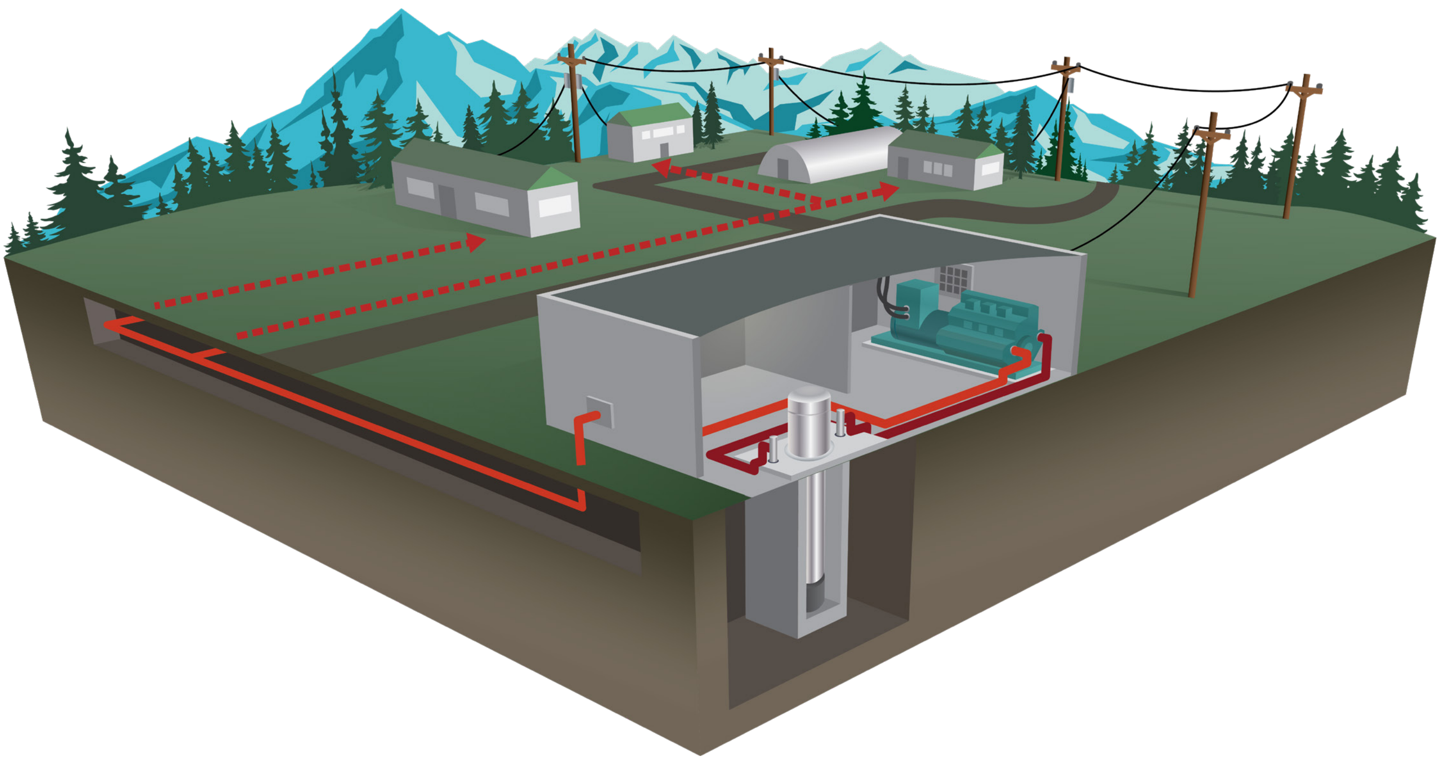
Small Scale Nuclear Power:
an option for Alaska?
Update January 2021



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ACEP: Center for Energy and Power, University of Alaska Fairbanks

ADEC: Alaska Department of Environmental Conservation

AEA: Alaska Energy Authority

CHP: Combined Heat and Power

CNL: Canadian Nuclear Laboratories

CNSC: Canadian Nuclear Safety Commission

COL: Combined Operator License (NRC license)

DOD: U.S. Department of Defense

DOE: U.S. Department of Energy

EBR-II: Experimental Breeder Reactor II

ERO: Electric Reliability Organization

ESP: Early Site Permit (NRC license)

FHR: fluoride-cooled high temperature reactor

FLIBE: lithium/beryllium fluoride eutectic

FNPP: Floating Nuclear Power Plant

GFR: gas-cooled fast reactor

GIF: Generation IV International Forum (https://www.gen-4.org/gif/)

IAEA: International Atomic Energy Agency

INL: Idaho National Laboratory

LFR: lead-cooled fast reactor

LWR: light water reactor (uses normal water as a coolant)

MNPP: Mobile Nuclear Power Plants (< 5MWe generation capacity)

MNR: Micro Nuclear Reactor (1-10 MWe generation capacity)

MSR: molten salt reactor

MTSPNR: Modular Transportable Small Power Nuclear Reactor

MWe: Megawatt electric

MWth: Megawatt thermal (heat)

NEI: Nuclear Energy Institute

NEIMA: Nuclear Energy Innovation and Modernization Act

NGNP: Next Generation Nuclear Plant

NRC: Nuclear Regulatory Commission (U.S.)

OFPU: Optimized Floating Power Units

PRISM: power reactor innovative small module

SFR: sodium-cooled fast reactor

SMR: Small Modular Reactor (10-300 MWe generation capacity)

TRISO: tristructural isotropic

Introduction and Acknowledgements

This report was authored by staff and faculty affiliated with the University of Alaska Fairbanks, Alaska Center for Energy and Power at the request of the State of Alaska Legislature. Its intent is to update material included in ACEP's 2011 publication, *"Small-Scale Modular Nuclear Power: An Option for Alaska?"* prepared for the Alaska Energy Authority, also at the request of the Alaska State Legislature.[1]

We sincerely appreciate the time and effort of the numerous Alaskans and nuclear industry experts who met with us and shared information and ideas related to small modular nuclear reactors and applications for Alaska. In particular, we would like to thank everyone who participated in and provided valuable input to ACEP's 4-part Educational Series on Nuclear Energy (see Appendix C). Over 100 Alaskans and numerous industry representatives participated in these events, held during the fourth quarter of 2020. The information disseminated, questions asked and discussions that took place during those events provided valuable insight used in generating this report. We would like to acknowledge several individuals also made invaluable contributions to this report directly, or through reviewing various drafts. For their contributions, we specifically would like to thank:

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[1] Available for download at: http://acep.uaf.edu/media/147559/Small-Scale-Modular-Nuclear-Power-an-option-for-Alaska-2011-ACEP-and-ISER.pdf

1. Executive Summary

1.0 Overview

Over the past 20 years, much of the progress in nuclear power technology has been in the field of Small Modular Reactors (SMRs) and, more recently, Micro Nuclear Reactors (MNRs). These differ significantly from legacy gigawatt-scale light water reactors that are still in use around the world. SMRs and MNRs are much smaller and could be considered for a variety of uses in Alaska. These potential uses include military and industrial combined heat and power applications powering portions of the Railbelt grid, as well as heat and power in rural communities.

For this reason, there has been significant interest in these technologies across numerous Alaska stakeholder groups.

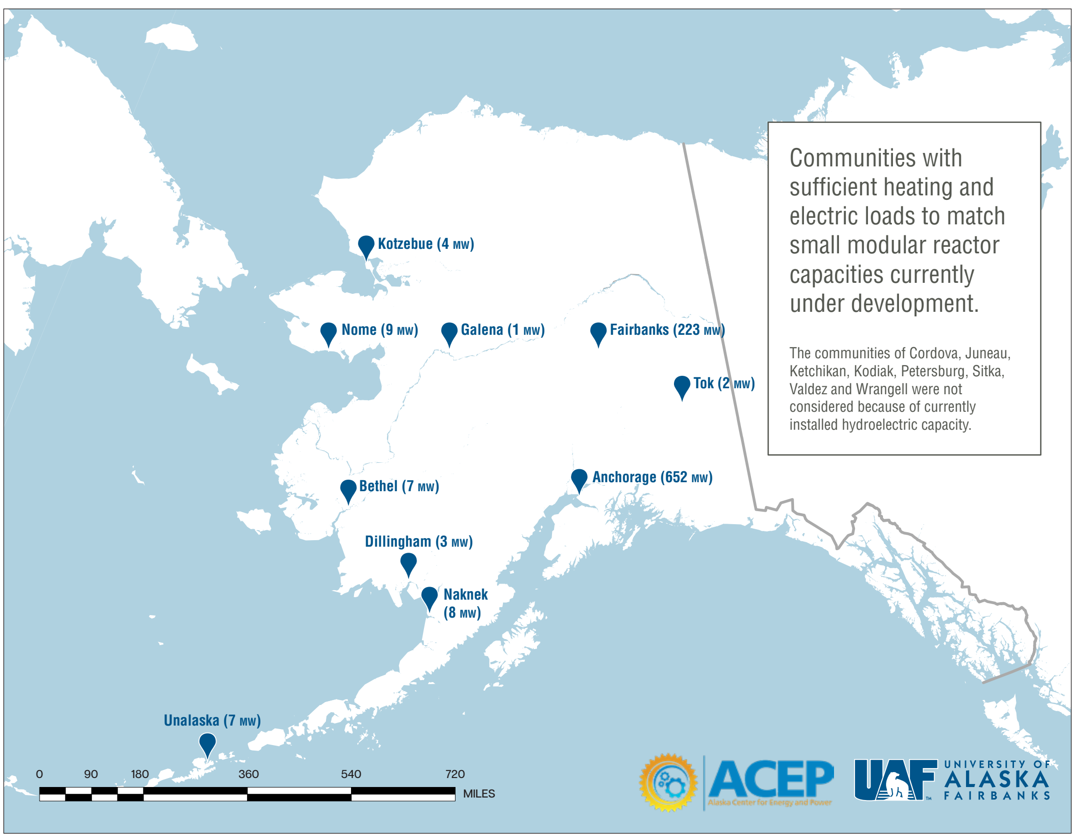

Figure 1. Sample non-hydroelectric communities in Alaska with sufficient heating and electric loads to match Small Modular Reactor (SMR) or Micro Nuclear Reactor (MNR) capabilities currently under development. Note that loads included in this figure represent maximum electric loads only. Industrial and military sites are not included.

This report provides Alaskans with a snapshot of the current status of SMR and MNR technologies, relevant state and national policies and regulations, and economics related to potential deployment in Alaska. It updates portions of a 2011 study completed by the Alaska Center for Energy and Power (ACEP, University of Alaska Fairbanks) in partnership with the Institute of Social and Economic Research (ISER, University of Alaska Anchorage) titled "Small Scale Modular Nuclear Power: An Option for Alaska?" It also complements a 2020 market survey prepared by the Center for Economic Development at the University of Alaska Anchorage titled "Microreactors in Alaska: Use Case Analysis" for the U.S. Department of Energy.

This report does not discuss the prior history of nuclear energy projects in Alaska such as the Fort Greely SMA-1 reactor, Project Chariot, or the proposed Toshiba 4S "nuclear battery" for Galena. It also does not consider past or potential uranium mining in Alaska, or options for managing spent fuel, which remains a major concern in the U.S. and globally. For information on those topics, please refer to the 2011 study, which is available for download on the ACEP website.[2]

At this time, no SMR or MNR technologies are commercially available in the U.S. However, approximately a dozen companies or consortiums are actively working on designs, and several demonstration projects are planned for the next few years. The key distinctions between SMRs and MNRs relate to their energy output, physical size, amount of on-site construction/assembly, size of the surrounding safety zone, and requirements for mid-life refueling. Individual SMRs are in development that range in size from 10 megawatts electric power (MW) to 300 MWe, and MNRs typically range in size from less than 1 MWe up to about 10 MWe.[3] In general, MNRs are much smaller than SMRs, with many MNRs designed to be packaged within CONEX-style containers. Small Modular Reactors require more on-site installation construction and larger exclusion zones due to their larger size, power, and amount of radioactive material. Also, SMRs are designed for multiple fueling cycles over their lifetime. Most MNR developers are focusing on single use implementations (i.e., when its fuel is spent, the MNR is replaced with a new unit and fuel charge, and the old MNR and spent fuel are returned to their source for reprocessing).

MNRs and all major elements of SMRs will be manufactured and pre-assembled in factories, allowing for standardized design and fabrication, high quality control, shorter power-facility construction times, and lower financing costs during construction. For larger applications, multiple

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[2] Available for download at:
http://acep.uaf.edu/media/147559/Small-Scale-Modular-Nuclear-Power-an-option-for-Alaska-2011-ACEP-and-ISER.pdf

[3] For a point of comparison, a rural hub community such as Bethel might require ~4 megawatts electric power (MWe), existing or proposed mines in Alaska might require 10-40 MWe (Donlin Creek Mine average load is estimated at 157MW), and the Golden Valley Electric Association service territory serving the greater Fairbanks area has a peak demand of 210 MWe. A typical rural Alaska community generally has a peak load of 500 kWe or less.

SMR or MNR modules are designed to be combined to form a larger power plant complex, which would also have several advantages over a single large reactor, including reduced downtime for maintenance and enhanced safety characteristics. The fuel types/formats, fission reaction control strategy, and cooling medium vary among the various developers. Current trends in the evolving certification guidelines for SMRs and MNRs make it probable that the systems and fuel must be shipped separately and arrangements made for fueling/defueling at the energy plant location. All of the designs incorporate fail-safe/no-run architectures and rely on highly automated monitoring of their instrumentation to reduce the requirements for on-site staffing. In addition, both SMRs and MNRs can be implemented as power-only, heat-only, or combined heat and power (CHP) systems. A key area of interest for Alaska CHP applications is the degree to which a given SMR or MNR unit can accommodate seasonal changes in the ratio of thermal and electrical loads that it serves. All of the systems include provisions for some level of transient load following and/or can be implemented as part of an integrated technology suite that may include dispatchable loads, external energy storage systems, complementary "peak" power units, and/or auxiliary heat generating systems.

While the nuclear industry has historically been dominated by the United States, by many measures Russia and China are now leading the global nuclear renaissance. The U.S. federal government is determined to reestablish American leadership in the field and has committed significant funding to support risk reduction in design and development of analytic tools, the full range of the fuel life cycle and the certification process (including system testing and demonstration). As a result, numerous systems are under development for both military and civilian applications. For example, three companies were selected in 2019 to move forward with their designs for small (<5 MWe designs) mobile reactor designs as part of Project Pele under the U.S. Department of Defense Strategic Capabilities Office. Examples of utility-scale demonstration plans actively moving forward include the Utah Associated Municipal Power System (UAMPS) public power consortium's Carbon Free Power Project (CFPP) and initiatives by Ontario Power Generation. In addition, reactor demonstrations are scheduled to take place at both the DOE's Idaho National Laboratory (INL) and Canada's Chalk River Laboratories site in the next few years. Appendix A of this report provides a list of known SMR and MNR technologies with capacities less than 300 MWe that are currently in development or have been proposed by U.S.-based companies, or non-U.S. entities interested in deploying their systems in the U.S. market.

