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Microreactor Applications in U.S. Markets

March 2023

Evaluation of State-Level Legal, Regulatory, Economic and Technology Implications

DOE Microreactor Program

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Emerging Energy Markets Analysis Initiative

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SUMMARY

This report provides an evaluation of primarily state-level legal, regulatory, economic, and technology implications for microreactor (MR) applications in U.S. markets. The initial focus is on the Alaska and Wyoming energy markets serving location-specific energy needs for electricity and heat. A state-by-state evaluation of current carbon/carbon-related policies and nuclear policies is conducted to assess broader market applicability in states undergoing energy transitions.

This work is conducted as part of the Emerging Energy Markets Analysis (EMA) initiative led by Idaho National Laboratory (INL) and includes the University of Alaska, Energy Policy Institute at Boise State University, University of Michigan, Massachusetts Institute of Technology, and the University of Wyoming. EMA's objective is to identify sustainable, regionally acceptable, and high-value energy solutions that are secure and equitable. Unlike short-term, least-cost choices that can narrowly account for traditional options, EMA's focus on emerging energy markets recognizes that new or adapted practices and technologies can alter the frontier of solutions and advance a community's social, economic, and natural pathways. Such change requires a more comprehensive analysis of societal input, resources, capabilities, and infrastructure. These considerations lay the foundation for community decision-making models that are responsive to community values, as well as history and drivers. The result is a community-based decision and engagement model that will be valuable to decision-makers and developers of advanced and emerging energy solutions, seeking a social license to operate prior to project development.

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All authors and contributors are collectively referred to as the EMA team.

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ACRONYMS

AK	Alaska
BSU	Boise State University
CCUS	carbon, capture, use and storage
CHP	combined heat and power
DAC	direct air capture
DOE	Department of Energy
EMA	Emerging Energy Markets Analysis Initiative
EPI	Energy Policy Institute
ESG	environmental, social and governance
HALEU	high-assay low-enriched uranium
HP	heat pipe reactors
HTGR	high-temperature gas reactors
INL	Idaho National Laboratory
LEU	low-enriched uranium (LEU) fuel
LMR	liquid metal reactors
MIT	Massachusetts Institute of Technology
MR	Microreactor
MSR	molten-salt reactors
RPS	renewable portfolio standards
TRISO	tristructural isotropic fuel
UA	University of Alaska
UACED	University of Alaska Center for Economic Development
UM	University of Michigan
UW	University of Wyoming
WY	Wyoming

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Microreactor Applications in U.S. Markets

1. INTRODUCTION

The objective of this work is to provide an evaluation of state-level legal, regulatory, economic and technology implications for microreactor (MR) applications in U.S. markets. The initial focus is on Alaska (AK) and Wyoming (WY) energy markets serving location-specific energy needs and potential for electricity and heat. A state-by-state evaluation of current carbon/carbon-related policies and nuclear policies is conducted to assess broader market applicability for states undergoing energy transitions.

The Emerging Energy Markets Analysis Initiative (EMA) team recognizes that more enduring energy strategies account for local values, input, and opportunity. EMA does so by engaging with communities and other stakeholders to qualitatively develop a value profile, locationally specific/cultural priorities, and sensitivities that inform the range of technically and economically feasible choices and related assumptions. EMA's differentiated capabilities and approach are distinct from technoeconomic ones that are employed by many current labs and university energy centers. Specific to markets, the EMA team performs multivariate, multidisciplinary value analyses to create a basis for deployment considerations and to evaluate the potential value for varied markets. Attributes of 'value' are analyzed and compared qualitatively and quantitatively to the baseline conditions. The value of a market application is a complex intersection of system attributes that may address a given community or market's needs (INL 2021).

1.1 EMA Methodological Framework

This section describes the general EMA framework and how the current study fits into the methodology. The EMA team evaluates several energy solutions for each profile market, creating a basis for understanding how the elements of value 'stack-up' in creating value-informed solutions that consider social, environmental, economic, and technical dimensions. Outputs from the study may be used as the basis to inform consensus building and community-driven future facility siting processes. The EMA framework for value-informed decision-making is illustrated in Figure 1 (INL 2021).

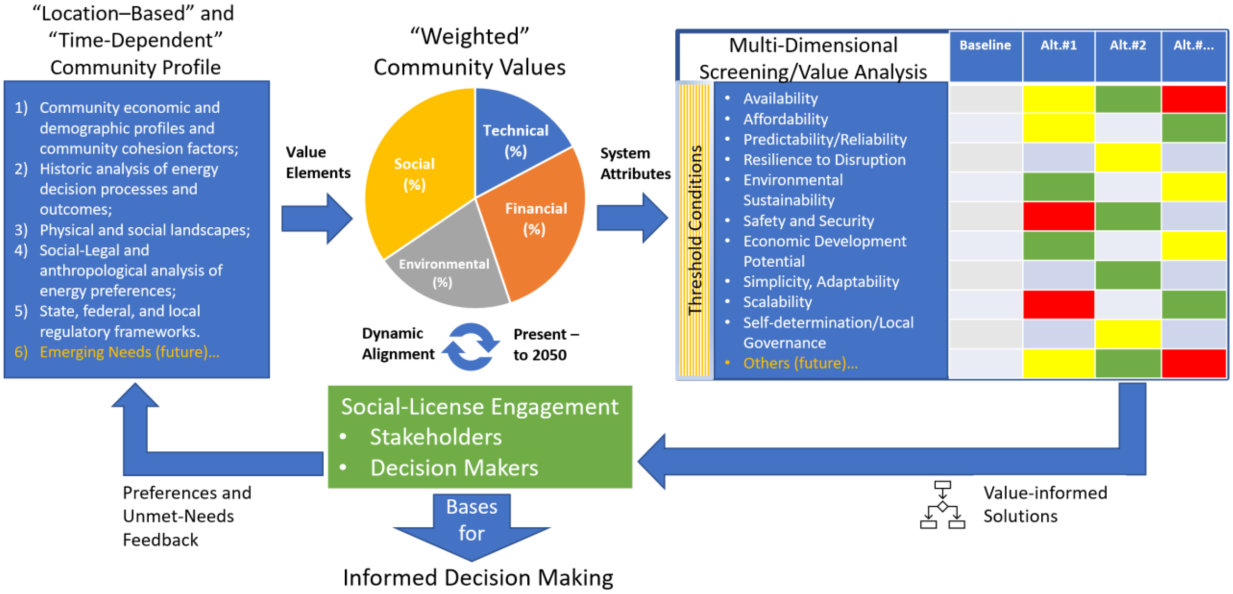

Figure 1. Framework for value-informed decision-making (INL 2021).

This decision process involves cycling between alternatives and exploring the values (i.e., social, technical, financial, and environmental) represented by the stakeholders and decision makers. In the conceptual EMA framework, the ‘weighted’ community values are not preset values, but instead may vary over time and conditions for a given community. When the analysis of alternatives is conducted, the ‘costs’ and ‘trade-offs’ needed to support the defined value set becomes better defined. This provides grounds in the decision analysis for negotiation between stakeholders and compromise toward common ground. While any segment of the framework can be used for analysis, the importance of the value identification process to decision-making is recognized.

