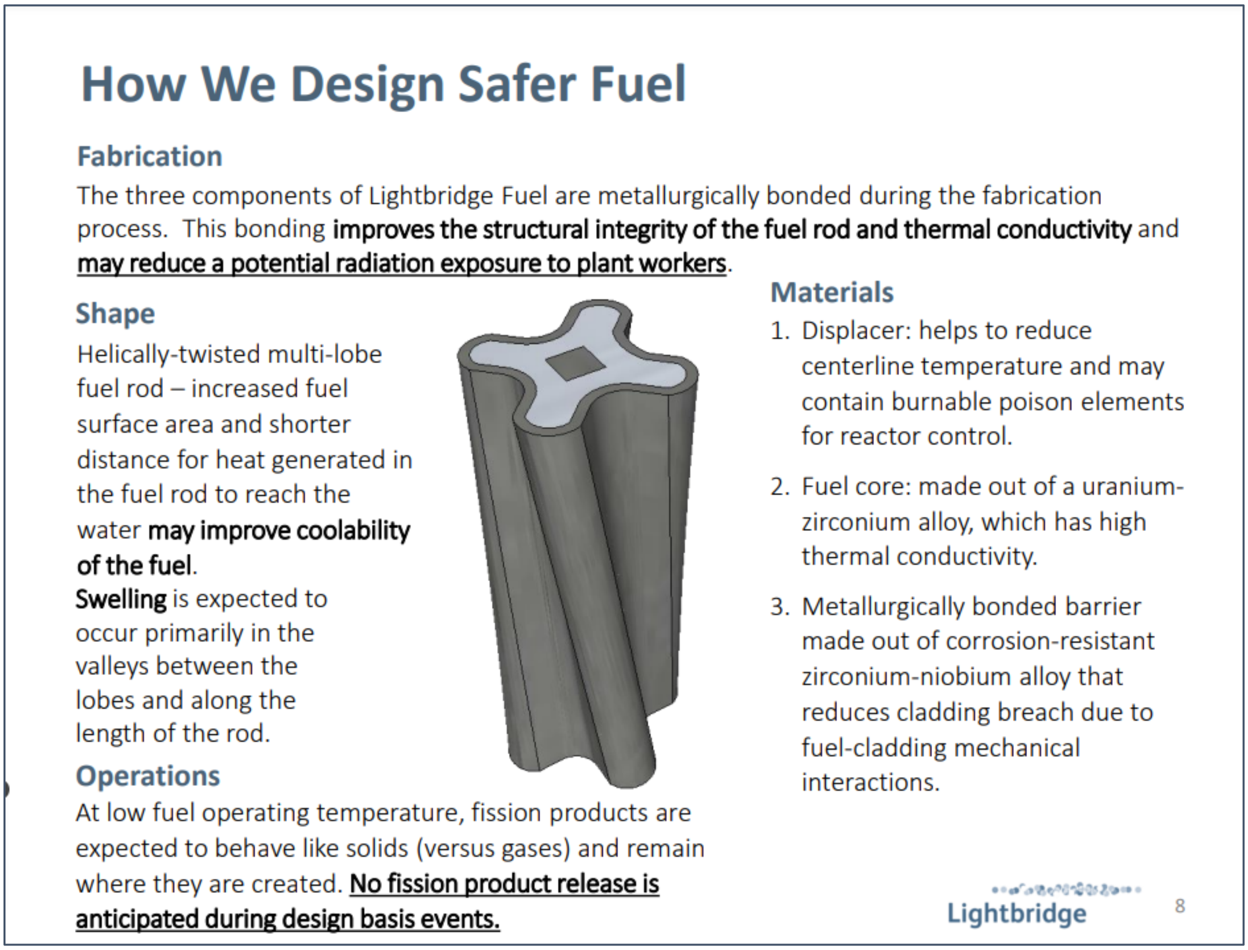
Concerning manufacturers involved in the production of TRISO fuel, BWX Technologies stands out as a prominent industry player. Notably, their facilities dedicated to TRISO fuel production currently hold valid licenses and are operational, with ongoing expansions to their production capacity. Another noteworthy entity, X-energy, boasts a subsidiary known as TRISO-X, poised to become one of the nation's inaugural High-Assay, Low-Enriched Uranium (HALEU) fuel fabrication facility.

Numerous entities within the nuclear sector have a compelling need for TRISO fuel to support their reactor designs. Noteworthy examples include X-energy, Kairos Power, and the Department of Defense, which plan to employ TRISO fuel in their small modular reactor and microreactor designs. Additionally, BWX Technologies is developing a transportable microreactor that utilizes an alternative variant of TRISO fuel featuring a uranium nitride fuel kernel for heightened performance. Furthermore, the Canadian Nuclear Safety Commission (CNSC) has collaborated with two vendors, namely X-energy and Ultra-Safe Nuclear Corporation, both of which have proposed the utilization of TRISO fuel in their advanced reactor designs.

## Lightbridge's Metallic Fuel Rod Technology

Lightbridge Corporation is driving an initiative to redesign nuclear fuel completely using new metallurgy and scientific principles. Their fuel rods incorporate a zirconium alloy matrix and high-assay, low-enriched uranium fuel. This combination allows for extended reactor operation, significantly boosting power output and increasing revenue. Their fuel rods exhibit improved heat transfer properties and operate at temperatures approximately 1000°C lower than conventional fuels. Lightbridge has secured numerous patents on fuel rod design and fabrication technology.

Lightbridge has formed a collaboration with the Idaho National Laboratory through a Strategic Partnering Program agreement. This partnership enables Lightbridge to manufacture and rigorously test fuel rod samples within the Advanced Test Reactor, and it provides access to high-assay, low-enriched uranium from government stockpiles. The primary goal of this collaboration is to generate data that meets licensing standards. During his presentation to the commission, CEO Seth Grae strongly advocated that small modular reactors (SMRs) are crucial for achieving climate goals, and he believes that Lightbridge's fuel technology offers even more significant advantages when applied to SMRs. Ongoing research, supported by a Department of Energy grant, explores integrating this fuel into NuScale's SMR design.




## Disposal

Regarding disposal, the industry acknowledges the capacity to safely store used nuclear fuel on-site. However, efforts are also underway to explore consolidated interim storage sites. One innovative approach in the disposal field is the development of spent fuel recycling processes aimed at creating affordable fuel for advanced reactors and reducing waste. This strategy could address the waste management challenges and align with broader sustainability goals, but it remains to be seen if the process will be commercially viable.

# Non-electrical applications

Nuclear energy has long been associated with electricity generation, but recent advancements in reactor technology are expanding its applications into non-electric sectors. The NEI overview highlighted that advanced reactors could provide electricity and essential utilities such as heat, hydrogen production, and water desalination. These capabilities facilitate various applications, including industrial decarbonization, synthetic fuel production, and expanded market opportunities. Companies like NuScale and TerraPower have embraced this multifaceted approach, implementing their SMR and Natrium reactor technologies to produce high-temperature steam and heat that can enable industrial processes like hydrogen production.

The versatility of nuclear energy is further evidenced by the innovative designs and applications developed by companies like Oklo and X-energy. Oklo's reactor design focuses on providing heat and electricity, supporting industrial decarbonization, and creating resilient microgrids. Meanwhile, the high-temperature operation of X-energy's Xe-100 reactor offers flexibility in providing process heat for various industrial applications. High-temperature gas reactors were also noted for their ability to provide process heat flexibly. Together, these developments mark a significant shift in how nuclear energy can be leveraged, demonstrating its potential beyond merely generating electricity and contributing to critical areas such as water purification, alternative fuel production, and enhancing industrial efficiency.

## *Hydrogen Production*

Several presentations emphasized the growing interest and potential in utilizing nuclear energy for hydrogen production, marking a potential emerging use case for advanced reactors. NuScale, for instance, revealed that their small modular reactor (SMR) technology could generate hydrogen alongside electricity. TerraPower's Natrium reactor design was noted for its ability to produce hydrogen through electrolysis or thermo-chemical processes, thanks to the high temperature steam it generates. High-temperature gas reactors were also cited as adaptable for flexible hydrogen production, given their high-quality process heat. Our discussions introduced the idea that new nuclear plants could substitute natural gas for emissions-free hydrogen generation in the future. However, further analysis is likely necessary to assess how competitive nuclear-powered hydrogen production might be compared to renewable or fossil fuel alternatives.

## *Medical Isotopes*

The NRC presentation by Michael Wentzel highlighted that SHINE Technologies is building a medical isotope production facility in Janesville, Wisconsin that is nearing completion of construction. This facility will produce medical isotopes using nuclear technology. Medical isotopes are essential in various diagnostic and therapeutic applications, including cancer treatment and heart disease monitoring. Utilizing nuclear technology for isotope production offers a reliable and efficient method to meet the growing demand in healthcare. The Wisconsin facility's nearing completion signifies a step towards increased accessibility and innovation in medical treatments.

## *Desalination*

NuScale's presentation highlighted the potential of nuclear energy for desalination and water purification. The consistent heat energy from nuclear reactors can drive water desalination processes, making them suitable for coastal or arid regions lacking freshwater resources. The modular nature of designs like NuScale's enables coupling with desalination plants to produce potable water alongside zero-carbon electricity.

## *Industrial Heat*

Industrial heat refers to generating and utilizing thermal energy in various industrial processes. This form of energy is essential across various sectors, including manufacturing, chemical processing, food production, and many others. Industrial heat is typically used for drying, melting, smelting, refining, cooking, and sterilization. The quality and characteristics of industrial heat, such as its temperature range, intensity, and distribution method, are crucial factors that vary depending on the specific requirements of each application.

Historically, industrial heat has been generated primarily by burning fossil fuels such as coal, natural gas, and oil. However, this traditional approach is associated with significant carbon emissions and environmental concerns. As a result, there is a growing interest in alternative, more sustainable sources of industrial heat, especially in global efforts to reduce carbon footprints and combat climate change.

Nuclear energy, with its capacity for high-temperature heat generation and low carbon emissions, is emerging as a viable alternative for providing industrial heat. Advanced nuclear reactors, in particular, are being developed to meet these needs more efficiently and safely. These reactors offer the potential for cleaner, more sustainable industrial processes by providing a stable and reliable heat source without the significant carbon emissions associated with fossil fuels.

Recent advancements in nuclear reactor technology have broadened the scope of applications, particularly in industrial heat. Manufacturers like Kairos Power, Oklo, TerraPower, and X-energy are pioneering technologies that extend beyond traditional electricity generation to provide versatile industrial heating solutions. Several manufacturers leverage their reactor technology for industrial heat applications.

Kairos Power focuses primarily on producing carbon-free electricity with its advanced reactor designs. However, they acknowledge the significance of industrial heat applications. Their technology's potential extends to providing industrial heating solutions, which could be a crucial aspect of their business plan. This dual capability demonstrates Kairos Power's dedication to exploring innovative uses of nuclear technology beyond electricity generation.

Oklo's reactors are not just electricity generators but also capable of producing process heat. This makes them highly versatile, catering to various needs across the industrial sector. Their approach includes a fission-as-a-service business model, which could greatly simplify the deployment and operation of their reactors in industrial settings. This flexibility positions Oklo as a key player in providing industrial-process heat solutions.

TerraPower has developed a strategy for load-following, where the heat from their reactor is utilized to heat a molten salt energy storage system. This ability to adjust output makes their technology suitable for industrial heating applications. TerraPower's integration of nuclear power with energy storage solutions presents a novel approach to meeting industrial heat demands efficiently.

X-energy reactors are designed to produce high-temperature steam that can be used in various industrial applications, including clean hydrogen production. This capability of generating substantial heat aligns well with industrial processes that require high energy inputs. X-energy's focus on leveraging reactor technology for industrial heat production highlights the expansive potential of nuclear energy in the industrial domain.

Using nuclear reactor technology for industrial heat applications represents a significant evolution in nuclear energy. Manufacturers like Kairos Power, Oklo, TerraPower, and X-energy are at the forefront of this transformation, demonstrating that nuclear technology can provide comprehensive solutions for electricity generation and industrial heating needs. This expansion into industrial heat applications broadens the scope of nuclear energy and presents new opportunities for efficiency and sustainability in various industrial processes.

### *Data Centers and Bitcoin Mining*

At our November 6, 2023, meeting, Ryan McLeod, a chemical technologist at Canadian Nuclear Laboratories, presented a detailed overview of his ideas on advancing nuclear technology by pairing it with Bitcoin mining. He began by discussing his participation in the Innovation for Nuclear contest, which focused on nuclear power, small modular reactors (SMRs), and the U.N.'s sustainable development goals. His interest in Bitcoin mining, particularly in various grid applications, sparked an idea about its potential to advance nuclear power.

McLeod expressed his enthusiasm for nuclear power, emphasizing its role in energy security, reliability, and emissions reduction. He highlighted the development of new reactors and the expansion of existing ones, citing examples from Canada and other countries. He also emphasized Canada's opportunities in SMRs, especially for remote areas and small grids. He mentioned the work of CNL's hybrid energy system modeling team on scenarios for deploying SMRs alongside other technologies.

Much of McLeod's presentation focused on the potential of Bitcoin mining to support nuclear power by providing a flexible load for demand response applications. This approach, he argued, would maximize the economic utility of power assets, and assist in debt servicing for new reactors. He covered the importance of demand response in managing grid stability and efficiency, particularly with integrating intermittent renewable sources.

Evaluating Bitcoin mining as a demand response technology, McLeod highlighted its potential as a sizable, flexible, and predictable load. He discussed different Bitcoin mining applications, including off-grid opportunities and partnership models, and addressed the financial aspects, such as attracting investors and managing risks.

McLeod also explained the basics of Bitcoin and its mining process, emphasizing its role as a digital commodity and potential integration with energy markets. He acknowledged the challenges and controversies surrounding the intersection of Bitcoin mining and nuclear power but remained optimistic about its future potential.

Specific case studies, such as TeraWulf's partnership with a nuclear power plant and NuScale's venture with Standard Power, were discussed to illustrate the practical application of the ideas presented. In conclusion, Ryan McLeod's presentation explored innovative ways to leverage Bitcoin mining for advancing nuclear technology, suggesting a new energy generation and consumption paradigm despite acknowledging the complexities and challenges involved.

# Risks of Nuclear Technology

## Financial Risks

During our inquiry, the commission has identified significant financial risks associated with developing and adopting advanced nuclear reactors. These risks pose substantial challenges to the successful implementation of these innovative technologies.

One of the primary financial risks revolves around the status of being the first adopter of advanced nuclear technologies. Early adopters often encounter uncertainties related to these novel reactors' performance, regulatory approval, and market acceptance. These uncertainties can lead to increased costs, potential project delays, and unforeseen technical complexities, making it a critical risk factor.

The capital-intensive nature of advanced nuclear reactor projects is another significant financial risk. These projects demand substantial initial investments, covering expenses for research and development, licensing, construction, and supply chain establishment. Such significant financial commitments increase vulnerability to risks, especially in budget overruns or project delays.

Financial risks associated with ensuring an adequate fuel supply for advanced nuclear reactors, particularly High-Assay Low-Enriched Uranium (HALEU), are a significant concern. Challenges in procuring specialized nuclear fuels and developing a reliable supply chain involve substantial investments in fuel fabrication facilities and technology. These challenges pose financial risks due to the high costs of establishing and maintaining such infrastructure. Additionally, fluctuations in fuel prices and supply disruptions can impact operational costs and project feasibility.

Furthermore, the evolving regulatory landscape and market uncertainties surrounding advanced nuclear technologies add to the financial risk profile. Lengthy and unpredictable regulatory processes can impact project schedules and costs, while market fluctuations and competition from alternative energy sources can affect the overall financial viability of these projects. Hence, these financial risks require meticulous consideration and strategic planning to ensure the successful development and adoption of advanced nuclear technologies.

## Safety Considerations

Advanced nuclear reactors, while offering the promise of enhanced efficiency and sustainability, do indeed present a unique set of safety concerns. These concerns primarily arise from these reactors' innovative designs and operational methods, setting them apart from their conventional counterparts. Unlike traditional reactors, advanced variants operate in unique ways, necessitating careful evaluation of their safety aspects.

One notable safety concern is using novel fuel types in advanced reactors. These fuels, such as HALEU, Tri-structural Isotropic particles, molten salts and metals, introduce distinctive safety considerations due to their unconventional properties and behaviors. The handling and containment of these materials require careful attention to ensure the reactors' safety.

Another safety aspect pertains to adopting modular designs and factory-based fabrication in constructing advanced reactors. While these approaches offer advantages in terms of cost-effectiveness and scalability, they also introduce potential risks. The manufacturing process may be susceptible to flaws that could manifest as safety hazards during operation. Furthermore, the modularity of the design can pose challenges during the regulatory approval process, as each module may necessitate separate safety assessments.

Additionally, the security requirements for advanced reactors, in terms of physical and cyber aspects, present a noteworthy challenge. Recognizing the distinctive features of these reactors, the U.S. Nuclear Regulatory Commission (NRC) has proposed extensive modifications to enhance physical security measures. These measures include comprehensive considerations for safeguarding against both physical and cyber risks.

It is important to emphasize that despite these inherent safety and security challenges, advanced reactor designs are developed and operated with a sensitive awareness of these risks. The NRC plays a pivotal role in ensuring the rigorous oversight and regulation of existing and proposed nuclear power plants.

## Understanding Radiation

Understanding radiation requires appreciating its various forms, sources, and potential effects on our health and environment. Radiation is energy that travels through space or matter, either as waves or particles. It is broadly classified into two types: non-ionizing and ionizing radiation. Non-ionizing radiation includes visible light, microwaves, and radio waves, typically considered harmless at low levels. In contrast, ionizing radiation, which includes X-rays, gamma rays, and alpha and beta particles, carries enough energy to remove electrons from atoms, creating ions. This type of radiation can be derived from both natural and man-made sources. Natural sources include cosmic rays, which penetrate the atmosphere from space, and terrestrial sources like radon gas, a radioactive element found in the soil that can accumulate in buildings. The average annual radiation dose per person in the U.S., including from natural and man-made sources, amounts to about 6.2 millisieverts (mSv), varying with geographical location.

The impact of ionizing radiation on biological tissues is a subject of considerable study and concern, particularly regarding the long-term health effects of low-level exposure. The linear no-threshold (LNT) model, a cornerstone in radiation protection guidelines, posits that cancer risk increases linearly with the radiation dose with no safe threshold. However, the accuracy of the LNT model, especially at low radiation levels, is debated. Critics argue that the model oversimplifies the complex interaction of radiation with biological systems and does not account for the body's ability to repair damage from low-dose exposure. For instance, exposure to radiation during a commercial flight or from eating foods like bananas, which contain naturally occurring radioactive potassium-40, is considered low. The scientific community continues investigating the effects and risks of such low-level exposures to better inform public health guidelines.

Effective radiation management involves principles of radiation protection, such as justification, optimization, and dose limitation. International bodies like the International Atomic Energy Agency (IAEA) and national health organizations set standards for safe exposure levels, often guided by models like the LNT. Understanding radiation also involves public education about its natural occurrence in our environment and the risks and benefits associated with its use, particularly in medicine and industry. It is crucial to educate the public about everyday radiation exposure from natural sources and its contrast with higher, potentially harmful levels. This knowledge is essential for informed decision-making regarding radiation exposure, especially in regard to power generation, and for a balanced view of the role of radiation in modern society.

## Nuclear Waste Management

Nuclear energy generates spent fuel that remains highly radioactive for an extended duration. Several presentations to the commission delved into the current methods for managing this used nuclear fuel. According to the Nuclear Energy Institute, dry cask storage technology offers a secure means of containing used fuel assemblies. These assemblies are encased in robust steel and thick concrete containers. The Nuclear Regulatory Commission has officially endorsed the safety and security of dry cask designs for storage, spanning decades or even centuries, with minimal maintenance or monitoring requirements. Thirty-four states utilize dry cask facilities at nuclear plant sites. Furthermore, a dedicated Nuclear Waste Fund, holding over $40 billion, is earmarked to cover the complete costs of permanent underground disposal if Congress approves a consent-based national repository location.

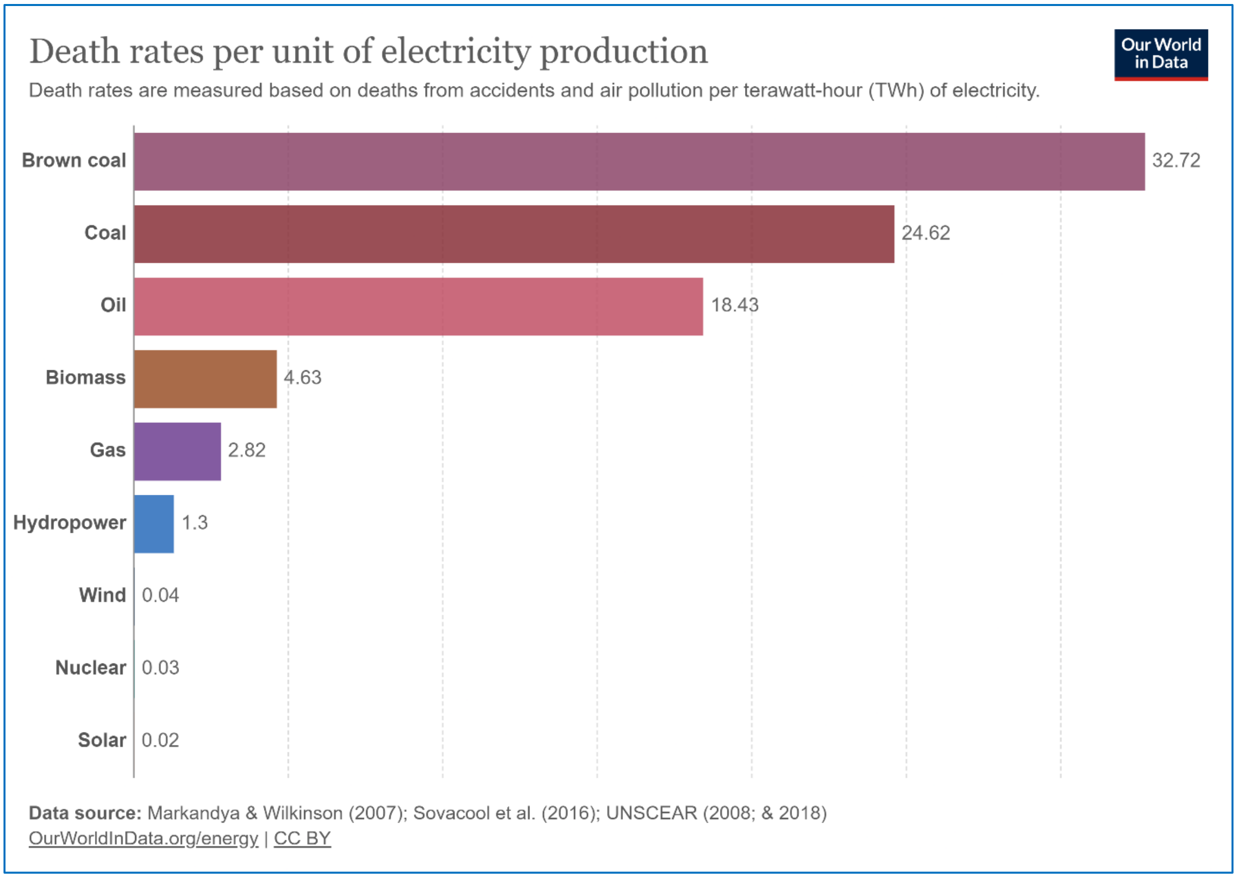
While used nuclear fuel remains radioactive and necessitates appropriate security measures, it's important to understand its characteristics and relatively modest accumulated volumes. After supplying 20% of the U.S. electricity demand for over four decades, the entire inventory of used fuel would occupy an area roughly equivalent to a football field, stacked to a height of just 12 feet. This compactness is attributable to the extraordinary energy density inherent in fission fuel assemblies. The U-235 isotope, for instance, possesses an energy density nearly one million times greater than other standard fuels like oil or coal. Since used fuel primarily consists of solid uranium oxide pellets housed within steel rods, storage doesn't require active ventilation or handling liquid or gaseous effluents. Additionally, advanced reactors under discussion are exploring on-site recycling methods to extract the remaining energy value from spent fuel through multiple reuse cycles and exploring alternative waste reduction technologies still in the research and development stages.

Lastly, some advanced designs presented to the commission incorporate dry cask facilities that can seamlessly integrate within project site boundaries for interim storage periods. This approach circumvents the need for unnecessary waste transportation until off-site repositories become available. Responsible on-site storage aligns with international best practices for used fuel management. Consequently, through strategies such as fuel recycling, diminishing future reactor waste production, and viable storage solutions, multiple avenues exist for the responsible long-term management and isolation of these hazardous materials.