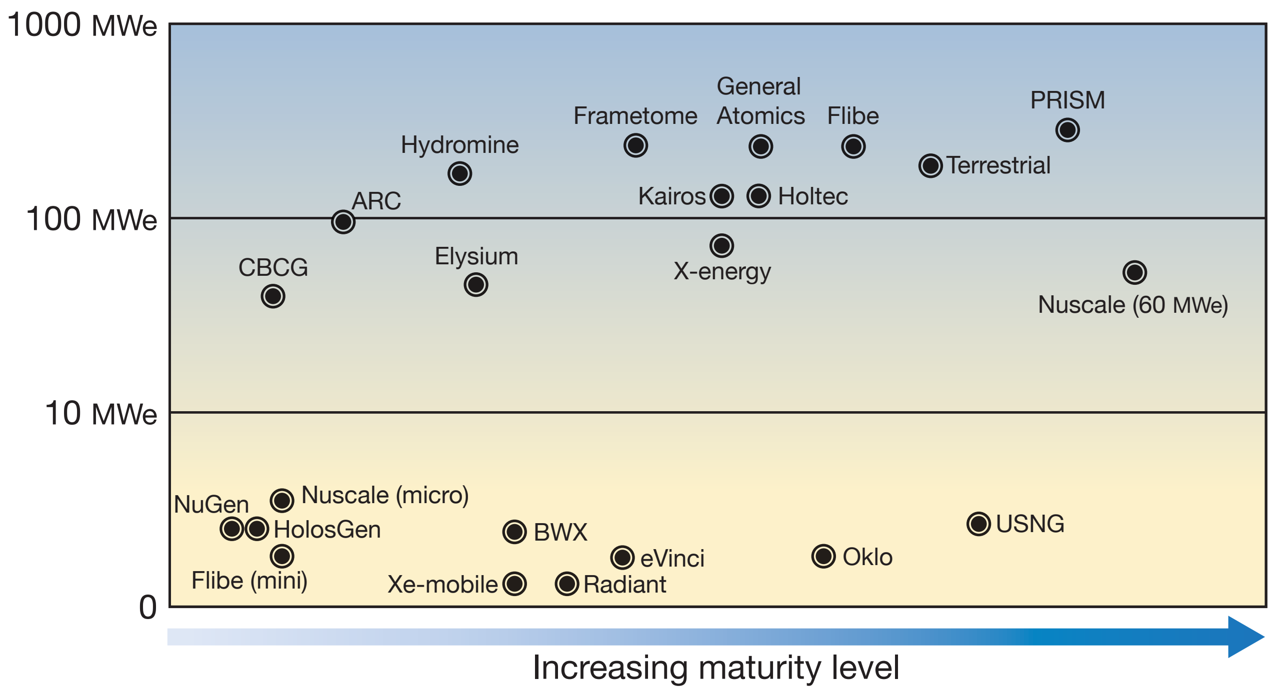

Figure 2.1 Maturity level and size of SMRs and MNRs currently under development. There are over two dozen companies with varying levels of technology readiness that are U.S. owned, and/or are planning to pursue licensing through the U.S. Nuclear Regulatory Commission (NRC). A complete list of these companies is included in Appendix A. MNRs are generally expected to have a faster path to market due to their lower overall complexity, and pilot projects could occur within 2-3 years (for example, Project Pele-funded systems). NuScale and USNC, the leading SMR contenders are expected to follow with deployments in 2026 and 2029, respectively. *Note: this scatterplot is not intended as a precise comparison between individual technologies or companies. It is intended to represent the evolution of the industry as a whole, with individual reactor technologies depicted based on the current best estimate of the report authors.*

Capital and operating expenses associated with SMR and MNR implementations are fairly uncertain, given the evolving nature of the designs and criteria for their certification. We have found no persuasive evidence that they have changed significantly during the past decade, though new ownership models are being explored to address high up-front costs. The 2011 economic screening analysis determined that the 45 MWe NuScale reactor (since upgraded to 60 MWe) could generate electricity at a production cost ranging from about 10 to 14 cents per kWh in today's (2020) dollars. This cost was determined to be competitive in Fairbanks under scenarios where the price of crude oil exceeds about $80 per barrel, and in Anchorage if natural gas prices exceed about $14.00 per thousand cubic feet (mcf).

During the past decade, the Railbelt utilities have added about 700 MWe of efficient new gas-fired and coal-fired capacity,[4] leaving the Railbelt with more than 2,000 MWe installed capacity to serve

[4] This calculation counts GVEA's Healy 2 coal plant as an additional generation source effective 2015.

a stable or declining peak load of less than 900 MWe. Natural gas prices have stabilized at about $8.00 per thousand cubic feet; oil price projections are lower; and there is no price on carbon. All of these factors tend to make SMRs less economic on the Railbelt than they appeared to be in 2011. An exception to this may be the need to replace aging coal-fired combined heat and power (CHP) infrastructure at Interior military bases, including Fort Wainwright and Eielson Air Force Base.

While there are still many unanswered questions, the initial economic analysis completed in Chapter 5 indicates that nuclear power from an MNR could be quite competitive with diesel power in a hub community setting, provided that the system can be set up to allow for the diesels to be essentially turned off almost all of the time. Additional work on specific rural scenarios is warranted, including not only the value of electric power but also space and water heating.

In order to continue tracking this technology and to make sure Alaska applications and opportunities are considered at the national level, we make the following recommendations:

1. **Track technology trends and ensure Alaska is part of the national discourse.** The small nuclear energy industry is evolving quickly. Therefore, it will be necessary to continue to monitor technology trends as they relate to Alaska and ensure Alaska is actively involved in discussions at the national level. Identifying a lead agency or group will be an important part of ensuring ongoing engagement.

2. **Establish a nuclear energy technology working group.** We recommend establishing a formal Nuclear Energy Technology Working Group, similar to what has been done for other emerging technologies of interest to the Alaska energy sector. This group could convene regular stakeholder meetings to understand Alaska interests and concerns, extend the Educational Series initiated by ACEP, develop use cases with Alaska-germane functional performance attributes and evaluation criteria, and identify possible/preferred deployment sites.

3. **Conduct an umbrella study involving critical state agencies.** Since state agencies have little experience or expertise with nuclear power, an umbrella study with the involvement of critical state agencies would be an appropriate near-term step. This could then inform recommendations 4 and 6 below.

4. **Organize a scenarios planning workshop related to nuclear safety.** Nuclear safety is an overriding concern of Alaskans. Working through specific scenarios and understanding potential repercussions would be helpful in gaining a better understanding of the risks associated with nuclear energy systems deployed in Alaska. This exercise could include Alaskans and subject matter experts and be informed by the umbrella study suggested in Recommendation 3.

5. **Complete a More Robust Economic Analysis.** One of the weaknesses of this report is that it is difficult to fully analyze the economics of an Alaska deployment, including costs and benefits as well as possible financing and ownership structures. A more thorough analysis, including a full analysis of the value of heat in addition to electric power generation, would be helpful in fully understanding SMR and MNR technologies in comparison to the status quo.

6. **Review Alaska statutes as pertaining to nuclear energy.** Alaska's statutes address nuclear energy in several places and were written at a time when SMR and MNR technologies were not part of the state or national discourse. SB194, "An act related to advanced nuclear reactors," was introduced last year by the Senate Community and Regional Affairs Committee during the 32nd legislature in order to address these new technologies, but did not pass. Recommendations for Amendment to Alaska State Statutes are included in Appendix B.

7. **Create a Roadmap for Alaska.** The first six recommendations listed above lend themselves well to providing the background information needed to develop a strategic roadmap for Alaska related to SMR and MNR technologies. This roadmap could follow a similar format to the Canadian roadmap discussed previously, which solicited input from a wide range of stakeholders to chart a path for Canada and the role it wants to play in future nuclear technology development. This Alaska-focused roadmap should address the yet-unanswered questions and concerns of Alaskans, and establish a process for how those concerns could be mitigated through additional testing, information dissemination, or adjustments to the permitting and licensing process.

This report is organized into six main sections. Following the Executive Summary, Chapter 2 provides an overview of U.S. small nuclear technologies, including definitions and basic attributes of these systems, example technologies, and both U.S. and international development in this field. Chapter 3 covers the licensing of SMR and MNR technologies, and Chapter 4 provides a general overview of policy at the federal and State level, as well as recommended changes to state statutes. Chapter 5 reviews the economics of SMR and MNR reactors, building on the analysis originally completed as part of our 2011 report. Finally, Chapter 6 outlines possible next steps and additional details related to the recommendations introduced above.

2. Overview of Small Nuclear Technologies

2.0 Introduction

The International Atomic Energy Agency (IAEA) defines 'small nuclear technologies' as reactors capable of supporting less than 300 Megawatts (MW) of electric power generation.[5,6] Many small reactor designs are intended to be installed as modules, creating a single larger nuclear power plant consisting of a series of individual small reactors. These modules are intended to be permitted in advance,[7] constructed in a factory, and transported to the construction site. This approach is intended to reduce cost, decrease timelines for completion, and provide a high degree of precision in manufacturing, resulting in improved quality control.

MNRs are an emerging category of very small reactors targeted for non-conventional nuclear markets. They are generally considered to be sized under 10 MW and are designed to be installed as either a stand-alone system or in a modular configuration like SMRs. Many of these systems could be regarded as analogous to a long-life nuclear battery, with no refueling in the field. Instead, the reactor is returned to the manufacturer for replacement after a set period of time (typically around 10 years). Other MNR offerings are designed for in-field refueling, using the reactor power plant building as the defuel/refuel facility and returning the spent fuel to the manufacturer for processing.

Mobile Nuclear Power Plants (MNPP) are a further subcategory of MNRs that are specifically designed for field deployment. These are less than 5 MW in size and are under active development in both the U.S. and Russia. Project Pele is a U.S. Department of Defense (DOD)-led program managed through the Strategic Capabilities Office that is funding the design and future construction of a transportable nuclear power reactor for remote operating bases. DOD awarded three development contracts through this program in March 2020, including BWX Technologies ($13.5 million), Westinghouse Government Services ($11.95 million), and X-energy ($14.3 million).[8] One design will be selected to be built as a prototype in 2022, with a possible future demonstration at an Alaska DOD facility.

[5] In comparison, the average size of conventional nuclear power plants is approximately 1000 MW, or 1 Gigawatt.

[6] This is an arbitrary cutoff, and there are some reactors that are slightly above this size that are still considered small reactors. For example, TerraPower is a company backed heavily by Bill Gates which uses liquid sodium as a coolant and is designed to generate 345 MW of electric power.

[7] Permitting through the Nuclear Regulatory Commission (NRC) is a two-step process. Modular designs can help streamline permitting because the technology is permitted separately from the site.

[8] From "DOD Awards Contracts for Development of a Mobile Microreactor," (March 9, 2020), Retrieved December 27, 2020, from https://www.defense.gov/Newsroom/Releases/Release/Article/2105863/dod-awards-contracts-for-development-of-a-mobile-microreactor/.

To date, there are no SMR or MNR technologies that have been deployed as part of the commercial U.S. nuclear fleet. Current federal executive and legislative actions have demonstrated a commitment to establishing a pathway for commercialization. There are a number of companies actively working on reactor designs, and these systems are in various phases of development as part of defense-related and/or industry-driven applications.

Small-scale nuclear reactors are not a new concept. When nuclear power generation first became established in the 1950s, reactor units were relatively small. For example, the first commercial nuclear power plant to become operational in the United States was a 60 MW reactor installed in Shippingport, Pennsylvania in 1957. The early industry was heavily influenced by designs pioneered by the U.S. Navy, including the decision to use light water reactor (LWR) technology, which is the dominant technology for the majority of the current commercial nuclear power landscape[9] (Hewlett and Duncan, 1974). Five years later, the only nuclear power plant ever operated in Alaska was energized at Fort Greely in Interior Alaska, generating 2 MW of electric power along with 20.2 MW of heat energy[10] (Holdmann et al, 2011).

Over time, economics of scale favored larger systems, and today, the 20% of the nation's domestic electric power supplied by nuclear energy comes from 95 operating commercial nuclear power reactors with a total net capacity of 98 gigawatts.[11] Globally, installed capacity of nuclear power at the end of December 2019 was 392.1 GW, comprising 443 operational nuclear power reactors in 30 countries. This represents a gradual growth trend over the past decade, with 23.2 GW of new capacity added since 2011.[12] This trend is continuing. At the end of 2019, 54 reactors representing an additional 57.4 GW of capacity were under construction in 19 countries, including four that are building their first nuclear reactor. The most active region is in central Asia, which at the end of 2019 reported 35 reactors totaling 36.5 GW of nuclear power capacity under construction (Schneider and Froggatt, 2019).

While the utility industry has focused on gigawatt-scale reactors, many hundreds of smaller

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[9] The first nuclear-powered submarine, the USS Nautilus, was launched in 1954 powered by a 10 MW reactor. In 2018, the U.S. Navy had 80 operational vessels using nuclear propulsion, including submarines and aircraft carriers. (From "About the US Navy," Retrieved December 28, 2020 from https://www.navysite.de/navy/).

[10] This power plant used enriched uranium, and represented a foray in nuclear energy pursued by the U.S. Army based on previously developed naval reactors. Most commercial reactors use low enriched uranium, which poses a lower risk in terms of safety and proliferation.

[11] Based on 2019 data from the U.S. Energy Information Agency.

[12] An exception is in 2019, when total global capacity decreased by some 4.5 GW(e) compared with 2018, a figure that reflects Japan's decision to permanently shut down five reactors that had not generated electricity since 2011 in the wake of the Fukushima Daiichi nuclear accident.

power reactors have also been built over the past several decades. In the U.S., these have been developed for naval use or civilian applications, such as research, training, or isotope production for use in the medical industry. As a result, there is a substantial amount of U.S. expertise related to the engineering of small reactors. This know-how has been leveraged to support significant renewed domestic and international interest in small nuclear reactor designs for commercial power applications. This interest has been driven by an emphasis on low-carbon energy sources, including carbon emission goals set by utilities and others, as well as concerns related to safety and waste management in legacy nuclear power systems. Many small reactor technologies are also designed to be capable of providing regulation services to the grid,[13] complementing non-firm renewable energy resources, such as solar or wind energy. This renewed interest has also contributed to more advanced reactors designs beyond light water technology. These advanced reactor technologies are safer and produce less waste, and some represent opportunities for recycling existing waste streams. The U.S. Department of Energy is supporting a wide variety of advanced reactor designs, including gas, liquid-metal, molten-salt, and heat-pipe-cooled concepts and prototypes.

This Chapter provides a brief overview of nuclear energy technologies with a focus on technologies that could be appropriate for the Alaska market. A table of relevant reactor technologies less than 300 MW is included in Appendix A.

2.1 Relevance to the Alaska Market

Why should Alaska be paying attention to SMR and MNR technologies? With Alaska's abundant fossil and renewable energy resources, importing nuclear energy may seem unnecessary. However, there are some attractive elements to nuclear energy that could alleviate some of the energy challenges Alaska faces today and more importantly, in the future. Chief among these advantages is that nuclear power plants are heat engines, and can supply heat in addition to electric power. This could provide opportunities for high thermal efficiencies if the heat can be effectively utilized. One challenge however, is that few places in Alaska have established district heat systems or requirements for industrial process heat, a requirement to effectively use heat from a nuclear plant. While additional infrastructure and new tariff mechanisms for heat would be required, this is a common strategy in other Arctic countries, most notably Iceland but also in cold locales elsewhere — the Russian Far East, Finland and Greenland commonly use district heat systems.

For parts of Alaska that rely on imported fuel oil, nuclear energy could introduce a path to reduce

[13] Regulations services adjust electric power output to meet customer demand. The increase of intermittent renewable energy sources, such as wind and solar power, requires improved methods for reliable, low-cost services.

this reliance, offering better price stability, lower emissions, and reduced or eliminated risk from fuel spills. Even though Alaska is an oil-exporting state, prices for imported fuel oil are set by global markets that are difficult to predict long-term. Nuclear energy, like renewable energy, may have higher initial capital costs but should have fairly predictable and stable operational costs over the expected lifetime of the reactor. This could be particularly beneficial for rural Alaska, where price stability and the possibility of excess energy could result in new economic opportunities. Additionally, a shift to MNRs would eliminate potential supply line vulnerabilities related to imported fuel oil, as well as costs related to environmental contamination associated with fuel oil delivery, transfer and long-term storage.[14] Each of these benefits needs to be carefully weighed against the costs and potential risks associated with nuclear reactors and radioactive fuel.