Value identification, if done with collaborative decision-making, engages stakeholders in collectively making a choice from the alternatives before them (Smutko 2021). The process is formal, typically consensus-oriented, and deliberative in which participants define the decision opportunity or problem to be resolved; identify the interests and fundamental objectives of each party; generate alternatives that can more or less satisfy the interests of each party; evaluate each alternative based on objective criteria; negotiate the trade-offs among each alternative; and reach agreement (Smutko 2021). A key to successful group decision-making is cycling iteratively with a facilitator resolving differences and finding common ground (Smutko 2021).

This draws on negotiation, mutual gains concepts, and consensus building that is highlighted in Figure 2 and Figure 3. Iterative engagement in decision-making with multiple methods that mutually inform is how a more locationally relevant and value-driven decision-making may be completed (Araújo and Shropshire 2021).

INCREASING IMPACT ON THE DECISION

	INFORM	CONSULT	INVOLVE	COLLABORATE	EMPOWER
PUBLIC PARTICIPATION GOAL	To provide the public with balanced and objective information to assist them in understanding the problem, alternatives, opportunities and/or solutions.	To obtain public feedback on analysis, alternatives and/or decisions.	To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered.	To partner with the public in each aspect of the decision including the development of alternatives and the identification of the preferred solution.	To place final decision making in the hands of the public.
PROMISE TO THE PUBLIC	We will keep you informed.	We will keep you informed, listen to and acknowledge concerns and aspirations, and provide feedback on how public input influenced the decision.	We will work with you to ensure that your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision.	We will look to you for advice and innovation in formulating solutions and incorporate your advice and recommendations into the decisions to the maximum extent possible.	We will implement what you decide.

Figure 2. Public participation (iap2 n.d.).

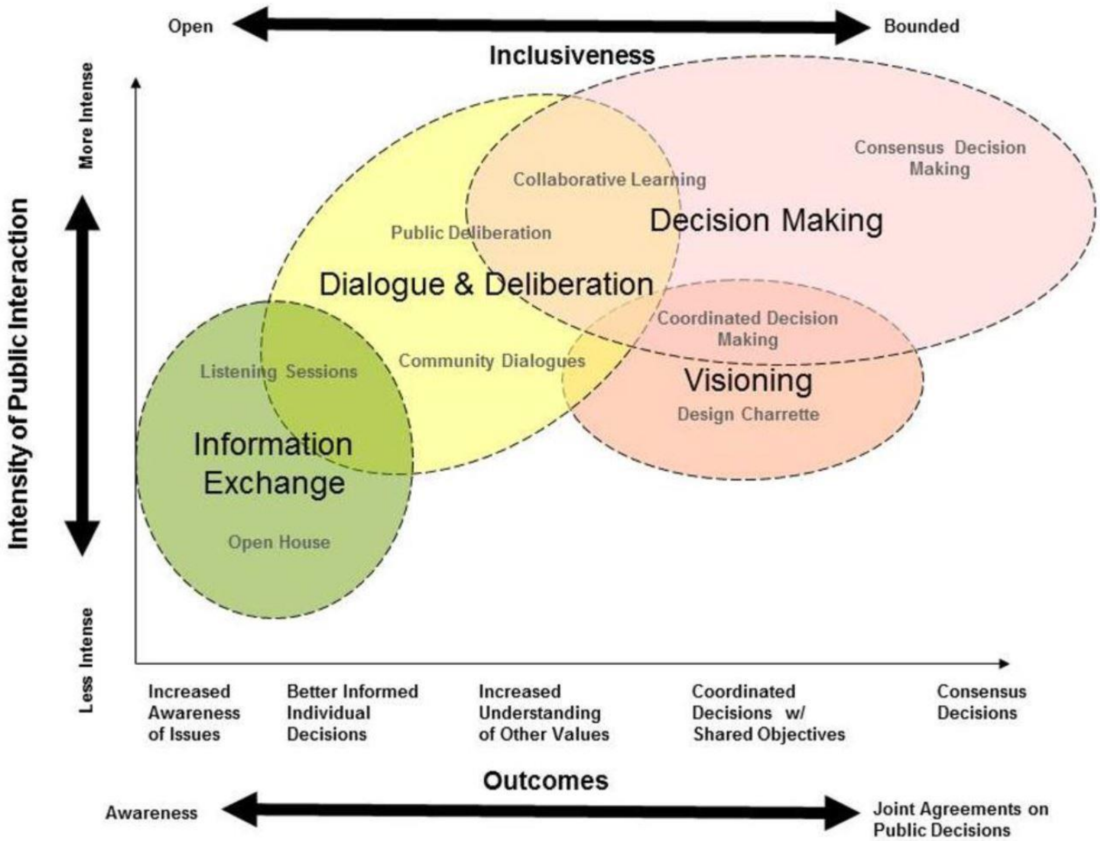

Figure 3. Public involvement (Smutko 2021).

Appendix C expands on the above processes under the heading, "How and Why Firms Make Energy Decisions." It describes how cost continues to be a primary driver behind energy decisions, but identifies other goals including sustainability, environmental impacts, and ensuring continuous operations. Firms are also responding to internal pressures as well as external, such as government oversight, ethical standards, and environmental responsibility. In addition, energy operations decisions that are currently faced by large energy consumers are explored for independent generation versus relying on utilities. The University of Alaska (UA) Center for Economic Development (UACED) defines market drivers for energy choices by large-scale energy users to include cost, reliability, resiliency, and environmental, social and governance (ESG) goals (Johnson, 2020).

2. ASSESSMENT OF BARRIERS AND OPPORTUNITIES FOR MICROREACTORS

This report examines opportunities and barriers for MRs. In addition to a broad review of the subject, this report includes a market suitability assessment of possible applications in energy-intensive industries (e.g., mining, chemical processing, hydrogen production, digital economies) and in the reduction and storage of carbon dioxide in Wyoming. For this, researchers evaluated alternative futures for industries, assessing the size and growth potential, current workforce, locations, energy needs, access to global export markets, and time-phased legal and regulatory requirements. Methods include literature review and expert/stakeholder elicitations. The purpose of this analysis is to help define key preconditions for MR deployment including economic, environmental, workforce, government intervention/regulatory, and tax revenue implications.

The following sections summarize research conducted by the EMA team, with more in-depth research provided in its entirety in the report appendices.

2.1 Energy System Changes and Energy-Intensive Developments

On the energy demand side, changes to energy systems are driven by demands for decarbonizing energy sources, increased resilience and reliability, operational flexibility, non-carbon emitting heat sources, etc. Decarbonization is no longer driven purely by regulatory mandates such as renewable portfolio standard (RPS), but is increasingly sought by shareholders for increased sustainability and to support global competitiveness. States that are net energy producers, like WY, are also recognizing changes to energy consumption practices in neighboring states. In doing so, net energy producing states are finding emerging markets for carbon removal, including direct air capture (DAC), and new ways to deploy carbon, capture, use, and storage (CCUS) technologies. In AK, the mining industry is beginning to recognize their energy demands as part of a greater ecosystem of energy choices in the region, and is adopting more distributed generation systems. Demand for low-carbon and affordable energy is acute in remote regions dependent on expensive fuel deliveries. Increased focus on resilience, reliability, and flexibility is needed to reduce potential disruption from external events and to improve the capability of the local economy to recover from a disruption. It is also instrumental for the community's ability to problem-solve and adjust, to provide the local adaptive capacity of natural systems and to protect the critical infrastructure, fuel, and transportation systems (Araújo and Shropshire 2021).