## Risk Assessment of Various Energy Sources

In assessing the risks associated with different energy sources, it's crucial to consider both immediate and long-term impacts. The evaluation of health risks must take into account air pollution, accidents, and greenhouse gas emissions. Fossil fuels, responsible for most air pollution and greenhouse gas emissions, pose the most significant immediate health risks and long-term environmental impacts. Conversely, nuclear and renewable energy sources exhibit far lower health risks. Accidents in the nuclear sector, while significant, are less frequent and less impactful in terms of human casualties compared to the continuous harm caused by fossil fuels.

A quantitative approach to risk assessment involves analyzing the number of deaths per unit of electricity generated. This method reveals a stark contrast between the safety profiles of different energy sources. Nuclear, solar, and wind energy result in substantially fewer deaths than fossil fuels when evaluated on this basis. The persistent, widespread impacts of fossil fuels overshadow the infrequent but notable accidents in the nuclear and hydropower sectors. This data-driven assessment emphasizes that renewable and nuclear energy are cleaner and significantly safer in terms of direct human health impacts than fossil fuel-based energy.




# Federal Regulatory Considerations

The NRC presentation offered insight into the evolving regulatory landscape, with particular emphasis on creating more flexible and risk-informed licensing processes specifically tailored for advanced reactors, including the development of a technology-inclusive Part 53 rulemaking. A significant shift is happening in emergency preparedness rules, with a growing focus on performance-based requirements that can be scaled according to reactor size and risk profile. Physical security requirements are also being adapted to align with a consequence-based approach, recognizing the lower radiological inventories in many advanced designs compared to large traditional reactors. Efforts are being made to review advanced reactor license applications more efficiently, with several reviews already in progress. There's also a recognition of the need to develop a regulatory framework for fusion energy, something the NRC plans to work on. Moreover, discussions highlighted the possibility of the NRC learning from recent large reactor projects, aiming to apply those lessons to effectively regulate emerging technologies such as small modular reactors and non-light water designs. These regulatory changes reflect an accommodating approach towards innovations in the nuclear industry, focusing on adaptable and risk-aware policies that align with the unique characteristics of advanced reactor technologies.

# Federal Programs

## GAIN Program and R&D Voucher System

On August 7, 2023, Chris Lohse, representing the GAIN (Gateway for Accelerated Innovation in Nuclear) Program, presented a detailed overview to the commission. He introduced GAIN and its primary initiative, the GAIN voucher program, which is designed explicitly for advanced reactor developers and administered by the Department of Energy's Office of Nuclear Energy.

Lohse emphasized GAIN's role in providing technical information and support through workshops and webinars to states and decision-makers interested in advanced nuclear technologies. GAIN's objective is to offer information without providing advice.

Regarding the GAIN voucher system, Lohse clarified that these vouchers, unlike typical funding opportunities, do not directly fund companies. Instead, the funds are allocated to national laboratories to assist companies in experimental work, technical support, and licensing. He noted that detailed information about completed voucher projects is available on GAIN's website, offering insights into the practical applications of these projects.

Lohse also discussed GAIN's assessment of the advanced reactor supply chain, emphasizing the importance of robust supply chains for implementing and scaling advanced nuclear technologies. He highlighted the diverse applications of voucher funding, including experimental work, licensing, and design efforts, and stressed the role of national labs in these processes.

Additionally, Lohse mentioned GAIN's state-level outreach efforts, particularly in the context of the coal-to-nuclear transition. He indicated ongoing pilot studies and collaboration among organizations to optimize resource utilization and avoid duplication of efforts. He explained the process of selecting reactors for transitioning from coal stations to nuclear plants and providing technical information to utilities to aid their decision-making.

Lohse pointed out that GAIN vouchers, valued at up to **$500,000** with a 20% cost share, are available to U.S. companies, including energy suppliers, utilities, and end users within states. These vouchers play a crucial role in accessing national laboratories' experimental capabilities, technical expertise, and infrastructure. He also discussed the challenges associated with licensing microreactors, emphasizing the need for innovative approaches to regulatory frameworks for these new reactor types.

In summary, Chris Lohse's presentation on the GAIN program provided a comprehensive overview of the program's objectives, processes, and impact, particularly emphasizing the role of vouchers in advancing nuclear technology and facilitating the coal-to-nuclear transition.

## DOE Loan Programs Office

Julie Kozeracki, a Senior Advisor with the Department of Energy's Loan Programs Office (LPO), presented the latest projections regarding the levelized cost per megawatt hour metrics for nuclear power plants over the next several decades. Her detailed analysis covered cost estimate ranges in 2023 dollars, extending from the commissioning of advanced reactors to the attainment of mature and stable cost levels after replicating identical plants and advancements down the manufacturing learning curve.

Considering the current availability of 30% investment tax credits, which can reach 50% for nuclear, Ms. Kozeracki forecasted a cost reduction. The approximate cost range of **$66-$109 per megawatt hour** for plants coming online in 2023 is expected to decrease to **$58-$79 per megawatt hour by 2050**. This analysis was presented in the context of nuclear energy's competition with solar photovoltaics, battery storage, and natural gas-fired generation with carbon capture technologies, all of which are options for expanded reliable, low-carbon electricity capacity within an evolving grid mix. Advanced nuclear power should be cost-competitive with solar and natural gas when long-duration storage, carbon capture, and transmission build-out are factored in.

Furthermore, Ms. Kozeracki highlighted the Loan Programs Office's (LPO) significant role in supporting clean energy projects, particularly nuclear. The LPO's lending authority, now exceeding $300 billion, includes a substantial allocation of $250 billion for the Energy Infrastructure Reinvestment Program, which aims to support emissions reduction infrastructure projects. Conceived initially to focus on large-scale nuclear power advancement, the LPO is positioned as a critical financing entity for emissions-free, nuclear electricity generation and related supply chain development.

Ms. Kozeracki also presented findings from an in-depth LPO analysis of long-duration clean electricity storage alternatives, emphasizing nuclear power's role as a consistent and stable generation source alongside intermittent renewables. The analysis suggested a need for approximately **200 gigawatts of new nuclear generation** within the U.S. clean electricity mix transition.

While highlighting the advantages of nuclear power, Ms. Kozeracki acknowledged barriers hindering advanced reactor deployment. These challenges include the absence of current commercial demonstrations, which delays investment certainty, and the need to construct identical multi-unit nuclear plant replications to achieve economies of scale cost gains. She suggested utility consortium collaborations and cost overrun protections as potential solutions to incentivize initial orders. She highlighted the localized job growth and tax-base retention opportunities associated with new nuclear development.

In summary, Ms. Kozeracki presented a comprehensive overview of nuclear power's prospects and challenges within a carbon-constrained energy landscape. It also underscored the DOE Loan Programs Office's strengths in supporting private-public partnerships and project finance assistance, which will likely facilitate the commercialization of nuclear energy projects.

## DOE Office of Nuclear Energy Priorities

Dr. Billy Valderrama, from the U.S. Department of Energy’s Office of Nuclear Energy, presented to the commission an overview of the department's work and priorities in advancing nuclear technologies on August 7, 2023. His presentation covered various initiatives and projects within the Office of Nuclear Energy.

Dr. Valderrama acknowledged the work at the Department of Energy through the GAIN program within Idaho National Lab and support from the Loan Programs Office. He then discussed the general priorities and mission of the Office of Nuclear Energy and its efforts to advance nuclear technologies.

He addressed the recycling of LEU fuel for use at existing commercial plants, emphasizing economic aspects primarily related to High-Assay Low-Enriched Uranium (HALEU). Dr. Valderrama also mentioned collaboration between the Canadian regulator and the U.S. NRC in licensing GE Hitachi's BWRX 300 reactor, highlighting international cooperation in nuclear technology development.

A critical demonstration project he mentioned was the carbon-free power project of the NuScale power module at the Idaho National Laboratory site, managed by the Utah Associated Municipal Power Systems (UAMPS). This project is innovative in nuclear power generation and is expected to be operational by 2029. (NuScale and UAMPS have since mutually canceled the project in November 2023.)

Dr. Valderrama explained the department's work in ensuring developers have the necessary testing infrastructure, mainly through the DOME test bed at INL, which facilitates the testing and licensing of microreactors. He discussed the MARVEL project, a 100-kilowatt microreactor to be deployed at INL by the end of 2024. He emphasized its role in R&D and its ability to test load-following, integration into energy systems, and hydrogen production.

The presentation also covered the department's support for extending the life of commercial nuclear plants and the development of accident-tolerant fuels. Dr. Valderrama highlighted ongoing work commercializing these fuels and exploring new markets, particularly hydrogen production within the existing nuclear fleet.

Regarding hydrogen production demonstrations, Dr. Valderrama mentioned collaborations with other DOE offices, focusing on using nuclear energy for hydrogen production at plants like David-Bessie, Nine Mile Point, Prairie Island, and Palo Verde.

Dr. Valderrama underscored the Office of Nuclear Energy's four main priorities:

1. Maintaining the existing reactor fleet
2. Deploying new advanced reactors
3. Ensuring a secure nuclear fuel supply chain
4. Expanding international cooperation

He also mentioned the office's partnerships with various state and national organizations, forming collaborative efforts like the Advanced Nuclear State Collaborative. The ANSC is an initiative formed by the National Association of Regulatory Utility Commissioners (NARUC) and the National Association of State Energy Officials (NASEO) with support from the U.S. Department of Energy.

Finally, he touched on the process toward interim nuclear waste storage facilities, noting the planning and capacity-building stages and allocating funds to entities interested in exploring this option. Dr. Valderrama's presentation highlighted the Department of Energy's comprehensive approach to advancing nuclear energy, focusing on innovation, international cooperation, and developing new technologies and markets.

# Recent Federal Policy Initiatives

The following are some recent bipartisan federal legislation introduced to advance the nuclear power generation industry in the U.S. It remains to be seen whether all of these bills will be passed into law. Still, they do indicate that there is growing support for nuclear energy in the United States.

## Nuclear Energy Innovation and Modernization Act (NEIMA),

This legislation aims to enhance the transparency and efficiency of the Nuclear Regulatory Commission (NRC). Supported by a bipartisan group of Senators, NEIMA laid out provisions for the NRC to clarify its budgeting process, establish performance metrics for licensing and regulation, and develop a regulatory framework for advancing nuclear technologies. The legislation also included a pilot project for predictable fees for uranium producers. After receiving widespread backing from stakeholders and passing through the Senate and the House, President Trump signed NEIMA into law on January 14, 2019.

## Infrastructure Investment and Jobs Act of 2021

Passed by Congress and signed into law by President Biden on November 16, 2021, this legislation included substantial provisions to support nuclear energy within its $1.2 trillion package. Specifically, the legislation allocated $6 billion to prevent the premature retirement of existing zero-carbon nuclear plants, ensuring that those certified as safe can continue operations and prioritizing plants using domestically produced fuel. Furthermore, $2.5 billion is earmarked for developing advanced nuclear technologies through the Department of Energy's Advanced Reactor Demonstration Program (ARDP). The Act aligns with the U.S. goal of reaching net-zero by 2050 and represents a significant commitment to nuclear energy's role in reducing carbon emissions and fostering clean energy innovation.

## The Inflation Reduction Act of 2022

This legislation contained significant provisions to incentivize the construction and development of new nuclear power plants and related facilities. These incentives include a choice between a production tax credit (PTC) of $25 per megawatt-hour for the first ten years of a new plant's operation or a 30 percent investment tax credit (ITC) for new nuclear electricity facilities, with a 10-percentage point bonus for facilities in specific energy communities. The Act also expands the Department of Energy Title 17 Loan Guarantee Program, unlocking up to $40 billion for innovative, large-scale energy projects to reduce greenhouse gas emissions through September 2026. Additionally, $5 billion is provided for an energy infrastructure reinvestment financing program, $700 million for increased production of advanced nuclear reactor fuel, and $5.8 billion for advanced industrial facilities deployment. The Act also includes tax credits for hydrogen derived from nuclear power and expanded credits for domestic investments in energy manufacturing in communities affected by coal plant or mine closures.

## CHIPS and Science Act of 2022

This legislation enhanced support for nuclear research and physics programs, authorizing $390 million to establish up to four new research reactors and nuclear science and engineering facilities. In addition to increasing authorizations by $75 million for nuclear science education scholarships, fellowships, and research and development projects, the Act also aims to promote the transition from coal to nuclear energy. It establishes a new Department of Energy program that provides federal financial assistance to eligible entities. It authorizes $800 million to support the research, development, and demonstration of advanced nuclear reactors at retiring or retired coal generation sites, prioritizing projects that reduce emissions and benefit the surrounding population.

## International Nuclear Energy Act of 2023

This legislation would strengthen U.S. leadership in civil nuclear cooperation and exports by establishing new coordination mechanisms within the federal government, launching initiatives to provide alternatives to Chinese and Russian nuclear financing, easing restrictions on foreign investment in U.S. civil nuclear infrastructure, and promoting nuclear safety, security, and nonproliferation through Cabinet-level conferences and support for partner nations developing nuclear energy programs. It was introduced in the Senate in December 2022. The bill would establish an office within the Department of Energy to promote the export of U.S. nuclear technology. The Senate still needs to pass the International Nuclear Energy Act.

## Strategic Nuclear Infrastructure Act

This bill would establish a working group composed of senior-level officials across various federal agencies to provide input on the feasibility of creating a Strategic Infrastructure Fund. The fund would support projects related to civil nuclear technologies and microprocessors that are deemed strategically important. The working group would advise on the fund's design and administration and submit a report to Congress with recommendations, including suggested legislative language, within one year of the bill's enactment. The goal is to support capital-intensive nuclear and semiconductor infrastructure projects critical to national security.

## Recoup American Nuclear Global Leadership Act

This bill would strengthen U.S. civil nuclear cooperation and exports by establishing new coordination mechanisms within the federal government, providing financial assistance and support to partner nations developing nuclear energy programs, easing restrictions on foreign investment in U.S. civil nuclear infrastructure, and promoting nuclear safety, security, and nonproliferation. It aims to exert American nuclear leadership globally by launching initiatives to engage partner nations on nuclear development, establishing cooperative financing relationships, developing a 10-year nuclear export strategy, and supporting the fullest utilization of U.S. civil nuclear technologies worldwide. The goal is to provide competitive alternatives to Russian and Chinese nuclear exports and financing.

## Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy (ADVANCE) Act

A bipartisan group of senators introduced this bill in the Senate in March 2023. The bill aims to strengthen U.S. leadership in nuclear energy innovation and exports. It establishes new regulatory efficiencies, workforce policies, and technology development initiatives at the Nuclear Regulatory Commission and Department of Energy to promote advanced nuclear reactor deployment. Key provisions include streamlining licensing and regulation of advanced reactors, extending the Price-Anderson Act nuclear liability program, enabling siting at brownfield sites, providing technical assistance for international nuclear development, authorizing R&D funding, addressing nuclear waste management, and enhancing partnerships with Canada on Great Lakes issues. The overall goals are to drive innovation in nuclear technology, preserve existing nuclear generation, and expand nuclear energy globally to address climate change. Both nuclear industry advocates and environmental groups have praised the ADVANCE Act. This bipartisan bill passed the U.S. Senate as part of the NDAA on July 27, 2023.

# Organized Opposition

New Hampshire and the broader New England region have seen significant grassroots resistance to nuclear power over the past several decades. One of the most influential groups was the Clamshell Alliance, formed in 1976 to oppose the construction of the Seabrook Nuclear Power Plant located on the New Hampshire seacoast. The Clamshell Alliance organized large protests and civil disobedience actions, which led to the arrests of over 1,400 activists. They were ultimately unsuccessful in stopping Seabrook's construction, but their protests raised awareness about the risks of nuclear energy.

More recently, the C-10 Research and Education Foundation (C-10) is a nonprofit organization focused on ensuring public health and environmental safety around NextEra's Seabrook Station nuclear power plant in coastal New Hampshire and Massachusetts. C-10 operates a real-time radiological monitoring network and actively speaks out on safety and security concerns at the plant. C-10's funding comes from various sources, including the Commonwealth of Massachusetts, grants, and private community donations. Since 1992, the Massachusetts Department of Public Health has contracted C-10 to provide real-time radiation monitoring, funded partly by taxes paid by nuclear power plants like Seabrook Station.

Beyond Nuclear is a national non-profit organization based in Takoma Park, Maryland, that aims to educate the public about the risks of nuclear power, weapons, and waste. It advocates for an energy future free of nuclear risks, focusing on concerns like accidents, security threats, and waste management. The organization prefers renewable energy sources like wind and solar and works through press outreach, reports, and webinars to prevent new nuclear plants and promote renewable energy. Beyond Nuclear focuses mainly on policy and advocacy.

# Need for Public Engagement

Some presentations the commission heard underscored the importance of conducting effective public outreach and education to foster greater awareness and acceptance of advanced nuclear power. This endeavor entails providing realistic information to improve the general understanding of nuclear technology and dispel outdated perceptions of its risks. Several speakers emphasized the need for policymakers to take on the responsibility of imparting science-based knowledge, especially concerning the health effects of radiation. Comprehensive workforce development programs spanning from K-12 education to vocational training are necessary to meet the demand for skilled talent. They can play a vital role in cultivating a capable workforce equipped for the high-demand jobs in the nuclear industry.

Additionally, establishing certification courses to facilitate the transition of workers from the oil, gas, and coal industries into nuclear roles can effectively leverage transferable skills and create new opportunities. Successful public outreach would highlight the local community benefits associated with siting advanced reactors. For the state to achieve this goal, dedicated education campaigns and resources will be necessary to engage the public, demystify nuclear science, clear misconceptions, and foster the growth of specialized workforces. The commission perceives this investment in educational initiatives as a sensible approach to empowering informed citizens and facilitating the expansion of nuclear energy.

# Input from ISO New England

Eric Johnson's presentation on October 2, 2023, delved into the ongoing energy transition in New England and its impact on the power grid. The region is shifting from coal and oil to primarily using natural gas. This transition is part of the broader energy transformation in New England. Johnson stressed the necessity of integrating substantial clean energy into the system due to the anticipated doubling of summer and tripling of winter grid demand by 2040-2050, assuming the achievement of electrification goals in sectors like transportation and building heating.

Johnson also addressed the challenges of incorporating weather-dependent renewable resources like wind and solar into the energy mix. The region must have adequate backup resources to ensure a reliable power supply because of the variability of renewable energy sources. Additionally, Johnson emphasized the importance of expanding the transmission infrastructure to move power effectively across New England, considering that the location of renewable resources may not always align with customer concentrations.

As part of its responsibility for regional transmission planning, ISO New England administers an interconnection process for new generators seeking to connect to the power grid. Mr. Johnson provided an overview of this queue process, which involves submitting detailed project plans and undergoing feasibility, system impact, and facilities studies to evaluate grid reliability impacts. He noted that over 38,000 megawatts of predominantly renewable projects are working through interconnection requests as changing economics and state clean energy policies incentivize wind, solar, and storage development. Johnson emphasized merchant generators today must cover the costs of any transmission upgrades required to interconnect, with no regional cost sharing. However, discussions are occurring industry-wide around socializing upgrade expenses more broadly to facilitate grid enhancements that will be crucial to managing the influx of weather-dependent generation seeking to connect to the system. Johnson also touched on the separate process for interregional transmission tie-lines that may be proposed to import power from neighboring areas like Quebec and Maine.

Regarding the future of nuclear energy in New England, Johnson indicated that the current assumption is that no new nuclear plants will be constructed in the region over the next 40 years. However, he acknowledged the potential for this assumption to change if a compelling case for nuclear power development arises. This highlighted the dynamic nature of energy planning. Johnson also noted that natural gas currently constitutes a significant portion of New England's annual energy supply, with hydro and imports remaining relatively stable. He projected that renewables will play a much more significant role in the energy mix by 2040 to meet increasing demand and clean energy objectives.

# Input From NH's Consumer Advocate

Donald Kreis, New Hampshire's Consumer Advocate, provided his perspective on potential new nuclear power in the state during our May 12, 2023, meeting. Having previously analyzed legal issues around the forced closure of the Vermont Yankee plant, Mr. Kreis noted he is not reflexively anti-nuclear. However, he discussed the nuclear industry's need for financial help and regulatory easing. These needs pose challenges for technology-neutral states in supporting nuclear power, though adding it to renewable standards could be an option. As ratepayer advocate, Mr. Kreis focused on who pays for energy policies, given new nuclear plants in deregulated New Hampshire would likely be merchant plants. He expressed great interest in the commission's work examining nuclear power's future role but emphasized leaning into questions around ratepayer impacts. He highlighted the competition with China and Russia in nuclear technology and the importance of supporting the domestic nuclear industry to keep pace with these nations. Overall, while intrigued by the conversations, Mr. Kreis stressed that as Consumer Advocate, a key consideration is who bears the cost of any potential new nuclear generation.

# Summary of Key Findings

1. **Crucial Role of Advanced Nuclear in Carbon Reduction:** Advanced nuclear technology is essential if the goal of zero net carbon emissions is to be pursued. Limiting its use could significantly escalate the cost of carbon reduction efforts, possibly making net zero goals infeasible with current technologies.

2. **Nuclear Energy's Reliability and Efficiency:** The inherent reliability and efficiency of nuclear power, particularly in terms of grid stability and frequency response, are key strengths.

3. **Progress in Nuclear Fuel Recycling:** The development and implementation of spent nuclear fuel recycling methods could be important steps forward in nuclear waste management, provided the methods are economically viable and avoid proliferation risks.

4. **Innovation in Nuclear Business Models:** The emergence of innovative business models for advanced nuclear technologies is a notable trend, such as the power-as-a-service model.

5. **Modernizing Nuclear Licensing Processes:** Efforts are underway to update and streamline the nuclear reactor licensing process, focusing on achieving a balance between flexibility, safety, and predictability.

6. **Learnings from Advanced Nuclear Projects:** Key lessons include the importance of complete design development before construction, collaboration with experienced contractors, and ensuring a robust supply chain.

7. **Advanced Reactors Combining Novel Technologies:** Innovative reactor designs are being developed that combine high-temperature operations, thermal energy storage, with enhanced fuel stability and safety.

8. **Goal for Cost Competitiveness with Fossil Fuels:** There is an industry-wide goal to make advanced nuclear reactors cost-competitive with fossil fuel power plants, without relying on subsidies. Cost reduction will be achieved through the accumulation of experience, streamlined processes, and economies of scale during the manufacturing and deployment of successive reactors of the same design.

9. **Target for Commercial Deployment by 2030:** Many in the industry aim to achieve commercial deployment of advanced reactor technologies by 2030 or earlier.

10. **Increasing Demand for Computation and Carbon-Free Energy for Large Data Centers:** The demand for computation, particularly for large and growing computing projects like AI modeling and Bitcoin mining, is rising. This increase in computational demand is concurrently driving the need for carbon-free, always-on energy sources, with developers considering advanced nuclear reactors to provide this essential energy to data centers.

11. **Strategic Approaches to Reactor Development:** A strategic development approach, prioritizing rapid learning and innovation, is being adopted across the industry.

12. **Interest in Commercializing Advanced Nuclear:** There is a broad interest in the commercialization of advanced nuclear technologies, signaling a potential transformation in the energy sector.

13. **Preferential Development in Regulated Markets Over Deregulated Ones:** First-of-a-kind nuclear reactors are more likely to be constructed in vertically integrated, regulated markets due to mechanisms that spread out construction costs over time to ratepayers and mitigate risk for developers. In deregulated markets, by contrast, the significant financial challenges and risks would be borne primarily by industry, directly affecting industry profits. This dynamic makes early FOAK reactor deployments less likely in deregulated markets like New Hampshire’s.

# Potential State Policy Options

The commission's discussions highlighted several potential new state-level policies for developing and integrating advanced nuclear energy generation. However, some policy considerations that were considered are a better fit for states that favor broad subsidies or have vertically integrated market structures.