Both SMRs and MNRs are emissions-free, which is a major reason for the global nuclear renaissance currently underway. According to an article authored by several leading climate scientists, "Nuclear will make the difference between the world missing crucial climate targets or achieving them. We are hopeful in the knowledge that, together with renewables, nuclear can help bridge the 'emissions gap' that bedevils the Paris climate negotiations. The future of our planet and our descendants depends on basing decisions on facts, and letting go of long-held biases when it comes to nuclear power."[15]

Finally, SMR and MNR technologies are designed to be flexible and capable of adjusting to follow demand, or to complement the output from variable renewable resources. This is different from conventional nuclear power plants which provide baseload power to the grid and are not easily ramped up or down in output.

[14] Diesel fuel contamination as a result of bulk fuel transfer and storage is a significant source of environmental contamination in rural communities.

[15] From "Nuclear power paves the only viable path forward on climate change," by Hansen, J., Emanuel, K., Caldeira, K., & Wigley, T., (December 03, 2015), Retrieved December 19, 2020, from https://www.theguardian.com/environment/2015/dec/03/nuclear-power-paves-the-only-viable-path-forward-on- climate-change.

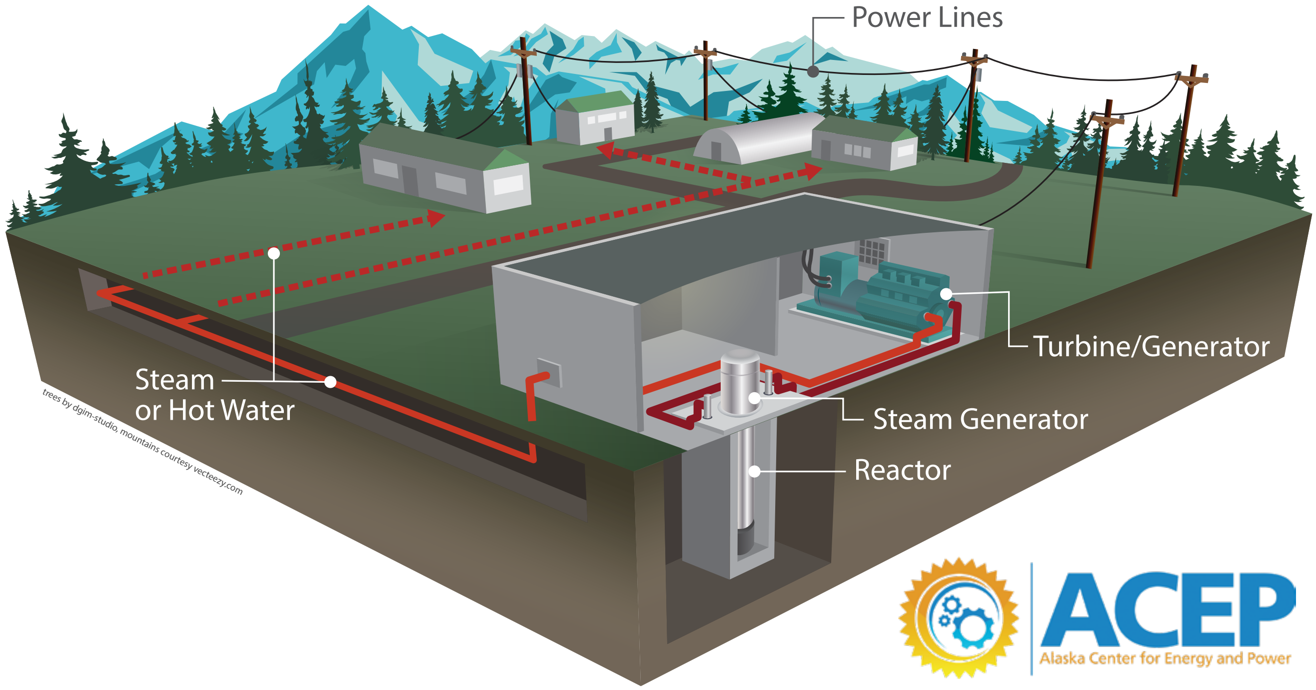

Figure 2.2. Conceptual layout of a generic SMR or MNR plant. An SMR or MNR is designed to be delivered to the site with key components (or in some cases the entire system) packaged in self-contained housing that is designed to be placed below grade. Many of these reactors generate steam which is used to generate power. Heat can be delivered via a steam or hot water district heating system.

2.2 General Attributes of Small Nuclear Reactors

One of the reasons that small nuclear reactor technology has attracted interest domestically and internationally is that they are designed to overcome specific concerns inherent to legacy nuclear energy technologies. Broadly stated, these include enhanced safety features and shorter permitting and development timelines. From a safety standpoint, small reactors have an advantage over conventional nuclear power plants by incorporating both passive and inherent safety features such as:

1. *Passive cooling.* Historically, many of the most notable nuclear power accidents have involved some failure in the reactor cooling. This has led to a meltdown of the containment vessel and/or fuel and a release of radioactive material into the environment. Even though most nuclear plants have multiple redundant safety features to prevent such an event from occurring, they rely on active safety features and availability of electric power to operate. In contrast, many small reactors rely mostly or entirely on passive safety features and are not at risk of catastrophic failure. Instead, the coolant circulates through the nuclear core by natural convection, eliminating the need for pumps and thus greatly reducing the risk of an accident involving a containment breach.

2. *Advanced Fuels.* In addition to reactor cooling, many small reactors are designed to use novel fuel configurations that further reduce the potential for environmental contamination. For example, many developers plan to use "TRISO" (TRi-structural ISOtropic) particle fuel. Each TRISO particle includes a uranium fuel kernel that is enclosed within three layers of carbon and ceramic-based materials. The entire particle is tiny — about the size of a poppy seed — and virtually indestructible. They are designed to withstand temperatures well beyond those that will be encountered during normal operation or under any worst-case scenarios.

3. *Factory built.* Conventional nuclear power plants were traditionally built on site, which introduced possibilities for human error in construction and fabrication. SMRs and MNRs are designed to be assembled and tested in a factory under controlled processes. In addition to better quality control, factory assembly enables series fabrication with faster production times at a lower unit cost.

4. *Below-grade installation.* In many SMR and MNR designs, the reactor is intended to sit below grade in a seismically robust housing that is an integral part of the reactor design. The system is inherently seismically stable and less likely to be damaged by any natural phenomena hazard scenarios. Below grade installation can also reduce vulnerabilities to sabotage or terrorist attacks, since the reactor is less accessible.

SMRs are often designed to be installed in parallel, within a larger nuclear power complex comprising several modules. This allows some flexibility in plant size, and enables scalability to meet future demand. The total output of such a power plant is considered too large for Alaska's small energy market.[16] However, a single module such as a 60 MW Nuscale module could replace aging generation at some future date if capable of operating as a stand-alone unit.[17] The Alaska Railbelt grid is the mostly likely candidate for such an installation, with possible co-location at a military base. Increased use of electric heating and vehicles could dramatically increase loads on the Railbelt with the right incentives.

MNRs share many of the same attributes as SMRs, but have additional features enabled by their small size that are unique. These include transportability (some are designed for mobile operation), and self-regulation (capable of operating independent of a grid). In addition, MNRs are generally not designed to be fueled onsite. Instead, the entire reactor and housing are removed, returned to the manufacturer, and replaced when the fuel is spent.

[16] For example, a Nuscale 12-module power plant would be capable of generating 720 MW. In comparison, the peak demand of the Golden Valley Electric Association grid is 220 MW, and the Railbelt in total is approximately 800 MW.

[17] Currently, Nuscale is focusing on multi-module installations, and considering a heat pipe-based alternative for smaller or remote applications which remains in the conceptual phase.

The intended market for MNRs is quite different from most SMRs. This includes remote communities and mining sites, remote defense bases, humanitarian assistance, and disaster relief missions. Their small size and transportability mean MNRs are potentially more appropriate rural Alaska applications, potentially as a replacement for diesel engines (with heat as an important byproduct).

2.3 Fuel and Fuel Safety for SMRs and MNRs

2.3.1 Fuels

Advanced nuclear reactors are designed to use many different fuel configurations and assemblages. Most LWRs use pelletized uranium oxide housed in zirconium alloy rods (commonly called "fuel rods") that are stacked into bundles to provide the fuel for the reactor. The Nuscale reactor is designed to use these types of conventional fuel rods, which use fuel enriched with less than 5% uranium-235, the fissile isotope in nuclear fuel that produces energy during a fission chain reaction.

Many non-LWR designs are fast reactors that require a more highly enriched fuel to sustain the reaction because they do not use a neutron moderator (see explanation on previous page). However, there are no commercial facilities in the U.S. currently capable of producing these sorts of fuels. Therefore, the U.S. The Department of Energy is taking the lead on reprocessing uranium from a decommissioned experimental reactor at Idaho National Lab used to produce "high-assay, low-enriched uranium," (HALEU). With this supply, INL can produce up to 10 tons of HALEU for research, development and demonstration purposes

Classes of Nuclear Reactors

Nuclear fission reactors can be categorized in two major classes — thermal reactors and fast reactors:

Thermal Reactors: Thermal reactors use a medium such a water to moderate, or low down, neutrons giving them a higher probability of plitting fissile atoms, and hence sustaining the chain reaction that is needed to produce power. Thermal reactors constitute more tha 97% of the currently active power reactor fleet. The Nucale SMR is a thermal reactor.

Fast Reactors: Fast reactor do not contain a neutron moderator. The lower fision probability of thee non-moderated "fast" neutrons requires higher fuel enrichments to maintain criticality, typically on the order of 20%. Low moderation and enriched fuel allows these reactors to have a much smaller core volume, but the necessity of low moderation also restricts the choice for coolant, and thus fast reactors are typically cooled by liquid metal. Fast reactors help reducing radioactive waste by continuously disintegrating heavier isotopes and thus reducing the readiotoxicity of the spent fuel. The term "breeder reactor" is also sometimes applied to this class of reactor, because a portion of fertile material gets converted into fissile materials, thus spontaneously generating more fuel.

to address a short-term fuel supply gap. Several manufacturers are planning to use HALEU, including Oklo.[18] While still categorized as a low-enriched uranium fuel, it contains between 5-20% uranium-235, the fissile isotope in nuclear fuel. This is very important for many MNR designs that require higher levels of uranium-235 so the reactors can operate for years without having to be refueled.

A newer fuel is TRISO (TRi-structural ISOtropic) particle fuel. Each TRISO particle includes a uranium fuel kernel that is enclosed within three layers of carbon and ceramic-based materials which are then combined to create a "compact." Compacts can be assembled into different shapes and sizes for different purposes. This NRC-approved fuel is undergoing testing and qualification at INL, and is becoming the basis for a number of different reactor designs.[19] These include X-energy and Kairos Power, along with the Department of Defense, which is planning to use TRISO fuel for their sponsored designs such as those supported under Project Pele.

Other fuel configurations are also under development. Metallic fuel is similar in assembly to light water reactor fuel rods, and can be fabricated into different forms. Molten salt fuels are unique in that the nuclear fuel is dissolved directly in the molten salt coolant. An example of this approach is represented by Terrestrial Energy, a Canadian-based company, which is developing an SMR design called the Integral Molten Salt Reactor (IMSR).[20]

One of the main challenges associated with SMR and MNR technology, particularly those based on non-LWR designs, is developing manufacturing processes and supply chains for fuel. Many pilot projects are relying on specialized fuel supplied through the U.S. DOE. For example,

2.3.2 Fuel Transportation and Storage

In the nuclear industry, fuel is transported separately from other components under highly controlled conditions. We are aware of no significant accidents related to fuel transport in the U.S. Some SMRs, such as NuScale, are designed to be refueled on-site using similar conventions to those

[18] From "INL to provide Oklo access to recovered fuel for microreactor demonstration project," (February 20, 2020), Retrieved December 30, 2020, from http://www.bizmojoidaho.com/2020/02/inl-to-provide-oklo-access-to-recovered.html.

[19] Information on TRISO fuel available from "TRISO particles: The most robust nuclear fuel on earth," (July 19, 2019), by Idaho National Lab, from https://art.inl.gov/News%20Highlight%20Attachments/TRISO-particles-most-robust.pdf.

[20] The IMSR design is currently undergoing licensing in Canada of a 400MW thermal (190MW electrical) reactor design, with the first phase of a prelicensing review completed by the Canadian Nuclear Safety Commission in 2017. This first phase provided a regulatory opinion that the design features are generally safe enough to eventually obtain a license to construct the reactor. (From "Pre-Project Design Review of Terrestrial Energy Inc. Integral Molten Salt Reactor," (November, 2017), Retrieved December 30, 2020, from http://nuclearsafety.gc.ca/eng/pdfs/Pre-Project_Design_Review/Terrestrial-Energy-Pre-Project-Design-Review-Exec-Summary-eng.pdf.)

already established in the industry. However, transportation of an irradiated sealed MNR fuel core could create unique challenges. While existing transportation packages may have sufficient capacity for MNR cores, they would still require relicensing for the unique characteristics of that particular fuel core. The transport of larger sealed SMR fuel cores could be fundamentally different from conventional fuel transportation and require the development of new transport packages.

Among the concerns expressed in Alaska, is that the state may be required to retain spent fuel for long periods of time if there are issues with the downstream fuel processing system, which would necessitate siting, design, construction and management of special holding facilities. It is a concern shared by many others. This topic, and the many other matters associated with the overall fuel cycle, are receiving focused attention by the DOE's Office of Nuclear Energy.[21] Fuel management considerations warrant careful attention in Alaska's evaluation of nuclear energy application opportunities.

2.3.2 Disposal of Spent Fuel

Disposal of spent nuclear material is a major challenge. According to the NRC, there are two acceptable storage methods for spent fuel after it is removed from the reactor core. Currently, most spent nuclear fuel is stored in specially designed spent fuel pools at individual reactor sites around the country. Secondly, some spent nuclear fuel is stored in dry cask storage systems at independent spent fuel storage facilities either at the reactor site where it was used, or at a designated and approved off-site location.[22] A long-term solution for storing nuclear waste has long presented a challenge. The Nuclear Waste Policy Act (NWPA) of 1982 dictated that the federal government would identify a permanent geological repository and begin transferring waste from nuclear power plants to that repository by 1998. For several years, the DOE studied a number of locations to determine their suitability, ultimately settling on Yucca Mountain, a site in Nevada about 80 miles northwest of Las Vegas. Development of this site has been delayed for many reasons, chief among them local opposition. It will likely take decades before either a repository or interim consolidated storage site is sited and constructed. In the meantime, nuclear waste will continue to be stored at reactor sites.

MNR and most SMR locations would not be equipped to handle spent fuel or unused fuel for significant periods of time. In theory, MNRs would be shipped with pre-fueled reactor cores, and

[21] An overview of DOE-NE's fuel cycle efforts is available at: "Fuel Cycle Technologies," (n.d.), from https://www.energy.gov/ne/initiatives/fuel-cycle-technologies.

[22] From "Storage of Spent Nuclear Fuel," (December 23, 2020), by the National Regulatory Commision, Retrieved December 30, 2020, from https://www.nrc.gov/waste/spent-fuel-storage.html.

the entire reactor would be returned to the manufacturer at the end of life. SMRs may or may not require on-site fueling. In any case, nuclear fuel management and disposal is a significant concern that should be more fully addressed prior to full commercialization.