On the energy supply side, the emergence of advanced nuclear technologies is creating a pathway for new energy solutions to support the clean energy transition. Although there has been development of small modular reactor (SMR) technology for more than a decade, in recent years microreactors have gained interest, particularly in remote markets with high energy costs. A summary of the MR concepts is presented in Table 1 (GAIN 2023). At this juncture, a dominant design for microreactor technology has not emerged, rather there is a range of reactor designs, sizes, fuels and coolants.

Table 1. Summary of Microreactor Concepts (GAIN 2023).

Developer	Name	Type[a]	Power Output (MWe)	Fuel[b]	Coolant
Alpha Tech Research Corp.	ARC Nuclear Generator	MSR	12 MWe	LEU	Fluoride Salt
BWXT	BANR	HTGR	17 MWe	TRISO	Helium
General Atomics	GA Micro	HTGR	1-10 MWe	—	gas
HolosGen	HolosQuad	HTGR	13 MWe	TRISO	Helium/CO2
Micro Nuclear, LLC	Micro Scale Nuclear Battery	MSR/heat pipe	10 MWe	UF4	FLiBe
Nano Nuclear	ZEUS	FR/HTGR	1 MWe	UO2	Helium
NuGen, LLC	NuGen Engine	HTGR	2-4 MWe	TRISO	Helium

[a] Microreactors technologies include molten-salt reactors (MSRs), high-temperature gas reactors (HTGRs), liquid metal reactors (LMR), and heat pipe (HP) reactors.

[b] Microreactor fuels range from use low-enriched uranium (LEU) fuel with typical enrichments of 3% to 5% 235U. However, most microreactor designs use high-assay low-enriched uranium (HALEU) fuels with enrichments above 5%, but below 19.75% 235U. HALEU may be used in tristructural isotropic (TRISO), metallic, and uranium-fluoride (UF4) fuels.

Developer	Name	Type[a]	Power Output (MWe)	Fuel[b]	Coolant
NuScale Power	NuScale Microreactor	LM/heat pipe	< 10 MWe	Metallic	Liquid Metal
Oklo	Aurora	SFR/heat pipe	1.5 MWe	Metallic	Sodium
Radiant Nuclear	Kaleidos Battery	HTGR	1.2 MWe	TRISO	Helium
Ultra Safe Nuclear	MicroModular Reactor	HTGR	5 MWe	TRISO	Helium
Westinghouse	eVinci	Heat pipe	5 MWe	TRISO	Sodium
X-energy	Xe-Mobile	HTGR	7.4 MWe	TRISO	Helium

The possibility of a microreactor market has brought attention to this technology option for AK, as evident from the request for proposal released for the Eielson Air Force Base Micro-Reactor Pilot Program (Air Force 2022); and for WY, based on the planned opening in 2030 for TerraPower's Natrium reactor near a retiring coal plant in Kemmerer (Wyoming Public Radio, 2022). Also, the U.S. Department of Defense Strategic Capabilities Office selected BWXT Advanced Technologies LLC, Lynchburg, Virginia, to build a Project Pele microreactor (World Nuclear News, 2022). These initial advanced nuclear applications could pave the way for commercialization where financial risk is shared between entities exploring first units, not unlike what happened in the commercialization of light water reactor technologies in the 1970's (Hansen et al, 2020).

Appendix A highlights broad energy system changes, as well as opportunities and barriers for MRs in emerging markets. It identifies the emerging need for changes to energy and related markets tied to geopolitics and extreme weather, among other conditions. Opportunities for MRs are differentiated from large capacity nuclear technology, including niche markets in remote regions, areas with energy-intensive industries including mining and data centers, and uses in distributed microgrids, for disaster relief, and marine propulsion (Shropshire et al. 2021). Barriers also exist in terms of uncertainties in reactor designs (i.e., fuel type, sensors, electronics, materials, load-following and black-start capabilities, and semi-automated functions), safety systems, capacity for factory manufacturing, remote operations, and waste management. The review points out the need for new or revised regulations and related learning where MRs differ from traditional reactors.

2.2 Wyoming Market Assessment

In WY, energy system changes are evident, with additional adaptations expected. As a major exporter of fossil energy, particularly of low-sulfur coal, WY is experiencing considerable energy pressures from the global recession, unconventional oil and gas, and increased interest in low-carbon energy, resulting in shifts in the demand for coal, as discussed further in Appendix A. Additionally, oil and gas sectors are subject to boom-bust cycles tied to global markets. Meanwhile, electricity from wind power has doubled since 2019, adding to energy exports from the state. Nuclear power is now emerging on the scene in WY, advanced by the Nov. 2021 announcement by TerraPower to convert Kemmerer, currently a coal site, to an advanced reactor demonstration site. For further details on historical and current energy trends within the state, see Appendix A.

In the WY market assessment, as indicated in Appendix B, the potential value chain for industrial MR applications in the state is investigated. The research explores whether and why WY industries are motivated to decarbonize and their level of openness to MRs. The focus is on energy-intensive industries that are either currently prevalent or have high potential to be developed in WY and the Rocky Mountain Region. Based on these criteria, four industry sectors were analyzed including: Trona mining and processing, hydrogen production, DAC, and digital economies—including cryptocurrency mining and data and computational centers. Most of these sectors are either new and/or growing and represent the type of industries that may utilize MRs in the future. Their industries were studied to better understand the market context and economic incentives. Interviews were conducted with industry representatives to gain insights about the specific motivations of different companies, the decisions they are making regarding decarbonization, and their openness to MRs. The research highlights insights about the specific needs, opportunities, and limitations presented by the state's geography, infrastructure, regulations, and markets. Findings from the interviews are detailed in Appendix B.

In addition, more targeted analysis of the fossil fuel exporting region of Gillette, WY, as discussed in Appendix A, examines the diversification potential for uranium mining and additional economic prospects in more depth with energy mix adaptations. The analysis finds that the surrounding Gillette region is primed to restart uranium mining once global prices and/or supply security policies signal sufficient domestic priorities. The study also highlights the presence of an entrepreneurial hub that is currently focused on carbon management with coal adaptations. However, strong interest exists among some local entrepreneurs in creating a Wyoming hub for global nuclear technology, the fuel cycle and adjacent services. This study integrates historical and case analysis with interviews of stakeholders from across sectors to shed light on the background, feasibility, and perceived interest in emerging economic development over the next 5–10 years around Gillette. Increased fossil fuel use with carbon management technology and nuclear energy are seen as the two energy options of greatest interest for fueling the prospective change.

2.3 Alaska Market Assessment

Energy system changes are similarly driving a strong tide of interest in new energy options for AK. As a fossil fuel-producing state with high per capita consumption, Alaska's energy shift is already observed, for example, with the Prudhoe Bay oil field that is now in decline (see Appendix A). Natural gas has maintained output for on-shore production, while off-shore has declined by more than a factor of three (Ibid.). Meanwhile, only one coal mine is in operation. While many rural communities using microgrids continue to rely on diesel, renewable energy sources have gained shares recently in the energy mix. Interest in MRs for remote locations began in the early 2000s, but the technology and regulatory processes were not in place. Since that time, the technology has advanced and several users from local utilities and the UA, are taking interest. The state appears receptive, as the AK legislature passed nuclear friendly legislation (Senate Bill 177) in May 2022. Eielson Air Force Base was also announced as a site for a MR project. For more details on historical and current energy trends within the state, see Appendix A.