1. **Enact Legislation for 'Clean' Nuclear Energy:** Designate nuclear energy as a "clean" technology under renewable portfolio standards and other state clean energy programs, aligning with New Hampshire Department of Energy's 2021 State Energy Strategy on page 56.
2. **Feasibility Studies for Advanced Reactor Sites:** Conduct studies to identify suitable sites for advanced reactors, focusing on potential applications and end-users like industrial facilities or retiring coal and biomass plants.
3. **Workforce Development and Public Awareness:** Implement workforce training programs and public awareness campaigns to foster talent pipelines and increase public understanding of nuclear technology.
4. **Streamline Licensing and Permitting Processes:** Simplify and expedite advanced reactors' licensing and permitting processes, reducing regulatory delays.
5. **Invest in Nuclear Supply Chain Capabilities:** Encourage public and private investments in the nuclear supply chain, including component manufacturing.
6. **Appoint a State Nuclear Development Coordinator:** Revive the "Coordinator of Atomic Development Activities" position from a 1955 state statute (RSA 162-B) to advise and manage pro-nuclear policies and initiatives, guiding the Legislature, Executive Council, and Governor.
7. **Financial Incentives for Nuclear Projects:** Identify potential federal financial support through grants, loans, and tax credits to facilitate advanced reactor demonstrations and deployments while being mindful of potential political resistance in New Hampshire.
8. **Legislation to Update Atomic Energy Statutes:** Draft and propose legislation to update the state's atomic energy statutes, incorporating the federal definition of advanced nuclear.
9. **Consult state policy suggestions by Nuclear Energy Institute:** The NEI compiles reports on potential state policy options for states to support new nuclear energy.
10. **Reevaluate New Hampshire's participation in the NRC Agreement State Program:** The NRC assists states in establishing programs to assume regulatory authority under the Atomic Energy Act of 1954, allowing states to license and regulate various materials. This assistance includes reviewing requests for agreements, conducting training and evaluation, and coordinating event reporting with Agreement States. Currently, 39 states have such agreements, including New Hampshire.
11. **Engagement with the Advanced Nuclear State Collaborative:** Policymakers can optimize their engagement with the Advanced Nuclear State Collaborative (ANSC) by actively participating in its events and utilizing its array of resources from organizations like NARUC, NASEO, and the U.S. Department of Energy. This approach includes proactive policy formulation, interstate collaboration on nuclear initiatives, and educational outreach to inform and align stakeholders on advanced nuclear generation objectives.
12. **Encourage Nuclear Energy Stakeholders to Engage with GAIN:** Stakeholders in the nuclear energy sector can be encouraged to engage with the Gateway for Accelerated Innovation in Nuclear (GAIN) program. The program's extensive resources, expertise, and networking opportunities can be instrumental in accelerating the development and commercialization of innovative nuclear technologies.
13. **Urge ISO New England to seek advanced nuclear proposals:** While ISO New England remains neutral on energy generation it does take direction from member state policy cues.
14. **Urge the NRC to review and approve licenses:** The state legislature can pass resolutions urging the Nuclear Regulatory Commission to not delay license approvals for advanced nuclear projects.
15. **Declare nuclear energy in the state/national interest:** The state legislature can pass resolutions declaring nuclear energy to be in the state and national interest.

16. **Consider Utility Ownership**: Electric distribution utilities are currently permitted to invest in distributed energy resources 5 megawatts in size and smaller and to recover their prudent costs through their distribution rates with the approval of the Public Utilities Commission, with certain limitations. The legislature could consider providing distribution utilities with a circumscribed authority to invest in advanced small-scale nuclear generation up to a limited number of megawatts, recover their prudent costs through their distribution rates, and encourage the development of new nuclear facilities within the state.

The conversations had by the commission focused on state-level policies that correctly classify nuclear as clean energy, integrate it into renewable energy programs, investigate federal financial incentives, and form a supportive regulatory framework for advanced reactor deployment.

# Conclusion

In conclusion, New Hampshire may stand at a critical juncture in its energy policy, having the potential to become a net exporter of electricity to the rest of New England through strategic decision-making. The foundation of this transformation may lie in adopting advanced nuclear energy technologies that promise to bring reliable and cost-competitive electricity generation to commercial realization within the next decade.

The analysis conducted by the study commission reveals significant progress in nuclear energy, particularly in developing advanced reactor technologies. These new designs offer enhanced efficiency and safety, making nuclear power more viable and attractive for large-scale energy production. By focusing on these innovative technologies, New Hampshire can establish itself as a leader in the advanced nuclear sector, positioning itself as a major electricity supplier in the regional market.

Central to this vision is the emphasis on cost competitiveness. Advanced nuclear reactors promise to improve operational efficiencies and reduce lifecycle costs, which could be a potential opportunity for New Hampshire to produce electricity at a lower cost than traditional fossil fuel-based sources. If this economic advantage is realized, it could help alleviate the high energy costs that burden our citizens and job creators.

Moreover, focusing on advanced nuclear energy would align with broader energy reliability goals. Nuclear power plants can provide consistent and uninterrupted electricity, a critical factor in ensuring a stable and dependable energy supply for New Hampshire and the broader New England region, especially during the harsh winters we experience here.

While the aspect of climate change is a significant consideration in the shift towards nuclear energy, the focus of this conclusion is predominantly on the economic and reliability benefits of this energy source. New Hampshire's adoption of advanced nuclear technologies would be a step towards a more sustainable energy future and a strategic economic move that can reshape the state's role in the regional energy landscape.

With informed policy decisions, public and private focus, and investment in advanced nuclear technology, New Hampshire could transform its energy sector into a leading provider of reliable and cost-efficient electricity, becoming a net energy exporter within New England. This move could benefit the state economically and contribute to a more stable and diversified energy network in the region.

# Appendix A

## Commission Charge and Study Purpose

**RSA 125-O:30 Commission to Investigate the Implementation of Next Generation Nuclear Reactor Technology in New Hampshire.**

III. The commission shall investigate:

(a) Advances in nuclear power technology, including "generation IV" reactors, by conducting research and seeking counsel and testimony from experts in the field;

(b) The most promising generation IV designs as determined by the Gen IV International Forum:

(1) Gas-cooled Fast Reactor (GFR);

(2) Lead-cooled Fast Reactor (LFR);

(3) Molten Salt Reactor (MSR);

(4) Supercritical Water-cooled Reactor (SCWR);

(5) Sodium-cooled Fast Reactor (SFR); and

(6) Very High-temperature Reactor (VHTR);

(c) Large-scale, small-scale, microreactor, modular and breeder reactor designs;

(d) The safety of modern designs, including "passive safety systems";

(e) Various types of fuel consumption, including the ability for new designs to safely consume nuclear waste, such as the waste in long-term storage facilities;

(f) Nonelectric applications including:

(1) Hydrogen or other liquid and gaseous fuel or chemical production;

(2) Water desalination and wastewater treatment;

(3) Heat for industrial processes;

(4) District heating;

(5) Energy storage; and

(6) Industrial or medical isotope production;

(g) Potential siting options;

(h) Partnerships with industry participants or investors;

(i) Partnerships with federal agencies, such as the U.S. Nuclear Regulatory Commission;

(j) Federal incentives for nuclear power generation; and

(k) Shall identify potential obstacles with federal nuclear regulation.

# Appendix B

## External Links

An electronic version of this document is hosted on the official state website and an unofficial information portal. The electronic version is useful for accessing hyperlinks embedded in the document.

- State website: https://gencourt.state.nh.us/statstudcomm/details.aspx?id=1600
- Unofficial information portal: https://nuclearnh.energy/about/#reports

# Appendix C

## Glossary

1. **Advanced Reactor Demonstration Program (ARDP):** The Advanced Reactor Demonstration Program (ARDP) is a U.S. Department of Energy initiative that supports the demonstration and development of advanced nuclear reactor technologies. It aims to accelerate the deployment of innovative and next-generation nuclear reactors that are safer, more efficient, and more sustainable.

2. **Baseload Power:** The minimum level of demand on an electrical grid over a span of time. Baseload power plants can produce consistent electricity to meet this basic demand.

3. **Black Start Capability:** Black start capability refers to the ability of a power generation facility, typically a power plant or a grid, to initiate or restart operations without relying on an external power source. This is crucial during emergency situations, such as widespread power outages, to restore the electrical grid from a completely "black" or unpowered state.

4. **Boiling Water Reactor (BWR):** A type of Light Water Reactor (LWR) where water acts as both the coolant and the method for heat transfer, boiling within the reactor to produce steam, which drives a turbine.

5. **Breeder Reactor:** A nuclear reactor that generates more fissile material than it consumes, typically using a fast neutron spectrum and a closed fuel cycle.

6. **Canada Deuterium Uranium (CANDU):** The Canada Deuterium Uranium (CANDU) reactor is a type of pressurized heavy water reactor (PHWR) developed in Canada. It is known for its flexibility in using natural uranium fuel and heavy water as a coolant and moderator. CANDU reactors are used for electricity generation in several countries.

7. **Chain Reaction:** A self-sustaining series of nuclear fissions in a mass of fissile material, releasing energy and additional neutrons.

8. **Control Rods:** Devices inserted into a nuclear reactor's core to control the fission rate by absorbing excess neutrons.

9. **Coolant:** A fluid circulating through a nuclear reactor to remove heat from the reactor core and transfer it to the steam generators or directly to turbines. It can be water, gas, or liquid metal.

10. **Decarbonization:** The process of reducing carbon dioxide emissions, often in the context of energy generation.

11. **Decommissioning:** The process of safely closing and dismantling a nuclear power plant or other nuclear facility after it has reached the end of its useful life.

12. **Department of Energy (DOE):** The U.S. Department of Energy (DOE) is a federal government agency responsible for the oversight and management of energy-related policies, research, and programs in the United States. Its mission includes advancing scientific and technological innovation in various energy sectors, ensuring national security, and addressing environmental challenges related to energy production and use.

13. **Dose (Radiation Dose):** A measurement of radiation exposure, typically measured in units of sieverts or rems.

14. **Dry Cask Storage:** A method of storing spent nuclear fuel in large, airtight steel and concrete containers outside a reactor building.

15. **Economic Simplified Boiling Water Reactor (ESBWR):** The Economic Simplified Boiling Water Reactor (ESBWR) is a type of nuclear reactor design. It is characterized by its simplified and efficient design, aimed at reducing construction and operating costs while maintaining safety standards. The ESBWR utilizes the boiling water reactor technology to generate electricity by using nuclear fission.

16. **Enrichment (Nuclear):** The process of increasing the proportion of the isotope U-235 in uranium used as fuel in nuclear reactors.

17. **Fast Neutron Reactor:** A reactor in which the nuclear fission chain reaction is sustained by fast neutrons, allowing it to use fuel more efficiently and reduce nuclear waste.

18. **Fission Reactor:** A device that generates energy by splitting atomic nuclei into smaller parts, releasing significant energy. Fission reactors maintain controlled chain reactions of uranium or plutonium to produce heat. This heat generates steam, powering turbines to produce electricity, making them central in nuclear power plants.

19. **Fluoride-salt Cooled High Temperature Reactor (FHR):** The Fluoride-salt Cooled High Temperature Reactor (FHR) is a type of advanced nuclear reactor design. It employs a high-temperature fluoride salt coolant as a key component in its cooling system. FHRs are known for their potential to operate at high temperatures, which can enhance energy efficiency and safety in nuclear power generation.

20. **Fuel Cycle:** The series of processes involved in supplying fuel to a nuclear reactor and managing it after use, including mining, enrichment, fabrication, irradiation, and waste management.

21. **Fusion Reactor:** A nuclear reactor in which energy is produced by fusing atomic nuclei, mimicking the processes of the sun.

22. **Gamma Radiation:** High-energy electromagnetic radiation emitted by radioactive decay, typically more penetrating than alpha or beta radiation.

23. **Gateway for Accelerated Innovation in Nuclear program (GAIN):** The Gateway for Accelerated Innovation in Nuclear program (GAIN) is a U.S. Department of Energy initiative aimed at promoting and accelerating the development and deployment of advanced nuclear technologies. GAIN provides access to expertise, facilities, and resources to support research and innovation in the nuclear energy sector.

24. **Generation III+ Reactors:** A set of nuclear reactor designs derived from Generation III designs, offering significant enhancements in safety and efficiency. These reactors feature improved systems for severe accident management, including better core cooling and containment of radioactive materials, reduced core meltdown risk, and increased automation in safety systems.

25. **Generation IV Reactors:** A set of nuclear reactor designs currently under development expected to improve safety, efficiency, and waste management over current reactor models.

26. **Grid Reliability:** The ability of the power grid to provide continuous power supply, even when there are disruptions or unusual demand patterns.

27. **Heat Pipe Technology:** A passive heat transfer method where heat is efficiently transferred using the principles of thermal conductivity and phase transition.

28. **Heavy Water Reactor:** A type of reactor that uses heavy water (deuterium oxide, D2O) as a neutron moderator and coolant.

29. **High-Assay Low-Enriched Uranium (HALEU):** A type of nuclear fuel that is enriched to a higher degree than conventional low-enriched uranium greater than 5% but below 20% concentration of U-235.

30. **High-Temperature Gas-cooled Reactor (HTGR):** A type of nuclear reactor where the coolant is a gas (usually helium) and operates at very high temperatures. It is efficient and can be used for electricity and heat production.

31. **Ionizing Radiation:** Radiation that carries enough energy to liberate electrons from atoms or molecules, thereby ionizing them. Examples include alpha, beta, gamma, and neutron radiation.

32. **Isotope:** A variant of a chemical element with a different number of neutrons in the nucleus, resulting in different atomic masses but the same chemical properties.

33. **Light Water Reactor (LWR):** A type of nuclear reactor where ordinary water (H2O) is used as both the coolant and neutron moderator.

34. **Linear No-Threshold (LNT):** The Linear No-Threshold (LNT) model is a hypothesis used in radiation protection. It suggests that even low levels of ionizing radiation exposure pose a risk of causing cancer, and this risk increases linearly with the dose, without a safe threshold. The LNT model is used as a basis for setting radiation exposure limits and safety standards.

35. **Load Following:** The ability of a power plant, particularly a nuclear reactor, to adjust its output to match the varying demand of the power grid.

36. **Low-enriched Uranium (LEU):** Uranium that has been enriched to contain 3% to 5% U-235, commonly used as fuel in commercial nuclear power plants.
37. **Microreactor:** A type of very small, compact nuclear reactor with a power output typically less than 10 MWe, designed for remote applications and smaller electrical grids.
38. **Molten Salt Reactor (MSR):** A type of nuclear reactor where the fuel is dissolved in a molten salt mixture. They operate at high temperatures and lower pressures and are capable of reducing nuclear waste.
39. **Nuclear Fusion:** A process in which two light atomic nuclei combine to form a heavier nucleus, releasing a significant amount of energy. It is the opposite of nuclear fission and is the process powering the sun and other stars.
40. **Nuclear Proliferation:** The spread of nuclear weapons and weapon technology is often a concern related to the use of nuclear technology and materials.
41. **Nuclear Regulatory Commission (NRC):** The federal agency responsible for regulating commercial nuclear power plants and other uses of nuclear materials in the United States.
42. **Passive Safety Systems:** Safety features in a nuclear reactor that require no operator action to function and are not dependent on external power sources or moving parts.
43. **Pebble Bed Reactor:** A type of reactor design that uses spherical fuel elements called "pebbles." These contain TRISO particles and are cooled by a gas, usually helium.
44. **Physical Vapor Deposition (PVD):** Physical Vapor Deposition (PVD) is a materials processing technique used to deposit thin films of various materials onto solid surfaces. It involves the physical vaporization of a source material, followed by its condensation onto a substrate. PVD is commonly used in manufacturing and electronics industries for coatings and surface modification.
45. **Pressurized Water Reactor (PWR):** A type of LWR where water is kept under pressure to prevent it from boiling. The heat generated is transferred to a secondary water system where steam is produced to drive a turbine.
46. **Radioactive Waste:** Waste that contains radioactive material. It is usually a byproduct of nuclear power generation and other applications of nuclear fission or nuclear technology.
47. **Reactor Core:** The central portion of a nuclear reactor containing the nuclear fuel, control rods, and other materials where the fission reaction takes place.
48. **Regional Transmission Organization (RTO):** A Regional Transmission Organization (RTO) is a regulatory entity responsible for overseeing the operation and management of high-voltage electric transmission grids in specific regions of the United States. RTOs facilitate the efficient and reliable transmission of electricity, ensuring fair access to the grid for various electricity generators and consumers.
49. **Reprocessing:** The chemical process of extracting usable fissile material from spent nuclear fuel, allowing for the recycling of nuclear materials.

50. **Safety Margin:** The degree to which the operational limits of a nuclear reactor are below its maximum limits for safety.
51. **Small Modular Reactor (SMR):** A smaller, more compact nuclear reactor design that can be manufactured at a plant and transported to a site to be assembled. They offer flexibility and lower initial capital costs.
52. **Sol-Gel:** The sol-gel process is a wet-chemical technique used for the fabrication of both glassy and ceramic materials. It involves the transformation of a liquid solution (sol) into a gel-like substance, followed by controlled drying and heat treatment to create solid materials with tailored properties, such as optical, electrical, or mechanical characteristics. Sol-gel processing is widely utilized in the production of coatings, sensors, and advanced materials.
53. **Spent Fuel:** Used nuclear reactor fuel that is no longer efficient in sustaining a nuclear reaction due to the depletion of fissile material.
54. **Steam Generator:** A device that uses heat from a nuclear reactor core to convert water into steam, which drives the turbines in a nuclear power plant.
55. **Thermal Efficiency:** The efficiency of a power plant in converting the energy in the nuclear fuel to electrical power. It's a measure of how well a power plant converts heat from nuclear reactions into electrical energy.
56. **Thermal Neutrons:** Slow-moving neutrons that are in thermal equilibrium with their surroundings, effective for sustaining nuclear chain reactions in reactors using certain fuel types.
57. **TRISO Fuel:** A shortened form of TRi-structural ISOtropic fuel. A type of nuclear fuel that consists of uranium particles coated in carbon and ceramic layers. It is highly resistant to damage from heat and radiation.
58. **Utah Associated Municipal Power Systems (UAMPS):** UAMPS is a collaborative organization representing municipal electric utilities in Utah and the western U.S. It works to develop and manage various energy projects, including nuclear and renewable energy, to meet member communities' power needs efficiently.
59. **Watt:** The basic unit of measure for electric power. One kilowatt (KW) is equal to 1,000 watts and is commonly used to express the power consumption of tools and machines. For example, a 600-watt microwave. One megawatt (MW) is equal to 1,000,000 watts and is commonly used to measure the output of a power plant or the amount of electricity required by an entire city. For example, a 600 MW coal plant. One gigawatt (GW) is 1,000,000,000 watts. The unit is often used in context of large power plants and entire power grids. For example, the Seabrook Nuclear Power Plant produces 1,250 MW or 1.25 GW.

# Appendix D

## Meetings

### October 11, 2022, Meeting

#### *Overview*

The Commission to Investigate Implementation of Next Generation Nuclear Reactor Technology in New Hampshire held its first meeting on October 11, 2022. The commission elected officers, discussed tapping into resources to learn about new nuclear technologies, and determined to direct its focus on newer, safer reactor designs. There was some skepticism expressed about nuclear feasibility in the US, but overall the commission aims to take an open-minded, consensus-building approach to evaluating whether advanced nuclear could benefit New Hampshire.

Meeting event page: https://nuclearnh.energy/event/organizational-meeting/

#### *Minutes*

**Attendance:**

Commission Members: Representative Michael Harrington, David Shulock, Bart Fromuth, Marc Brown, Representative Keith Ammon, Cathy Beahm, Dan Goldner, Christopher McLarnon. Absent: Senator Bill Gannon, Alex Fries, Matthew Levander

Public: Representative Doug Thomas, Michele Roberge, Douglas Mailly, Jodi Grimblas, Bruce Berke, Vikram Mansharamani, Alvin See

**Meeting:**

1. Representative Harrington opened the meeting and followed with introductions from each Commission member; then members of the public introduced themselves.
2. The Commission members then voted on officers and unanimously voted for:
3. Chair — Representative Keith Ammon
4. Vice Chair – Representative Michael Harrington
5. Clerk –Marc Brown
6. A sign-up sheet was passed around for Commission members and guests.
7. Representative Ammon referenced the need to tap into resources; Representative Harrington brought a copy of Nuclear News Magazine and Marc Brown mentioned that the Nuclear Energy Institute and Georgia Power are members of Consumer Energy Alliance and could be helpful.
8. Representative Ammon emphasized that the focus be on next generation technologies; Virginia Governor Glenn Younkin committed Virginia to be the centerpiece of SMR manufacturing. Hopes that this will be a consensus building process.
9. Christopher McLarnon voiced skepticism on feasibility of nuclear power in the US because we don't build nukes here; China builds them cheaply and poorly
10. Bart Fromuth asked if we are getting any components from China
11. Representative Harrington responded that the US is not getting parts from China; referenced Sumner's failures in South Carolina; brought up the success that South Koreans have had constructing reactors. Stated that SMRs are generally 50-80 MW, can be shipped via rail.

Commented that no nuclear generation plant has ever been built by investors assuming risk—always been rate based. NuScale has a design approved by the Nuclear Regulatory Commission.

12. Representative Thomas stated that he is personally bullish on nuclear technology; he is a de facto member of the NCSL energy supply task force; there are no less than 80 nuclear technologies out there—which ones survive? Mentioned that abandoned coal plants are good locations for SMRs. Asked Commission to focus on PR re: "new, safe nuclear technology."
13. Representative Harrington thought Rep. Thomas' comments regarding PR were well-stated and mentioned Germany's overreaction to Fukushima.
14. Representative Ammon hopes that this Commission will utilize as many relationships as possible.
15. Commission scheduled the next meeting for Monday, November 21st at 8:30 AM
16. Meeting adjourned ~ 11:00 AM

    Minutes submitted by Marc Brown.

## November 21, 2022, Meeting

### *Overview*

On November 21, 2022, representatives from the Nuclear Energy Institute (Marc Nichol) and NuScale Power (Christopher Colbert). Mr. Nichol discussed the status of advanced nuclear technology and considerations for state utilization, including benefits for decarbonization and grid reliability. Mr. Colbert provided an overview of NuScale's small modular reactor technology, its projected costs and timeline, and potential applications. There was discussion of whether to define "clean energy" in legislation to potentially include nuclear. There was also discussion of whether nuclear facilities require initial public funding support and the potential they have to provide carbon-free baseload energy.

Meeting event page: https://nuclearnh.energy/event/regular-meeting-nov-21-2022/

### *Minutes*

**Attendance:**

Commission Members: Representative Keith Ammon, Representative Michael Harrington, Bart Fromuth, Cathy Beahm, Dan Goldner, Matthew Lavender, David Shulock, Christopher McLarnon (remote). Absent: Senator Bill Gannon, Alex Fries, Marc Brown

Public: Representative Doug Thomas, Bruce Berke, Vikram Mansharamani, Douglas Mailly, Alvin See, Joe Fontaine, Michele Roberge, Griffin Roberge

**Meeting:**

1. A quorum was established, and Rep. Ammon opened the meeting at 8:33 a.m.
2. Rep. Ammon appointed David Shulock as substitute clerk.
3. The commission unanimously approved the draft minutes of the commission's October 11, 2022, meeting.
4. Rep. Harrington stated he has worked with the Nuclear Energy Institute and that it is a good resource. He also recommended the American Nuclear Society as a resource. Rep. Harrington discussed the need for nuclear generation if the region goes forward with a climate agenda, stating that approximately 3000 new MW of carbon-free generation will be required in addition to any renewable generation. Rep. Harrington stated that advanced nuclear will be more load-following than existing nuclear generation.
5. Rep. Thomas agreed with Rep. Harrington and stated that he is a member of the bipartisan Energy Supply Task Force of the National Congress of State Legislators.
6. Marc Nichol, Senior Director of New Reactors at the Nuclear Energy Institute gave a presentation of the status of nuclear technology, commercial deployments, major topics related to advanced reactors, and issues relating to interfacing with the federal government. Some key points were that it would be $449 Billion more expensive to reach 0 net carbon emissions if nuclear technology were be constrained going forward; advanced nuclear would provide black start capability to the grid; advanced nuclear builds in inherent safety features that in many cases would limit the planned emergency response to the property boundary; that waste handling technology is mature, but requires 8-10 years of licensing work prior to construction; advanced nuclear can be located on the sites of existing coal plants to take advantage of infrastructure and trained staff; and that there is strong federal support for advanced nuclear deployment. Mr. Nichol also stated that consideration had been given to lessening delay and cost overrun by integrating energy (steam) generation into the reactor design, simplifying the design, conducting more work in the factory and less in the field, and allowing for parallel factory and field construction timelines. He

stated that currently overruns are due to increases in labor and material costs over time. He stated that "one-stop" construction and operating permitting at the federal level reduces protest and litigation. He believes that state can support advanced reactor deployment by conducting feasibility studies, providing tax incentives, providing for advanced cost recovery, and working on workforce development and infrastructure. Last, there is currently a lack of fuel with the required 5-20% enrichment that will continue until sufficient demand for that level of enrichment is established.