2.4 Nuscale, Oklo, and USNC — Representative SMR and MNR Technologies

Three companies have emerged of specific interest to the Alaska market, and both have engaged with Alaska-based organizations as potential customers. The first, NuScale Power, is a SMR light water reactor technology that is closest to commercialization in the U.S. The other two, Oklo Inc. and the Ultra Safe Nuclear Corporation (USNC), are non-light water MNRs designed to generate 1.5 MW and 5 MW of electric power respectively. These companies are described in more detail below and are used as the basis for our economic modeling in Section 5.[23]

2.4.1 NuScale Power

The NuScale Power SMR is considered by many to be the most mature of the domestic small reactor designs. NuScale is currently on track to break ground on a pilot plant at the Idaho National Laboratory (INL) in 2025.[24] Its system incorporates a pressurized light water reactor[25] consisting of twelve individual 60 MW modules packaged together as a combined 720 MW electric plant. This project is scheduled to be commissioned in 2029,[26] and will provide power to communities that are part of the Utah Associated Municipal Power Systems (UAMPS) through power purchase agreements with member communities. The project is being developed through the wholly-owned UAMPS subsidiary, the Carbon Free Power Project (CFPP),[27] which received $1.355 billion from the Department of Energy in October 2020 to match funds from UAMPS members and support project development. NuScale is also engaged in possible international development, with a preliminary commitment to deploy up to 2.5 GW of NuScale modules in South Africa.[28]

[23] NuScale was also used for the economic model developed for ACEP's 2011 report (Holdmann et al, 2011).

[24] This project is heavily subsidized by the U.S. Department of Energy.

[25] The family of nuclear reactors known as light-water reactors (LWR) are cooled and moderated using ordinary water. These tend to be simpler and cheaper to build than other types of nuclear reactors and make up the vast majority of civil nuclear reactors and naval propulsion reactors in service throughout the world.

[26] The first unit is scheduled to come online in 2029, with the rest of the plant commissioned in 2030.

[27] UAMPS is a public power agency that provides electricity at wholesale to more than 40 community-owned electric utilities in six Western states: Utah, California, Idaho, Nevada, New Mexico, and Wyoming. UAMPs is supporting the project through the special-purpose subsidiary the Carbon-Free Power Project (CFPP). Not all communities are supportive of the project, and several UAMPS communities have dropped out of the project.

[28] From "Commercial NuScale SMR in Sight as UAMPS Secures $1.4B for Plant," by Patel, S., (October 22, 2020), Retrieved December 30, 2020, from https://www.powermag.com/commercial-nuscale-smr-in-sight-as-uamps-secures-1-4b-for-plant/.

A NuScale 12-pack would be too large to be considered for deployment in Alaska. As a point of comparison, the peak demand of the Golden Valley Electric Association grid is 220 MW, and the Railbelt, in total, is approximately 800 MW. However, NuScale is proposing smaller systems that might be more applicable to future Alaska-based deployments. This includes a 10 to 50 MW stand-alone "micro NuScale" power module, and a smaller 1 to 10 MW heat pipe reactor. The micro NuScale power module design is more developed than the heat pipe reactor since it builds on their existing PWR design. According to company representatives, the micro reactor would be targeted at small power grids, remote and off-grid communities, off-grid industrial facilities including mining sites and military installations. Applications for the heat pipe reactor would include remote off-grid communities, remote mining operations with shorter lifespans, temporary power for disaster relief and potentially space travel. Both designs are still in the conceptual phase and are not expected to be available until after the INL deployment has been completed.[29]

2.4.2 Oklo Inc.

Oklo represents an entirely different class of nuclear reactor from the NuScale system. It is categorized as a sodium-cooled fast reactor (see previous page), which permits a very compact reactor design. To transfer heat away from the reactor for utilization, Oklo plans to use heat pipes. A heat pipe is a heat-transfer device that takes advantage of transition of a substance between a vapor and liquid phase in order to transfer heat between two areas without the need for pumps or fans. A good example of this, albeit at very different temperatures, are the ammonia-filled heat pipes used to keep the ground under the Trans-Alaska Pipeline frozen. In this case, conduction of heat from the relatively warm ground in the winter vaporizes the ammonia which then travels upward along the heat pipe to the air-cooled fins at the top of the pipe. Here, the ammonia condenses back into a liquid, releasing latent heat which is transferred to the surrounding cold air. It then falls via gravity back down through the heat pipe to the warmer interface where the process repeats. In the case of Oklo, the concept is the same but the temperatures and materials are very different, with high temperature liquid sodium taking the place of ammonia as the heat-transfer fluid and much greater amounts of heat involved in the process.

The Oklo MNR is also very tiny — its initial design, the Aurora Power Plant, is expected to be capable of sustaining only 1.5 MW of electric power. However, its high fuel efficiency means it is designed to operate for 20 years without refueling. In addition, the high reactor temperatures allow use of supercritical CO2 instead of steam to drive the turbine, improving efficiencies and reducing turbine sizes, further resulting in a smaller footprint and reduced infrastructure costs.

[29] This information is based on a NuScale presentation to GVEA on October 6th, 2020.

Figure 2.3. An artist rendering of the Aurora, Oklo's 1.5 MW MNR design. With a small footprint and a reactor installed below grade, this system bears little resemblance to a conventional nuclear plant. (Image courtesy of Oklo).

In March 2020, Oklo submitted a combined license application for the design and operation of a "compact fast micro-reactor," which is currently under review by the Nuclear Regulatory Commission (NRC).[30] Assuming the NRC process is not delayed, Oklo hopes to construct their first Aurora Power Plant at INL in 2022 or 2023. This would be significantly sooner than NuScale, despite the fact that they are much more recent market entrants. This is enabled by two factors. First, the small size and relative simplicity of MNRs even compared to SMRs means that permitting and, ultimately, construction have the potential of being accelerated. Secondly, Oklo has a different business approach than traditional entrants into the nuclear energy industry. It is a true start-up company based in Silicon Valley, and has generally eschewed government grants to raise smaller, venture capital-backed funding rounds. This seems to have allowed it to iterate much more quickly on its designs as it moves through the application process than its competitors.[31]

[30] Documents related to Oklo's application can be reviewed on the NRC website: "Oklo Power Combined Operating License Application for the Aurora at INL.," (March 26, 2020), https://www.nrc.gov/docs/ML2007/ML20075A000.html.

[31] Information provided is derived from ACEP's nuclear educational series presentation by Jacob DeWitte, Cofounder and CEO of Oklo on December 3rd, 2020

Oklo has had an interest in the Alaska market almost since inception. It successfully competed in Round 2 of the Alaska Center for Microgrid Technologies Commercialization (ACMTC) competition in 2017. Their proposal "Integrating Alaska-scale nuclear power in rural microgrids" requested assistance to define the market for MW-scale reactors in Alaska. As part of the project, ACEP did initial modeling for utilization of heat and power on the scale that would be generated by the Aurora reactor. Launch Alaska, a business accelerator based in Anchorage, also selected Oklo as part of their 2019 cohort and Oklo is part of their current portfolio of companies.[32]

2.4.3 Ultra Safe Nuclear Corporation

Ultra Safe Nuclear Corporation (USNC) is a Seattle-based developer whose primary commercial design, the Micro Modular Reactor Energy System (MMR), is on track to be the first systems designed for the North American market to be demonstrated in the field. The MMR is designed to produce 15 MW of thermal power continuously with no refueling for 20 years and can be installed either individually or in configurations with several units installed in parallel. Like Oklo, the USNC MMR is part of a new generation of proposed very small reactors. The MMR is a gas-cooled reactor using helium gas as the reactor's primary coolant, transferring heat from the reactor to a molten salt heat storage system. The molten salt then supplies heat to the power generation components to produce electricity or to be used for other applications.

The heat storage unit decouples the nuclear system from the power utilization system and greatly simplifies operation, which is desirable for off-grid remote operations. USNC envisions incorporating the thermal storage unit as the heart of a versatile "adjacent power plant" for uses as diverse as power production, space heating, hydrogen production, and integration with renewable energy sources.[33]

USNC is currently focused on licensing and demonstrating their technology in Canada rather than the U.S.[34] The reactor completed the first phase of the Canadian Nuclear Safety Commission (CNSC) pre-licensing vendor design review process in January 2019. A joint venture has been formed between Ultra Safe Nuclear Corporation (USNC) and Ontario Power Generation (OPG) to build, own and operate an MMR reactor project at the Canadian Nuclear Laboratories (CNL) Chalk

[32] Launch Alaska website: http://www.launchalaska.com/.

[33] Information provided is derived from ACEP's nuclear educational series presentation by Wendy Simon-Pearson, General Counsel, Ultra Safe Nuclear Corporation presented December 17th, 2020.

[34] There are various reasons why a vendor would choose to license their technology in Canada rather than the U.S. Although initially having different approaches with the CNSC more flexible in addressing the unique needs of small reactor technology, today the CNSC and US-NRC are converging on harmonization of the licensing process, so the licensing work done for one country will be broadly applicable to the other.

River site by 2026.[35] The joint venture is equally owned and funded by OPG and USNC-Power, the Canadian subsidiary of USNC. USNC is interested in entering into a similar venture with a U.S. nuclear operator or electric utility to deploy a power plant in the U.S.

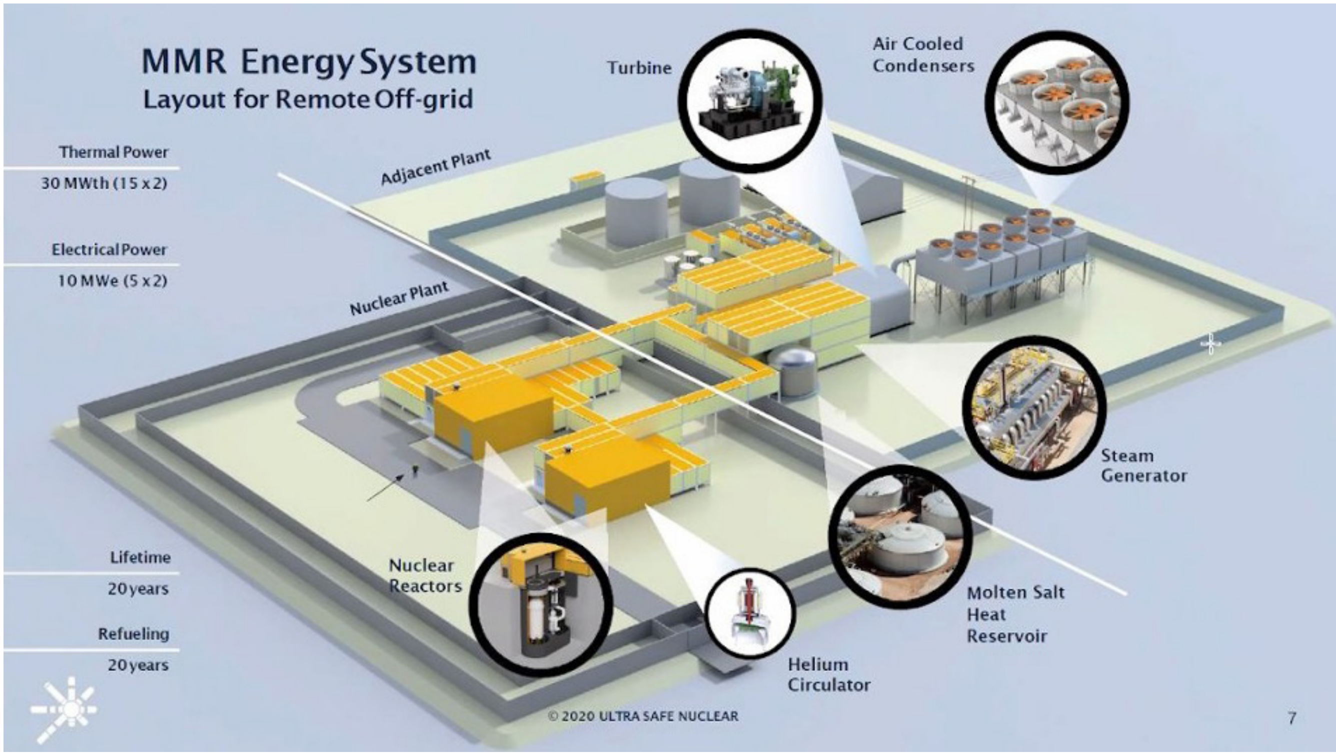

Figure 2.4. A proposed layout for the Ultra Safe Nuclear Corporation Micro Modular Reactor Energy System (MMR), which incorporates two reactors each capable of supporting 5 MW of electric power generation. Other configurations are also possible, including a single unit or multiple units. (Image courtesy of USNC)

2.4.4 Other Technologies Relevant to the Alaska Market

The SMR and MNR landscape is continually evolving. New companies are emerging, while other technologies are shelved or abandoned. When ACEP completed an initial survey of the MNR landscape in 2011, neither Oklo nor USNC had been formed (Holdmann, 2011). Of the ten technologies mentioned in that report, only three are still in active development (including NuScale). We have attempted to capture the major technologies that are active in the U.S. and sized under 300 MW in Appendix A of this report.

[35] According to a personal communication from USNC, they hope to achieve first power by as early as 2024.

2.5 International Development in MNRs and SMRs

The U.S. is not the only country with a renewed interest in nuclear energy. Internationally, there are over 50 commercial SMRs and MNRs at various stages of design and development. However, the majority of these are SMRs designed to replace conventional nuclear power. The two exceptions are Russia and Canada, which are actively pursuing SMR and MNR technologies for many of the same reasons they are of interest to Alaska. Because of these similar interests and geographic proximity, this section focuses on activities in these two countries. For additional information on activities in other countries, the World Nuclear Association maintains a comprehensive report on global activities related to SMR and MNR development, organized both by country and technology type. Because it is an online publication, it is updated regularly as new information is made available.[36]

2.5.1 Russia

Russia has an extensive history related to nuclear energy and has an interest in developing modular or transportable systems. Russia's Dollezhal Research and Development Institute of Power Engineering has been engaged in the design of a mobile nuclear power plant (MNPP). This Modular Transportable Small Power Nuclear Reactor (MTSPNR) is reported to be capable of producing 2.5 MW of electric power, and is designed to supply heat and electricity supply of remote regions for 25 years before refueling. In 2015 it was reported that the Russian defense ministry had commissioned the development of small mobile nuclear power plants for military installations in the Arctic, specifically a "mobile low-power nuclear unit to be mounted on a large truck, tracked vehicle or a sledged platform. Production models will need to be capable of being transported by military cargo jets and heavy cargo helicopters, such as the Mil Mi-26. They need to be fully autonomous and designed for years-long operation without refueling, with a small number of personnel, and a remote control center" (World Nuclear Energy Association, 2020).

Russia recently deployed a Floating Nuclear Power Plant (FNPP) in the Arctic Ocean. The FNPP, Akademik Lomonosov, comprises two reactors with a combined capacity of 70 MW electric. Its design life is 40 years; the repair interval is 12 years (used fuel is stored on-board for up to 12 years). Similar to NuScale, this system is expected to have a refueling schedule of three to four years. Once moored, it does not require additional infrastructure associated with land-based plants. Construction of the vessel began in 2007 and commercial operations of the plant commenced in May 2020. The vessel is moored at Pevek, Chukotka, a port town on the East Siberian Sea in Far East

[36] Available from "Small Nuclear Power Reactors," (updated November 2020), by the World Nuclear Association, from https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx.

Russia, approximately 750 miles NW of Nome. The plant is connected to the region's electric grid, heat and water supply. Production and process heat supply is planned to be fully implemented by 2021.