Alaska is also home to energy-intensive industries. A market assessment of Interior regions of AK (see Appendix C) details the economy, relevant industries, and background for state regions that include the Fairbanks North Star Borough, Denali Borough, Yukon -Koyukuk Census Area, and the Southeast Fairbanks Census Area. The assessment then focuses on core energy-consuming industries in AK, including: the military (four defense installations), hard rock mining for coal and gold, the oil and gas sector (including Trans-Alaska Pipeline System and three refineries) and higher education (UA system consisting of three campuses). Researchers analyze each industry and recognize that cost and availability of energy—both heat and power—are intrinsically tied to economic growth in the region. However, energy in the region is at a crossroads with decarbonization and fuel availability. How energy choices take shape within the state could substantially impact economic opportunities and growth, energy security, and energy burdens in the area.

Specific to the Interior Alaska mining industry assessment (see Appendix C), context is provided for energy production in terms of the regulated industry and the Golden Valley Electric Association service area, contracting with independent power producers and non-electric applications for heat. A case study is presented for hard rock mining that provides an example of large-scale energy users (e.g., coal, gold mining), whereby the mines may act as both energy consumers and suppliers. The mining companies are examined from the perspective of ESG goals, drivers, and detractors for alternative energy adoption, highlighting the possible economic trade-offs (e.g., job losses, lower revenues) associated with shifts to new energy technology. Value-added product development (i.e., manufacturing, processing) in Alaska is identified as key to mines and the regional economy, however the feasibility is limited by energy cost.

A broad view is also examined of energy systems within the regional power system, revealing needs for baseload power replacement due to reduced reliance on coal, diminishing natural gas resources in the Cook Inlet and the addition of renewable energy sources. Distributed systems are considered that can cogenerate heat for space heating and industrial processes, be co-located with large energy users to help moderate adoption of intermittent energy sources, and provide mobility for future relocation to accommodate mine production cycles. Implications for mines to disconnect from the grid and options to manage system changes, such as use of a sleeved power purchase agreement for grid-tied industrial users, are also explored.

More targeted analysis of the coastal region around Nome, AK (see Appendix A), then assesses the diversification potential for a deep-water port, graphite mining and related economic prospects with energy mix adaptations. The analysis finds that Nome is in the early stages of constructing a deep-water port. A prospective graphite mine, if constructed, would serve as an important source for a national graphite supply chain. The study emphasizes how high energy prices and limited fuel shipping months per year present a very strong case for looking beyond diesel options. This study integrates historical and case analysis with interviews of stakeholders from across sectors to shed light on the background, feasibility, and perceived interest in emerging economic development over the next 5–10 years around Nome. Increased utilization of wind power with storage or the adoption of a MR present energy mix adaptations that are worth exploring in more depth. Such changes could better support the region's energy demands, while also enabling more advanced manufacturing.

2.4 Economic Assessment of Markets

The U.S. Department of Energy (DOE) Microreactor Program conducted economic and market assessments for MRs in U.S. and global markets during 2019–2021. Shropshire et al. (2021) conducted a global market analysis of microreactors. This study focused on future, global microreactor markets and their potential for replacing fossil sources and for complementing variable renewable technologies (solar and wind) in distributed systems, with regulatory aspects noted. Studies of potential applications for microreactors were conducted for Alaska, Puerto Rico, and U.S. federal facilities under the Microreactor Program. These studies were conducted by the University of Alaska Anchorage, University of Wisconsin-Madison and the Nuclear Alternative Project.

The U.S. DOE Microreactor Program prepared several papers for a Nuclear Technology special issue on MRs (Jackson and Sabharwall 2023). One paper covered the prospects for nuclear MRs (Black et al. 2022) that extended the study by Shropshire et al., 2021. This paper included an evaluation of the characteristics that differentiate microreactors from SMRs and other energy technologies to make MRs suitable for unique and localized applications, if they can be economically competitive with other energy technologies, as well as meet regulatory and other societal requirements.

A modeled economic assessment was also completed for a MR in representative emerging markets for Alaska and Wyoming (see Appendix D). A system cost approach is applied in the evaluation of energy options for Nome, Alaska using MIT's and Princeton's GenX capacity expansion and dispatch optimization model. The analysis is extended to cogeneration along the Alaskan Railbelt in the Fairbanks region for district heating and industrial heat applications. This analysis identifies a key problem of pricing sales when co-generators are sized for the heat load and sell excess electricity to the local grid.

2.5 Summary of Market Assessments

High potential markets that are prevalent or have potential for development in WY and the Rocky Mountain Region are also examined (see Appendix B). These include trona mining and processing, hydrogen production, DAC, and digital economies—including cryptocurrency mining and data and computational centers—and possible uses in conventional mining, oil and gas, carbon refining, ammonia production, and other industries.

In Alaska, there are several relevant MR use cases under consideration (see Appendix C) where interest is driven by high prices and supply constraints for baseload electricity and heat. Potential MR applications range from remote industrial operations (e.g., mining) and U.S. Department of Defense (DOD) applications (e.g., military bases), to becoming a provider of baseload energy for urban areas of the state referred to as the 'Railbelt.'

A case profile comparison of Nome, AK, and Gillette, WY (see Appendix A), emphasizes similarities in terms of remote locations, and industry shifts due to net zero priorities. Both states export much of their natural resources, which could be retooled with advanced manufacturing/processing if the energy-economic ecosystem were framed differently. The recent passage of new policies in both states is creating more favorable contexts for MR siting. Important differences are also evident, including higher population and tax revenues for Gillette, while Nome is smaller, more remote, and is an important regional hub serving a more diverse population. More detail on these communities, their employment, and industries for possible use of MRs is provided in Appendix A.

A summary of the findings from the AK and WY studies, including a compilation of common market opportunities is provided in Table 2. Although these states have their own niche markets (e.g., seafood processing in AK or Trona mining in WY), there is commonality in the remoteness of the applications, mobile uses for MRs in mining, and energy use for refined products derived from mined resources.

Table 2. Findings for potential MR market opportunities in AK and WY.

Market Area	Opportunities in AK	Opportunities in WY
Niche markets with high energy costs.	Remote regions (graphite mining, deep water ports, seafood processing plants).	Remote regions (uranium and Trona mining, possible data centers).
Energy-intensive industries.	Mining, distributed microgrids, support to large industrial loads.	Mining, distributed microgrids, cryptocurrency mining, DAC, data centers, hydrogen and potentially ammonia production.
Cogeneration.	Heat needed for health and safety, and industrial heat demands.	Steam to process Trona.
Value-added materials manufacturing.	Refining for mined resources.	Refining for mined resources (soda ash) and hydrogen-based products.
Decarbonization policy driven (ESG, RPS).	Fill gaps left by renewable energy sources, electrification, hydrogen.	DAC and hydrogen, trona with low-carbon footprint.

Market Area	Opportunities in AK	Opportunities in WY
Mobile applications.	Move generation source between mining operations.	Haber-Bosh applications for ammonia production.
Co-locating MR at end of a transmission line.	Serve remote mines and utility grid end points.	N/A.
Military installations.	Air Force base, potential Coast Guard base, search and rescue.	N/A.