7. Christopher Colbert, Chief Financial Officer of NuScale Power gave a presentation of his company's technology. NuScale Power has engineered the first small modular reactor to undergo licensing at the Nuclear Regulatory Commission at a cost of $500 million. The company has a goal of placing the first modular reactor online by 2029. NuScale's modular reactor would produce 77 MW of electricity. The design would allow up to 12 modules to be combined at one facility and to operate independently or in sync. NuScale's reactor has black start capability, and inherent safety features that do not require external power or support in an emergency, resulting in an impact area of approximately 300 meters. Mr. Colbert stated that the factory design takes years off of filed construction; essentially, one could build a shell structure and easily then integrate the reactor. Mr. Colbert sees the design as useful in supporting renewables, replacing coal, and creating hydrogen during a period of energy transition. NuScale has a customer that plans to bring one of its reactors online in 2029. Original forecasts for the cost of that facility were at $58 per MWh. Inflation and the rise in interest rates has driven that cost up. Mr. Colbert stated that despite the rise in cost, the reactor is still the best alternative.
8. Rep. Ammon stated that he plans on drafting the report due December 1, and that he will send the report around electronically for sign-off.
9. Rep. Thomas described an LSR that he plans on introducing next year. The bill would define clean energy, which appears numerous times in statute without a uniform definition. Rep. Thomas suggested that this committee work on a definition, and that it be similar to the European Union's definition, which Rep. Thomas stated includes nuclear energy. Rep. Harrington agreed that clean energy should be energy that reduces fossil fuel use to reduce greenhouse gas emissions. Rep. Ammon stated he found support for this in the state's 10-year energy plan.
10. Rep. Harrington stated that there has never been a nuclear facility built without taxpayer or ratepayer funding. We need to understand that we are a less regulated state now, and that all generation plants are merchant plants. Investors are unlikely to build a nuclear plant here until one has been successfully built elsewhere, and everyone sees that it can work. He stated that this is not unique to nuclear plants, that offshore wind is in a similar state.
11. The meeting was adjourned at 10:38 a.m.
    Minutes submitted by David Shulock.

## December 12, 2022, Meeting

### *Overview*

On December 12, 2022, the commission heard presentations from Meredith Angwin on how nuclear power benefits the electrical grid, and from Jackie Siebens of Oklo on their company's development of small, advanced fission reactor systems. Key topics discussed included nuclear energy's reliability, inertia, frequency response, recycling of spent fuel, and business models for advanced nuclear. The commission made plans for future meeting topics and speakers. Also discussed were updates to the nuclearnh.energy website.

Meeting event page: https://nuclearnh.energy/event/regular-meeting-dec-12-2022/

### *Minutes*

**Attendance**:

Commission Members: Representative Keith Ammon, Cathy Beahm, Dan Goldner, Matthew Levander, David Shulock, Christopher McLarnon, Marc Brown, Representative Michael Harrington, Bart Fromuth.

Representative Carry Spier (remote), Richard Steeves, Alex Fries

Absent: Senator Bill Gannon

**Meeting**:

1. A quorum was established. Rep. Ammon opened the meeting at 1:42pm
2. A motion was made by Cathy Beahm to approve the minutes from the November 21, 2022, meeting. Barth Fromuth seconded the motion, and the commission voted unanimously to approve the minutes.
3. Rep. Ammon invited the public to introduce themselves and share comments. No members of the public responded.
4. The first presentation was given by Meredith Angwin, author of *Shorting the Grid*. Ms. Angwin discussed the 3 components that comprise a strong electrical grid: reliable electricity, electricity that is relatively inexpensive, and a manufacturing process that creates minimal pollution and ecosystem disruption. She then went on to discuss the juxtaposition between the physical grid (the people and the infrastructure that make electricity work) and the policy grid (which is essentially how the physical grid is paid for). She then introduced the concept of a “could” grid, which explores other options such as wind and solar power.

   Ms. Angwin next discussed how energy auctions work, and the implications they have to both grids. She explained how the system works with energy payments, capacity payments, and out of market payments all contributing to the equation. The failures in the system stem from reliance on a “fatal trifecta” of renewables that start and stop on their own schedules, overdependence on neighbors for resources a given location doesn’t have (which is impacted by demand), and baseload, which is the minimum amount of power in use, or constant demand.

   She then described how nuclear is good for the grid, for several reasons:

   - It has a solid baseload
   - It has over a year of fuel stored on-site
   - Inertia keeps a nuclear system functioning during minor glitches

- It has a small footprint
- It is not weather dependent

Mr. McLarnon asked Ms. Angwin to speak a little further on inverter-based issues. She shared that although there is still research in progress on this topic, it's a matter of creating virtual inertia on an inverter-based grid. Frequency plays into it as well, but inertia is the primary driver.

Rep. Ammon asked for more information about the subject of frequency response, its importance, and its pitfalls. Ms. Angwin explained that as demand goes up, frequency goes down unless you add more supply. So, there is a very tight boundary that grid operators use to manage this, and if it's not done well, it can lead to equipment damage which can create rolling brownouts and blackouts across a grid.

Rep Spier asked what will happen with nuclear waste as the world moves to using more and more nuclear energy. Ms. Angwin explained that comparatively speaking, it's a minimal amount of waste, and is very contained. She also pointed out that there are plants that can reuse that waste.

5. Rep. Ammon introduced the next speaker, Jackie Siebens, Director of External Affairs and Policy for Oklo. Her company develops small, advanced reactor systems. Some of the benefits of the type of reactors they are building include:

   - Small carbon footprint (about the size of a single-family home)
   - Smaller inherently safe and robust safety systems
   - Greater flexibility for where to operate
   - Requires minimal water resources

   Ms. Siebens next reviewed the Aurora powerhouse, a model for this new type of reactor. She explained how it is built and how it functions. A primary change in this type of reactor is the use of fast neurons. This enables the reactor to unlock a lot more of the energy that lives in that uranium than the existing reactors are able to do. They also have the ability to recycle used fuel and are cooled via liquid sodium which is very safe and effective.

   Ms. Siebens cited several cost & operating benefits to their reactors, such as

   - Requiring 1000 times fewer parts to construct,
   - Requiring less complex and less expensive components,
   - The ability to construct offsite in a more efficient manner,
   - Site flexibility and the ability to build close to where the fuel is used.
   - They can produce process heat in addition to electricity, which can be utilized across the industrial sector.

   Oklo is also planning to use a business model which allows end users the option to subscribe to fission-as-a-service. This helps to eliminate deployment hurdles and operational burdens. They are also working closely with NRC to modify the licensing process to accommodate this new reactor design.

   Ms. Siebens shared that Oklo is also working hard on projects surrounding fuel recycling. This recycling effort will be leveraged with the new reactor design to create a paradigm shift from large, complex, and expensive programs to smaller, simpler, cost-effective recycling models. Current plans include starting construction on their own pilot recycling facility in 2027 with hopes to bring it online by the end of the decade. Ms. Siebens responded that is dependent upon the location, as some locations would still require the sale of a certain percentage of the power.

Ms. Beahm asked about purchase power agreements and if that meant Oklo would have agreements with an industry or community directly and you wouldn't be part of an RTO system and how that would play into the reliability of the entire grid?

Mr. Richard Steeves asked if thorium mixed with uranium, of course, has a future in your Aurora system. Ms. Siebens stated that it does not, that they are pursuing exclusively the high-assay, low-enriched uranium, without thorium.

Rep. Spier asked if selling the recycled fuel to plants like Seabrook was part of the recycling planning Oklo is doing. Ms. Siebens responded that it is not, because of the type of reactor they are developing, and the recycling process that stems from that. Rep. Spier asked for some additional information regarding recycling policy, and Ms. Siebens agreed to provide it via email to Rep. Ammon for distribution to the commission.

Rep. Walter Stapleton asked if the experimental breeder reactor in Idaho that was mentioned is operational, or if there were other reactors in the world of similar design that are operational at this point? Ms. Siebens indicated that the Idaho reactor is not yet operational, but similar fast reactors are already in use in China and Russia.

Matt Levander discussed the Seabrook facility and potential for a recycling model there based on what Oklo is doing. He noted it could be a potential option for Seabrook for the future.

Chris McLarnon asked when the efficient products are pulled during the recycling process, do they go back to the original fuel supplier? Who takes ownership of that material? Ms. Siebens stated that this is still under discussion and development.

Mr. McLarnon also asked if Aurora was load-following. Ms. Siebens shared that while it may look a little different than traditional models, yes, Aurora is designed to be load-following.

6. Rep. Ammon asked if there was any further public comment. None was presented.
7. Rep. Ammon next gave an overview of what the monthly meetings for the next year will look like. He discussed several ideas for presenters, and members provided other suggestions, such as Tom Popik on resiliency, and the NRC for a discussion on their timeline and regulatory improvements. Ms. Beahm will get contacts for an EPA presenter, and Mr. Levander will get a contact at NRC.
8. Rep. Ammon shared updates to the nuclearnh.energy website, including commission bios. He asked each member to review theirs, and for Mr. Fries to provide a headshot. Mr. Fromuth volunteered to be the backup administrator to Rep. Ammon.
9. No other questions or issues were presented by the commission.
10. A poll of commission members will be taken to determine the next meeting date and finalize the location.
11. A motion to adjourn was made by Bart Fromuth and seconded by Marc Brown. Meeting adjourned at 3:36 PM.

Minutes submitted by Marc Brown.

# January 23, 2023, Meeting

## *Overview*

On January 23rd, 2023, public comments were heard expressing concerns about nuclear construction costs, concrete issues, and adequacy of radiation monitoring. Presentations were given by the US Nuclear Regulatory Commission on improving licensing efficiency for advanced reactors, and by Westinghouse on lessons learned from recent AP1000 projects. Westinghouse stressed the importance of complete designs, experienced contractors, and reliable suppliers. They discussed features and future plans for the AP1000 and small modular reactors. The committee was also referred to a Virginia report on assessing nuclear capacity.

Meeting event page: https://nuclearnh.energy/event/regular-meeting-jan-23-2023/

## *Minutes*

**Attendance**:

Commission Members: Representative Keith Ammon, Cathy Beahm, Dan Goldner (remote),

Matthew Levander (remote), David Shulock, Christopher McLarnon, Marc Brown (remote), Representative Michael Harrington

Absent: Senator Bill Gannon, Alex Fries, Bart Fromuth

Public: Paul Gunter, Sarah Abramson, Gary Woods

**Meeting**:

1. A physical quorum was not established. Rep. Ammon opened the meeting at 1:34pm
2. Rep. Ammon confirmed Marc Brown will function as clerk.
3. The commission will seek to approve the minutes of the commissions December 12, 2022, gathering at the next meeting.
4. Rep. Ammon invited the public to share introduce themselves and share comments.
    - Paul Gunter from Beyond Nuclear spoke first. He raised concerns about the failure of nuclear construction projects to reach completion, and the costs continuing to spiral out of control. Their group feels it a nationwide issue that is worsening over time.
    - The next speaker was Sarah Abramson C-10 Foundation. Her concerns lie with the State of New Hampshire's Radiation Monitoring Program, expressing that it does not seem nearly as robust or adequate as our real-time monitoring network can provide. She asked that the State makes sure it thinks very clearly and thoroughly about what radiation monitoring should look like with today's technology. Ms. Abramson also expressed concerns about concrete issues with Seabrook and other projects, and that rushing to select materials and contractors that may be less than desirable adds to these concerns.
    - Mr. Gary Woods was the final public commenter, noting he is just an interested citizen.
5. The first presentation was given by Michael Wentzel, Branch Chief at the US Nuclear Regulatory Commission (NRC). He first gave a historic perspective of where things have been, and then discussed where the NRC is headed next with respect to licensing, regulation, safety, and efficiency. He noted that improving the efficiency of licensing and shortening the licensing process, making these licensing a little bit more predictable are some of the key areas of focus. He

examined three examples of projects already in process: Shine Technologies, a medical isotope facility currently under construction in Janesville, Wisconsin that is nearly complete, and two projects, Kairos Power and Abilene Christian University, which are both licensing applications for advanced reactor concepts. Kairos and Abilene are currently in the first phase, getting a construction permit, and will be requesting an operating permit when the facility nears completion. Mr. Wentzel discussed Part 53, which proposes combining the two licenses into one in the appropriate situations. The intent is to modernize the licensing process and strike an optimal balance between flexibility and predictability by providing some clear and specific performance-based requirements that ensures an efficient and effective licensing process.

6. Rep. Ammon introduced the next speaker, David Durham, Westinghouse. He discussed the AP1000 projects, and the success Westinghouse has had with them so far. He also shared 3 major lessons learned from the Vogtle Project:

    - Don't start construction without a 100% complete design
    - Only work with a contractor experienced in nuclear construction
    - Only work with experienced suppliers to keep the supply chain flowing

    Mr. Durham shared other key data points and performance metrics such as safety and operating availability. In response to a question from Rep. Harrington, Mr. Durham explained the difference between availability factor and capacity factor, citing that capacity looks at what the reactor could be doing, and availability measures what it is actually doing, the percentage of time it's up and running.

    Mr. Durham also discussed the AP1000's ability to keep cool for 72 hours with zero human intervention and without boron cycles, as well as its ability to load follows with ramp rates faster than a gas plant, one megawatt per second. He also only reactor capable of station blackout cope, which is considered it is game-changing technology.

    Several questions were posed about potential supply chain issues, and Mr. Durham assured the commission that they are working with a global supply chain that they monitor carefully, and right now, there are no issues presenting themselves for expansion of this project. Mr. Durham also discussed future technology that is being developed to allow for non-diesel reactors that are capable of generating electricity for 8 years, and are then simply swapped with a new reactor, and the old one is taken off-site for refueling and storage of cement fuel. It is anticipated that this will be more cost-effective method of operation, with the flexibility to attract both full-scale power plant customers and customers who are looking just for electricity.

    Mr. Durham also touched on SMR application, and the role Westinghouse is having in its development. He stated that many more details are yet to come on these initiatives, as they are in the beginning of the application process with NRC. It was suggested that the Science Technology and Energy committee make a site visit to the Newington facility.

7. Rep. Ammon asked if there were any other agenda items or discussion from the committee members. Matt Levander had previously distributed Virginia Innovative Nuclear hub document, also available at https://nuclearnh.energy, for discussion. Mr. Levander explained that the State of Virginia has prioritized efforts to determine whether building nuclear is a good fit for their state, and this paper outlines some of their thought process.

8. No other questions or issues were presented by the commission.

9. A poll of commission members will be taken to determine the next meeting date.

10. The meeting was adjourned at 3:15pm.

Minutes submitted by Marc Brown.

# March 6, 2023, Meeting

## *Overview*

On March 6, 2023, the commission heard presentations from TerraPower on their Natrium advanced nuclear reactor project in Wyoming as well as from Centrus Energy on their plans to produce high-assay low-enriched uranium (HALEU) fuel. Key discussion points included the challenges around financing and fuel supply for advanced reactors, the licensing process with the NRC, and the potential to leverage national security needs to help accelerate commercial nuclear power development. The commission also discussed updates on other nuclear companies, the open Coordinator of Atomic Development Activities position in New Hampshire, and potential future meeting presenters.

Meeting event page: https://nuclearnh.energy/event/regular-meeting-mar-6-2023/

## *Minutes*

**Attendance**:

Commission Members: Rep Keith Ammon, Rep Michael Harrington, Sen Howard Pearl, Cathy Beahm, Dan Goldner, Matthew Lavender, David Shulock, Bart Fromuth (remote), Christopher McLarnon (remote)

Absent: Marc Brown, Alex Fries

Public In-Person: John Schneller

Public Remote: John Tuthill, Vikram Mansharamani, Christine Csizmadia - NEI, Andrew Richards, Karen Testerman, Connor Woodrich, Gary Woods

**Meeting**:

1. The New Hampshire Commission to Study Nuclear Technology meeting was called to order by Rep Keith Ammon at 1:40 pm. The commission had a quorum present.
2. Welcome New Member: Sen Howard Pearl was welcomed as the newest member of the commission. Sen Pearl introduced himself and shared maple fudge with the commission members.
3. Approval of Minutes: The commission approved the December 12th meeting minutes, with one abstention from Sen Pearl. The commission approved the January 23rd meeting minutes, with one abstention each from Sen Pearl and Bart Fromuth. The minutes will be posted on the commission's website: https://nuclearnh.energy/.
4. Presentation by Jeff Navin of TerraPower.

   Introduction:

   - Jeff Navin, Director of External Affairs at TerraPower
   - Discussing the Natrium reactor project in Kemmerer, Wyoming

   Background of TerraPower:

   - Founded by Bill Gates
   - Focused on advanced nuclear technology to address climate change and global energy poverty

   Natrium Reactor:

   - Differences from conventional nuclear reactors:
     - Uses sodium instead of water as a coolant

    - Smaller in size (345 MW compared to 1 GW)
    - Employs molten salt energy storage system
- Provides a safer, more economical, and flexible power generation solution

Project in Kemmerer, Wyoming:

- Part of the Department of Energy's Advanced Reactor Demonstration Program
- Expected to come online around 2030
- Will be licensed for 60 years with an opportunity to extend for another 20 years
- Partnership with Rocky Mountain Power PacifiCorp
- Selected site due to enthusiastic community support

Community impact:

- Kemmerer is a small town with a population of 2,700
- The Natrium project will help retain jobs from the retiring coal plant and coal mine
- 109 IBEW members currently working at the coal plant will be offered jobs at the Natrium plant
- Expected to have 200-250 full-time employees and around 1500 jobs

5. Q&A with Jeff Navin of TerraPower

Q: Rep Michael Harrington: Is Wyoming a non-restructured state in that this plant would be approved by the PUC out there, and then the rate would be on the hook to fund it? Is that correct?

A: Jeff Navin: Yes, Wyoming is a regulated state, but the deal is structured to set a fixed price for the sale of the plant, and the rate payers will not be on the hook to pay for that until the plant can be delivered at that set price.

Q: Rep Michael Harrington: Where are you going to get the HALEU?

A: Jeff Navin: Currently, Centrus is producing small amounts of HALEU in Piketon, Ohio as part of a project with the Department of Energy. There is a HALEU fuel program authorized by the Energy Act of 2020 to help address the chicken and egg problem of HALEU production and customer demand. The funding for the program is around $600 million, and TerraPower is waiting for the DOE to release their draft RFP for companies like Centrus to apply. TerraPower's reactor was initially planned to come online in 2028 but has been pushed back to 2030 due to HALEU challenges. Some small amounts of HALEU might be available from the Department of Energy's weapons program through down-blending highly enriched uranium from nuclear warheads.

Q: Rep Michael Harrington: In normal operations, would you be putting the 345 megawatts out on the grid, and then when there was a lot of solar or a lot of wind, would you continue to produce 345 and dump that into thermal storage or load follow?

A: Jeff Navin: TerraPower intends to load follow. The heat from the reactor will go through an intermediate loop heat exchanger and be used to heat up the salt in the molten salt energy storage system. All electricity generation will come from a steam turbine attached to the molten salt energy storage system, and the system can ramp up and down from about 40 to 50 megawatts up to 500 megawatts.

Q: John Schneller: Is there a minimum baseline number of acres where a production facility could be built, and what level of stability would be required for that site?

A: Jeff Navin: The current layout for TerraPower's reactor is 44 acres. While they try to keep it as compact as possible, there might be some flexibility to accommodate a smaller site. The Nuclear Regulatory Commission process requires a robust site assessment, including geological and meteorological studies, to determine the feasibility and safety of the site.

Q: John Schneller: How would the construction and operation of a nuclear power plant with a useful life of over 60 years be financed?

A: Jeff Navin: The financing of new nuclear power plant construction is under active discussion. In the past, the costs of reactor construction were spread out over the plant's life through rate basing in regulated markets. The financing mechanisms for nuclear power plants are still being developed for the current market situation. The government's Advanced Reactor Demonstration Program has stepped in to help finance the first plant with a federal cost-share. TerraPower also has a memorandum of understanding with Rocky Mountain Power to build five additional plants, which could help drive down costs and develop financing mechanisms for future projects.

(Jeff Navin's connection dropped. More questions were asked of him later in the meeting.)

6. Presentation by Dan Leistikow of Centrus Energy.

Introduction:

- Dan Leistikow from Centrus presents an overview of the company and its history.
- Centrus is the only publicly traded uranium enrichment company in the world.
- They are working on high assay low enriched uranium (HALEU) production in Ohio.

Company history:

- Centrus grew out of the Manhattan Project.
- It operated the US government's enrichment plants until the last one shut down in 2013.
- Centrus played a significant role in the "Megatons to Megawatts" program to repurpose Soviet nuclear material for civilian use.

HALEU production:

- Centrus is working on deploying its HALEU technology in Piketon, Ohio.
- The goal is to scale up production to meet the needs of advanced reactors.

Nuclear fuel enrichment process:

- Uranium is mined, converted into uranium hexafluoride (UF6), and sent to enrichment plants.
- Centrifuges separate U-235 from U-238, increasing the U-235 content to usable levels.
- The enriched UF6 is sent to fuel fabrication facilities to be turned into fuel rods for nuclear power plants.

Enrichment levels:

- Natural uranium is less than 1% U-235.
- Low enriched uranium (LEU) is enriched to just under 5% U-235, which is used in

Benefits of LEU Plus

- Allows for fewer refueling outages

- Increases power production efficiency

US Government Requirements

- Need for additional HEU for naval reactors
- Need for LEU for tritium production
- Importance of non-proliferation and safety standards

Challenges

- Chicken and egg problem: Private capital hesitant to invest without customers, customers need fuel supply

Public-Private Partnership Proposal

- Accelerate investments in enrichment capabilities
- Reestablish US leadership in nuclear fuel production
- Leverage government investments for commercial requirements

Centrus Technology Readiness

- 3.5 million machine operation hours
- Full-scale cascade production capability
- 42-month timeline to HALEU production

Importance of Supply Diversity

- Greater global market resilience
- Reestablish American producer presence

Centrus Unique Position

- Able to meet both commercial and US government requirements
- Demonstration cascade in Piketon to begin production by year-end

7. Q&A with Dan Leistikow of Centrus Energy

   Q: John Schneller: What is the total capital investment that you need to start the 36-month LEU production?

   A: Dan Leistikow, Centrus: They haven't talked about specific dollar figures, and as a publicly traded company, they have to be careful about disclosing financials. It's hard to give a precise number because it varies depending on what they are deploying. Large enrichment plants producing large amounts of LEU are multi-billion-dollar projects.

   Q: Rep Michael Harrington: When the fuel is no longer useful, what's the end of cycle enrichment left with the fuel?

   A: Dan Leistikow, Centrus: It varies a lot based on the reactor design, and there's no definitive answer provided.

   Q: Rep Michael Harrington: Is there any talk of the processing or would this fuel be just handled the same way that the lower-level enrichment fuels handle that?

   A: Dan Leistikow, Centrus: Some advanced reactors have the ability to burn off used fuel. There is discussion about reprocessing, but Centrus doesn't see a big need for it and doesn't consider it a viable solution. They believe the priority should be on making investments to produce fresh HALEU through enrichment.

Q: Rep Michael Harrington: Is the NRC's licensing for reactors using HALEU an issue?

A: Dan Leistikow, Centrus: Centrus had a good experience with the NRC in their project and already received their license for HALEU. However, the NRC still needs to look at the reactor designs themselves.

Q: Rep Keith Ammon: Where will the demonstration reactors that are being planned get their fuel?

A: Dan Leistikow, Centrus: It's up to the reactor developers to determine their own fuel sourcing, but Centrus would like to be their source of supply. They need to get started quickly to meet the timelines for these developers.

Q: Rep Keith Ammon: Is there any coordination inside the industry to solve the chicken and the egg problem?

A: Dan Leistikow, Centrus: Centrus has been talking to many companies about this issue, but it's challenging because reactor developers invest their capital in building reactors while Centrus invests in building enrichment. A public-private partnership is needed to solve the problem, leveraging national security requirements to provide a source of fuel.

Q: Rep Keith Ammon: Were the 36 months for LEU and 42 months for HALEU consecutive timeframes?

A:Dan Leistikow, Centrus: No, they are not consecutive timeframes. It would take 36 months for LEU and 42 months for HALEU. They can do both at the same time, but with LEU, there would be a much larger deployment.

8. Q&A resumed with Jeff Navin of TerraPower.

   Q: Rep Michael Harrington: Does TerraPower expect to spend as much as NuScale for their design approval by the NRC, and does the use of HALEU present any particular hard spots with the NRC?

   A: Jeff Navin, TerraPower: TerraPower does not anticipate their licensing fees to cost anywhere near what NuScale spent. They don't think HALEU will be a particular issue. They are working with the NRC during the pre-application process to identify issues to focus on. TerraPower expects to submit their license for their construction later this year.

   Q: Rep Michael Harrington: Has TerraPower solved the issue of material corrosion with their molten salt reactor design?

   A: Jeff Navin, TerraPower: The US has successfully operated sodium-cooled test reactors at Idaho National Laboratory for many decades. Sodium is not particularly corrosive with the materials used. TerraPower has been running many loops of salt through different materials in their laboratory to understand the interactions. Advances in material science since the sixties and advanced computing help TerraPower design their reactor.

   Q: John Tuthill: Is the $500 million figure total cost for the NuScale project or just the licensing cost?

   A: Rep Michael Harrington: The $500 million figure includes engineering and licensing costs combined. It is not just what NuScale paid the NRC, but also what they paid engineers to develop their design and do calculations before talking to the NRC.

   Q: Rep Keith Ammon: Can a Natrium plant be built from scratch without requiring retrofitting an old coal plant?