In July 2017 Rosatom announced the second generation of FNPPs, now called Optimized Floating Power Units (OFPUs), which would use two 50 MW reactors derived from those used in the newest Russian icebreakers. These would be fast reactors using enriched fuel and requiring refueling only every 10-12 years at a service base. Operational lifetime is 40 years, with possible extension to 60 years.[37]

2.5.2 Canada

Canada has also invested in SMR and MNR technologies and is working to position itself as a global leader in prototype testing and technology development support. On December 18th, 2020, Canada's Small Modular Reactor (SMR) Action Plan[38] was published which outlines Canada's strategy to support "the development, demonstration and deployment of SMRs for multiple applications at home and abroad." This follows the publications of an SMR Roadmap published by the Canadian government in November 2018.[39] The Roadmap concluded that interest in SMR development is a response to market forces for "smaller, simpler and cheaper" nuclear energy, and the large global market for this technology will be "driven not just by climate change and clean energy policies, but also by the imperatives of energy security and access."

The first step outlined in the Canadian Action Plan is the demonstration of an SMR plant. The Canadian Nuclear Laboratories (CNL) plans to construct a demonstration SMR plant by 2026 at their Chalk River Laboratories test site in Ontario.[40,41] There are several developers who are choosing a Canadian path to commercialization, including USNC, which is widely expected to be the first advanced reactor to progress to full-scale demonstration. The project is currently in the third phase (environmental assessment) of a four-stage process. There are three other companies that

[37] From "Nuclear Power in Russia: Floating nuclear power plants," (Updated November 2020), by the World Nuclear Association, Retrieved October 15, 2020, from https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx#FNP P

[38] Available from "Canada's Small Modular Reactor (SMR) Action Plan," (n.d.), from https://smractionplan.ca/.

[39] Available from "Canada's Small Modular Reactor (SMR) Road Map," (n.d.), from https://smrroadmap.ca/.

[40] A recent Request for Expressions of Interest (RFEOI) by CNL yielded 19 proposals for a prototype or demonstration reactor at a CNL site.

[41] From "Technology developers advance in CNL's process to site a small modular reactor," (February 15, 2019), by Canadian Nuclear Laboratories, Retrieved November 23, 2020, from https://www.cnl.ca/en/home/facilities-and-expertise/smr/progressupdate.aspx.

have completed the first stage, including: U-Battery Canada Ltd, with a design for a 4 MWe high-temperature gas reactor; StarCore Nuclear, with a proposed 14 MWe high-temperature gas reactor; and Terrestrial Energy, with a 190 MWe integral molten salt reactor.

2.6 References

The vast majority of references used for this section are via websites, news articles, presentations, and personal communications. These are notated as footnotes throughout the chapter. Formal publications are listed below.

Canadian Small Modular Reactor Roadmap Steering Committee (2018). "A Call to Action: A Canadian Roadmap for Small Modular Reactors." Ottawa, Ontario, Canada. Retrieved October 22, 2020, from https://smrroadmap.ca/wp-content/uploads/2018/11/SMRroadmap_EN_nov6_Web-1.pdf

SMR Roadmap Technology working group (2018). "Canadian SMR Roadmap: Technology Working Group Report." Retrieved October 22, 2020, from https://smrroadmap.ca/wp-content/uploads/2018/12/Technology-WG.pdf.

Cowan, R. (1990). "Nuclear Power Reactors: A Study in Technological Lock-in." *The Journal of Economic History,* 50(3), 541-567. doi:10.1017/s0022050700037153

Hewlett, R. G., & Duncan, F. (1974). *"Nuclear navy, 1946-1962."* Chicago: Univ. of Chicago Press. Available at: https://www.energy.gov/lm/downloads/hewlett-and-duncan-nuclear-navy-1946-1962.

Holdmann, G., Fay, G., Witmer, D., Williams, F., Schwoerer, T., Pride, D., & Stevens, R. (2011). *"Small-Scale Modular Nuclear Power: An Option for Alaska?."* 127 pages. Technical report prepared for the Alaska Energy Authority at the request of the Alaska State Legislature. Available at: http://acep.uaf.edu/media/147559/Small-Scale-Modular-Nuclear-Power-an-option-for-Alaska-2011-ACEP-and-ISER.pdf

Schneider, M. & Froggatt, A. (2020). *"The World Nuclear Industry Status Report 2020."* Available at: https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2020-HTML.html

3. Licensing SMR and MNR Technologies

3.0 Licensing SMR and MNR Technologies

The Nuclear Regulatory Commission (NRC)[42] is the lead permitting agency for the U.S. There are many different paths to a licensed operating plant, which can almost be considered as building blocks. Currently, there are two main licensing frameworks in the U.S. These are called by their portions in the Code of Federal Regulation, Title 10: "Part 50" and "Part 52" licensing. Both were originally formulated primarily for light water reactors, but could be used for advanced or non-light water reactors. Part 50 is a two-part licensing path for construction and operation. Because of the risk inherent in this older process, there was a movement to update the Part 52 process, allowing for a construction and operation license in one step. This is called the "combined license." Notably, there are a number of possible building blocks for a Part 52 license, including allowances for manufacturing, design certifications,[43] (which have the finality of a rule), standard design approvals (which offer less finality than a design certification, but with more flexible definition), the ability to get an early site permit,[44] and approvals on various topics through "topical reports." Importantly, the Part 52 process allows for a direct combined license application (COLA) without other steps being required, which is the method for the first and only COLA accepted for review by the NRC for a non-LWR.

The NRC issues standard design certifications, early site permits, limited work authorizations, construction permits, operating licenses, and combined licenses for three types of reactors:

- Large Light Water Reactors (LWR). These represent the vast majority of conventional nuclear power plants in the U.S. For reactors in this category, a well-established regulatory framework is in place.
- Small Modular Reactors (LWR designs). NuScale is an example of an SMR based on light water technology. For this category, the regulatory framework is following a modified version of the one in place for large-scale LWRs.
- Advanced Reactors (non-LWR designs). This would include Oklo and USNC, along with all other MNR designs.

[42] Nuclear Regulatory Commission website: https://www.nrc.gov/

[43] NRC Design Certification Applications: https://www.nrc.gov/reactors/new-reactors/design-cert.html

[44] NRC Early Site Permit Applications: https://www.nrc.gov/reactors/new-reactors/esp.html

Although the NRC differentiates between these categories, the licensing process is not separate for the 3 types. In all cases, Congress limits the NRC time in review of that application to 3 years from the time of acceptance of the application, depending on the type of application.

This statutorily defined timeline for review is intended to speed the permitting process which has historically taken a very long time to complete. For example, the Design Certification for the most recent LWR certified by NRC, the Westinghouse AP1000, took approximately 3 years (2002-2005) from application submission to publishing of the Design Certification Rule. The combined operating license (COL) associated with the AP1000 then required an additional 4 years (2008-2012) to finalize.

The Oklo combined license application for a very small advanced fission plant (1.5 MWe) was submitted in 2020 and has been given a 3 year timeline for review, as limited by Congressional mandate. The NRC has implemented a number of new processes to review new application structures and new technology types. However, there remain challenges in interpretations of old regulations formulated for large light water reactor plants and how to apply them to small and advanced reactor technologies.

The NRC receives all of its funding from the U.S. Congress but is required by law to recover 90% of the budget (cost recovery) from the vendors they provide services to. Each year, estimated budgets are created with assumptions on necessary activities, and both hourly and annual fees are set. Fees for pre-application and application activities fall under 'Special Projects' and are charged at 'full cost' meaning every hour an NRC employee spends on the project is charged at $279/hr (professional staff current 2020 rate).[45]

The challenges in utilizing outdated frameworks are significant. Industry and government have acknowledged these regulatory hurdles, and are working together in an attempt to establish a framework that may enable licensing a commercial non-light water reactor through a new "Part 53" process. One example of this collaboration is the Nuclear Energy Innovation and Modernization Act (NEIMA).[46] NEIMA was signed into law in January 2019. As required by Sections 103(b) and 103(c), the NRC prepared two reports to Congress regarding (1) expediting and establishing stages in the licensing process for commercial advanced nuclear reactors; and (2) increasing, where appropriate, the use of risk-informed and performance-based evaluation techniques and regulatory guidance

[45] Federal Register/Vol. 85, No. 32/Tuesday, February 18, 2020/Proposed Rules, available at https://www.govinfo.gov/content/pkg/FR-2020-02-18/pdf/2020-03054.pdf

[46] "S.512 — Nuclear Energy Innovation and Modernization Act", available at https://www.congress.gov/bill/115th-congress/senate-bill/512.

in licensing commercial advanced nuclear reactors within the existing regulatory framework. These reports were sent to Congress on July 12, 2019.

The staff has begun efforts to establish a "Risk Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors" for optional use by applicants for new commercial advanced nuclear reactor licenses by December 31, 2027. The staff presented its proposed plan for this rulemaking to the Commission for approval in SECY-20-0032 dated April 13, 2020.[47]

The NRC has also engaged with the Licensing Modernization Project (LMP) led by Southern Company, coordinated by the NEI, and cost-shared by DOE.[48] The interactions between the NRC staff and LMP are an attempt to provide optional guidance for applicants to utilize a risk-informed method for accident analysis, component classification, and demonstrating "defense-in-depth." One milestone of this project was achieved when NRC published Regulatory Guide 1.233, "Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light Water Reactors," in the Federal Register on June 9, 2020.[49]

In 2018, the NRC worked with Oklo to pilot an entirely new application structure for potential use for advanced or non-LWR technologies for use in the current Part 52 framework. Importantly, this application structure right-sizes key content and focuses on exactly what the regulations require instead of relying on guidance for LWRs. Oklo submitted a COLA based on this structure in 2020, and it is expected that more applications may utilize it prior to the potential creation of a new Part 53 or even as an option after Part 53 is finalized.

3.1 SMR and MNR Companies Seeking NRC Approval

NuScale was the first company to work with the NRC to license a light water SMR. Their pre-application process with the NRC began in 2008. A Design Certification application was submitted in Dec 2016 and NRC issued Final Safety Evaluation Report (FSER) in 2020.[50] NuScale has been

[47] "Rulemaking Plan on 'risk-informed, technology-inclusive regulatory framework for commercial advanced nuclear reactors in response to the Nuclear Energy Innovation and Modernization Act (NEIMA)' RIN-3150-AK31; NRC-2019-0062)", available at https://www.nrc.gov/docs/ML1934/ML19340A056.pdf.

[48] "Licensing Modernization Project for Advanced Reactor Technologies: FY 2018 Project Status Report", available at https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_7242.pdf.

[49] "Guidance on using a technology-inclusive, risk-informed, and performance-based methodology to inform the licensing basis and content of applications for non-light-water reactors (non-LWRs)", by the NRC, available at https://www.nrc.gov/docs/ML2009/ML20091L698.pdf.

[50] "NuScale Safety Evaluations", by the NRC, available at: https://www.nrc.gov/reactors/new-reactors/smr/nuscale/ser-open-items.html

given a Site Use Permit to locate on the INL Site by the DOE, and has been working with the utility UAMPS to sell power from the first plant. To date the NRC has not reported any submission for the NuScale COLA. The timeline for such a COLA review would be expected to be limited to 3 years in review. The company hopes to break ground at INL in 2025 and commission a pilot project in 2029-30.

Non-LWRs have engaged in a range of NRC approval activities. Oklo Inc was the first non-LWR company in recent years to engage the NRC in formal pre-application beginning in 2016 and remained the only company for a couple years. Oklo submitted a combined license application (COLA) on March 11, 2020, which the NRC accepted for review in June 2020. The NRC published a review schedule of 36 months for this COLA. A number of other companies with non-LWR designs are engaging the NRC regarding topical reports, including Kairos, GE, and others.

It should also be noted that Idaho National Laboratory is not the only prospective site seeking a license through the NCR. The Tennessee Valley Authority (TVA), a U.S. Government Agency, has also received an Early Site Permit from the NRC, which could be an additional location for an early SMR.

4. Policies and Roadmaps: U.S. and Alaska

4.1 U.S. Nuclear Roadmaps

Two roadmaps relevant to nuclear developments in the U.S. were recently released: the Department of Energy's Nuclear Fuel Working Group (NFWG) task force devised a new Strategy to Restore American Nuclear Energy Leadership[51] for rebuilding the country's nuclear energy sector which was unveiled on April 23, 2020. The strategy includes a commitment to strengthening the U.S. uranium mining industry in an effort to end reliance on foreign supplies and leverage technological innovation to regain American nuclear energy leadership, especially in the nuclear technology export markets. Senator Murkowski recently re-introduced her American Mineral Security Act[52] in an attempt to rebuild the domestic mineral supply chains for some of the 35 minerals[53] that are critical to our society, including uranium.

The second strategy is a Road Map for the Deployment of Micro-Reactors for U.S. Department of Defense Domestic Installation[54] prepared by the Nuclear Energy Institute (NEI) and published on October 4, 2018. The primary suggestion of the report is to "deploy the first micro-reactor for a U.S. Department of Defense (DOD) domestic installation before the end of 2027." Recommendations for actions include "to identify a host installation and site requirements, perform an assessment of the designs, and enter into a contract or agreement with a commercial entity by the end of 2019." Alaska military bases have gotten consideration as a first host installation and are currently being evaluated. The Department of Defense will not regulate nuclear reactors and will instead work with the NRC to get the technology, design and site certified. This means general NRC guidelines will apply to military bases. Another critical action item pertains to High Assay Low Enriched Uranium (HALEU)[55]: "The Department of Energy (DOE) should provide this fuel for the commercial nuclear industry by the end of 2022, and begin supporting the design, qualification, licensing and fabrication of larger HALEU transportation packages by the end of 2019." This is an important step forward as

[51] "Restoring America's Competitive Nuclear Energy Advantage — A strategy to assure US national security," (April 2020), by the DOE, available at: https://www.energy.gov/sites/prod/files/2020/04/f74/Restoring%20America%27s%20Competitive%20Nuclear%20Advantage_1.pdf.

[52] "Murkowski, Manchin, Colleagues Introduce Bipartisan Legislation to Strengthen America's Mineral Security", (May 3, 2019), by the Senate Committee on Energy and Natural Resources, Retrieved October 29, 2020 from https://www.energy.senate.gov/2019/5/murkowski-manchin-colleagues-introduce-bipartisan

[53] "35 Minerals That Are Critical To Our Society," (November 19, 2019), by Conca, J., Retrieved October 29, 2020, from https://www.forbes.com/sites/jamesconca/2019/11/19/35-minerals-that-are-critical-to-our-society/.

[54] "Roadmap for the Deployment of Micro-Reactors for U.S. Department of Defense Domestic Installations," (October 4, 2018), by Nuclear Energy Institute, Retrieved October 29, 2020, from https://www.nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/Road-map-micro-reactors-depa rtment-defense-201810.pdf.

[55] HALEU is uranium fuel enriched to between 5% and less than 20% and is required for Gen IV reactors (liquid metal reactors).

HALEU is required for the next generation of reactors and is currently not commercially available.

4.2 Alaska Regulations Guiding the Siting of Nuclear Reactors

Alaska regulations on nuclear reactors are governed in the Alaska Nuclear Energy Statues 2019, Section 18, Chapter 45: Atomic Energy.[56] In 2010, the Alaska Legislature passed the Alaska Sustainable Energy Act (SB 220).[57] The omnibus bill was intended to "level the playing field for nuclear energy projects in Alaska, ensuring that as new technologies are developed, Alaska can consider them alongside other options." Its purpose was to "modernize AK statutes, clarify jurisdictional responsibility, put nuclear on a level playing field with other alternative energies, and remove gubernatorial approval of facility siting permits." AS 18.45.025(b)(1) is amended to give the Legislature the authority to designate lands in the state for the use of nuclear utilization facilities provided they act in the interest of regulating the economics of nuclear energy rather than the interest of public health and safety in designating lands. The authority to regulate public health and safety of nuclear rests solely with the NRC. "The other significant component of this bill qualifies that a person may not construct a nuclear facility in the state without first obtaining a permit from the Alaska Department of Environmental Conservation (ADEC). This permit, if the proposed site was located in a municipality, would require municipal approval before it could be issued. According to the staff at ADEC, although the Act mandated the creation of an authorization program, funds have yet to be allocated for the development of one. Further, ADEC states that nuclear facility proponents would first have to go through the entire NRC permitting process before there could be a local one. If an application for an Early Site Permit (ESP) or Combined Operating License (COL) was submitted for a location in Alaska, the legislature would then need to appropriate the funding for the state authorization program."[58]

In 2020, the Alaska State Senate Community and Regional Affairs Committee authored SB 194, "An Act relating to advanced nuclear reactors."[59] The purpose of this bill was to propose modifications to the Alaska Statutes pertaining to nuclear energy. Specifically, the bill provided a definition of what an "advanced nuclear reactor" is, and clarified permitting requirements in Alaska. It also removed

[56] "Alaska Nuclear Energy Statues 2019, Section 18, Chapter 45: Atomic Energy," Retrieved December 30, 2020, from http://www.akleg.gov/basis/statutes.asp#18.45.020.