The EMA surveys and assessments did not explicitly address MR design requirements. However, in review of the high potential MR markets and their associated constraints, one may derive potential preferences for capabilities, as listed below:

- Cost competitive in electricity and heat markets, comparable (if not better) in remote locations with diesel sources, and in other markets with low-carbon sources including wind, solar, geothermal, and energy storage
- Modular designs that allow transport to remote sites by road, sea (barge), or aerial delivery on rough, dirt airstrips
- Suitable capacities[c,d] that meet state-level requirements and exemptions.
- Sized (single or in multiples) that meet end-user requirements:
    - Cryptocurrency mining (range 1-100MW, medium size 10 MWe)
    - Remote villages such as Nome AK are estimated to need 8-16 MW to support future economic development
    - AK defense installations use combined heat and power (CHP) with installed capacity of 7.4 to 33.5 MW
    - UA Fairbanks newest steam generator has a 17 MW nameplate capacity.
- Minimize site infrastructure needs:
    - Remote locations with little existing infrastructure and unstable siting conditions due to warming of permafrost
    - Replacement of coal generation to support baseload power without significant site infrastructure replacement.
- Mobility to move between demand centers:
    - Move between sites when mines are no longer economic or due to market shifts.
- Long refueling cycles:[e]
    - Minimize refueling in remote applications where transport costs are very high and subject to access restrictions for portions of the year due to weather.

[c] Loans under the AK Power Project Fund appear to be available to nuclear projects, provided certain conditions can be met. While microreactors range from one to 50 megawatts in capacity, only 10 megawatt and smaller facilities would be eligible under the program.

[d] In May 2022, a new bill was signed in AK that would exempt microreactors from certain state-level siting requirements for nuclear reactors. A microreactor is defined by the bill as "a nuclear utilization facility that is a nuclear fission reactor consistent with the definition of 'advanced nuclear reactor' in 42 U.S.C. 16271 and capable of generating not more than 50 megawatts of capacity."

[e] For microreactor technology that can refuel on site, the States may wish to consider State-Federal agreements on nuclear waste management or new consent-based siting calls.

- Black-start capabilities:
  - Minimize need to retain diesel generators on-site in remote applications
  - Increase in resiliency in case of network shut-down for interconnected applications.
- Semi-automated operation and/or Lease Options with Owner Managed Maintenance:
  - Remote users may lack access for trained nuclear operators and support staff.
- Near-term timeframes for deployment:
  - Some potential customers want to see operational experience with MRs before committing to use.
- Supply heat:
  - Low-carbon steam and cogeneration are needed for industry decarbonization.

3. REVIEW OF STATE POLICIES FOR CARBON REDUCTION

This section includes a review of current and prospective state policies under consideration for carbon reduction.

3.1 Review of State Policies

A systematic review of recently passed and prospective U.S. state policies plus related developments may be found in Appendix A for carbon reduction and nuclear support with focus on: RPS, Clean Energy Standards, nuclear adoption/plant extension support, carbon-related targets/related policies, and other state specific developments. The policy review for the 50 states was completed using national sources, primarily the Database of State Incentives for Renewables & Efficiency, National Conference of State Legislatures, and Nuclear Energy Institute that were cross-checked with state policy updates.

3.2 Wyoming Carbon-Policy Sensitivity Analysis

Current and prospective policies under consideration for carbon reduction are detailed with a focus on the sensitivity of WY industries to carbon governance in Appendix B. Stakeholders were identified in established WY industries and among developing industries in the decarbonization sector. Interviews and focus groups were employed to assess industry awareness of and sensitivity to carbon governance, including carbon regulations, carbon markets, ESG disclosures, procurement requirements, supply chain, or contract provisions. The research identified areas of carbon governance with the most impact on WY industries and to what extent industries are motivated to make new investments to decarbonize. Notably, drivers for decarbonization differed between established industries, such as trona production and industries that are primarily focused on decarbonization. In the former group, motivations to decarbonize are focused on consumer demand and supply chain vulnerabilities related to the current systems, whereas the latter group was much more focused on the cost relative to carbon intensity for purposes of claiming federal credits. Informational requirements, barriers, and opportunities to MR applications in established WY industries are identified. Potential barriers including uncertainty, familiarity/know-how, infrastructure, and public perception were also identified. Key stakeholders were identified in industries trying to decarbonize (e.g., mining) and those in the decarbonization/climate mitigation sector. Interviews were initiated with representatives that will be highly relevant in WY in the coming years and have high potential to adopt MRs including the trona industry, DAC companies, hydrogen companies, and digital data centers.

Policy clarifications are important to companies working to decarbonize that need assurance of nuclear technology's cost relative to net-carbon benefit. Uncertainties remain on the eligibility classification for MRs for claiming carbon credits and federal tax credits (e.g., carbon sequestration, hydrogen). Agency guidance that clarifies how nuclear would be considered for purposes of claiming tax credits could help address these concerns.

3.3 Alaska Carbon/Emission Reduction Policies

AK's high-power costs and dependence on fossil fuels have driven a suite of energy policies and programs in the state's statutes and regulations. AK's power generation history, current state policies for AK, and a review of proposed legislation that may be relevant to nuclear energy production, such as the proposed Clean Energy Standards, and other advanced nuclear-specific legislation are examined in Appendix C. Current funding programs and subsidies (e.g., Power Cost Equalization Program, Power Project Fund, Southwest Energy Fund, Renewable Energy Grant Fund) and recently adopted legislation (e.g., Non-Binding Renewable Energy Goal, Nuclear-Specific Statute, Electric Reliability Organizations) are elaborated, comprising the majority of AK's energy policies, with possible implications for nuclear energy projects.

In May 2022, a new bill was signed that would exempt MRs from certain state-level siting requirements for nuclear reactors. Additional energy policies (e.g., House Bill 301, Senate Bill 179) have been introduced in recent legislative sessions, signaling a shift in AK's energy mix. Appendix C sheds light on how MRs may be of particular interest to AK's remote communities as a potential source of electricity generation.

3.4 Summary of State Policies

Appendix A provides a summary of recent carbon and nuclear policies for the 50 states, with some discussion of trends and federal policy to situate the trends from the past few years. This summary describes major pieces of federal legislation that incentivize industries and can amplify state resources. Carbon policies driven by U.S. commitments internationally on greenhouse gas emissions are distilled to understand impacts at the state level. Nuclear energy is for example, incentivized by the 2022 Inflation Reduction Act promoting continued generation from the existing fleet and providing credits for new advanced nuclear deployments. Other legislation supporting nuclear science and innovation is detailed. Proposed and adopted carbon or nuclear-related state policies underscore an increased interest in carbon-free solutions, as summarized in Table 3.

Table 3. Carbon and Nuclear-related policy and developments.

Policy and Developments	States
Adopted a clean energy standard or an RPS	AK, AZ, CA, CO, CT, DE, HI, IL, IN, IA, KS, ME, MD, MA, MI, MN, MO, MT NE, NV, NH, NJ, NM, NY, NC, ND, OH, OK, OR, PA, RI, SC, SD, TX, UT, VT, VA, WA, WI (Note: AK is considering a more rigorous RPS/CES policy)
Nuclear Adoption/Extension Support	AK, CT, GA, ID, IL, IN, KY, LA, MD, MI, MS, MT, NE, NC, UT, VA, WV, WY (Note: CA support for Diablo Canyon is an area to monitor)
Expanding policy definitions with nuclear as zero-emission/carbon-free/clean energy	CA, CT, ID, IL, IN, NJ, VA (Note: NH is considering adding Gen IV or later nuclear energy systems as a new class for the renewable energy portfolio)

Policy and Developments	States
Repealed prohibitions on nuclear development or updated siting authority	AK, CT, KY, MT, WV
Proposing/advancing studies aimed at potential for siting or permitting advanced reactors	MD, MI, NE, NH, PA, SC, VA (Note: In WI, NuScale and a cooperative signed an MOU to assess the potential for an SMR.)