A: Jeff Navin, TerraPower: TerraPower's plans are not to retrofit the plant, but they will use the workforce, grid interconnect, and water resources from the existing coal plant. Building a nuclear reactor on an existing coal site presents some challenges, and in some cases, older infrastructure or adjacent activities (like blasting in a coal mine) might pose problems.

Q: Rep Michael Harrington: Is TerraPower's project in Wyoming in the same ballpark range of about $89 a megawatt hour like NuScale's contract in Utah?

A: Jeff Navin, TerraPower: TerraPower plans to be quite a bit lower than that. They anticipate being in the $55 to $60 a megawatt hour range with integrated energy storage included in the cost, after they have built a few reactors.

9. The members discussed the importance of resolving the fuel issue for nuclear power and tie it to national security needs.
10. The members discussed updates on NuScale power and a failed bill in Virginia related to SMR production.
11. The Coordinator of Atomic Development Activities position in New Hampshire is brought up, and they discuss filling the position and making it a tie-in for the commission's reports.
12. Southern Company is a potential presenter for the next meeting, and there are suggestions for future meetings with X-Energy and a company that may make disposable reactors.
13. The meeting was adjourned at 3:15 pm.

Minutes submitted by Keith Ammon.

## April 7, 2023, Meeting

### *Overview*

On April 7, 2023, the commission heard presentations from BWX Technologies and X-energy on advanced nuclear reactors and fuel technology. Discussion topics included supply chain issues, retrofitting coal plants, safety mechanisms, medical isotope production, hydrogen generation, regulatory matters, and decommissioning costs. Plans were made to draft an interim and final report with commission member input. Suggestions for future speakers were provided and the potential benefits of hydrogen energy storage were noted. The meeting concluded with intentions to continue coordination over the summer and identify opportunities to update relevant statutes.

Meeting event page: https://nuclearnh.energy/event/regular-meeting-apr-7-2023/

### *Minutes*

**Attendance**:

Commission Members: Rep Keith Ammon, Cathy Beahm, Dan Goldner, Marc Brown, David Shulock, Bart Fromuth (remote), Christopher McLarnon

Absent: Rep Michael Harrington, Sen Howard Pearl, Alex Fries, Matthew Lavender

Public In-Person: Rep Alvin See, Douglas Mailey, Richard Barry, Vikram Mansharamani

Public Remote: Carol Lane - X-energy, Christine Csizmadia NEI, Connor Woodrich, Dave Pyles, Don Bettencourt, Gary Woods, Jackson Bouley, John Tuthill, John Valentino, Joshua Parker, Karen O'Neil-Roy NH DHHS/EPRR, Paul Gunter, Scott Kopple - BWXT, Scott Nagley - BWXT, Rep Walt Stapleton

**Meeting**:

1. The New Hampshire Commission to Study Nuclear Technology meeting was called to order by Rep Keith Ammon at 10:35 am. The commission had a quorum present.
2. BWX Technologies Presentation: Scott Nagley, Vice President of Business Development, and Joshua L. Parker, Director of Business Development, presented the information.

   Company Overview:

   - BWXT is a leading nuclear technology innovation company known for manufacturing naval nuclear reactors for U.S. submarines and aircraft carriers.
   - The company has a workforce of over 6,600 employees and achieved $2.1 billion USD in revenues in 2021.
   - BWXT operates 12 major manufacturing facilities totaling 3.9 million square feet.
   - They have over 60 years of experience in manufacturing naval nuclear components and reactors and have produced over 300 commercial nuclear steam generators and 1.5 million Canada Deuterium Uranium (CANDU) fuel bundles.

   BWXT's Reach:

   - Apart from manufacturing, BWXT is involved in U.S. Department of Energy (DOE) laboratories, environmental cleanup projects, and NASA sites.
   - They have delivered more than 8,000 fuel elements to national laboratories, universities, and international customers.
   - BWXT has joint ventures with several organizations for specialized projects and operations.

Company History:

- BWXT has a 165-year history of innovation, including contributions in the non-nuclear sector such as the invention of the water tube boiler.
- Their nuclear history dates back to 1946 when they were awarded their first contract with the U.S. Navy for propulsion systems.
- BWXT designed components for the first nuclear-powered submarine in 1953 and has been involved in the manufacturing of commercial nuclear power plant components since 1956.
- The company has made recent advancements in various fields, including nuclear plant design and manufacturing, space technology, medical isotope production, and advanced nuclear fuel manufacturing.

Business Operations:

- BWXT operates in both government and commercial sectors.
- In the government sector, they are involved in naval nuclear propulsion, nuclear environmental restoration and site management, and space and defense nuclear power and propulsion.
- In the commercial sector, they contribute to nuclear power generation, nuclear manufacturing, nuclear fuel production, and nuclear medicine.

The Nuclear We Need:

- BWXT emphasizes the importance of nuclear power in various applications and technologies, including space exploration, defense, and medical isotope production.
- They are developing advanced microreactors, which are scalable and transportable, to meet energy needs in off-grid and remote military applications.

Fuel Development and Manufacturing:

- BWXT has rapid product development capabilities, enabling efficient progression from R&D to full-scale production.
- They focus on design and fabrication development, utilize advanced techniques such as Sol-Gel kernels and PVD coatings, and have production capabilities for reactors and fuel elements.
- Fuel production facilities are strategically located across multiple facilities, including NOG-L and the BWXT Innovation Campus, and specialize in the development and testing of novel fuel concepts.

BANR Technology:

- The BANR reactor is based on HTGR design, offers passive and inherent safety features, and has a flexible power conversion capability.
- It is a modular system, and each module conforms to standard shipping requirements.
- The BANR technology enables rapid modular installation, refueling, and deployment of reactors.

Cost Reduction and Target Markets:

- BWXT focuses on increasing core power and extending core life to reduce the number of reactors needed and associated costs.
- They aim to improve manufacturing throughput, reduce operations and maintenance costs, and expand target markets to include mining/oil

3. BWXT Q&A:

Rep Keith Ammon: Excellent. Are there concerns about delays or issues you might have to overcome in the fuel supply chain and regulatory hurdles?

Joshua Parker - BWXT: We are currently facing supply chain issues with Project Pele, but the Department of Defense is providing funding for that. We are vertically integrated and manufacture various components for the reactor. The fuel for the reactor is sourced from the strategic stockpile of enriched material. Regulatory hurdles are being addressed, and we have the necessary licenses for fuel manufacturing.

Rep Walt Stapleton: What kind of enrichment factor do you use in these reactors? Is it variable depending on the application?

Joshua Parker - BWXT: We primarily use high assay, low enriched uranium with enrichment just below 20 weight percent uranium 235. We may slightly adjust the enrichment for specific power requirements, but the target is up to 28% enrichment.

Rep Walt Stapleton: Is the gas reactor replacing the water reactor? Are you phasing out water reactors in favor of gas reactors?

Joshua Parker - BWXT: Gas reactors, specifically high-temperature gas reactors, are not intended to replace light water reactors. Light water reactors have their role and are being extended in operation. Gas reactors are focused on industrial processes that require higher temperatures. Different reactor technologies, including gas, molten salt, and liquid metal-cooled reactors, are being developed to meet different market demands. Light water reactors will continue to play a role in electricity generation.

Paul Gunter - Beyond Nuclear: How do you plan to overcome the issue of suppliers not investing in new capacity without strong order books from your company?

Joshua Parker - BWXT: We are having discussions with end users who recognize the limitations of renewable energy sources like solar and wind. Nuclear power provides energy density and reliability, which becomes valuable for customers who need consistent power. The economics of green energy and decarbonization are being considered, and as the market grows, suppliers will find opportunities to invest in new capacity.

Rep Keith Ammon: What are the non-electrical applications of your technology, particularly in medical isotopes?

Joshua Parker - BWXT: Nuclear reactors can be used to generate medical isotopes. Our focus is on producing medical isotopes through processes involving reactors like the CANDU reactors in Canada. We have the expertise to handle fuel and materials safely, which aligns with our fuel manufacturing capabilities. Medical isotopes are an important application of our technology.

4. X-Energy Presentation:

Carol Lane, Vice President of Government Relations and John Valentino, Director of Customer Relationship Management presented on behalf of the company.

X-energy Overview:

- X-energy is a reactor design and fuel manufacturing company established in 2009.
- The company focuses on high-temperature gas reactors and TRISO fuel.
- X-energy was founded by Dr. Kam Ghaffarian, who recognized the need for accessible and clean electricity globally and saw the potential of high-temperature gas reactors.
- X-energy has experienced significant growth, currently employing over 440 people.

High-Temperature Gas Reactors:

- X-energy's high-temperature gas reactor is a grid-scale reactor known as the "four pack" consisting of four modules.
- The pebble bed reactor design allows for high burnup of the fuel, with pebbles cycling through the reactor multiple times.
- X-energy has been working on making TRISO fuel and operates a pilot manufacturing facility.
- The company plans to build a commercial-scale TRISO fuel fabrication facility in Oak Ridge, Tennessee.

Advanced Reactor Demonstration Program:

- X-energy was selected as one of the awardees for the Department of Energy's Advanced Reactor Demonstration Program.
- The program provides a bridge for customers to adopt advanced reactors without taking on the risks of being the first adopter.
- X-energy is designing a four-pack reactor for deployment with Dow Chemical at a Gulf Coast site.
- The company is also constructing a commercial-scale TRISO fuel facility in Oak Ridge, Tennessee.

Other Initiatives and Advantages:

- X-energy is involved in strategic government R&D initiatives for space nuclear reactors and small terrestrial reactors.
- The company aims to modularize and standardize components to enhance manufacturability and supply chain resilience.
- X-energy's reactors offer load-following capability, providing flexibility to blend loads with renewable energy sources.
- The high-temperature steam produced by the reactors has various industrial applications, including clean hydrogen production.

Regulatory and Political Support:

- X-energy has been in discussions with the Nuclear Regulatory Commission since 2018 for both reactor and fuel facilities.
- The company has submitted topical reports and white papers, with plans to submit a construction application in late 2023.
- The federal government has shown bipartisan support for advanced nuclear through initiatives like the Advanced Reactor Demonstration Program and funding for HALEU fuel production.
- X-energy is closely following changes in state environments and is open to collaborating with stakeholders.

Future Plans:

- X-energy aims to deploy its reactors within the next few years.
- The company is currently engaged in fundraising efforts and plans to go public in 2023.
- X-energy is working on operator training simulation and building a plant support center for operational training.

Closing Remarks:

- Carol Lane concluded her presentation by emphasizing the potential of advanced reactors to address energy challenges and contribute to decarbonization efforts. She highlighted the power and energy density of nuclear reactors and expressed X-energy's commitment to advancing the deployment of advanced nuclear technology.

5. X-energy Q&A:

   Q: Cathy Beahm: Is the Maryland generation study on converting coal plants to nuclear readily available?

   A: Carol Lane - X-energy: Yes, there is a public version available on the Maryland Energy Administration website. I can send you a link to it and also provide the PDF if needed.

   Q: Cathy Beahm: Can you explain how the TRISO pebble becomes an active power source once it's in the reactor?

   A: John Valentino - X-energy: The TRISO pebbles contain uranium 235, and when they are exposed to a neutron field in the reactor, some of the uranium 235 splits, releasing heat. The heat is then extracted by pumping helium or water over the pebbles.

   Q: Rep Keith Ammon: How is the heat regulated in the reactor and what are the safety mechanisms?

   A: John Valentino - X-energy: The heat is regulated by controlling the fluid flow, either helium or gas, over the pebbles. In case of a shutdown, control rods are inserted into the reactor core to absorb the neutrons and prevent further reactions and heat generation.

   Q: Rep Keith Ammon: Is there any waste of heat or energy during load-following that could be utilized for other purposes like hydrogen production?

   A: John Valentino - X-energy: During load-following, if there is excess heat generated, it can be diverted to other uses such as hydrogen production, thermal storage systems, or desalination plants, depending on the setup. The goal is to avoid wasting heat and maximize efficiency.

   Q: Rep Keith Ammon: How would you retrofit a coal plant to accommodate nuclear power generation?

   A: John Valentino - X-energy: Retrofitting a coal plant involves evaluating the existing infrastructure, transmission systems, and trained workforce. Some equipment may be reusable, while specific nuclear components would need to be added. The focus is on utilizing existing resources and adapting them for a new purpose.

   Q: Rep Keith Ammon: What is the required buffer zone or population distance around your reactor?

   A: John Valentino - X-energy: The buffer zone is typically measured by distance, and for our reactor, it is around 400 meters, which is much smaller than the current 10-mile zone around reactors like Seabrook.

   Q: Paul Gunter – Beyond Nuclear: Can X-energy provide confidence in its containment strategy by not participating in the Price Anderson Act?

   A: Carol Lane - X-energy: We are still in the final design phase and going through the regulatory process. The decision regarding containment strategy and liability coverage will be made between us and our customer in the future.

6. Discussion:

Richard Barry expressed his concerns about the amount of money that has been invested in the decommissioning of the Seabrook Nuclear Power Plant. He suggested that the government should take action to mitigate the costs associated with decommissioning. The possibility of modular reactors was also mentioned, with the understanding that the dynamics and costs may differ from traditional reactors.

Cathy Beahm proposed creating a grid that outlines the different speakers and their respective reactors and tools covered in the discussions. Rep Keith Ammon supported this idea and mentioned the possibility of involving an intern to help with the task.

Douglas Mailey, a member of the public, asked about the final objective of the session and whether specific recommendations or an overview report would be produced. Rep Keith Ammon clarified that one aspect would be to propose adjustments to state statutes and to explore the potential for the industry's development in the state. The engagement of the federal delegation and the availability of funds for the industry were also discussed.

Vikram Mansharamani shared his conversation with the management team of Oklo, a nuclear energy company, and their potential interest in exploring opportunities in New Hampshire. Rep Keith Ammon expressed interest in keeping in touch with Vikram to stay updated on any progress.

Various potential future speakers were mentioned, including representatives from the Department of Nuclear Energy, Holtec, Q Hydrogen, and LightBridge. The importance of understanding the supply chain ecosystem, desalination, and hydrogen as an energy storage option was also emphasized. The potential involvement of the federal government and the need to update relevant statutes were discussed.

Rep Keith Ammon provided updates on his request to the executive council regarding the vacant position responsible for monitoring atomic energy. He shared that the request was acknowledged, and that the governor's office was looking into the matter. He also mentioned a report issued by the Department of Energy, titled "Pathways to Commercial Liftoff for Advanced Nuclear," which outlines the federal government's vision for advancing nuclear technology.

Rep Keith Ammon proposed drafting an interim report due in July and a final report due in December, with the intention of including input from all commission members. He suggested taking a break during the summer and continuing to plan future meetings. Attendees were encouraged to provide suggestions for potential speakers and connections.

Lastly, the meeting concluded with a discussion on the potential benefits of hydrogen as an energy storage solution and the viability of pump storage systems.

7. The meeting was adjourned at 12:20 PM.
   Minutes submitted by Keith Ammon.

## May 12, 2023, Meeting

### *Overview*

On March 6, 2023, the commission received presentations from the American Nuclear Society and Holtec International on the current state and future prospects of nuclear energy. Key topics discussed included growing interest in nuclear energy, new investments in advanced reactor technologies, challenges related to fuel supply, waste management, and workforce development, the potential of small modular reactors, and the importance of nuclear energy as a reliable, resilient, and clean source of electricity. The commission also had discussions regarding nuclear education programs, engaging the public on nuclear topics, and ratepayer interests.

Meeting event page: https://nuclearnh.energy/event/regular-meeting-may-12-2023/

### *Minutes*

**Attendance**:

Commission Members: Rep Keith Ammon, Cathy Beahm, Marc Brown (arrived 9:18 AM), Pradip Chattopadhyay (substitute for Golder), Bart Fromuth, Rep Michael Harrington, Christopher McLarnon, David Shulock

Absent: Alex Fries, Daniel Goldner (Chattopadhyay was substitute), Matthew Lavender, Sen Howard Pearl

Public In-Person: Hon Richard Barry, Rep Steven Bogert, Mailly Douglas, Donald Kreis, Vikram Mansharamani, Rep Alvin See, Rep Doug Thomas

Public Remote: Craig Piercy - ANS, Gareth Thomas - Holtec, Tanya Donnelly, Guido, Paul Gunter, Jeremy Hitchcock, Pat O'Brien, Joy Russell, Timothy Smyth, Rep Carry Spier, Rep Walt Stapleton, John Starkey, John Tuthill

**Meeting**:

1. The New Hampshire Commission to Study Nuclear Technology meeting was called to order by Rep Keith Ammon at 9:05 am. The commission had a quorum present.
2. Rep Ammon introduced PUC Commissioner, Pradip Chattopadhyay, who filled in for Daniel Goldner.
3. Approval of the minutes from the March 6th meeting was moved by Rep Harrington, seconded by Bart Fromuth. The minutes were approved by unanimous voice vote.
4. Approval of the minutes from the April 7th meeting was moved by Cathy Beahm, seconded by Chris McLarnon. The minutes were approved by unanimous voice vote.
5. Craig Piercy, the Executive Director and CEO of the American Nuclear Society, presented before the New Hampshire Commission to Study Nuclear Energy Technology. He discussed the current state and prospects of nuclear energy, highlighting its relevance in the context of climate change and the need for decarbonization. Piercy provided insights into public opinion, investments, reactor designs, challenges, and the role of nuclear energy in a renewable energy grid.
    1. American Nuclear Society (ANS):
        - ANS serves as the Technical and Professional Society for Applied Nuclear Science.
        - It supports its 10,000 members through meetings, publications, professional development, and engagement with policy and journalism.
        - ANS is expanding its programs to improve K-12 education programs related to nuclear science.
    2. Growing Interest in Nuclear Energy:

- Piercy noted that nuclear energy is currently experiencing a surge in interest and popularity.
- He mentioned examples of recent events, such as the premiere of the movie "Nuclear Now" and the support expressed by influential figures like Elon Musk.

3. Nuclear Renaissance vs. Nuclear Enlightenment:
    - Piercy differentiated between the previous "nuclear renaissance" era and the current "nuclear enlightenment" phase.
    - The nuclear enlightenment focuses on addressing the challenges of climate change, decarbonization, and maintaining a reliable grid with increased renewable energy penetration.
    - Nuclear energy is recognized as a proven source of clean, firm power in a carbon-constrained world.
4. Historic Investments and Generation IV Technologies:
    - Piercy highlighted the significant public investments in nuclear energy, particularly through the Inflation Reduction Act and the Infrastructure and Jobs Act.
    - These investments support the expansion and development of new nuclear technologies.
    - He discussed various reactor designs, including Generation III+ light water plants, high-temperature gas reactors, pebble bed reactors, heat pipe reactors, and fusion energy.
5. Challenges and Focus Areas:
    - Fuel Supply: Piercy discussed the challenges related to low enriched uranium (LEU) and high assay LEU (HALEU). He mentioned efforts to establish domestic supply chains and the development of enrichment technologies like laser enrichment.
    - Regulatory Readiness: Piercy acknowledged the challenges faced by the U.S. Nuclear Regulatory Commission (NRC) in adapting its regulatory framework for advanced reactors. He expressed confidence in the NRC's ability to handle future license applications.
    - Nuclear Waste: Piercy noted that nuclear waste management faces policy challenges, despite the safety of current storage methods. Private companies show interest in extracting usable uranium from spent fuel rods.
    - Skilled Workforce: The nuclear industry faces the challenge of attracting and retaining skilled professionals. ANS is working on expanding education programs and developing certification programs for professionals from adjacent industries.
6. Nuclear Energy as a Grid Anchor:
    - Piercy emphasized the importance of nuclear energy as a reliable and resilient source in a grid with high penetrations of intermittent renewable energy.
    - He encouraged the commission to consider the role of nuclear energy in creating a reliable and resilient grid and its feasibility in meeting clean energy goals.
7. Conclusion: Piercy concluded by highlighting the need for timely action and strategic decision-making regarding the incorporation of new nuclear generation into energy plans. He emphasized the advantages of nuclear energy in terms of reliability, resilience, and its potential contribution to decarbonization efforts. Piercy expressed readiness to address any questions from the commission members.

6. Gareth Thomas, Senior Program Manager for Holtec, introduced himself and discussed the purpose of the speech. Holtec is a technology development company specializing in nuclear fuel storage.

A. Holtec's History and Core Business

- Holtec was founded in 1986 by the current owner and CEO, initially focusing on heat exchanges and plant equipment.
- The company transitioned to solving the storage issue of spent nuclear fuel, starting with underwater racks and high-density racks, and later moving to dry gas storage.
- Fuel storage became Holtec's core business for the past 15 to 20 years.

B. Expansion into Reactor Decommissioning and SMR Development
- In the last five years, Holtec expanded its operations to include reactor decommissioning and small modular reactor (SMR) development.
- The SMR 160 program began in 2010, aiming to design a fail-safe and walk-away-safe reactor using existing technology.
- Holtec developed a 160-megawatt electrical pressurized water reactor (PWR) suitable for single or multiple units on one site.

C. Progress and Current Focus
- Holtec completed the Canadian VDR phase one and received a DOE fund under the Advanced Reactor Demonstration Program.
- They are working on developing the licensing documentation and preparing to submit a Construction Permit Application.
- Engaging with the NRC for feedback and ensuring a smooth construction permit application process.
- Identifying the location for the first commercial SMR project, with the Oyster Creek site in New Jersey as the primary candidate.

D. Commercial Project Challenges
- Securing power purchase agreements and ensuring competitive electricity prices.
- New Jersey's historically competitive and stable power market poses challenges in pricing the electricity.
- Exploring other potential sites owned by Holtec and initiating discussions with utilities in the southern US.

E. Construction and Cost Considerations
- Holtec is partnering with construction company Kiewit to refine the plant design and cost estimates.
- Focusing on achieving an executable status for the design and ensuring high confidence in the project budget.
- Striving to stay on budget and on schedule for the first plant, while aiming for competitiveness in construction costs.

F. Conclusion and Future Prospects
- Holtec's goal is to obtain a Construction Permit Application and license the first SMR under the standard process.
- The company is actively pursuing the Oyster Creek site for the first commercial SMR project.
- Challenges include first-of-a-kind risks, keeping projects on time and on budget, and reducing costs over time.
- Holtec aims to bring their SMR technology to market efficiently, capitalize on cost reductions, and expand their project portfolio.

7. Holtec Q&A:

Rep. Michael Harrington: Why did Holtec choose a two-part licensing approach instead of a combined license like Vogtle?

Gareth Thomas, Holtec: The combined construction and operating license can have its challenges. At Vogtle, they certified the design but encountered difficulties in making design changes during construction. They had to go back to the NRC for approval, which caused delays. So we opted for a two-part licensing approach to avoid such issues.

Rep Michael Harrington: Does Holtec take on the construction cost risks in the PPA model? Would you bear the consequences of cost overruns or benefit from cost savings?

Gareth Thomas, Holtec: Yes, in the model we presented for the Oyster Creek project, we would be liable for the construction costs. We would negotiate power purchase agreements (PPAs) with a utility, and any cost overruns or savings would be our responsibility.

Rep Michael Harrington: This seems like a significant change in the way nuclear plants are built. Could you elaborate on that?

Gareth Thomas, Holtec: Indeed, it is a substantial change. Traditionally, nuclear plants have involved owner-operators and risk-sharing approaches. However, currently, there aren't many owner-operators in the US willing to build the first-of-a-kind SMRs. We are exploring options and engaging with potential partners. If those discussions don't progress, we have the Oyster Creek project as an option.

Rep Michael Harrington: Could you provide more information about the Oyster Creek project and its implications for the merchant plant model?

Gareth Thomas, Holtec: The Oyster Creek project follows a merchant plant model. It involves negotiating with utilities and assuming the risks associated with construction costs.

Rep Michael Harrington: New Hampshire is a merchant plan market as well and would have to explore a similar model for its nuclear projects.

Rep Keith Ammon: How is Holtec interfacing with recent federal programs like the Inflation Reduction Act?

Gareth Thomas, Holtec: We have been evaluating the impact of the Inflation Reduction Act and other federal programs on our projects. While I may not have all the details, it has allowed us to assess the potential financial benefits, such as the tax credit. The exact dollar amount per megawatt hour is something we have been analyzing, and it appears that with the Inflation Reduction Act and associated credits, the cost could increase from around $45 to potentially $80 or $90 per megawatt hour. I recommend reaching out to me offline, and I can connect you with the relevant person at Holtec for a more detailed answer.

Rep Keith Ammon: Holtec has expertise in handling nuclear waste, as seen with the recent project in New Mexico for temporary storage. Could you share some insights on this aspect?

Gareth Thomas, Holtec: Our owner has been passionate about consolidating spent nuclear fuel at a central facility instead of storing it at multiple sites across the country. This approach allows for the decommissioning of sites and frees them up for redevelopment or other purposes. Licensing a central facility provides our existing clients, like those in California looking to exit nuclear, with the option to move their fuel to our facility in New Mexico. For the sites we acquire and decommission, it enables us to transfer the fuel to the central facility and release the site for other uses or SMR development. We have obtained the license, and the next step will be identifying the first customer, which will determine the construction timeline.