[57] "Alaska Sustainable Energy Act (SB 220)", Retrieved December 30, 2020, from http://www.akleg.gov/basis/get_documents.asp?session=26&docid=8040.

[58] From "Research in Advanced Nuclear Development and Planning," by Kuca, M., (2014), Retrieved December 30, 2020, from http://hdl.handle.net/11122/8842.

[59] "Alaska State Senate Community and Regional Affairs Committee Bill SB 194, 'An Act relating to advanced nuclear reactors'", Retrieved December 30, 2020, from http://www.akleg.gov/basis/Bill/Detail/31?Root=SB%20194

the requirement that the legislature should designate lands for a nuclear reactor for advanced nuclear reactors less than 300 MW. This bill did not pass out of committee and would need to be reintroduced during a future legislative session if there is still interest in making these changes. Further amendments and revisions might be required once nuclear microreactor technologies have matured to a level of regulatory acceptance through the NRC. One of the issues to be addressed should be reactor decommissioning.[60]

A recent review of the Alaska Nuclear Energy Statues has identified several potential changes that build on those proposed in SB 194. These are itemized in Appendix B of this report. Most importantly, we agree with the authors of SB 194 that it is important to clarify site permitting requirements in Alaska (with the DEC as the lead agency), and remove the requirement that the state legislature should designate lands for a nuclear reactor.[61] This is consistent with regulations and statutes in other U.S. states, and removes overt politics from future

decision-making related to SMRs or MNRs. Instead, we recommend decision making be deferred to the local level with environmental and permitting led by the DEC. Also, since state agencies have little experience or expertise with nuclear power, an umbrella study with the involvement of critical state agencies would be an appropriate near-term step.

It should also be noted that numerous stakeholders have recommended that the first microreactor project in Alaska should be at a military base, possibly Eielson Air Force Base. While DOD is not required to comply with State law, public sentiment might affect potential decisions.

[60] "Decommissioning nuclear reactors is a long-term and costly process," (November 17, 2017), by Gospodarczyk, M.M., & Kincer, J., Retrieved December 30, 2020, from https://www.eia.gov/todayinenergy/detail.php?id=33792.

[61] A personal discussion with a legislator involved in the original development of these statutes acknowledges they were developed in response to concerns about nuclear proliferation and waste disposal and were not intended to hinder small-scale development that was not envisioned as a possibility at the time of authorship.

5. Economics of SMR and MNR Technology in the Alaska Context

5.0 Introduction

This chapter provides a partial update to the analysis of SMR and MNR technology that was presented in the 2011 study. Generally, the costs of SMR and MNR construction and deployment generally remain too uncertain to enable conventional cost-effectiveness or cost-benefit calculations for specific use cases. However, it is possible to use some new information that is emerging for MNR's to consider whether these technologies are "in the ballpark" when compared to the avoidable cost of existing fossil fuel electricity generation sources. The questions of how much, how, and at what cost direct thermal energy could be provided in addition to — or perhaps in place of — electricity loom large when considering the ability of nuclear energy to meet Alaska's unique energy needs.

5.1 Summary of 2011 Report

It is useful to first revisit the results of the 2011 report. That study provided an economic screening analysis that considered 4 SMR's: mPower (125 MWe), NuScale (45 MWe), Hyperion (25 MWe) and Toshiba 4S (10 MWe and 50 MWe). Of these, only the NuScale design is currently under active development (now increased in projected output to 60 MWe). MNR's were not evaluated in the 2011 report because they were not yet being actively developed.

The key assumptions about the cost of energy from a potential NuScale 45 MWe reactor were the following:

- "Overnight" capital cost (neglecting capitalized interest due to multi-year construction) ranges from $4,500 to $8,000 per kilowatt of electric capacity.
- Licensing cost ranges from $1,100 to $1,560 per kilowatt of electric capacity.
- Annual cost of 8 security staff plus 35 operators totals $4 million.
- Nuclear fuel cost ranges from $2.5 million to $4.9 million per year
- Mobilization and demobilization cost equals $2.6 million per year

In addition, a key assumption was that heat equal to 3 times the electric energy output could be sold for $5.00 per million Btu into a pre-existing district heating network.

Under these assumptions, the 2011 analysis determined that the NuScale reactor could generate electricity at a production cost ranging from about 9 to 13 cents per kWh in today's (2020) dollars.

This cost was determined to be competitive in Fairbanks under scenarios where the price of crude oil exceeds about $80 per barrel, and in Anchorage if natural gas prices exceed about $14.00 per thousand cubic feet (mcf). The NuScale reactor was not competitive in any of several hub or small rural communities, due in large part to being oversized for the electric and thermal loads. The pattern of results did not change when a modest carbon price — starting at $15 per metric ton CO2 and increasing 5% per year in real dollars — was included in the cost of diesel or natural gas.

5.2 SMR Costs Remain Highly Uncertain

Several recent reviews of SMR costs[62,63,64] provide no persuasive evidence that the wide range of potential SMR construction and licensing costs presented in 2011 should be adjusted at this time. The MIT study on *The Future of Nuclear Energy*[65] did provide evidence that cost estimates tend to increase as they become more certain, noting:

> The cost patterns seen in other technologies are also relevant to advanced reactor systems, as evidenced by large increases in projected costs for a number of reactors… Advertised overnight costs for the AP1000 have increased from a "certified" public utility commission value of approximately $4,500/kWe to $8,600/kWe. Early pre-conceptual cost estimates for NuScale were $1,200/kWe but are now projected to be approximately $5,000/kWe. (page 74)

In addition, the comprehensive review by Mignacca & Locatelli highlights the distinction between single-unit costs and overall programme costs:

> Most of the studies are at plant-level (1 SMR vs 1 LR) or site-level (X SMRs vs 1 LR of equivalent total size), neglecting the focus at the programme-level and the interdependency between the programme and the strategy of each country. Furthermore, most of the methodologies for the cost-benefit analysis are often inadequately applied, by not considering that the development of a nuclear programme involves a wide range of

[62] From "Economics of Nuclear Power, " (Updated March 2020), by the World Nuclear Association, Retrieved December 30, 2020, from https://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx.

[63] From "Economics and finance of Small Modular Reactors: A systematic review and research agenda," by Mignacca, B., & Locatelli, G., (2020), Renewable and Sustainable Energy Reviews, Volume 118, 109519, Retrieved December 30, 2020, from http://www.sciencedirect.com/science/article/pii/S1364032119307270.

[64] From "Lazard's Levelized Cost of Energy Analysis Version 14.0," by Lazard & Co., (October 2020), Retrieved December 30, 2020, from https://www.lazard.com/media/451419/lazards-levelized-cost-of-energy-version-140.pdf.

[65] From "The Future of Nuclear Energy in a Carbon-Constrained World," by the Massachusetts Institute of Technology, (2018), Retrieved December 30, 2020, from https://energy.mit.edu/research/future-nuclear-energy-carbon-constrained-world/.

> stakeholders. The SMR world strongly needs a standardised approach at the programme level taking a holistic and realistic perspective in the evaluation of SMR economic and financial competitiveness to foster SMR development. (page 13).

This distinction would seem to be particularly relevant to factory-fabricated units that, by definition, will have significant program-level (or product-level) fixed costs that must be amortized over many reactors.

Notwithstanding the continuing general uncertainty about SMR costs, there is some important new information available for MNR's from the Nuclear Energy Institute in its 2019 report Cost Competitiveness of Micro-Reactors for Remote Markets.[66] Some of the NEI findings are discussed below, but the entire report is valuable because it provides an excellent compilation of cost estimates and a thorough discussion of scale and learning curve effects.

5.3 Alaska Conventional Electricity Costs Are Lower

There have been several major changes to Alaska's electricity situation during the past decade. The most important development is that the Railbelt utilities have added about 700 MW of new gas-fired and coal-fired capacity to their interconnected system.[67] These additions have two effects on the economics of nuclear SMR's. First, they essentially eliminate the need for new Railbelt electric generating capacity for the next decade, as the Railbelt now has more than 2,000 MW installed capacity to serve a peak load that is currently less than 900 MW and appears to be declining.[68] Therefore, absent significant new loads, any nuclear project would have to compete by undercutting the fuel and variable O&M cost of Railbelt generation, which is significantly lower than the average cost used in the 2011 analysis.

Second, most of the new Railbelt capacity is highly efficient gas-fired generation, which can produce power at an avoided cost of only about 6 cents per kWh when natural gas costs $7.50 per mcf. Golden Valley Electric Association also added 50 MW of low-cost coal-fired generation (Healy 2) to its fleet in 2015.

Another important change to the Railbelt system is the advent of new natural gas contracts with

[66] From "Cost Competitiveness of Micro-Reactors for Remote Markets," (April, 2019), by the Nuclear Energy Institute, Retrieved December 30, 2020, from https://www.nei.org/resources/reports-briefs/cost-competitiveness-micro-reactors-remote-markets

[67] This calculation counts Healy Unit 2 as an addition effective 2015. Healy 2 was constructed during the 1990s, but was in very limited service prior to 2015.

[68] According to EIA data reported on Form 861, Railbelt electricity sales declined by 1.1 percent per year from 2010 to 2019. Sales per capita declined by 1.4 percent per year.

Hilcorp that peg the price to about $7.50 per mcf plus minimal adjustments for inflation. For example, Enstar in May 2020 executed a contract for gas at $7.55 with a maximum annual increase of only 1.5 per cent in nominal dollars through 2033.[69] Although it greatly exceeds the current Henry Hub price of about $2.40,[70] this price of $7.55 per mcf is at the low end of the range that was forecast in 2011. Figure 5.1 shows this shift in the price of natural gas. Because the 2011 analysis found a "breakeven" gas price of $14.00 per mcf, which is more than twice the price now under contract for the next decade, the shift is quite unfavorable for the economics of SMRs potentially serving the large Railbelt loads.

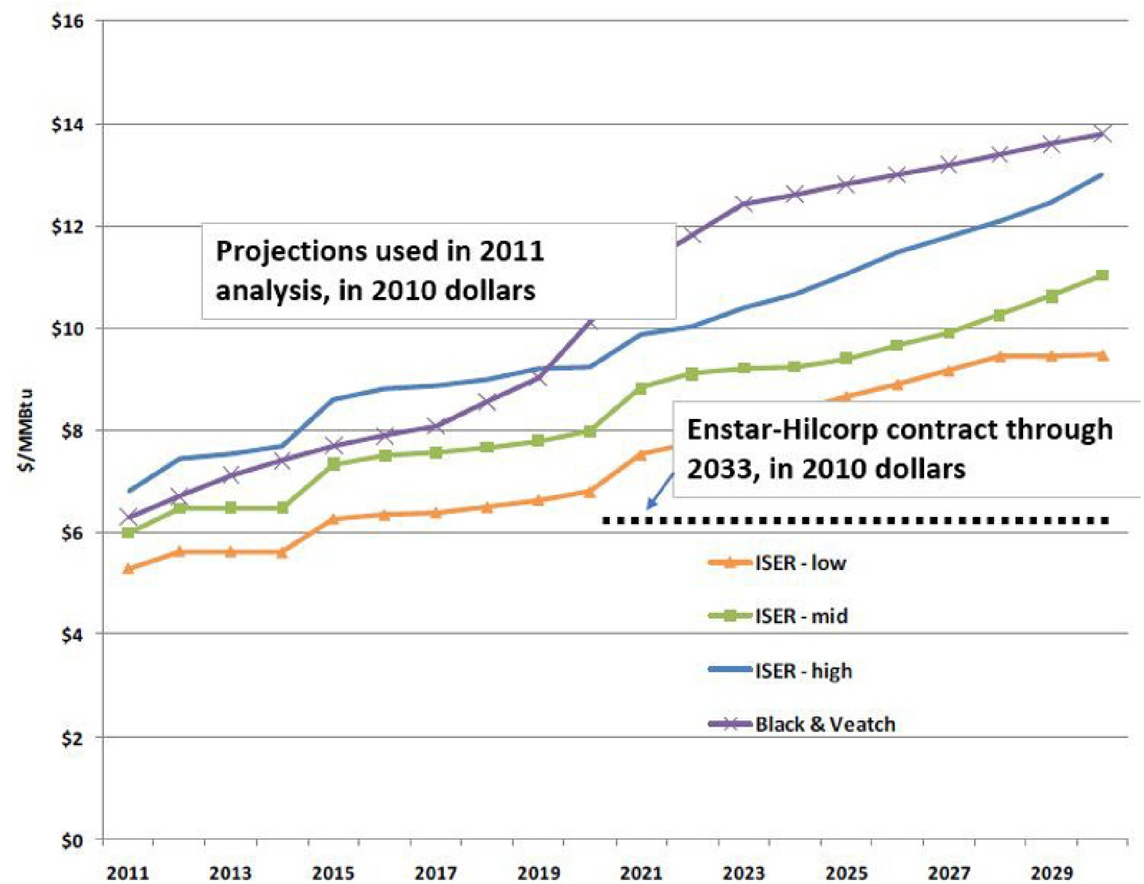

Figure 5.1 Projected natural gas prices used to evaluate SMRs in 2011, compared to actual Enstar contracted price through 2033.

[69] From "Enstar, Hilcorp deal may bring $53.6M in Alaska gas saving," (May 15, 2020), by AP News, Retrieved December 31, 2020, from https://apnews.com/article/685638d327901e0fefc4bd00ef7cd028

[70] "Henry Hub Natural Gas Spot Price," by the U.S. Energy Information Administration, Retrieved December 31, 2020, from https://www.eia.gov/dnav/ng/hist/rngwhhdD.htm.

A third key change affects not just the Railbelt but all of Alaska: The outlook for crude oil prices is much lower than it was in 2011. The 2020 *Annual Energy Outlook* Reference Case[71] [1] projects that Brent Crude prices will gradually rise from $50 to $65 per barrel during the coming decade. These projections are essentially equal to the "Low" case projections used in the 2011 analysis (Figure 5.2). Lower oil prices make nuclear electricity and heat less competitive throughout the state.