Source: Adapted from Appendix A.

4. CHALLENGES AND POSSIBLE ACTIONS

Challenges for deployment of MRs in initial markets and possible actions that may be taken:

- Concerns about public perceptions suggest a lack of knowledge about MRs and uncertainties in terms of cost, waste and fuel management.
  - The nuclear industry and national labs can increase communications about the technology and create a clear differentiation between MRs, small modular reactors, and large reactors.
  - Hone messaging about nuclear energy in early adopter states that expressed interest in MRs.
  - Define MR demonstrations for specific industries to help potential users understand how MRs could work within their companies' energy systems.
- Companies want decarbonized energy now, and they have concerns over when MR will be commercially available, given expectations for a long permitting process:
  - Engage with industries/utilities to design systems that prevent lock-in. Develop bridging strategies with phased deployment of lower-carbon energy sources in near-, medium-, and long-term plans. Assist utilities in making informed choices on whether to buy and train their staff or lease the technology in such a manner that expert maintenance would be handled by the owner.
  - Work with regulatory groups like the National Association of Regulatory Utility Commissioners (NARUC) through implementation of regulations to address regulatory uncertainty and other potential adaptations for the MR licensing process.
- Energy costs as a barrier to MR project development:
  - Produce comparisons between MRs and other comparable low-carbon energy sources, in such a way that differentiates MRs from the high cost of large reactors.
  - Define the specific cost constraints of the industries, and the potential costs of MR to inform cost-based decision-making.
  - Identify funding strategies with federal policies (Infrastructure Reduction Act [IRA], Infrastructure Investment and Jobs Act (IIJA], Defense Production Act [DPA], and others) and state energy funds (loans), as appropriate, to reduce the cost gap for building the first MRs.
  - Assess the impacts on Power Cost Equalization in AK rural communities.
- Disruption to existing supply chains (AK), and retention of jobs (AK), e.g., fossil fuel suppliers:
  - Produce economic/workforce development case studies to show the potential benefits to a community, region and state beginning with studies for early adopter states like Idaho, WY and AK.

- Need for new or revised regulatory approaches (relative to large reactors) to appropriately size and serve speculative load and new industrial loads:
  - Educate on how advanced reactor designs can use a functional containment strategy to keep costs in line with risks.
  - Encourage potential adopter states to consider modelling legislation and learn how other states revise or adopt policies specific to microreactors.
  - Work with electric reliability organizations and state legislatures to address interconnection access issues.
  - Examine regulatory considerations on MRs that potentially arrect direct use/deployment by industry.
  - Determine the barriers to direct use of heat (not electricity) from MR output.
  - Work with utilities to develop use cases to address barriers to MR service for large new load customers.
  - Assess the regulatory issues associated with transportation of MR technology when considering service to prospective new load customers (mining, bitcoin miners, server farms).
  - Evaluate cost recovery mechanisms for prospective load customers that consider total system benefits as opposed to strict unit cost per kilowatt methodologies.
  - Develop use case studies that assess avoided costs such as transmission enhancements, substation upgrades, and distribution hardening and alternate costs that are associated with the distributed generation nature of MR technology.
- Exclusions for use of MRs, e.g., renewable energy grant funds, proposed AK Renewable Portfolio Standard, U.S. states' prohibitions and barriers on nuclear development:
  - Demonstrate that MRs can be safely deployed at national labs and in the DOD Pele project, as well as military bases (e.g., Eielson Air Force Base).
  - Monitor and report on deployment of advanced reactors, e.g., Natrium reactor at Kemmerer, WY.
- Uncertainties regarding MRs classification in carbon markets and federal credit programs:
  - Increase communications on the life cycle emissions from low-carbon energy sources, also promote the increase reliability and resilience inherent in the technology.
  - Show how MRs can support ESG goals and decarbonization policies.
- Concerns about job losses in an 'Energy Community:'
  - Show connections with funding opportunities in new laws (e.g., Inflation Reduction Act, IIJA, DPA) and business models that prioritize jobs and continued incomes for fossil fuel service providers. Leverage existing resources, e.g., Interagency Working Group on Coal & Power Plant Communities & Economic Revitalization (n.d.).

5. FUTURE RESEARCH

Based on the findings from these studies, there are several areas where further research is recommended, including:

- Develop deeper analysis of the specific public acceptance and resistance points related to MRs.
- Evaluate other possible MR markets including conventional mining, oil and gas extraction operations, carbon refining, ammonia production, synthetic fuels and other industries.
- Evaluate the cross-jurisdictional regulatory considerations for land use, siting, carbon reduction, transmission corridors, and mining.

- Research the regulatory issues associated with industry use of MRs, and the access to and interconnection with the grid or the ability to sell excess power into deregulated markets.
- Examine and develop business models for utilization of heat from a MR under different use cases such as an industrial heat and power user, community distributed heat system or electric heating.
- Evaluate the MR supply chain to evaluate tax and incentive packages for manufacturers, workforce training and job analysis.
- Evaluate considerations for siting MRs in northern latitudes, e.g., permafrost considerations, district heating, economic impacts from opening the Northwest passage, use of MRs for emergency management and disaster response, analysis of critical mineral extraction and refining, etc.

6. CONCLUSION

This report provides an evaluation of state-level legal, regulatory, economic and technology implications for MR applications in U.S. markets. The focus is on AK and WY energy markets serving location-specific energy needs for electricity and heat. An economic assessment of MRs was performed to understand the economic sizing of an individual MR (or multiples of MRs) supporting energy-intensive applications for candidate sites. A state-by-state review of current carbon/carbon-related policies and nuclear policies is conducted to assess broader market applicability in states undergoing energy transitions.

This work is conducted as part of the EMA activities. This initiative aims to identify sustainable, regionally acceptable, and high-value energy solutions that are secure and fair. EMA's focus on emerging energy markets in WY and AK recognizes that new or adapted practices and technologies can alter the frontier of solutions and advance a community's social, economic, and natural pathways. Such change requires more comprehensive analysis that accounts for added societal input, resources, capabilities, and infrastructure. These considerations lay the foundation for community decision-making models that are responsive to community values as well as history and current drivers. The result is a community-based decision and engagement model that will be valuable to decisionmakers and developers of advanced and emerging energy solutions, seeking a more socially informed and inclusive path to development.

7. REFERENCES

Air Force, 2022. “Request for proposal released for Eielson Air Force Base Micro-Reactor Pilot Program”, Last modified on September 26, 2022. https://www.safie.hq.af.mil/News/Article-Display/Article/3169035/request-for-proposal-released-for-eielson-air-force-base-micro-reactor-pilot-pr/

Araújo, K. and D. Shropshire. 2021. “A Meta-Level Framework for Evaluating Resilience in Net-Zero Carbon Power Systems with Extreme Weather Events in the United States.” *Energies* 14(14): 4243. https://doi.org/10.3390/en14144243.