8. American Nuclear Society (ANS) Q&A:

Rep Doug Thomas: How does Holtec plan to introduce the nuclear science curriculum to schools across the states?

Craig Piercy, ANS: We have already developed a K-12 curriculum in partnership with the Department of Energy and Discovery Education. This curriculum, called Navigating Nuclear, is available on our website ans.org and covers elementary, middle, and high school levels. It aligns with the Next Generation Science Standards. While each state has its own specific education policies, our goal is to provide teachers with the necessary resources and materials to teach nuclear science effectively. We are working on expanding our resources, including physical materials like Geiger counters and cloud chambers, to support teachers in delivering the curriculum. Additionally, we have programs like nuclear ambassadors and the Pathways to Nuclear program to further engage students and provide them with additional resources for their interests in nuclear science.

Rep Keith Ammon: Does the curriculum implementation depend on individual state education policies?

Craig Piercy, ANS: Yes, the implementation of the curriculum can be influenced by state education policies. Our focus is on providing materials and training for teachers, but to ensure successful adoption, engagement at the state level is important. We need to work together to ensure that standards-aligned lessons can be taught and encouraged in classrooms as much as possible. While we are not currently at that stage as an organization, we are open to exploring opportunities and ideas to assist schools in New Hampshire or any other state.

Rep Keith Ammon: Are there programs available at the university level that address workforce development needs for nuclear plants?

Craig Piercy, ANS: Our curriculum development primarily focuses on the high school level. However, we are working on certification activities for professionals interested in transitioning into the nuclear field. This certification program aims to provide the necessary knowledge in nuclear science, regulatory systems, reactor operations, fuel cycle, radiation, and radioactivity. Our goal is to support professionals from related fields, like electrical engineers, who can bring their expertise to the nuclear industry with a solid understanding of its broader context. While universities play a significant role in nuclear education, including nuclear engineering programs, workforce development for tradespeople necessary for plant construction is also a priority. Programs supported by the Nuclear Energy Institute, Nuclear Regulatory Commission, and Department of Energy at two-year institutions are helping to increase the supply of qualified workers.

Rep Michael Harrington: Considering past challenges with projects like Vogtle, is this our last opportunity for non-government funded nuclear plants?

Craig Piercy, ANS: While it may be too stark to say it's the last chance, there is a recognition that we need to learn from past mistakes. We have to improve business practices and regulatory approaches to ensure projects are completed on time and within budget. Small modular reactors (SMRs), especially those built in a factory environment, offer opportunities for increased efficiency and cost competitiveness. However, industry must set realistic expectations and regulators must act in a timely manner. While it's challenging, the combination of lessons learned, improved practices, and factory production can provide a good opportunity for success.

Rep Michael Harrington: With safety-related components in SMRs, how do you see the qualification of these parts through part 21? Will there be a third party involved or will each designer and manufacturer need to qualify the parts themselves?

Craig Piercy, ANS: While not my area of expertise, I believe it will be a combination of both. There is an opportunity for companies within the industry to specialize in qualifying safety-related parts and providing those services. It may involve a mix of third-party qualifications and internal qualification efforts by designers and manufacturers like Westinghouse and Holtec.

Bart Fromuth: What can we do at a state level to promote nuclear technologies in New Hampshire, such as changes in our renewable portfolio standard?

Craig Piercy, ANS: State policies should be technology neutral and avoid barriers to nuclear development. Changes to the RPS/CES to support clean firm dispatchable energy in a technology-neutral manner would be beneficial. Engaging with interested entities and creating an environment that prioritizes clean firm dispatchable energy will foster competition and encourage nuclear technologies to be ready to compete.

Marc Brown: What contributes to South Korea's success in building economically viable nuclear plants?

Craig Piercy, ANS: South Korea's success cannot be solely attributed to nuclear technology itself. While projects like Vogtle in the US face challenges, it is not a fundamental issue with the technology. South Korea has shown efficient execution of projects, and similar plants in China are built on time and on budget. The US needs to address the execution of large-scale projects to improve outcomes and cost-effectiveness. The focus should be on project execution rather than inherent problems with nuclear technology.

Pradip Chattopadhyay: Can you provide more information about heat pipe reactors and nuclear batteries?

Craig Piercy, ANS: Heat pipe reactors are small, self-contained reactors with no moving parts that can be deployed in remote locations. They generate heat and can provide clean energy without operator intervention for several years. Nuclear batteries are a concept where small reactors are used to power individual homes or facilities for extended periods. These technologies are being developed by companies like Westinghouse and Oklo, although they are not yet commercially available.

Paul Gunter, Beyond Nuclear: What is the American Nuclear Society's position on consensus-based sighting for high-level radioactive waste repositories, specifically in relation to the Cardigan Pluton site in New Hampshire?

Craig Piercy, ANS: The Department of Energy is pursuing a consent-based process for interim storage facilities rather than new repositories. The focus is on finding willing host communities for storage rather than selecting new sites. The American Nuclear Society emphasizes the importance of defining safety standards and engaging in discussions about repository options. At present, there is no active discussion within the DOE about selecting a new repository. The emphasis is on innovation and giving technology time to develop.

9. Discussion:

During the discussion, Rep Keith Ammon mentioned a question raised in the Zoom chat by Timothy Smyth about restarting the Seabrook Science Center. Rep Michael Harrington and Rep Keith Ammon reminisced about their past visits to the center. Rep Steven Bogert, a visitor from the Public Works Commission, shared his experience visiting a nuclear reactor in North Carolina and emphasized the importance of educating the public to alleviate fears and prevent legal complications.

Rep Michael Harrington highlighted the difference between vertically integrated utilities like Duke in North Carolina, which can pass on education costs to ratepayers, and merchant plant states like New Hampshire, where such costs come directly from profits. Marc Brown suggested exploring funding options for education, possibly through the Department of Energy.

Dick Barry clarified his question about spending on spent fuel reserves, mentioning a friend who served on nuclear-powered submarines without any issues from radiation. Rep Keith Ammon and Dick Barry discussed the safety of living near a nuclear reactor for extended periods in a submarine underwater.

Rep Michael Harrington brought up the analysis group report on Seabrook that highlighted potential cost savings for Massachusetts ratepayers through long-term contracts with Massachusetts utilities. Don Kreis, the State Consumer Advocate, expressed interest in the commission's work and emphasized the industry is expressing a need for government support to de-risk the advanced nuclear industry financially.

Rep Keith Ammon mentioned the possibility of adding nuclear power to the state's renewable portfolio standard, and Don Kreis expressed his duty to ensure that New Hampshire ratepayers are not burdened by the energy policies of other states. They discussed the importance of addressing ratepayer interests and securing clean, baseload power.

Rep Keith Ammon informed the attendees about the premiere of Oliver Stone's Nuclear Now movie, which explored the history and potential of nuclear power. He mentioned he will notify the group if when finds out the movie available for streaming.

Rep Keith Ammon provided an update on the vacant position in existing NH statutes related to the "peaceful use of atomic energy," stating that he will follow up further with the Executive Council and Governor's office for further information and report any updates.

10. A motion to adjourn was made by Rep Harrington and seconded by Bart Fromuth. The motion passed by voice vote and the meeting was adjourned at 11:10 AM. Minutes submitted by Keith Ammon

## June 19, 2023, Meeting

### *Overview*

The June 19, 2023, meeting featured presentations by Lightbridge Corporation on their advanced nuclear fuel design using high assay low enriched uranium, and by Matthew Wald on emerging fission and fusion reactor technologies. Other agenda items included an overview of the refueling process at Seabrook Nuclear Power Plant, a proposed site tour for commission members, discussion of potential topics for future meetings, public comments, and planning for the next monthly session in early August.

Meeting event page: https://nuclearnh.energy/event/regular-meeting-june-19-2023/

### *Minutes*

**Attendance**:

<u>Commission Members</u>: Rep Keith Ammon, Cathy Beahm, Bart Fromuth, Daniel Goldner, Rep Michael Harrington, Matthew Levander, Christopher McLarnon, Mikael Pyrtel

<u>Absent</u>: Marc Brown, Sen Howard Pearl, David Shulock

<u>Public In-Person</u>: Mailly Douglas, Rep Alvin See

<u>Public Remote:</u> Matthew Abenante Lightbridge, Christine Csizmadia NEI, Brendan Flaherty, Seth Grae Lightbridge, Andrew Harmon, Jeremy Hitchcock, Vikram Mansharamani, Nathan Raike, Walt Stapleton, John Tuthill, Matt Wald,

**Meeting**:

1. The Commission to Investigate the Implementation of Next Generation Nuclear Reactor Technology in New Hampshire meeting was called to order by Rep Keith Ammon at 9:03 am. The commission had a quorum present.
2. Rep Ammon welcomed new member, Mikael Pyrtel, representative for the NH Department of Business and Economic Affairs.
3. Approval of the minutes from the May 12$^{th}$ meeting was moved by Bart Fromuth, seconded by Chris McLarnon. The minutes were approved by voice vote. Dan Goldner and Mikael Pyrtel abstained.
4. Presentation by Seth Grae of Lightbridge Corporation
    a. Introduction
        - Seth Grae, the CEO of Lightbridge Corporation, introduced himself and provided an overview of the company's focus on designing advanced fuels for existing and small modular reactors. He expressed his pleasure in joining the Nuclear New Hampshire Study Commission and acknowledged the presence of Matt Wald, a renowned analyst and writer in the nuclear power industry. Seth Grae mentioned his readiness to address any questions and comments from the attendees.

    b. Overview of Lightbridge's Fuel Design and Benefits
        - S.G. shared detailed information about Lightbridge's fuel design. He explained that the company aims to reimagine and redesign nuclear fuel by utilizing new metallurgy and scientific advancements. The fuel is designed to enhance the economics, proliferation resistance, and safety of nuclear power. S.G. discussed the ability of Lightbridge fuel to support the load-following capabilities of reactors, enabling them to work in conjunction with renewable energy sources on a zero-carbon grid.

    c. Potential Application of Lightbridge Fuel

- S.G. discussed the applicability of Lightbridge fuel in existing reactors and small modular reactors (SMRs) with similar technologies. He presented images of fuel rods and fuel assemblies developed by Lightbridge, emphasizing the use of high assay, low enriched uranium (HALEU). This type of fuel allows for longer fuel cycles, reducing the frequency of reactor shutdowns and increasing electricity production. He highlighted the absence of a fuel clad gap in Lightbridge fuel, reducing the risk of burst release of radioactive materials.

d. Partnerships with National Laboratories
   - S.G. provided an update on Lightbridge's strategic partnerships with Idaho National Laboratory and Pacific Northwest National Laboratory. He explained that the company is manufacturing fuel samples and conducting testing at these facilities. The long-term partnership with Idaho National Laboratory and the US Department of Energy is a pioneering collaboration that allows for data utilization in the licensing process and industry acceptance of Lightbridge's fuel.

e. Commercialization Pathways and Target Markets
   - S.G. discussed the commercialization pathways for Lightbridge fuel. He mentioned the interest in replacing Russian fuel supply in central and eastern Europe with fuel from friendlier countries. He also highlighted the potential market for Lightbridge fuel in small modular reactors, emphasizing its economic advantages, improved power output, and reduced cost per unit of electricity produced. He mentioned ongoing evaluations of different reactor types to determine the best commercial customers for Lightbridge fuel.

f. Role of Small Modular Reactors in the Energy Transition
   - S.G. expressed his belief that small modular reactors (SMRs) are crucial for the global energy transition. He discussed the energy density advantage of nuclear power and its importance in meeting clean energy goals. He presented an image of NuScale's Voyager SMR and explained Lightbridge's collaboration with MIT and NuScale for fuel development. He emphasized the potential benefits of SMRs in various industries, such as industrial processes and desalination, and their ability to support local grid resilience.

g. Coal-to-Nuclear Transition and SMRs
   - S.G. discussed the feasibility of transitioning retired coal plant sites to small modular reactors. He shared insights on the benefits of repurposing existing infrastructure and grid connections, potentially reducing costs and accelerating the deployment of SMRs. The economic and environmental advantages of utilizing SMRs in areas where coal plants are being retired were examined, with a focus on job creation and carbon emissions reduction.

h. Economic and Strategic Advantages of Lightbridge Fuel
   - S.G. addressed questions regarding the cost competitiveness of Lightbridge fuel compared to other fuel designs. He highlighted the potential for reduced operational costs and increased revenue from longer fuel cycles, leading to enhanced profitability for nuclear power plant operators. The strategic benefits of domestic fuel supply and reduced dependence on foreign sources were also emphasized.

i. Milestones and Timeline for Lightbridge's Fuel Development
   - S.G. provided an update on recent milestones achieved by Lightbridge in fuel development. He discussed the progress in manufacturing fuel samples and the ongoing testing programs at Idaho National Laboratory and Pacific Northwest

National Laboratory. He presented a timeline that outlines the key steps leading to the commercialization of Lightbridge fuel.

j. Conclusion
   - S.G. addressed inquiries regarding the regulatory approval process, intellectual property protection, and the potential impact of Lightbridge fuel on non-proliferation efforts. He encouraged questions and comments from the attendees and provided Lightbridge's contact information for further communication (ir@ltbridge.com).

5. Lightbridge Q&A:

Rep Keith Ammon: For the spent fuel, what happens to it? Could you provide more details on its life cycle?

Seth Grae, Lightbridge: The fuel is designed to be handled similarly to current fuel. After use, it would be stored in spent fuel pools at reactors or transferred to dry cask storage. Eventually, it would be sent to a high-level waste repository or interim storage. The fuel could also undergo pyroprocessing, a non-proliferative method of reprocessing, which keeps plutonium mixed with other isotopes that are difficult to separate. Lightbridge fuel produces significantly less plutonium than current fuel and in a non-weaponizable isotopic mixture, even if reprocessed. Independent studies have confirmed the non-weaponizability of Lightbridge fuel, and we are further exploring its benefits in reprocessing our own fuel and handling reprocessed materials from other fuels.

Rep Michael Harrington: The average wholesale price you mentioned seems high compared to recent prices. Can you explain?

Seth Grae, Lightbridge: The price figure we presented is based on a 15-year average and forward projections. At any given moment, prices may vary regionally. However, we are considering a long-term perspective spanning a hundred years. The figure is based on government agency data and forecasts, taking into account different factors influencing pricing.

Rep Michael Harrington: Regarding load-following capabilities, how does the design address the limitations posed by existing reactors with pressure vessels and the ability to heat up and cool down quickly?

Seth Grae, Lightbridge: Load-following capabilities in existing reactors would see some improvement, but it would still be limited due to the existing equipment's constraints. However, in small modular reactors (SMRs) specifically designed to handle power surges and fluctuations, the load-following capabilities would be significantly enhanced. SMRs equipped with Lightbridge fuel could effectively integrate with renewable energy sources on a zero-carbon grid.

Rep Michael Harrington: The fuel source is a concern. Where will the enriched uranium come from? Is there a market for it?

Seth Grae, Lightbridge: The enrichment level required depends on the reactor type. For pressurized heavy water reactors like CANDU, our fuel uses less than 5% enrichment, which is readily available worldwide. For light water reactors such as PWRs and BWRs, our fuel uses high assay, low enriched uranium up to 19.75% enrichment. The uranium enrichment infrastructure currently exists but needs to be expanded to meet future demand. Companies hesitate to invest in capacity expansion without clear market signals. However, Urenco, for example, is actively considering additional enrichment capacity in New Mexico, awaiting increased demand from the industry. Building more capacity is a matter of time and investment rather than new technology.

Daniel Goldner: How does patenting your IP protect it from foreign entities copying it?

Seth Grae, Lightbridge: Patenting our intellectual property provides several advantages. It facilitates easier public discussion, release of data, and independent confirmation. While it is possible for foreign entities to access the technology through other means, patenting allows us to manage and protect our IP more effectively. In the nuclear fuel market, there are few producers worldwide, and even countries like Russia and China have become more responsible in handling IP, especially as they seek to expand their exports. Global patenting restricts their ability to export to countries where we hold patents, even if they intended to violate them.

6. Presentation by Matthew Wald
    a. Introduction
        - Matt Wald introduced himself as a non-engineer with extensive experience in the nuclear industry. He mentioned his affiliations with the American Nuclear Society and the Breakthrough Institute but clarified that he was not representing them in the meeting. He provided an overview of his experience with various reactors and new designs.
    b. Emerging Nuclear Landscape
        - Matt Wald discussed the growing demand for nuclear energy due to the need to reduce carbon emissions. He presented a chart from the Nuclear Energy Institute showing utility pledges to decarbonize electricity production. He highlighted the potential role of advanced nuclear reactors in meeting these goals.
    c. Fusion Reactors
        - Matt Wald mentioned the recent breakthrough in fusion reactor technology by the Department of Energy. He clarified that fusion reactors still face significant challenges in terms of scalability and fuel requirements. He noted the production of highly radioactive waste by fusion reactors.
    d. Fission Reactors
        - Matt Wald described the different categories of fission reactors based on innovation and nearness to commercialization. He introduced three reactors (NuScale, GE Hitachi BWRX, Westinghouse AP 300) as the closest to being commercially available. He highlighted their use of commercially available fuel, light water for neutron moderation and heat transfer, and their smaller and more flexible designs.
    e. Second Wave Reactors
        - Matt Wald presented two reactors (X-energy XE 100, Natrium) as more innovative and representing the second wave of new reactors. He discussed the unique features of these reactors, such as higher temperatures, alternative cooling methods, and the ability to provide process heat.
    f. Future Developments
        - Matt Wald mentioned the possibility of reactors like Kairos and microreactors becoming viable in the future. He noted the specific applications of microreactors in remote areas, mining operations, military bases, and computer centers.
    g. Detailed Descriptions
        - Matt Wald provided a detailed description of NuScale's reactor design and its advantages in terms of safety, ease of manufacturing, and flexible power output. He explained the features of GE Hitachi BWRX and Westinghouse AP 300 reactors, emphasizing their use of existing technology and passively safe designs.
    h. Natrium Reactor
        - Matt Wald discussed the Natrium reactor's ability to provide steady power and balance intermittent renewable energy sources like solar. He explained its use of a

thermal battery system with a salt heat transfer medium. He highlighted its potential to reduce the reliance on natural gas power plants for grid stability.

i. Pebble Bed Reactors
   - Matt Wald introduced X-energy's pebble bed reactor and its advantages, such as high-temperature operation and continuous refueling without shutdown. He mentioned the challenges related to fuel enrichment and the need for further development.

j. Other Reactor Designs
   - Matt Wald briefly mentioned Moltex and Terra Power's molten fluoride salt reactors, which are still in the early stages of development. He highlighted the common characteristics of emerging reactors, including black start capabilities, lower-pressure systems, and modular construction.

k. Conclusion
   - Matt Wald concluded the presentation and provided contact information for further inquiries (Matthew.L.Wald@gmail.com).

7. Matt Wald Q&A

Rep Michael Harrington: Can you provide any additional information on Centrus obtaining NRC approval for their uranium and HALEU production demonstration plant?

Matt Wald: Centrus is a company that emerged from bankruptcy after the government sold off the enriched uranium production business. They have a design divergence in their centrifuges, which are taller and more efficient compared to other models. Centrus has a preliminary cascade set up but requires significant funding to begin production. They would likely take enriched material from Urenco and further enrich it to meet the demands of new reactors. However, this process stops short of reaching military-grade levels.

Rep Michael Harrington: How will the chicken and egg scenario of HALEU production and reactor development be resolved? Will the federal government or private industry step in to fund it?

Matt Wald: The federal government is providing substantial subsidies to private industry, such as X-energy and Natrium, for the construction of advanced reactors. The government will act as a middleman, ordering a certain amount of HALEU and selling it to bridge the gap between HALEU production and reactor development. However, the budgetary challenges and dysfunction in Congress may delay the process, making it difficult to predict the timeline for government intervention.

Rep Michael Harrington: Is the federal government the primary source of funding for these endeavors, or can private industry like Dow Chemical contribute as well?

Matt Wald: Private industry, like Dow Chemical, is receiving significant funding from the federal government for their nuclear projects. The government's role in making low enriched fuel available incentivized private industry to enter the nuclear sector. However, the government will likely have to play a crucial role in providing funding and ensuring a market for HALEU until the industry reaches a self-sustaining point. The exact timing of government intervention remains uncertain due to budgetary challenges and political dynamics.

Rep Keith Ammon: Are there any other options or resources available to address the challenges in nuclear fuel production and supply?

Matt Wald: The government has resources at its disposal but has not effectively deployed them in the past. For instance, there is a surplus of weapons-grade plutonium that could be utilized in fast reactors to alleviate the shortage of enriched uranium. However, the technical complexities and cost considerations have hindered progress in this area. It is crucial to develop alternative sources of enriched uranium, as relying solely on unstable suppliers like Russia poses risks to the supply chain.

Rep Keith Ammon: Does fusion, despite being a future prospect, produce any radioactive byproducts?

Matt Wald: Yes, fusion reactions do produce radioactive byproducts. When atoms fuse, neutrons are released and can be captured by surrounding metal elements, causing them to become radioactive. While fusion does not generate residual heat like fission reactors, it does produce radioactive materials.

Rep Keith Ammon: In the recent heralded fusion experiment, did they achieve more energy output than the input?

Matt Wald: Yes, in the recent fusion experiment, they managed to achieve slightly more energy output than the input. However, it is important to note that fusion as a practical energy source is still uncertain. While investments should be made to explore its potential, it is advisable not to solely rely on fusion and consider other economically viable alternatives.

8. Discussion of Seabrook Refueling Process
    a. Matt Levander, who works at Seabrook, provided an overview of the refueling process at the power plant. He explained that Seabrook refuels every 18 months, with typical industry refueling outage duration ranging from 20 to 40 days. During this period, maintenance tasks that cannot be performed while the plant is operational are carried out. One-third of the core is replaced, while the remaining two-thirds continue to operate. The replaced fuel is stored in a spent fuel pool for several years before being transferred to dry cask storage on-site. Matt Levander highlighted specific maintenance work conducted during the recent 38-day refueling outage, such as reactor vessel head peening and steam generator bowl drain weld overlays.
    b. Rep Michael Harrington inquired about the consideration of longer fuel cycles and increased energy output at Seabrook. Matt Levander mentioned that although such options have been explored in the past, Seabrook is not currently pursuing two-year fuel cycles. He acknowledged that other NextEra-owned plants might be considering this approach but was uncertain about the reasons behind Seabrook's decision.
9. Potential Tour of Seabrook Nuclear Power Plant
    a. Rep Keith Ammon proposed organizing a tour of Seabrook for the commission members in July. He emphasized that participation would be voluntary but encouraged the members to take advantage of the opportunity to witness the turbines, buildings, and potential expansion areas at Seabrook. The tour could provide valuable insights into the power plant's operations and potential future developments.
10. Future Meeting Schedule and Topics
    a. Rep Keith Ammon discussed the upcoming meetings scheduled from August to November. He suggested selecting a regular meeting day, preferably the first or second Monday of the month. The proposed meeting time was 9:00 AM. Cathy confirmed that this timing would work for her.
    b. Rep Keith Ammon mentioned several topics to be covered in future meetings, including presentations on federal funding opportunities, siting considerations for interconnections with the grid, and discussions on large flexible loads, such as hydrogen production and

molten salt energy storage. He also mentioned having representatives from fusion companies, such as Helion and Zap Energy, present to the commission. Rep Michael Harrington raised the idea of exploring energy storage systems, and Rep Keith Ammon acknowledged its significance.

11. Public Comment
    a. Douglas Mailey raised a question about load leveling and whether it was necessary to have non-renewable sources, such as gas or nuclear, balancing the intermittent output of renewable energy. Rep Michael Harrington explained that the current push for renewable energy, coupled with the intermittent nature of wind and solar, necessitated backup sources to ensure a stable power supply. He highlighted the importance of striking a balance and the challenges associated with solely relying on renewables. Rep Keith Ammon mentioned the subsidies and guaranteed purchase power agreements associated with offshore wind projects and how the cost factors influenced.
12. The meeting was adjourned at 10:58 AM. A vote to adjourn was not taken due to a fire drill occurring. Members had to immediately vacate the building.
    Minutes submitted by Keith Ammon.

## August 7, 2023, Meeting

### *Overview*

The August 7th meeting featured presentations by Department of Energy (DOE) representatives, including Chris Lohse of the Gateway for Accelerated Innovation in Nuclear (GAIN) program. Lohse discussed the program's outreach, industry tracking, workshops, and voucher system for nuclear R&D funding, which now includes support for utilities and other end users. Julie Kozeracki, Senior Loan Program Advisor, highlighted the DOE Loan Programs Office's substantial financing capacity for new nuclear projects and presented a report advocating for the expansion of nuclear energy for low-carbon electricity generation. Dr. Billy Valderrama from the DOE Office of Nuclear Energy provided updates on the office's priorities related to existing and advanced nuclear reactors, fuel supply chain issues, international cooperation, federal funding increases for nuclear R&D, and initiatives concerning hydrogen production demonstrations and microreactor testing across multiple states.