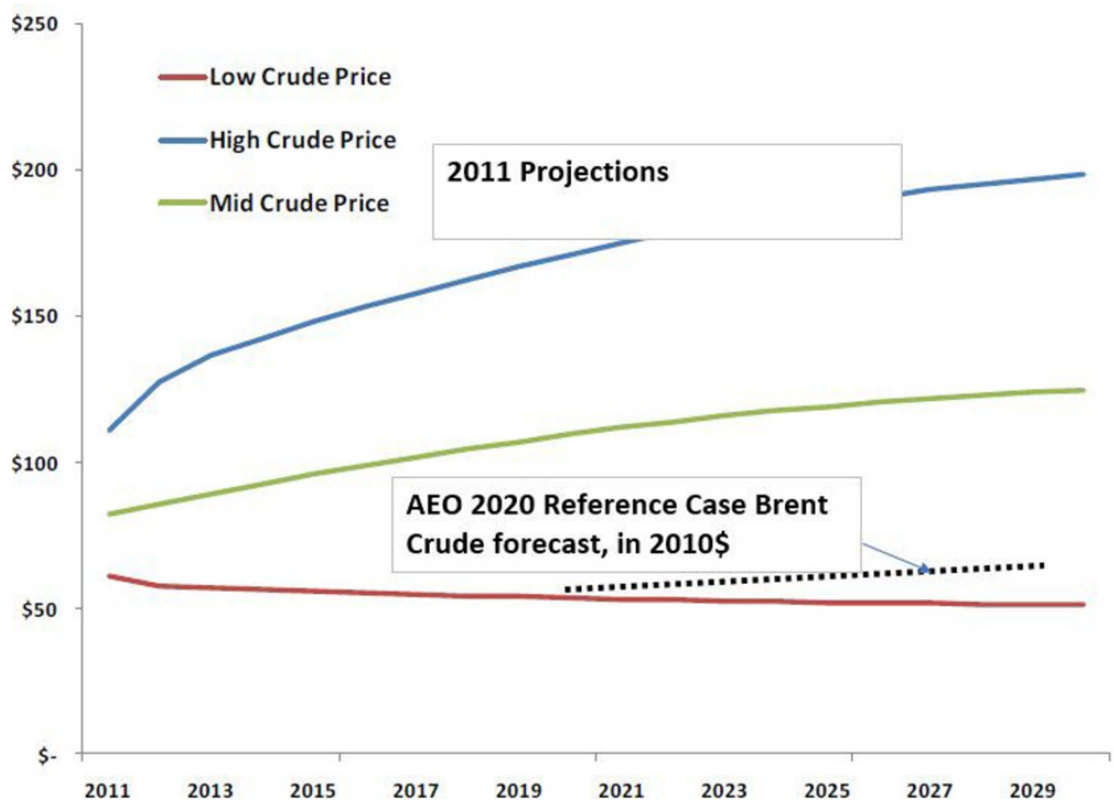

Figure 5.2 Crude oil prices projected in 2011 and current AEO projections. All prices are in 2010 dollars.

5.4 New Results for Potential Microreactors

As noted above, in 2019 the Nuclear Energy Institute released a compilation of possible capital and operating costs for a "reference" microreactor.[72] The NEI analysis assumed a 5 MWe capacity but this represents a range of sizes from one to 10 MWe and their list specifically includes the Oklo Aurora MNR. Using a wide range of assumptions about capital, O&M, fuel, and financing costs, NEI

[71] From "ANNUAL ENERGY OUTLOOK 2020 (Table 12)", (January 29, 2020), by U.S. Energy Information Administration, Retrieved December 31, 2020, from https://www.eia.gov/outlooks/aeo/tables_ref.php.

[72] From "Cost Competitiveness of Micro-Reactors for Remote Markets," (April, 2019), by the Nuclear Energy Institute, Retrieved December 30, 2020, from https://www.nei.org/resources/reports-briefs/cost-competitiveness-micro-reactors-remote-markets.

determined that the production, or "busbar," cost of electricity from an MNR deployed to a remote location would likely range from $.09/kWh to $.33/kWh once sufficient production had taken place. (The corresponding cost range for the first reactor deployed is from $.14/kWh to $.41/kWh.)

How might these potential MNR costs compare to the current production cost of diesel power? The answer depends partly on which components of the cost of the existing diesel power system are considered avoidable by the MNR. These costs were examined for a representative Alaska hub community looking at data for 2019 and 2020. Fuel, which cost more than $2.50 per gallon in 2019, is certainly avoidable and contributed about 17 cents per kWh to the cost of power. Costs booked as "Generation O&M" are largely avoidable if the diesel units are mostly turned off. Depreciation and interest on the diesel generation plant could also be avoided if capacity additions or replacements are deferred for many years.

For the hub community examined here, the avoidable costs range from a low of 11 cents per kWh (the summer 2020 cost of fuel) to a high of 30 cents per kWh (the 2019 fuel cost of $2.54/gallon plus diesel O&M plus diesel depreciation and maintenance). This range of avoidable costs fits within the nuclear MNR cost range of 9 to 33 cents as developed by NEI. Figure 5.3 shows the comparison. The figure shows that nuclear power from an MNR could be quite competitive with diesel power

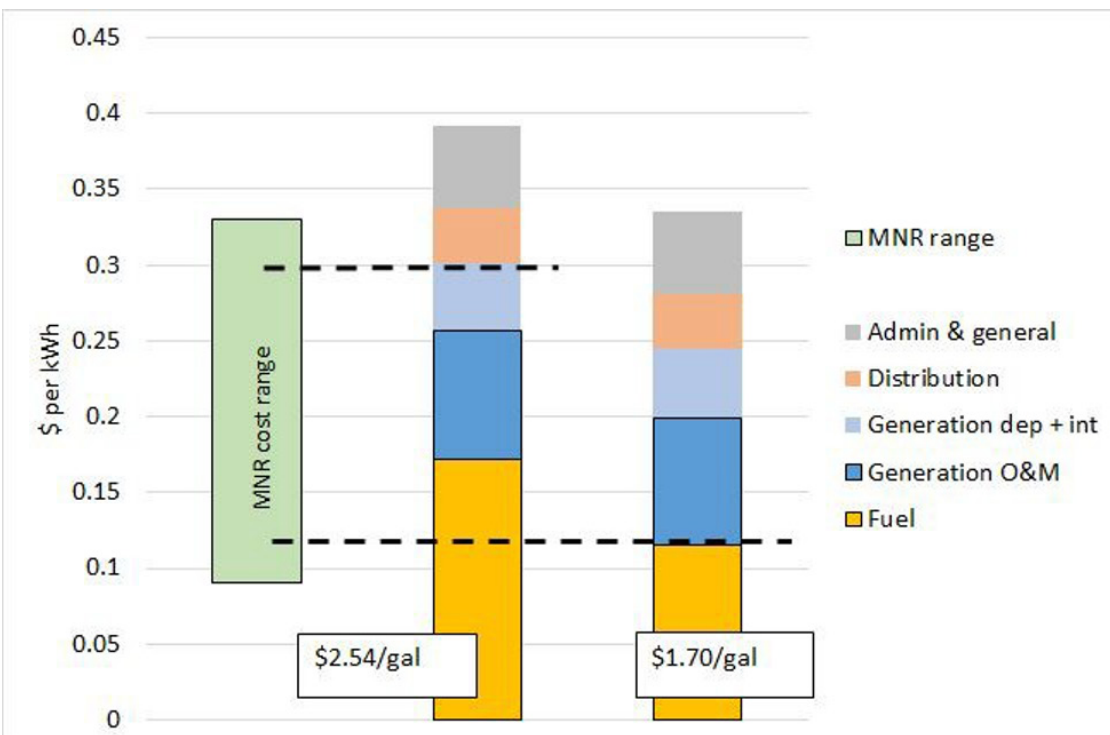

Figure 5.3 Comparison of the cost components of electric service in a representative Alaska hub community, under two different fuel prices, to the potential range of production costs for electricity from an MNR.

in a hub community setting, provided that the system can be set up to allow for the diesels to be essentially turned off almost all of the time. Indeed, the presence of an existing diesel system can serve to reduce the cost of nuclear power because it provides for a ready-made "backup power" system that might otherwise have to be built — at a mine, for example.

The overall message from this simple analysis is positive and somewhat surprising: If the costs identified by the NEI report are reasonably accurate, then microreactors — MNR's — could soon be competitive against diesel in relatively small hub communities, at the same time that the larger SMR designs are appearing somewhat less attractive for the much larger Railbelt loads.

5.5 The Importance of Thermal Energy

The NEI study of MNR economics, like most analyses in the literature, focuses on electricity. But remote Alaska communities use at least as much diesel fuel for heat as they do to produce electricity. The 2011 ACEP study recognized the importance of thermal energy as a potential value stream from SMR's, but that study only considered electric resistance heating except for one use case based on a connection to pre-existing district heating infrastructure in the Fairbanks area. Similarly, the 2004 analysis of the Toshiba "nuclear battery" for Galena focused on electric resistance heating — except where there was pre-existing distribution piping.

There are at least three broad and important questions surrounding the economics of heat from nuclear reactors in Alaska locations. First, what are the specific capabilities of the candidate reactor designs to produce heat in conjunction with, or instead of, electric power? Reactor capacity ratings and performance specifications could potentially be made more consistent and informative with respect to heat. Second, what infrastructure is needed to accept and distribute heat from the reactor location to the end users, and what will it cost in widely varying Alaska locations and use cases? End user equipment conversion costs cannot be overlooked and could be quite significant — even for conversion to electric resistance heating.[73] A critical cost difference *may* exist between "new construction" — of a subdivision, or even a relocated community — and "retrofit conversion" of existing buildings. Third, what is the ability of the nuclear resource to seamlessly integrate its output into some sort of combined heat-and-power energy system serving a variable load? Because many if not most Alaska use cases are isolated microgrids, this question bears directly on the economic feasibility of small reactors. This question encompasses the ramping capabilities of

[73] The 2011 ACEP Report assumed a cost of more than $3,500 per residential customer to convert their premises to electric resistance heat.

the reactor, but extends to other dimensions of integration. Storage will likely play a key role.[74]

Alaska is uniquely positioned to explore and potentially demonstrate the effective use of SMR's and microreactors to provide both power and heat. The economics of nuclear *energy* could prove to be significantly more favorable when thermal energy is kept front and center as a potential value stream.

[74] In his presentation to ACEP's nuclear educational series on December 3, 2020, Jacob DeWitte indicated that Oklo planned to bundle a 1 MWh battery with its 1.5MWe Aurora reactor.

6. Next Steps and Recommendations for Action

6.0 What next?

It is clear that there is a great deal of interest in MNR and SMR technology from a diverse array of Alaska stakeholders. There are also many unknowns, ranging from questions about economics, to fuel handling, management of spent fuel, as well as inherent and intrinsic safety. So what are the next steps? Is there a place for nuclear energy in Alaska's future energy portfolio? If so, when … and where? Does Alaska want to be an early technology adopter, or wait until the technology is more established with a proven safety track record?

These questions do not have easy answers. Fortunately, there is time to make thoughtful decisions about whether there is a role for small nuclear energy in Alaska's future. MNRs such as Oklo's Aurora system, the Ultra Safe Nuclear Corporation's Micro Modular Reactor, or the Mobile Nuclear Power Plant (MNPP), all funded through DOD's Project Pele, are anticipated to be the first technologies that will be available (based on plans for their certification testing and operational demonstrations at federal test facilities in the next 2-4 years). The larger and more complex SMRs, such as NuScale, will be later to market, potentially taking a decade or more based on current projections.

While there are no imminent decision points, there are still steps that we can, and should, take now. Chief among those are gathering more information and ensuring Alaska applications are part of the conversation at the national level. ACEP has started this process by holding an Educational Series on nuclear energy, which is summarized in the following section. Based on findings from this series, we introduce several recommendations for action in Section 6.2.

6.1 ACEP Educational Series

Creating awareness and educating stakeholders is recognized and valued as an important and critical step when considering new small scale nuclear technologies. The evolution of nuclear technologies to incorporate smaller and safer designs is not widely understood, and it is important to provide venues for gaining a better understanding of the technology and what it means for Alaska.

Over the last few years, there has been elevated discussion, interest, and visibility around SMR and MNR technologies among many Alaskan leaders. It became clear there was a need to provide education and a forum for discussion among these stakeholders with nuclear experts.

A series of sessions was organized and convened in the last quarter of 2020 and into January 2021. World-class experts were recruited, and all readily responded to provide information on a broad range of topics related to small-scale reactors.

In total, over three hundred individuals attended these online sessions, representing business, utilities, Alaska Native organizations, and research sectors. The information shared and discussed throughout the series form the basis of many of the recommendations developed below. Additional information related to topics and speakers is included in Appendix C of this report.

6.2 Recommendations

There appears to be good alignment between Alaska energy requirements and the capabilities of the emerging small reactor technologies. Based on the present analysis of available information and a series of stakeholder interactions, Alaska's interests would be well-served through implementation of the following recommendations, as a means of allowing Alaska decision makers to responsibly guide the state's engagement with these compact, zero emissions sources of heat and power.

6.2.1 Track Technology Trends and Ensure Alaska is at the Table

The small nuclear energy industry is evolving quickly. This report will begin to become outdated the moment it is published. Therefore, it will be necessary to continue tracking technology trends as they relate to Alaska. This can be done in coordination with DOE, DOE national laboratories, and industry sources and could include maintaining a database of technologies and systems relevant to Alaska. Public dissemination of information and emerging trends could be accomplished through an annual report or technology briefing for legislators and other interested parties. In addition, it is important for Alaskans to participate in discussions at the national level to ensure Alaska opportunities and concerns are included during design development, analysis, testing, and deployment.[75] One specific engagement warranting near-term attention is the ongoing discussion of possible deployment of a small reactor at one of Alaska's major defense sites — how could this be done in a way that would allow civil, as well as military, interests and issues to be addressed?

6.2.2 Establish a Nuclear Energy Technology Working Group

We recommend establishing a formal Nuclear Energy Technology Working Group, similar to what has been done for other emerging technologies of interest to the Alaska energy sector. This group

[75] The University of Alaska is a participant in the Emerging Energy Markets Analysis (EMA) consortium, along with INL, MIT, the University of Wyoming, and the University of Michigan. The EMA was established to facilitate funded studies of areas relevant to the application of advanced nuclear reactors. The kick-off task (ongoing as of December 2020) is a preliminary siting study for First of a Kind (FOAK) reactor and includes multiple possible locations in AK.

could be led by the Alaska Energy Authority or the University of Alaska. This group could convene regular stakeholder meetings to understand Alaska interests and concerns, extend the Educational Series initiated by ACEP, develop use cases with Alaska-germane functional performance attributes and evaluation criteria, and identify possible / preferred deployment sites. A key output from this team could be the development of a step-by-step characterization of all activities associated with the deployment and operation of an advanced reactor for each use case. This would address the whole life cycle of the system (transportation, commissioning, operation, service/maintenance, contingencies, and end-of-life removal/restoration) and should include characterization of any required support systems (e.g., construction equipment, communication and data services, security, etc.). The Working Group could maintain a group of interested stakeholders (Alaskans, nuclear industry, federal agencies, etc.) and be called upon to provide input to future work products or studies.

6.2.3 Conduct an Umbrella Study Involving Critical State Agencies

Since state agencies have little experience or expertise with nuclear power, an umbrella study with the involvement of critical state agencies would be an appropriate near-term step. This could be used to identify additional gaps or concerns, which could be further addressed in Recommendation 4, 6, and 7 below. The Alaska Department of Environmental Conservation is the lead agency related to environmental permitting and siting. However, the Alaska Energy Authority, the Division of Community and Regional Affairs, The Alaska Department of Fish and Game, and others will likely have an interest or active involvement related to a prospective small nuclear reactor project in the state.

6.2.4 Host a Scenarios Planning Workshop Related to Nuclear Safety

Safety is an overriding concern of Alaskans. This encompasses all aspects related to a potential nuclear energy project, including reactor design and inherent and intrinsic safety features incorporated in these designs, as well as fuel handling and life cycle. This concern is most acute for remote areas with sensitive environments and a high reliance on subsistence activities and fishing industries. Working through specific scenarios and understanding potential repercussions would be helpful in gaining a better understanding of the risks associated with nuclear energy systems deployed in Alaska. What are potential worst-case scenarios? What are the pathways by which contamination of the environment could occur, and how widespread would such an incident be? What are the repercussions, and how does this compare to the status quo? A proven approach for addressing these questions would be to host a scenarios planning workshop to help decision-makers identify ranges of potential outcomes and impacts.