Black, G., Shropshire, D., Araújo, K. and A. van Heek. “Prospects for Nuclear Microreactors: A Review of the Technology, Economics, and Regulatory Considerations,” Nuclear Technology, 209, S1-S20, Supplement 1, (2022). https://doi.org/10.1080/00295450.2022.2118626

GAIN, n.d., DOE Microreactor Program Winter Review on March 8-9, 2023. Accessed on March 17, 2023. https://gain.inl.gov/SitePages/MicroreactorProgram.aspx

Hansen, J., B. Dixon, A. Cuadra-Gascon, M. Todosow, A. Verma. 2020. “Retrospective Analysis of US LWR Technology Commercialization: Lessons for Today's Nuclear Industry”, Idaho National Laboratory, INL/EXT-20-58211, Revision 1. https://doi.org/10.2172/1635530

iap2. n.d. “Core Values, Ethics, Spectrum – The 3 Pillars of Public Participation.” Accessed October 4, 2021. https://www.iap2.org/page/pillars.

INL. 2021. “Emerging Energy Market Analysis Initiative, Methodological Framework.” INL/EXT-21-65347, Idaho National Laboratory, Idaho Falls. ID. https://doi.org/10.2172/1838119.

Interagency Working Group on Coal & Power Plant Communities & Economic Revitalization. n.d., Accessed on March 13, 2023. https://energycommunities.gov/

Jackson, J., P. Sabharwall. “Foreword: Special issue on the U.S. Department of Energy Microreactor Program”, Nuclear Technology, 209:sup1, pages iii-v, 2023. https://doi.org/10.1080/00295450.2022.2134723

Johnson, R. 2020. “Microreactors in Alaska: Customer Discovery and Perception.” University of Alaska Center for Economic Development. https://static1.squarespace.com/static/59f6b60bcf81e02892fd0261/t/60189afcbc397811525aca24/1612225286635/Customer+Discover+and+Perception+Analysis.pdf.

Shropshire, D., G. Black, and K. Araújo. 2021. “Global Market Analysis of Microreactors.” INL/EXT-21-63214, Idaho National Laboratory, Idaho Falls, ID. https://doi.org/10.2172/1806274.

Smutko, S. 2021. “Public Participation and Participatory Decision Process Protocol for Siting Small Modular Nuclear Reactor Technology in Alaska and on the Wind River Reservation in Wyoming.” White Paper, University of Wyoming.

World Nuclear News, 2022. “BWX Technologies selected to build Project Pele microreactor”. Last modified on June 9, 2022. https://www.world-nuclear-news.org/Articles/BWX-Technologies-selected-to-build-Project-Pele-mi.

Wyoming Public Radio, 2022. “The opening of TerraPower’s nuclear plant in Kemmerer will be delayed by two years”, Last modified on December 14, 2022. https://www.wyomingpublicmedia.org/natural-resources-energy/2022-12-14/the-opening-of-terrapowers-nuclear-plant-in-kemmerer-will-be-delayed-by-two-years.

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Appendix A

BSU An Assessment of Policies and Regional Diversification with Energy, Critical Minerals and Economic Development in Emerging Markets[f]

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Energy Policy Institute – Center for Advanced Energy Studies and Boise University

Report - February 2023

SUMMARY

The aim of this study is to primarily evaluate: (1) energy policies of the 50 U.S. states associated with carbon and/or nuclear energy, and (2) emerging market or regional diversification potential for Alaska and Wyoming communities in relation to energy, critical minerals mining and related economic development.

A 50-state analysis shows recent increases in carbon management policies, namely renewable portfolio standards (RPS), clean energy standards (CES), and targets, reflecting an intensification of net zero priorities. A review of state-wide nuclear policies shows a mix in the past 5 years of instruments being introduced, encouraging new nuclear or providing economic support for existing nuclear plants to remain in operation.

Case analyses of Nome, Alaska and Gillette, Wyoming highlight new opportunities with net zero priorities and infrastructure funding, if regional strategies and labor force needs are sufficiently factored.

[f] This work has been performed with funding support through contract No. 154754-71 from Idaho National Laboratory, operated by Battelle Energy Alliance, LLC, for the United States Department of Energy.

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PART 1: WORK SCOPE

- Participate in an assessment of the opportunities and barriers for microreactors in emerging markets.
- Review recent Microreactor Program reporting and related literature that is relevant to energy system change and industry developments for Wyoming and Alaska (in consultation with project lead).
- Review recent carbon and nuclear Policies in the 50 states for developments and trends.
- Perform expert and stakeholder elicitations, leverage Microreactor Program studies and snowball sampling, and develop a cross-sectoral list of policymakers and key stakeholders in two prospective communities (WY, AK) that is representative of pathway considerations and broader community interests. Conduct elicitations with constituents using semi-structured interviews, public meetings/focus groups, surveys, and/or other techniques.
- Evaluate the potential for graphite mining in conjunction with a microreactor versus an alternative form of energy in a community in AK. Complete a similar case for WY. This will include a focus on industry/infrastructure repurposing/adaptation, environmental sustainability, and community/workforce development.

PART 2: OVERVIEW OF MICROREACTORS AND CHANGE

Opportunities and Barriers for Microreactors in Emerging Markets

Participation in discussions about opportunities and barriers in emerging markets occurred with the Kawerak Incorporated Leadership Summit, Nome Workforce Summit, Wyoming Technology Summit and Frontiers Meeting, Alaska Nuclear Working Group, the Alaska Center for Energy and Power, Alaska Power Association, Alaskan stakeholders (including those in economic development, utilities and communities), and Wyoming stakeholders (including with the Wyoming Energy Authority, Wyoming Business Council, Wyoming Geological Survey, Jackson Hole Technology Partnership), Harvard's Growth Lab, U.S. DOE, the Nuclear Reactor Innovation Center, White House Office of Science and Technology Policy, U.S. Nuclear Regulatory Commission, Battelle, the Atlantic Council, Advanced Nuclear and Production Experts, Citizens for Responsible Energy Solutions, Clear Path, Nuclear Energy Institute, and C5 Capital. This is in addition to interviews which the EPI team completed (*see* list at the end of the Appendix A).

Energy System Change and Microreactor Potential in Emerging Markets

Broadly, there is a strong sense today that energy and related markets need to be managed differently (Araújo, 2023a, 2017). Whether planned or unplanned, public and private agendas increasingly highlight the importance of strategic planning that accounts for resilience and sustainability, safety, security, affordability, as well as other co-benefits (Ibid, Koerner, 2022). In recent times, geopolitics and extreme weather events have shown how global market dynamics and uncertainties can transform energy outlooks (Araújo 2023a; Araújo and Shropshire, 2021).

In conjunction with the above influences, conventional wisdom increasingly prioritizes mitigation and adaptation to the changing climate (IPCC, 2022). Among energy options, nuclear energy represents a proven, base load form of low carbon energy. Looking more closely, the disruptive potential of microreactors – a subset of small modular reactors on the order of 1-20 MWe – lies in their mobility, transportability, and long refueling intervals in addition to planned design enhancements with passive safety (Black et al, 2022).

Differences for microreactor technology from traditional GEN III nuclear technology present new markets for adoption, particularly where energy prices are at a premium and/or other energy resources are limited (Ibid). Microreactors may become competitive in locations where large power grids are not present, yet demand exists from communities or industries in which fuel delivery is limited/expensive, or economies of scale are not currently attainable (Ibid). Smaller facility footprints, design simplicity, and more efficient construction represent other distinctions (Ibid).