Meeting event page: https://nuclearnh.energy/event/regular-meeting-august-7-2023/

### *Minutes*

**Attendance:**

Commission Members: Rep. Keith Ammon, Cathy Beahm, Marc Brown, Daniel Goldner, Rep. Michael Harrington, Matthew Levander, Christopher McLarnon, Mikael Pyrtel (zoom), David Shulock

Absent: Bart Fromuth, Sen. Howard Pearl

Public In-Person: Mailly Douglas, Rep Alvin See, Elizabeth McKenna (Office of Sen. Jeanne Shaheen), Emma Greenberg (Office of Sen. Maggie Hassan), Tom Barrasso (NH Department of Administrative Services), Dr. Billy Valderrama (DOE Office of Nuclear Energy), Christopher Robert (UNH)

Public Remote: Adam Schmidt (J. Grimbilas Strategic Solutions), Cathy Wolff, Cheryl Herman, Chris Lohse - GAIN, Christine King GAIN, John Tuthill, Judith Kaufman, Julie Kozeracki, Marielle Kaifer, Molly (no surname), Nathan Raike, Nelia (no surname), Paul Gunter (Beyond Nuclear), Ryan Duncan (Last Energy), Sebastian Rowan, Shannon Kang, Walt Stapleton

**Meeting:**

1. Call to Order
    - The meeting was called to order at 9:06 AM by Rep. Keith Ammon. The commission had a quorum present.
2. Presentation by Chris Lohse from the Gateway for Accelerated Innovation in Nuclear (GAIN) Program
    - GAIN provides outreach and technical support to states, companies, and organizations interested in advanced nuclear technology. They track industry developments and offer workshops, webinars, etc.
    - The GAIN voucher program provides up to $500K in R&D funding to connect companies with expertise and capabilities at DOE national labs. Over $30 million has been awarded so far across 50 companies.
    - Vouchers support experimental work, analyses, licensing assistance, and other technical capabilities unique to the national labs. The funds go directly to the labs to perform work for the companies.

- GAIN is supporting preliminary feasibility studies on repurposing coal plants for nuclear power. For example, they are analyzing reactor options and economic impacts for a coal plant in St. Johns, AZ to inform the utility's decisions.
- The voucher program started as a way to assist advanced reactor developers but is expanding to support other end users like utilities, hydrogen producers, and manufacturers.
- In response to a question from Rep. Harrington, Mr. Lohse provided examples of the types of work funded by vouchers, including radiation testing of components, nuclear siting studies, integration analyses, and engineering design assessments.
- Rep. Ammon inquired whether Project Pele is part of the GAIN program. Mr. Lohse clarified that Pele is a separate project under the DOD, not part of GAIN.

3. Presentation by Julie Kozeracki, Senior Advisor with the DOE Loan Programs Office (LPO)
    - Ms. Kozeracki provided information that the LPO has over $300 billion available in loan authority, including $250 billion that was allocated through the Inflation Reduction Act for the Energy Infrastructure Reinvestment Program.
    - She communicated that the LPO is positioned to play a major financing role for new nuclear projects.
    - Ms. Kozeracki summarized the LPO report which made the case for nuclear's value as a firm, low-carbon source of electricity generation.
    - The report projected that approximately 200 gigawatts of new nuclear capacity will likely be needed in the U.S. by 2050.
    - Ms. Kozeracki outlined two key challenges to wide-scale nuclear deployment:
        - The lack of current commercial orders
        - The need for 5-10 nuclear plants of the same design to be built to achieve economies of scale
    - She suggested two possible solutions:
        - Using a consortium model to pool demand
        - Offering cost overrun insurance to incentivize plant orders
    - In response to a question from Rep. Harrington, Ms. Kozeracki noted conversations with merchant nuclear developers in deregulated electricity markets. She highlighted potential synergy in siting reactors at new chip manufacturing facilities which have massive electricity demands.
    - Ms. Kozeracki confirmed to Rep. Ammon that LPO loans are available beyond constructing new reactors, such as for supply chain development, upgrades to existing plants, etc.
4. Presentation by Dr. Billy Valderrama with the DOE Office of Nuclear Energy
    - Dr. Valderrama stated the office's four main priorities are:
        - Keeping the existing U.S. reactor fleet operating
        - Deploying new advanced nuclear reactors
        - Ensuring a secure and sustained nuclear fuel supply chain
        - Expanding international nuclear energy cooperation
    - He discussed that federal funding for nuclear R&D has seen significant bipartisan support from Congress, with the office's budget recently exceeding $1.7 billion.
    - Dr. Valderrama provided an overview of demonstration projects underway to produce hydrogen at existing nuclear plants, aiming to provide new revenue streams.
    - He highlighted the DOE's microreactor test bed and Project Pele with the DOD, which will demonstrate advanced reactor licensing approach separate from the NRC.

- Dr. Valderrama mentioned the DOE is engaging with states on nuclear topics through partnerships like the Advanced Nuclear State Collaborative.

5. Discussion
    - Supply chain readiness challenges for advanced nuclear reactors were discussed.
    - It was noted that NRC licensing is not currently a major bottleneck for advanced reactors, but increased readiness will be needed if many applications are submitted as the industry scales up.
    - The potential to recycle spent nuclear fuel into HALEU fuel for advanced reactors was discussed, but the economics are still unfavorable compared to using enriched uranium.
    - Rep. Ammon provided an update that the commission is working on drafting an interim report summarizing their activities so far.
    - The commission is also planning a September site visit to the Seabrook nuclear plant.
6. Administrative
    - The minutes from the previous June 19, 2023, meeting were approved.
7. Adjournment
    - The meeting was adjourned at 11:00 AM.

Minutes submitted by Keith Ammon.

## September 18, 2023, Meeting

### *Overview*

The September 18, 2023, meeting featured presentations from advanced nuclear technology companies Last Energy and Zap Energy. Last Energy discussed their micro modular reactor design using conventional pressurized water reactor technology and innovative construction methods, while Zap Energy provided an overview of their efforts to commercialize fusion energy through a venture-backed startup approach. There were also discussions around policy options, siting considerations, and infrastructure reuse in the state.

Meeting event page: https://nuclearnh.energy/event/regular-meeting-september-18-2023/

### *Minutes*

**Attendance:**

Commission Members: Rep. Keith Ammon, Catherine Beahm, Bart Fromuth (remote), Daniel Goldner, Matthew Levander (remote), Christopher McLarnon (remote) Sen. Howard Pearl, David Shulock

Absent: Marc Brown, Rep. Michael Harrington

Public In-Person: Hon. Dick Barry, Rep. Alvin See

Public Remote: Parker Alspach, Doug Bogen, Benj Conway, Ryan Duncan (Last Energy), Andy Freeberg (Zap Energy), Paul Gunter (Beyond Nuclear), Judith Kaufman, Phoebe Lind (Last Energy), Vikram Mansharamani, John Tuthill, Ryan Umstattd (Zap Energy), Gary Woods,

**Meeting:**

1. Call to Order
    - The meeting was called to order at 9:05 AM on September 18, 2023. Rep. Ammon noted that this commission was established by the legislature to study various advanced nuclear technologies and their potential applicability in New Hampshire. The meeting was held in Room 208c of the NH Department of Environmental Services offices in Concord, NH with optional Zoom videoconferencing.
2. Presenter: Ryan Duncan, Director of Government Relations, Last Energy
    - Mr. Duncan began by providing background on Last Energy. He explained that the company was founded in 2017 under the name Energy Impact Center, originally conceived as a think tank to research solutions to climate change. After exploring various energy options, they determined that nuclear power offered the most potential to make a significant dent in global carbon emissions.
    - Over the next few years, Duncan explained that Last Energy consulted with nuclear experts in the US and internationally to diagnose the major obstacles facing the industry. They identified three core problems that traditional nuclear projects consistently run into:
        1) Excessively long construction timelines, often taking over a decade.
        2) Massive cost overruns, commonly billions over budget.
        3) Reliance on government funding and large utilities who can finance billion-dollar plants.
    - To tackle these systemic issues, Last Energy developed a new approach combining proven reactor technology with innovative manufacturing and private financing methods adapted from other industries like oil/gas and renewables.
    - Mr. Duncan then provided an overview of their power plant design:

    - Uses conventional pressurized water reactor (PWR) technology that has decades of operating experience globally. This leverages existing supply chains rather than inventing new systems from scratch.
    - Modular construction in a factory setting, with the plant assembled on-site from approximately 40 prefabricated modules. Each module is the size of a standard 18-wheeler trailer for easy transport.
    - Digital instrumentation and control systems reduce the staffing required for plant operation. Some passive cooling methods also help minimize active intervention.
    - Compact footprint of about half an acre for the reactor area itself, reducing physical plant size.
    - 42-year lifetime with built-in spent fuel storage. Fuel assemblies are replaced every 6 years and the used fuel is stored on-site underground. This minimizes transportation and handling.
- Mr. Duncan presented a construction animation showing how the plant can be rapidly assembled on-site from the factory modules. He noted construction can be completed in around 90 days thanks to the modular design.
- Regarding projects, Mr. Duncan stated Last Energy is currently focused on Europe, with $25B worth of power purchase agreements signed for 51 units split between the UK, Poland, and Romania. They are in the pre-licensing phase and will soon enter formal licensing in those countries.
- Mr. Duncan noted they continue to monitor the US market but have not seen the same level of demand and favorable regulations compared to Europe at this stage. However, they plan to utilize the advanced licensing framework currently under development by the NRC for future US projects.
- In closing, Mr. Duncan emphasized their goal is to deliver cost-effective clean energy as fast as possible by leveraging proven technology in an innovative way. Their flexible, modular construction model combined with private financing aims to eliminate the pitfalls that have traditionally plagued large-scale nuclear projects.

Q&A:

- Daniel Goldner: What was the cost of the nuclear plants?
  Ryan Duncan: The plants cost around $100 million each.
- Keith Ammon: How do you control the reactor? Is it preset or actively controlled?
  Ryan Duncan: There is some proprietary passive cooling and physics built into the design, as well as physical construction of the core. He offered to provide more technical details later if desired.
- Keith Ammon: When you replace the fuel unit after 6 years, is the previous unit completely spent?
  Ryan Duncan: No, it won't be completely spent. We are looking into reprocessing the partially spent fuel. The 6-year timeframe is more about our operating model than full depletion of the fuel.
- Paul Gunter: Why aren't you going through the US NRC for licensing?
  Ryan Duncan: We believe licensing in Europe will be faster and less costly than the NRC process. But we are engaging with US stakeholders like the NRC and DOE to keep them informed.

- Paul Gunter: What is your backup power plan for grid failure?
  Ryan Duncan: Let me follow up with details on our backup power and shutdown systems.
- Keith Ammon: Could you use this for a single customer with a small energy need?
  Ryan Duncan: Yes, we can work with single customers, including those with needs as small as 10MW.
- Keith Ammon: Does your design fit into the NRC's advanced nuclear licensing process?
  Ryan Duncan: Yes, we plan to use the advanced licensing process if we decide to license in the US.
- Keith Ammon: What types of customers are you working with - municipalities, industries?
  Ryan Duncan: Mostly heavy industries like manufacturing, data centers, and economic zones with multiple industrial customers.
- Daniel Goldner: What motivates your European customers? Cost, coal replacement?
  Ryan Duncan: A mix - high energy prices, decarbonization goals, energy security and independence.
- Daniel Goldner: What is the levelized cost per kWh?
  Ryan Duncan: Around $70/MWh, but it varies by country and customer deal.
- Daniel Goldner: How close together can the modules be sited?
  Ryan Duncan: About 200 meters between modules if sited together.

3. Presenter: Ryan Umstattd, Head of Business Development, Zap Energy
   - Mr. Umstattd began by noting that fusion energy is fundamentally different from fission power. He stated fusion has minimal radioactive waste and does not have the same meltdown risks as fission reactors.
   - Umstattd explained that Zap Energy was founded to commercialize fusion energy based on research conducted at the University of Washington using a confinement method called a Z-pinch. This involves compressing plasma by running a pulsed electric current through it.
   - He provided a brief overview of how fusion works - light nuclei are fused together to generate energy. Zap Energy uses two isotopes of hydrogen - deuterium and tritium. The resulting reaction produces helium and a free neutron.
   - Umstattd explained that one of Zap's founders stabilized plasma compression by developing a sheared flow technique. This involves flowing the plasma at different velocities within a column, which mitigates inherent instabilities. Their experiments have successfully confined the plasma for significantly longer durations compared to traditional Z-pinches.
   - However, Umstattd cautioned that more research is needed to reach a self-sustaining fusion reaction that produces net energy gain. This scientific breakeven point is known as Q=1. He presented results from their latest experiment, FuZE-Q, showing promising increases in fusion output. But he noted they remain far from the reaction rates needed for a commercial power plant.
   - Regarding the development timeline, Umstattd stated Zap Energy is targeting construction of a pilot plant at a retired coal generation plant in Centralia, Washington in the early 2030s. The plant would demonstrate their reactor at scale and make electricity available to the grid.
   - He presented a conceptual design showing how the core fusion module can be combined with balance of plant components like the steam turbine and electrical generators.

- Umstattd noted they plan to build the plant using a modular approach so the components can be manufactured in factories and shipped to site.
- Umstattd estimated the levelized cost of electricity for their first commercial plants would be in the range of $30-60/MWh. However, he acknowledged substantial uncertainties still remain around their projected cost and timeline.
- In closing, Mr. Umstattd emphasized that rapid fusion progress will come from private efforts like Zap Energy that take a smaller, more agile approach compared to government programs. He reiterated that although significant research is still needed, Zap aims to deliver fusion power on a commercial timescale.

Q&A:

- Keith Ammon asked about the energy breakeven point shown on the graphs presented by Zap Energy and which data on those graphs represented the current status of their fusion experiments.
  Ryan Umstattd provided details on the graphs, explaining that the breakeven point represents when fusion would produce more energy than required for the reaction. He noted that their experiments are nearing the breakeven point scientifically but still have important work to do.
- Keith Ammon asked about the recent fusion breakthrough announced by the Department of Energy and where their result was on Zap Energy's breakeven graphs.
  Ryan Umstattd explained that the DOE result achieved the scientific breakeven line using high-powered lasers but was not on a commercially viable path due to the very high energy input required by the lasers to initiate fusion.
- Keith Ammon asked about the waste handling processes involved with fusion energy generation using Zap Energy's approach.
  Ryan Umstattd provided an explanation of how they recirculate unreacted fuel from each cycle to reuse deuterium and tritium gases that did not fuse. He noted the small amount of low-level radioactive waste produced can be safely stored on site until ready for recycling or disposal.
- Dick Barry asked what the potential cost would be for New Hampshire to host a sample fusion reactor as a pilot project with Zap Energy.
  Ryan Umstattd discussed potentially attractive options for states like joint development agreements to host pilot plants that could later transition to be commercially operational plants.
- Howard Pearl asked if fusion facilities could be sited at former nuclear power plant locations or co-located with existing nuclear plants, given similar security precautions needed.
  Ryan Umstattd discussed public perception issues related to associations between fusion and traditional nuclear fission, but noted technical feasibility of co-location once fusion is more established. He recommended distinguishing fusion currently before directly siting alongside existing nuclear plants.

4. Public Comment
    - Rep. Ammon opened the floor for additional public comments. No comments were made.
5. IV. Draft Commission Report

- Rep. Ammon noted that a draft report was issued and is available on the commission website (https://nuclearnh.energy/). He plans to use the draft as a starting point for the final report.
- Dick Barry had not seen the draft report yet. Rep. Ammon directed him to the link on the website.
- Rep. Ammon stated he has been in discussions with NEI about policy options to include in the final report. One recommendation was to define advanced nuclear in NH statutes to create a foundation for any future policy changes.
- Rep. Ammon drafted legislation to update the state's atomic energy statutes, including adding the federal definition of advanced nuclear. The bill is still in development.
- Rep. Ammon added caveats to the policy options list in the draft report based on feedback from Rep. Harrington. He also added testimony from the Consumer Advocate on market fit for various options.

6. Seabrook Station Tour Debrief
    - The tour of the plant took place on September 5, 2023.
    - Dick Barry noted the excess transmission capacity at Seabrook since only one reactor was built. He suggested siting future nuclear plants closer to load centers to minimize transmission needs.
    - Dan Goldner relayed that Seabrook's operator, NextEra, was not interested in developing the second reactor site.
    - Rep. Ammon and Cathy Beahm discussed NextEra's lack of interest in siting a small modular reactor at Seabrook. Industry may prefer to choose location without nuclear security considerations.
    - The group discussed siting reactors nearer to load centers to minimize transmission needs.
7. Administrative Matters
    - The minutes from the August 7, 2023, meeting was approved unanimously by the 6 members in attendance for the vote (Ammon, Beahm, Fromuth, Goldner, Pearl, Shulock). The motion was made by Fromuth and seconded by Goldner.
8. Next Meeting
    - The next meeting will be on October 2, 2023, at 9:00am.
    - Confirmed speakers so far are ISO New England and Moltex Energy.
9. Adjournment
    - The meeting was adjourned at 10:41 AM by Rep. Ammon.

Minutes submitted by Keith Ammon.

# October 2, 2023, Meeting

## *Overview*

The October 2, 2023, meeting featured presentations from ISO New England on electricity markets and changing grid dynamics, including an overview of the interconnection queue process for new generation resources. Moltex Energy and Ultra Safe Nuclear also presented their advanced reactor and fuel technologies. Commission members were able to engage the presenters with questions regarding forecasting variable renewable generation, prospects for commercial advanced reactors in merchant power markets, and nuclear fuel availability challenges. There were also discussions around the need to better integrate nuclear power into future electricity planning for the region and the importance of energy security and supply chain resilience.

Meeting event page: https://nuclearnh.energy/event/regular-meeting-october-2-2023/

## *Minutes*

**Attendance:**

Commission Members: Rep. Michael Harrington, Catherine Beahm, Marc Brown, August B. Fromuth, Matthew Levander, Christopher McLarnon (remote), David Shulock (remote), Rep. Keith Ammon

Absent: Daniel Goldner, Sen. Howard Pearl

Public In-Person: Thomas Barrasso, Hon. Richard "Dick" Barry, Douglas Mailly, Rep. Alvin See, Rep. Doug Thomas

Public Remote: Arnie Alpert, Andrea (no surname provided), Doug Bogen, Jodi Grimbilas (J. Grimbilas Strategic Solutions), Paul Gunter, Donald "Gus" Gustavson (USNC), Eric Johnson (ISO-NE), Nathan Raike (ISO-NE), Adam Schmidt (J. Grimbilas Strategic Solutions), Rep. Walt Stapleton, Tristan Jackson (Moltex), John Tuthill, Gary Woods

**Meeting:**

1. Call to Order
    - The meeting was called to order by Commission Chair Rep. Keith Ammon at 9:01 AM EST on October 2, 2023. The meeting was held in person at the New Hampshire Department of Environmental Services Office Building in Concord, NH with additional attendees participating via Zoom video conference.
    - Rep. Ammon noted logistical details, such as the use of microphones in the room to facilitate clear audio for both in-person and Zoom attendees, as well as for transcript creation.
    - Rep. Michael Harrington interjected briefly to extend congratulations to Mark Cowell on his retirement through Eric Johnson.
    - Rep. Ammon welcomed everyone to the meeting and noted that the agenda had been distributed via a link in the Zoom chat. He emphasized that the commission has been highly transparent, with all meetings recorded and materials publicly available on the unofficial information portal.
2. Presentation: Mr. Eric Johnson, Vice President of System Planning at ISO New England (ISO-NE).
    a. Overview of ISO-NE:
        - ISO-NE was formed in 1997 during restructuring of the electricity industry to open access to transmission. It is regulated by FERC and has an independent board.

- ISO-NE operates the high-voltage bulk power transmission system across New England, including ties to Quebec, New Brunswick, and New York. It does not own any power system assets itself.
- Its three core responsibilities are: 1) Operating the power grid and maintaining reliability per NERC standards; 2) Administering bid-based wholesale electricity markets for energy, capacity, and ancillary services; 3) Regional power system planning including interconnections.

- ISO-NE's mission is reliable, cost-effective wholesale electricity approved by stakeholders. Its vision is to enable a clean energy transition using markets and new technologies.

b. Electricity Resource Mix:
    - In 2000 at the start of markets, resources were mainly coal, oil, nuclear. Now about half of energy is from natural gas.
    - By 2040/2050, significant renewable expansion will be needed to meet state clean energy goals. One projected scenario shows the nuclear share shrinking while gas stays high, and renewables grow markedly.
    - The generator interconnection queue has over 38,000 MW proposed, mostly offshore wind, battery storage and solar. This is driven by state policies. Not all will necessarily get built.

c. Generator Interconnection Queue Process:
    - The queue manages the sequence of projects seeking to connect to the grid. ISO-NE studies the reliability impacts but does not judge technology types or viability.
    - Steps include optional feasibility study, full system impact study, detailed facility study, and executing an interconnection agreement. The average time is 15 months.
    - Resources can enter the capacity market after the queue, where they may receive additional revenues. State-jurisdictional projects follow different interconnection processes.

d. Integrating Renewables:
    - Adding significant variable resources like wind/solar will require backup power, adequate total energy supply, and expanded transmission.
    - ISO-NE's 2050 Transmission Study shows major grid upgrades needed to meet state electrification goals and the resulting high winter demand.
    - During extreme winter conditions, a mix of nuclear, gas, hydro imports and storage could provide backup if wind/solar output is very low.

Q&A:

- Rep. Harrington: Does the 2040 projection assume no new nuclear plants?
  A: Correct, no new nuclear was assumed in that study.
- Rep. Thomas: Since most queue resources like wind/solar are intermittent, how does ISO-NE factor in reliability when studying proposed interconnections?
  A: The queue process itself does not address overall reliability considerations. ISO-NE has the ability to forecast wind/solar output and understands their operating characteristics. Backup power sources like natural gas and transmission will be needed to integrate them.
- Rep. Harrington: What will be needed for backup power in 20 years if we have 20 GW of offshore wind but low wind/solar output during a winter storm?
  A: A mix of existing nuclear, gas, hydro imports and storage could provide backup during those rare low output periods. The region will need sufficient energy adequacy.

- Rep. Thomas: Why do minor amounts of imported hydro in ISO's projections warrant the siting challenges of proposed transmission line projects?
  A: Each new transmission line could import over 1,000 MW, which is significant relative to total regional energy needs.

3. Presentation: Tristan Jackson, Vice President of Corporate Development, Moltex Energy Canada.
   a. Introduction
      - Tristan Jackson of Moltex Energy presented to the commission about Moltex's nuclear energy technology. He is based in New Brunswick, Canada where Moltex Energy Canada is headquartered.
      - Moltex Energy has two entities - Moltex Energy Limited (UK) is developing a small 16MW reactor that uses fresh enriched uranium fuel. Moltex Energy Canada is developing a different waste-burning reactor.
   b. Moltex Energy Canada's Waste-Burning Reactor
      - The Moltex waste-burning reactor is a Generation IV fast reactor design that utilizes the used fuel from conventional reactors.
      - It separates used CANDU or lightwater reactor fuel bundles into three streams via a chemical separation process:
        - 99% becomes low level waste (uranium, zirconium, cladding)
        - 0.5% remains short-lived high-level waste with 300-year half-life
        - 0.6% is fuel for the Moltex reactor
      - The fuel for the Moltex reactor is a mixed plutonium chloride salt with other actinides. This makes it unsuitable for weapons use, reducing proliferation risk.
      - Moltex plans to build its first reactor at the Point Lepreau nuclear plant in New Brunswick along with a recycling facility. The entire site would fit on 20 acres.
   c. Economics
      - Moltex projects a levelized cost of electricity of $51/MWh for its reactor. Tristan estimates more realistically $70-80/MWh based on experience with large projects. This is competitive with fossil fuels and far cheaper than renewables coupled with storage.
      - The technology has support from the Canadian and US governments. Tax credits in the US Inflation Reduction Act make nuclear power more economically viable.
   d. Potential in New Hampshire/New England
      - New Hampshire and New England could potentially attract investment from Moltex and other advanced nuclear companies, as the region needs new firm power generation.
      - The region could put out an RFP for nuclear proposals, as Canada has done. This resulted in NB Power selecting Moltex.

Q&A:

- Rep. Doug Thomas asked whether the recycling facility needs to be co-located with the reactor or if fuel can be transported. Tristan responded that either approach could work, but co-location reduces transportation risk and logistical issues.
- Rep. Michael Harrington asked technical questions about the reactor being fast neutron versus thermal, and how proliferation risk is minimized. Tristan explained the reactor consumes transuranics over time and the chemical separation process results in a mixed plutonium salt unsuitable for weapons.