6.2.5 Conduct a More Robust Economic Analysis

One of the weaknesses of this report is that it is difficult to fully analyze the economics of an Alaska deployment. This is challenging in part because the full costs of reactor licensing and deployment are not well understood. However, fully incorporating all of the potential benefits into potential Alaska applications is equally challenging. For example, there are opportunities for using heat rejected from the power cycle for space and water heating, and the economics of this are currently not well understood. Conducting a more thorough economic analysis of both potential costs and benefits is an important step toward determining the viability of nuclear energy in Alaska across a range of prospective use cases. A more robust analysis could also explore ownership and financing structures associated with these use cases.

6.2.6 Address Alaska Statutes as Pertaining to Nuclear Energy

Alaska's statutes address nuclear energy in several places but were written at a time when SMR and MNR technologies were not part of the state or national discussion. Some concerns at the time these statutes were developed are of lower probability and/or consequence due to the size and design of the emerging advanced reactors. SB194, "An act related to advanced nuclear reactors," was authored to update some of these statutes, particularly related to regulatory and siting requirements for any project considered for development in-state. This bill was introduced by the Senate Community and Regional Affairs Committee during the 32nd legislature (March 11, 2020). We recommend re-introducing this bill after a thorough review of state statutes related to nuclear energy so that state interests, priorities, and restrictions ensure appropriate guidelines for evolving advanced reactor technologies. We have conducted a preliminary analysis with recommendations included in Appendix B.

6.2.7 Create a Roadmap for Alaska

The first five recommendations listed above lend themselves well to providing the background information needed to develop a strategic roadmap for Alaska related to SMR and MNR technologies. This roadmap could follow a similar format to the Canadian roadmap discussed previously, which solicited input from a wide range of stakeholders to chart a path for Canada and the role it wants to play in future nuclear technology development. This Alaska-focused roadmap should address the yet-unanswered questions and concerns of Alaskans and establish a process for how those concerns could be mitigated through additional testing, information dissemination, or adjustments to the permitting and licensing process. Whether SMRs and MNRs have a future in Alaska has not yet been determined. But a roadmap would help define a process for nuclear energy technologies as part of Alaska's future energy portfolio.

6.3 Conclusion

The purpose of this document is to produce a concise summary of the current status of nuclear energy technologies and how they are relevant to Alaska. It is not a complete review and represents a snapshot in time, ten years after Alaska's first comprehensive review of small nuclear energy technologies in 2011. Much has changed in the intervening decade, and this will continue as reactor designs, fuel processing, regulatory policies, market assessments, etc. evolve. Keeping Alaska applications and priorities at the forefront of the national conversation and maintaining a rigorous awareness of technology developments is critically important. It is imperative for Alaskans to make careful, well-informed decisions about nuclear development in our unique state.

7. Appendices

Appendix A:

TABLE OF REACTOR TECHNOLOGIES
(LESS THAN 300 MW)

Advanced Reactors Comparison, November 2020

Company	Type[1]	Technology[2]	Size (MWe)	Received gov. funds[3]	NRC engagement	Note
Advanced Reactor Concepts	MNR	MS	100	yes	no	Based on the EBR-II, a sodium-cooled fast-reactor power plant operated by Argonne National Laboratory in Idaho for 30 years. arcnuclear.com
BWX Technologies	MNPP	PWR	1-5	Project Pele	no	BWX is the prime contractor building the reactors on the U.S. Navy's nuclear-powered submarines and aircraft carriers. bwxt.com
Columbia Basin Consulting Group	SMR	LM	TBD	ANTD Path 2; GAIN	no	Received $400k in 2018 under the DOE advanced reactor development project pathway. cbcgllc.com
Elysium Industries	SMR	MS	50-1200	GAIN	no	Currently seeking approval/funding for a 10MWe pilot plant. elysiumindustries.com
Flibe Energy	SMR	MS	<5, 250	ANTD Path 2	yes	Proposes lithium fluoride/beryllium fluoride (FLiBe) salt as its primary coolant; also has been pursuing a MNR design. flibe-energy.com
Framatome	SMR	HTGR	272, 50	GAIN, DOE, ARPA-E	yes	Recently announced a partnership with General Atomics to develop a 50 MWe fast modular reactor. framatome.com
GE-Hitachi (Prism)	SMR	LM	165-311	extensive	yes	Planning a demonstration deployment at Department of Energy's (DOE) Savannah River site. nuclear.gepower.com
General Atomics	MNR	PWR	265	GAIN, ARPA-E, DOE	yes	Has historically developed many of the research reactors used in the U.S. (TRIGA). www.ga.com
Holtec	SMR	PWR	160	ANTD Path 2	yes	Completed the Vendor Design Review Phase 1 process in Canada. holtecinternational.com
HolosGen (Quad)	MNPP/ Modular	HTG	3-13	ARPA-E	no	Designed to be packaged in a standard shipping container with load following ability. holosgen.com
Hydromine	MNR	LM	200	GAIN	no	hydromineinc.com
Kairos Power	SMR	MS	140	ARPA-E GAIN	yes	Recently funded under DOE ARPA-E (GEMINA) program. kairospower.com
NuGen	MNR	HTGR	3	?	no	www.nucdev.com
NuScale	SMR	PWR	60	ANTD Path 1; GAIN	yes	Leading US manufacturer of SMRs; Current plans are to deploy in multiples of 60 MWe systems (up to 12 units); some discussion of smaller units in future. nuscalepower.com
NuScale (micro)	MNR	Heatpipe FNR	1-10	?	no	Still "paper reactor" but NuScale leading SMR company in US. nuscalepower.com
Oklo (Aurora)	MNR	Heatpipe FNR	1.5	GAIN	yes	Significant engagement in Alaska; has participated in Launch Alaska. oklo.com
Radiant Industries	MNPP	HTRG	~1	GAIN, ARPA-E, DOE	yes	radiantnuclear.com
Terrestrial Energy (IMSR)	SMR	MS	190	GAIN, Canadian Gov.	yes	Canadian based company; planning demonstration at Chalk River by 2026; planning to seek design approval through NRC in future. terrestrialenergy.com
Ultra Safe Nuclear (MMR-5) Corporation	MNR	HTRG	5	Canadian Gov.	yes	Plan to deploy demonstration reactor at Chalk River Laboratories (Canada) site in next few years. usnc.com
Westinghouse (eVinci)	MNPP	Heatpipe FNR	.2-5	Project Pele	yes	Los Alamos National Lab; funded through Project Pele. westinghousenuclear.com
X-energy (Xe-10)	SMR	HTR	80	ARDP, ARPA-E, GAIN	yes	Designed to be scaled as a four-pack to 320 Mwe. x-energy.com
X-energy (Xe-Mobile)	MNPP	HTR	1	Project Pele	no	x-energy.com

[1] SMR - Small Modular Reactor; MNR - Micro Nuclear Reactor; MNPP - Mobile Nuclear Power Plant
[2] PWR = Pressurized Water Reactor, HTR = High Temperature Reactor, LW = Light Water, LM - Liquid Metal, MS = Molten Salt
[3] DOE Advanced Reactor Demonstration Program (ARDP); DOE Nuclear Energy Funding programs: GAIN = Gateway for Accelerated Innovation in Nuclear; ANTD Path 1 = US Industry Opportunities for Advanced Nuclear Technology Development - first-of-a-kind nuclear demonstration; ANTD Path 2 = advanced reactor development projects; ANTD Path 3 = Regulatory Assistance Grant; ARPA-E = Advanced Research Projects Agency-Energy (ARPA-E) program

References: Gateway for Accelerated Innovation in Nuclear (GAIN) program at Idaho National Lab - Advanced Nuclear Directory, U.S. Department of Energy Office of Nuclear Energy, World Nuclear Association, U.S. Nuclear Regulatory Commission

Appendix B:

RECOMMENDATION FOR MODIFICATIONS TO ALASKA STATE STATUTES PERTAINING TO NUCLEAR ENERGY

Alaska Nuclear Energy Statutes and Recommended Amendments

The relevant sections of Alaska State Law fall under Title 18, Chapter 45: Atomic Energy. http://www.akleg.gov/basis/statutes.asp#18.40.070

The following notes reference each relevant section and provide a description. The recommendation follows in red.

1. Sec. 18.45.020 appears to simply require an applicant to follow the NRC regulations;
   - No change recommended
2. Sec. 18.45.025 is restrictive — requires DEC to provide permission to a nuclear developer, the state assembly to designate by law any land that would be used, and DEC to promulgate regulations for this section. If a municipality has jurisdiction over the proposed site, its approval is also required. These requirements constitute a high bar, but may be justified by the environmental, human health and economic risk posed by nuclear development.
   - No change recommended.
3. Sec. 18.45.027 may be problematic, especially in the case of a reactor that could potentially be operated by DoD and may be taken to multiple sites. If the fuel has been used for a period of time, this statute might restrict the reactor containing partially used fuel from being moved to an acceptable site for further use. It does not address low or high level nuclear waste, which is typically permanently stored on site in temporary containers. The Trump administration just reversed its support (2/7/20) for developing Yucca Mountain, Nevada as a repository for spent nuclear fuel and high level radioactive waste.
   - The storage and/or transportation of all forms of nuclear waste and spent fuel from a nuclear power facility should be permitted by DEC.
4. Sec. 18.45.030 is an authorization of exhaustive studies of nuclear development related risks by DH&SS, DOL, DOT, DCCED, DF&G, DNR and other State agencies. Such studies would possibly delay or impede nuclear power development in Alaska.
   - Some studies are necessary to assess the risks. Since State agencies generally have little experience or expertise with nuclear power, an umbrella study with the involvement of critical State agencies to cover many of the topics referenced in this section would be appropriate.

5. Sec. 18.45.040 is judicial enforcement of the law via governor-required processes.
    - No change recommended
6. Sec. 18.45.070 allows coordination with the federal government.
    - No change recommended
7. Sec. 18.45.090 is an exemption about mining uranium
    - No change recommended
8. Sec. 18.45.900 is filled with definitions.

Other Considerations:

- We recommend that the first microreactor project in Alaska should be at a military base, possibly Eielson Air Force Base. DoD is not required to comply with State law.
- Issues related to microreactor decommissioning should be addressed before the project is approved. https://www.eia.gov/todayinenergy/detail.php?id=33792
- Since state agencies have little experience or expertise with nuclear power, an umbrella study with the involvement of critical state agencies would be an appropriate near-term step.

Appendix C:

SUMMARY OF ACEP EDUCATIONAL SERIES ON SMALL SCALE NUCLEAR POWER

Summary: ACEP Educational Series on Small Scale Nuclear Power

What we did

Convene a 4-part series, "Small Scale Nuclear Power: an option for Alaska?" to educate Alaskans on emerging small modular and micro nuclear power technologies, which also served to provide much of the background material for this report.

Small scale nuclear power is advancing beyond the lab, becoming increasingly familiar across sectors and of interest to diverse groups of Alaska stakeholders.

The Alaska Center for Energy Power facilitated a series, "Small Scale Nuclear Power: an option for Alaska?" to advance awareness and understanding of small modular reactor and micro reactor technologies. These forums, provided in the last quarter of 2020, with the final session in mid-January, provided world-class expertise that included researchers, private sector developers and agencies responsible for piloting and commercializing SMR and MMR technologies.

As part of this series, civic, business, utility and government leaders of Alaska—encompassing urban, rural and indigenous, military interests—joined in discussion to better understand what small-scale nuclear energy could mean for Alaska and the developing Arctic.

These sessions provided a foundation for understanding differing technology, safety, policy, and economics as a means for further dialog in the future.

What we heard

The series was grouped around the following four topics:

- Session 1 **Advanced Nuclear: Regulatory Process and Timelines**
- Session 2 **Economics of Advanced Nuclear in Alaska**
- Session 3 **Safety: Fuel, Transportation and Disposal**
- Session 4 **Intersecting the Future: Alaska and the Arctic**

The following presenters participated in the series.

- Spencer Nelson, Senate Committee on Energy and Natural Resources
- Mr. Walter Ludwig, (Acting) Deputy Asst Secretary of Defense, Energy
- Jack Surash, Deputy Assistant Secretary, Energy and Sustainability for the Army
- Tom Sowinski, Director, Office of Nuclear Energy, Department of Energy

- Corey McDaniel, Idaho National Lab
- Steve Colt, Research Professor, Alaska Center for Energy and Power
- Dr. Everett Redmond, Senior Technical Advisor, New Reactor and Advanced Technology, Nuclear Energy Institute (NEI)
- Marc Nichol, Nuclear Energy Institute (NEI)
- Jacob DeWitte, CEO, Oklo
- Wendy Simon-Pearson, General Counsel, Ultra Safe Nuclear Corp
- Dr. Jose Reyes, Co-founder and Chief Technology Officer, NuScale
- Meera Kohler, Alaska Village Electric Cooperative

Key take-aways include:

Policy modernization as provided in the Energy Act of 2020,[76] led by Senator Lisa Murkowski, Chair Senate Energy and Natural Resources Committee. This important legislation represents the first comprehensive legislation in thirteen years. Spencer Nelson, Senior Staff and nuclear expert on the Energy Committee presented on the Nuclear content of the legislation. This comprehensive legislation addresses a broad spectrum of innovation and demonstration programs including research, demonstration and commercial use of advanced nuclear technology.

The Department of Defense presented the Army perspective as Deputy Assistant Secretary Jack Surash discussed the importance of meeting critical missions in Alaska and planning unexpected interruption in power. The challenges of aging infrastructure, a harsh environment, and the need to tap innovation and DOE partnerships are all part of future considerations. Walter Ludwig (acting) Deputy Assistant Secretary of Defense for Energy provided information on how the military may pilot micronuclear project(s) in Alaska to meet their mission. This is being explored, in part, through a request for information issued by the Air Force on micro-reactor technology to "provide insights on a potential pilot for possible location in the subarctic at an Air Force installation."

Department of Energy Dr. Corey McDaniel of Idaho National Lab (INL) and Tom Sowinski, Director of the DOE Office of Nuclear Energy each presented on differentiations of small nuclear and microreactor technologies. Each base technology and design are at various stages of maturity.

Industry showcased three different small-scale reactors — two microreactors and one small modular reactor (SMR). The companies included Oklo (1.5 MW), Ultra Safe Nuclear Corporation (5

[76] 116th Congress Rules Committee Print 116-68, Text of the House Amendment to the Senate Amendment to H.R. 133 Division Z—Energy Act of 2020, page 3194-3726; Title II-Nuclear, page 3288-3358.

MW) and NuScale Power (60 MW). Each span technologies and include a fast reactor, a gas cooled molten salt reactor and a light water reactor (LWR) — respectively. [GH2]

What we learned

This series was well received as the first step in advancing awareness and education around this compelling topic. Developing and advancing a collective awareness and better understanding of micronuclear power — within the context of multiple factors considerations must continue to unfold. Continued attention to this topic and hosting additional opportunities for learning and discussion was encouraged. Specific take-aways include:

1. Advanced nuclear power is nearing the commercialization stage. NuScale has received design approval from the NRC and other approvals are pending; Oklo has a combined application under evaluation by the NRC, and others are preparing to follow.

2. Participants expressed interest in further exploration into topics including technical, safety, economic and required training. The Energy Act of 2020 has numerous provisions for advancing this important technology, with DOE and DoD roles with potential Alaska and Arctic implications. Further exploration into topics introduced in this series is a clear next step, including further engagement between Alaskans and recognized subject-matter-experts.

3. Exploring and understanding multifaceted economics and cost comparisons are still unclear and sometimes contradictory and deserve additional consideration to better understand potential Alaska use cases.

4. Consideration of nuclear energy in the Alaska context is a time-sensitive issue. The military is evaluating options with expectation for micronuclear to be available by 2025. Alaska utilities are evaluating options for aging infrastructure and have set carbon emission reduction goals.