- Hon. Dick Barry asked if nuclear was included in recent state energy planning put forward by a previous speaker. Tristan said he didn't believe so, but states could actively solicit nuclear proposals if desired rather than passively accepting developer bids.
- Rep. Keith Ammon asked to see a diagram and about the small 20-acre land footprint. Tristan shared a diagram of the facilities - reactor, recycling, and grid reserve tanks.
- Rep. Keith Ammon inquired about the waste streams produced. Tristan explained in detail the three waste streams (low level, high level, and fuel salt) and disposal options for each.
- Rep. Michael Harrington asked about the projected electricity cost.
- Rep. Doug Thomas asked if Moltex has any signed contracts. Tristan confirmed contracts with NB Power for the site, offtake, and supply chain.

4. Presentation: Donald "Gus" Gustavson, Business Operations Manager for the fuels division at Ultra Safe Nuclear Corporation (USNC).
    a. Introduction
        - Donald "Gus" Gustavson, the business operations manager for the fuels division at Ultra Safe Nuclear Corporation (USNC), presented to the commission about USNC's micro modular reactor (MMR) design and fuel manufacturing capabilities.
        - Gus provided background on himself, including 4 years as a chemical engineer in oil/gas in Houston, 5 years as an army officer, 2 years in strategy consulting, and now 2 years at USNC. Projections on future energy sources while consulting convinced him nuclear power is needed to meet carbon reduction goals, prompting his industry shift.
    b. USNC Overview
        - USNC's mission is to provide carbon-free power for space and commercial applications. Their main focus is the MMR.
        - The MMR is a commercial land-based nuclear battery with variable power output from 1-15 MW electric (10-45 MW thermal) and a 40-year lifetime. It uses proprietary TRISO fuel embedded in silicon carbide pellets made via 3D printing, making it meltdown proof. Target customers include remote communities, mining operations, and server farms.
    c. USNC Fuel Production
        - USNC currently has a pilot TRISO fuel manufacturing facility in Oak Ridge, TN using commercial scale equipment. This strengthens their licensing basis for eventual commercial production.
        - Gus explained the decades-long history and inherent robustness of TRISO fuel, which retains fission products through layers of carbon and silicon carbide coating a uranium kernel.
        - He noted fuel costs are a much bigger proportion of opex for advanced reactors versus traditional reactors but that the fuel itself shoulders much more of the safety burden for retention of fission products and thereby making the reactor itself less costly and complex.
    d. Nuclear Fuel Cycle
        - Gus outlined the nuclear fuel cycle steps - mining, milling, conversion, enrichment, fabrication.
        - Currently the US imports most commercial nuclear fuel as enriched $UF_6$.
        - Deploying advanced reactors needs HALEU fuel and new TRISO production capabilities, requiring licensing changes at every step of the fuel cycle. There is no current US production capacity for HALEU enrichment or TRISO fuel fabrication.
    e. USNC Fuel Partnerships

- USNC has partnered with Urenco for LEU+ enrichment and Framatome for fuel fabrication in a joint venture.
- This partnership accelerates USNC's timeline by leveraging an existing Framatome facility with a current NRC license, as opposed to building a new "greenfield" facility which would require a lengthy licensing process.
- It provides USNC with Framatome's expertise and established infrastructure like material control programs.

f. Licensing Needs

- Gus emphasized that fuel production and transport licensing constraints are often overlooked in advanced nuclear discussions and will require changes to enable commercialization.

Q&A

- Rep. Harrington asked about the "chicken and egg" dilemma around HALEU production - would the government need to procure some first to spur private investment? Gus agreed this is the most likely scenario.
- Rep. Ammon asked if USNC's fuel could be used by other advanced reactor manufacturers. Gus said they are vertically integrated, and the immediate focus is supplying our own Micro Modular Reactor, but they also plan to sell TRISO fuel to other commercial reactor companies and have already sold quantities manufactured from their Pilot Fuel Manufacturing facility.

5. Meeting Minutes Approval
   - Rep. Keith Ammon presented a change in the minutes regarding Zap Energy.
- Original Text: "provide electricity to the grid"
- Modified Text: "make electricity available to the grid"
   - Marc Brown motioned to accept the modified minutes. Seconded by Bart Fromuth.
   - The motion was unanimously approved.
   - Names for the record: Cathy Beahm, Marc Brown, Bart Fromuth, Matt Levander, Michael Harrington, and Rep. Keith Ammon.
6. Old Business
   - Rep. Keith Ammon mentioned correspondence with Ryan Duncan of Last Energy.
   - Ryan Duncan followed up on a previously unanswered question.
   - The information was or will be forwarded to the commission members.
7. Scheduling Final Meeting
   - The final meeting is scheduled for November 6th.
   - The location might change due to facility maintenance.
   - Marc Brown offered to invite New Core to talk about their MLU with NuScale.
   - Rep. Keith Ammon requested confirmation within a week.
8. Miscellaneous Information Sharing
   - Michael Vose's link to a webinar on fuel recycling was shared.
     - Rep. Keith Ammon mentioned the $10 trillion worth of "slightly used nuclear fuel" in the country that can potentially be reprocessed.
     - https://centerforsecuritypolicy.org/webinar-clean-energy-is-a-terrible-thing-to-waste/
   - Rep. Michael Harrington expressed skepticism on fuel reprocessing due to cost and proliferation concerns.
9. Future Directions

        - Hon. Dick Barry expressed disappointment that ISO New England has not sought nuclear proposals.
    - Suggested the commission encourage ISO New England to do so.
        - Rep. Keith Ammon introduced a bill to update RSA (Revised Statutes Annotated) to require periodic studies on advanced nuclear.

10. Other Topics for Information Gathering
    - Rep. Michael Harrington offered access to the American Nuclear Society database for topics of interest. https://www.ans.org/webinars/view-opp2023/
11. Adjournment
    - Rep. Ammon requested a motion to adjourn the meeting. The motion was made by Rep. Harrington and seconded by Marc Brown. The meeting was adjourned by unanimous consent. The meeting was adjourned at 12:25 PM.

Minutes submitted by Keith Ammon

# November 6, 2023, Meeting

## *Overview*

The November 6 meeting featured presentations from Ryan McLeod of Canadian Nuclear Laboratories on using nuclear reactors to power Bitcoin mining operations and improve the economics of small modular reactors, James Walker of NANO Nuclear Energy on their passively-cooled microreactor technology that can fit in a shipping container for remote deployments, and Evan Cummings of Kairos Power on their 140MW molten salt cooled small modular reactor currently going through licensing with the NRC; there were discussions around utilizing advanced nuclear reactors like these to provide carbon-free, always-on energy for large and growing computing projects needed for AI modeling and Bitcoin mining data centers.

Meeting event page: https://nuclearnh.energy/event/regular-meeting-november-6-2023/

## *Minutes*

**Attendance:**

Commission Members: Catherine Beahm, August B. Fromuth (remote), Daniel Goldner, Matthew Levander, Sen. Howard Pearl, David Shulock, Rep. Keith Ammon

Absent: Marc Brown, Rep. Michael Harrington, Christopher McLarnon

Public In-Person: Thomas Barrasso, Hon. Richard “Dick” Barry, Douglas Mailly, Rep. Alvin See

Public Remote: Arnie Alpert, Evan Cummings (Kairos), Paul Gunter, Chris Heck, Ryan McLeod (CNL), Nathan Raike (ISO-NE), Adam Schmidt (J. Grimbilas Strategic Solutions), John Tuthill, James Walker (NANO)

**Meeting:**

1. Call to Order
    - The meeting was called to order by Representative Keith Ammon at 9:03 AM EST on November 6, 2023. The meeting was held in person at the New Hampshire Department of Environmental Services Office Building in Concord, NH with additional attendees participating via Zoom video conference.
2. Presentation: Ryan McLeod, Chemical Technologist at Canadian Nuclear Laboratories. Topic: Nuclear Technology and Bitcoin Mining
    a. Introduction
        - Ryan McLeod works as a chemical technologist at Canadian Nuclear Laboratories (CNL), a nuclear research company owned by Atomic Energy of Canada Limited (AECL), which is itself owned by the government of Canada [1].
        - He assembled a team and entered the Innovation for Nuclear contest hosted by the North American Young Generation in Nuclear (NAYGN) organization [2].
        - The contest sought ideas on how nuclear power and small modular reactors (SMRs) could help meet the United Nations Sustainable Development Goals.
        - Ryan’s winning entry proposed using Bitcoin mining as a flexible electricity load to support the deployment of nuclear reactors by guaranteeing demand.
    b. The Evolving Role of Nuclear Power
        - Many countries are concerned about having reliable, affordable, low-carbon emission energy sources to provide security for the electricity supply.
        - Nuclear power is seen as an obvious solution to help displace fossil fuels and meet sustainability targets.
        - Now is an opportune time to build more large-scale conventional nuclear reactors.

- Also, there is a chance to deploy next-generation small modular nuclear reactors (SMRs) at underserved sites.
- Canada is explicitly looking to expand nuclear generation capacity materially in the coming years.
- The Canadian government is courting companies like NuScale, Moltex, ARC Clean Energy, and Ultra Safe Nuclear Corporation to build small modular reactors (SMRs) for remote communities and mines [3].
- Meredith Angwin authored a book called "Shorting the Grid, " highlighting the complex challenges grid managers face with renewables integration, which energy storage and demand response seek to solve [4].
- Canadian Nuclear Laboratories has an internal modeling team examining the potential for pairing SMRs with intermittent renewables, energy storage, and other technologies into off-grid hybrid energy systems.

c. Potential Benefits of Integrating Bitcoin Mining with Nuclear Plants
   - Provides guaranteed electricity customers for purchasing nuclear plant output when online, regardless of whether transmission lines are ready to connect the facility to the wider grid.
   - Having financial certainty of a buyer in place improves investor confidence in capital-intensive new nuclear construction projects by contractually ensuring a revenue stream.
   - Recent trend of institutional investors expanding into the crypto asset class further enables major Bitcoin mining operations to serve as anchor customers for small modular reactor plant operators.
   - In addition to monetizing excess energy, Bitcoin mining serves as a financial incentive for miners to contribute extra computing resources to protect the security and integrity of the Bitcoin network.
   - This computing power enables other applications like verifiable timestamping important data, such as election results, in an immutable blockchain ledger.

d. How Bitcoin Cryptocurrency Mining Works
   - The underlying Bitcoin network protocol governs digital currency's total supply cap and the rate at which new coins enter circulation via an open-source algorithm.
   - Specialist Bitcoin mining computers validate transactions submitted to the network and organize them into "blocks" that form a chronological chain with complete history - this is the blockchain ledger.
   - Miners perform intensive cryptographic computations at high energy loads and compete to close each new block, for which they earn newly minted Bitcoin as rewards.
   - The latest generation custom Bitcoin mining machines optimize energy efficiency to use less electricity per unit of computational work performed.
   - Efficiency is measured in joules consumed per terahash, where one terahash equals one trillion cryptographic hash calculations per second.

e. Real-World Examples of Bitcoin Mining Integrating with Nuclear Energy Infrastructure
   - Early off-grid Bitcoin mining operations powered by waste methane gas flare streams or landfill gas sites, avoiding the release of these harmful greenhouse gases.
   - Flexible mining data centers strategically sited directly at solar and wind renewable energy installations to serve as useful electricity load sinks during periods of excess intermittent production.

- Some mining facilities implement complete immersion cooling infrastructure for computers to significantly reduce noise pollution and waste heat relative to traditional air-cooling methods.
- TeraWulf [5] owns a mining operation behind the meter at the Talen Energy-owned Susquehanna nuclear plant to utilize non-grid-exported power.
- NuScale [6] has an agreement with Standard Power [7] to provide up to 12 77MWe small modular reactor power modules to power a mining data center. Standard plans to build on a former coal generation site.

f. Pathways for Nuclear Plant Operators Looking to Integrate Bitcoin Mining
- Companies like CleanSpark [8] provide Bitcoin mining solutions optimized for grid stability and reliability.
- Cathedra Bitcoin [9], with facilities in New Hampshire, makes portable Bitcoin mining containers powered by flare gas engines and has firmware for optimizing mining computers.
- Foreman Mining [10] sells fleet management software to monitor and control groups of mining machines remotely.
- Hash Rate Index [11] and Braiins [12] offer data and tools to model mining profitability.
- Turnkey self-contained Bitcoin mining data centers can be purchased pre-installed inside shipping containers for simple plug-and-play deployment.
- Permanent custom-designed industrial-scale mining facilities can be constructed on the physical site of the nuclear plant to host computers long-term.
- A vertically integrated business model can be adopted with the operator owning the entire Bitcoin mining operation.
- Risks and rewards can be shared through partnerships, joint ventures, or hosting agreements with specialized external crypto-mining companies.
- Fabiano Consulting [13] provides expert guidance on deploying Bitcoin mining to improve grid economics.
- New software platforms in development, such as Synota [14], can enable direct streaming of Bitcoin payments from mining operations to energy providers in real-time based on actual electricity consumption rather than the traditional monthly billing system.

g. Conclusion
- Bitcoin cryptocurrency mining operations are gaining more mainstream institutional credibility
- Integrating mining to provide grid balancing and a guaranteed customer base can accelerate the global adoption of clean nuclear energy to benefit humanity by displacing fossil fuel generation

Q&A:

- Q: Paul Gunter - Beyond Nuclear asked about the recent report by Iceberg Research, which examined the relationship between Standard Power and NuScale. He highlighted that NuScale had entered into a $37 billion sale agreement with Standard Power for 24 77-megawatt SMRs, even though these SMRs were still uncertified. He emphasized that the Iceberg Research report had damaged investor confidence and led to lawsuits by investors in NuScale related to Bitcoin development in Ohio and Pennsylvania. He offered to share the report with the New Hampshire Commission.

A: Rep. Keith Ammon added that Iceberg Research is a short seller motivated to tank NuScale stock. He mentioned that NuScale had responded to the report, but the situation was still evolving.
A: Ryan McLeod agreed with the concerns raised by Paul Gunter and mentioned that Standard Power would need to demonstrate its capability in building data centers to alleviate these concerns. He acknowledged that Bitcoin mining and nuclear power intersection was uncharted territory.

- Q: Paul Gunter - Beyond Nuclear also expressed concerns about NuScale's under-subscription with UAMPS in Utah for their project with Idaho National Labs. Given its involvement in Bitcoin mining and national media coverage, he emphasized the critical timing of these controversies for NuScale.
  A: Ryan McLeod added that building good relationships with communities and power brokers was essential when venturing into such projects.

3. Presentation: James Walker, CEO and Head of Reactor Development at NANO Nuclear Energy [15], gave a presentation on micro nuclear reactors.
   a. Why Nuclear in New Hampshire?
      - Renewables like solar and wind require a large amount of land and have intermittent power generation dependent on environmental conditions.
      - Nuclear power provides consistent, high-capacity electricity production that is not hampered by intermittency issues, and nuclear plants can be located almost anywhere, not just in optimal sunlight or wind patterns.
      - While small modular reactors (SMRs) seem interesting, microreactors have an even bigger untapped market potential.
      - Microreactors can provide power for remote mines, oil & gas platforms situated offshore, military bases in remote locations, data centers requiring reliable energy, electric vehicle charging stations needing high capacity, and many other industrial processes located off the main grid.
      - Microreactors can compete directly with diesel generators in terms of cost per megawatt as well as reliability.
   b. NANO's Microreactor Development Approach
      - NANO asked technical teams to design microreactors capable of fitting inside standardized shipping containers so they can be transported anywhere using conventional transportation methods like trains, trucks, and ships.
      - The reactors should enable largely unmanned operation with passive cooling mechanisms for maximum safety.
      - They envision central monitoring and control of potentially hundreds of reactors from a main office, with just 1-2 security staff needed at each physical reactor site.
      - The reactors should require zero maintenance over targeted 10–15-year operational lifetimes between refueling cycles.
   c. First Reactor Design with UC Berkeley Scientists
      - The design utilizes a solid core battery reactor with no moving coolant parts.
      - It relies on direct thermal conduction from the fuel rods to the reactor vessel wall and ambient air.
      - This represents the simplest possible reactor design that can be engineered.
      - It is capable of passively cooling itself even in the event that all mechanical systems fail simultaneously.

- It operates at higher temperatures, enabling production of hydrogen through thermolysis.
- It uses conventional fuel rods and technologies with a large historical operational data set.

d. Second Reactor Design with University of Cambridge Scientists
- This design uses solar salt for cooling the reactor core.
- It has only a few working parts, making it simple and reliable.
- It is also engineered to passively cool itself even without active cooling pumps operating.
- While it operates at a lower temperature than the Berkeley design, it can produce a higher thermal output over the reactor's lifetime.

e. Business Model Benefits
- NANO plans to lease the microreactors themselves as well as sell the power they produce using a contracting model, so customers would not face large upfront costs.
- Operation, refueling, decommissioning, and complete site cleanup would be handled entirely by NANO with no long-term liability for customers.
- This leasing framework makes adoption of the technology much easier for clients.

4. Presentation: Evan Cummings, Director of Business Development at Kairos Power [16].

a. Company Background and Overview
- Kairos Power is an energy engineering, design and manufacturing company that is singularly focused on developing one nuclear reactor technology called the Kairos Power Fluoride Salt Cooled High Temperature Reactor (KP-FHR).
- The company forecasts that 60% of US baseload natural gas power capacity and 40% of nuclear power capacity from existing light water reactors will retire by 2030-2040. This retirement of baseload plants presents an opportunity for advanced nuclear technology.
- The company was founded in 2016 and currently employs approximately 368 people, with 90% of the staff being engineering employees who are focused on the KP-FHR reactor design and commercialization efforts.
- Kairos Power has set a goal to achieve commercial deployment of the KP-FHR technology by the year 2030 or earlier if feasible.
- A key commercialization goal for the company is for the KP-FHR reactor to be cost-competitive with natural gas power plants in the U.S. electricity market without requiring any subsidies.

b. KP-FHR Technology Overview
- The KP-FHR is an innovative reactor design that combines two proven nuclear technologies:
  1. It utilizes a high temperature molten salt as the primary reactor coolant. The high temperature operation of up to 700°C enables high efficiency electricity generation.
  2. The reactor uses Tristructural-isotropic (TRISO) fuel, which provides enhanced stability, higher energy density, and improved safety performance compared to traditional uranium oxide nuclear fuel.

c. Strategic Development Approach
- Kairos Power is taking a strategic development approach that utilizes rapid learning cycles, vertical integration, and a series of large-scale design demonstrations in order

to provide certainty regarding the technology performance, licensing, supply chain, constructability, and costs.
    - The plan is to demonstrate the KP-FHR reactor technology at increasing scales, first with non-nuclear test prototype units called Engineering Test Units (ETUs). This will lead to the eventual construction of a 15-megawatt thermal (MWth) Hermes nuclear demonstration unit.
    - Major infrastructure investments have been made to construct production facilities and laboratories in New Mexico, Tennessee, and Ohio to support the testing and demonstration plans.
d. Licensing Progress
    - A Construction Permit Application for the Hermes demonstration reactor was submitted to the U.S. Nuclear Regulatory Commission (NRC) in November 2021, following completion of extensive pre-application reviews and analysis by the NRC.
    - Kairos Power is the first advanced non-light water reactor developer to have obtained a firm 21-month review schedule from the NRC for a construction permit.
    - The company completed the final step required in the Construction Permit Application process on October 19, 2023. Approval to build the Hermes unit is expected from the NRC by the end of 2023.
e. U.S. Department of Energy (DOE) Partnership
    - Kairos Power was awarded $303 million through the DOE's Advanced Reactor Demonstration Program (ARDP) to construct the Hermes demonstration reactor at a site in Oak Ridge, Tennessee.
    - The ARDP award is a cost-shared award that specifically aims to reduce risks for advanced nuclear technology demonstrations.
    - Under the cost-share terms, Kairos Power will contribute an additional $326 million to the Hermes project, for a total budget of $629 million over 7 years.
    - Building and operating the demonstration reactor is projected to create 55+ full-time jobs and invest over $100 million into the East Tennessee regional economy.
    - This level of investment is prototypic of what would come in expansion to other states as well.
f. Industry Consortium Partnership
    - In 2022, Kairos Power formed the Kairos Power Operations, Manufacturing and Development Alliance (KP-OMADA) together with leading North American electric utility companies.
    - The industry consortium will collaborate on development, licensing, manufacturing, and eventual commercialization of the KP-FHR technology.

Q&A:

- Q: Rep. Keith Ammon asked if molten salt from the Kairos reactor could be used for industrial heating applications as part of the business plan.
  A: Evan Cummings (Kairos) answered that while their primary focus is on producing carbon-free electricity, they recognize industrial heat applications as an important potential opportunity to help decarbonize hard-to-decarbonize industries. This is on their roadmap for the future.
- Q: Rep. Keith Ammon asked about the expected electrical output size of Kairos' planned commercial reactors.
  A: Evan Cummings stated that the output for their first commercial reactor design would

be 140 megawatts electric per module. He added that the modularity of the design allows for economies of scale by locating multiple units together.

- Q: Paul Gunter (Beyond Nuclear) asked what the maximum projected modular design would be - how many 140MW reactor units could be co-located.
  A: Evan Cummings responded that the number of units would ultimately depend on customer demand and site constraints, but that the technology supports significant scalability.
- Q: Paul Gunter asked for confirmation that Kairos expects to receive a nuclear construction permit from the NRC by the end of 2023.
  A: Evan Cummings confirmed that they expect approval on a nuclear construction permit by the end of 2023.
- Q: Ryan McLeod asked if there are shared infrastructure capabilities between reactor modules to reduce costs with buildouts at scale.
  A: Evan Cummings confirmed that yes, there are opportunities for shared civil structures between units.

5. Commission Business
   - Rep. Ammon informed the commission that the statute requires one final meeting to be held by December 1st to approve the minutes from the current meeting and the final report. He has scheduled this meeting for Friday, December 1st at 1pm at the State House.
   - Rep. Ammon asked if any commission members anticipated issues with attending that meeting, but no concerns were raised. He stated he will aim to provide a draft of the final report to commissioners before the December 1st final meeting. Commissioners can provide input on the draft report prior to the final meeting.
   - Rep. Ammon brought up that Dartmouth's policy research shop will be using the commission's final report to have students conduct additional research projects related to financing and market conditions for potential SMR projects. The additional research could aid the Department of Energy.
6. Discussion
   - Former State Representative Dick Barry suggested the final report include some kind of cost-benefit analysis from companies currently working on SMR technology, to get a sense of the potential financial feasibility and benefits of pursuing SMR projects.
   - In response to Dick Barry's suggestion, Dan Goldner from the PUC noted that many of the companies that presented to the commission had already provided estimated costs per megawatt hour for SMR technology, typically in the range of $60-80/MWh. He suggested summarizing this existing cost information in a table in the final report.
   - Representative Alvin See asked if any businesses in New Hampshire that would be interested in using heat rather than electricity from potential SMR projects had been identified. Rep. Ammon responded that further investigation on heat utilization is still needed, and provided examples of a cement plant and Concord's municipal steam heating system that potentially could utilize SMR heating in the future.
   - In response, Rep. Alvin See stated he did not have any particular businesses in mind but noted that Concord's steam heating system alone is likely not large enough to be a viable project for SMR heating.
   - Dan Goldner from the PUC brought up that the Berlin biomass plant had plans to provide heated water to warm sidewalks in Berlin. However, Rep. Alvin See noted that after the news from the previous week, those plans may now change, referring to the challenges facing the Berlin biomass plant.

7. Approval of Meeting Minutes
   - The minutes from the October 10th commission meeting were presented and approved unanimously through a motion by Cathy Beahm, seconded by David Shulock. Two small amendments to the minutes were noted by Rep. Ammon. He also stated links to online webinars referenced in the minutes will be added for clarity.
8. Adjournment
   - Rep. Ammon requested a motion to adjourn the meeting. The motion was made by Sen. Howard Pearl and seconded by Dan Goldner. The meeting was adjourned by unanimous vote at 10:43 AM.

Minutes submitted by Keith Ammon.

References:

[1] https://www.cnl.ca/about-cnl/

[2] https://naygn.org/i4n/

[3] https://www.nrcan.gc.ca/our-natural-resources/energy-sources-distribution/nuclear-energy-and-uranium/canadian-small-modular-reactor-roadmap/21183

[4] https://meredithangwin.com/shorting-the-grid/

[5] https://terawulf.com

[6] https://nuscalepower.com

[7] https://standardpower.com

[8] https://www.cleanspark.com

[9] https://cathedra.com

[10] https://foremanmining.com

[11] https://hashrateindex.com/

[12] https://insights.braiins.com

[13] https://fabiano.consulting/

[14] https://www.synota.io/

[15] https://nanonuclearenergy.com/

[16] https://kairospower.com/