Focusing on energy transitions as well as other types of technology change, niche markets are seen as opportunities for demonstration (Schot and Geels, 2008; Raven et al, 2010; Araújo, 2023b). In such niches, learning by early adopters allows technological improvements as well cost reductions, while enabling later adopters to monitor progress (Rogers, 1995; Grubler, 1998; Araújo 2023a). Specific to microreactor technology, **opportunities** for niche markets are seen in remote regions, areas with energy-intensive industries including mining and data centers, distributed microgrids, disaster relief, and marine propulsion, among possibilities. **Barriers** also exist in terms of the uncertainty about the final designs and implications, such as the cost of manufacturing and operations, changes in permitting, and questions about waste management. Current designs regularly factor for adaptations in fuel type, sensors, electronics, materials, and safety systems (Black et al., 2022). These newer designs may be more suited for load-following, black-start capabilities, and more automated functions (Ibid). Regulatory and institutional challenges, in turn, exist in that there is a need for new or revised regulations and related learning where microreactors differ from their larger counterparts.

A number of recent studies by the Emerging Energy Markets Analysis Initiative, for the DOE Microreactor Program or related studies are outlined.

Shropshire and Araújo (2021) reviewed challenges for electric utilities in characterizing resilience in order to harden power systems. A meta-level framework was put forward that integrates economic, environmental and social attributes with a focus on locally-defined priorities and values. The framework integrates qualitative, qualitative and geospatial assessments. It was then applied to various examples of extreme weather events within the US, including the prospective use of a microreactor following Hurricane Maria in Puerto Rico.

Gerace (2022) completed a multi-study review of Wyoming residents' perceptions of energy, desires and values to highlight opportunities and barriers for the adoption of nuclear technologies in Wyoming. Specific to opportunities, many residents either support nuclear energy or report not being sure, indicating a level of openness for them to learn more and increase their support. In terms of barriers, Wyoming respondents remain opposed to risk (Ibid).

Wise et al. completed three studies. The first (2022a) examined western state renewable portfolio standards, finding that a significant portion of the western electricity markets remain available to nuclear generation, yet market restrictions may impact new investments in nuclear generation capacity. (RPS policies generally do not include nuclear energy.) A second study (Wise et al, 2022b) assessed conditions under which a microreactor could be considered a qualifying facility under the Public Utility Regulatory Policies Act of 1978. They found "it would need to be operated as a 'cogeneration facility' producing not only electricity but also producing heat or 'useful thermal energy' for use with other systems and applications (Ibid)." Finally, in an overview of the regulatory framework for nuclear microreactor applications in Wyoming, Wise et al (2022c) found that "Wyoming may be well-suited for the siting of nuclear facilities, including microreactors, due to its open spaces and its largely favorable state and local regulatory environment. Under state law, nuclear projects may require approval from the Industrial Siting Council approval and could be subject to county and city zoning laws."

Stoelllinger et al examined potential clean energy hubs and stakeholder road mapping for Wyoming (2022). They evaluated three case studies, representing a range of possibilities for the state, then detailed a stakeholder identification process and applied it to a hypothetical example of a microreactor hub for Trona mining and chemical processing.

Black et al (2022) produced a review of the technology, potential markets, economic viability, plus regulatory and institutional challenges of nuclear microreactors. This elaborated technological characteristics for the wide range of microreactor designs, distinguishing them from large nuclear power plants and small modular reactor designs. It also identified areas for regulatory address.

James and Watson (2022) completed an economic study, estimating the medium-term impacts from alternative energy capital investments. They found that newer low-carbon generation has much larger (positive) effects than fossil fuel generation on the local economy and affirmed that declining regional electricity prices attract new businesses, especially those that are energy-intensive.

PART 3: RESEARCH DESIGN FOR POLICIES AND CASES

Summary: Methods, data and logic are detailed for the in-depth sections of Appendix A.

The policy review for the 50 states was completed using national sources, primarily the DSIRE database, National Conference of State Legislatures, and Nuclear Energy Institute that were cross checked with state policy updates.

Background research for case studies was completed on historical and contemporary conditions in Alaska and Wyoming for socio-economic, environmental, energy and industry developments of interest, including the mining history, plus nuclear perspectives and activity. The research included the status of critical minerals in both states, based on the Defense Production Act, Title III Presidential Determination for Critical Materials in Large-Capacity Batteries, plus additional minerals which carry similar national security attributes.

Two community cases were selected for a more systematic study of interests and priorities tied to energy diversification. Nome was chosen for Alaska, based largely on its high energy prices as well as the new mining that is being considered for graphite. Special focus is on not only the prospective Graphite One mine, but also the development of a deepwater port. Gillette was selected for Wyoming, based on a decline in coal mining, plus its history, proximity and resources for uranium mining. Uranium is not currently on the DPA, but a domestic uranium supply is recognized as having national and energy security importance. Special focus, then, is on scaling renewed uranium mining in Wyoming.

The case studies assessed the following meta-level question through elicitation: What potential exists for energy diversification and economic development in the next 5-10 years, possibly with a microreactor or other alternative energy, for the communities of focus?

To do so, the meta-level question was broken down into 4 sub-questions:

1. What economic developments, including mining of graphite (AK) or uranium (WY), are likely in the communities of focus for the next 5-10 years?
2. What considerations were raised for a microreactor vs. another alternative form of energy vs. continued reliance on fossil fuel, if economic development were to scale up due to new mining and/or other development for the respective communities?

3. How would greater economic development (in the next 5-10 years) translate in terms of industry/infrastructure, environmental sustainability, and community/workforce development?
4. What are the opportunities and barriers for MRs in these communities?

A list of prospective interviewees was developed, beginning with a literature review of key actors, then purposive and snowball sampling to reflect stakeholders across the relevant sectors. More than 40 semi-structured interviews were completed in person, by phone and/or via Zoom.

PART 4: CARBON AND NUCLEAR POLICIES

Summary: This section examines trends in state policies, with an emphasis on the past several years, for carbon and nuclear support, against a backdrop of recent federal changes.

Federal and State Policy Focus

Priorities associated with decarbonization and resilience in the context of modernization have been at the foreground of federal and state level energy policies in recent years. With the ongoing conflict in Ukraine and related sanctions on Russia, energy security, extreme price flux, and shortages have further shaped energy agendas.

With the above conditions as the current context, industrial policy has emerged as a driving force. Several major pieces of federal legislation — namely, the Inflation Reduction Act, the CHIPS and Science Act, and the Infrastructure Investment and Jobs Act—aim to strategically leverage the resources and capabilities of the federal government to spur production and create industries at the state and regional levels. As the legislative branch of the U.S. remains in a state of contest, executive use of the Defense Production Act has focused on energy-related priorities, specifically critical minerals.

Carbon Policies

The U.S. is pursuing multiple decarbonization goals in alignment with the Paris Agreement and other commitments which target greenhouse gas emissions. The long-term national strategy targets both carbon-pollution free electricity (2035) and net-zero emissions (2050) which need to be rooted in policy and implemented by governmental and non-governmental actors (U.S. Dept of State, 2021). Though the federal government recognizes the need to rapidly decarbonize, non-federal entities, such as states, large corporations, and utilities are leading the way, while the federal government provides financial support for developing technologies and programs through the Inflation Reduction Act, and Infrastructure Investment and Jobs Act. A variety of solutions have been proposed and begun in response to these problems. Individual state responses are categorized and explained in Table 4. In response to international energy market demands, the Executive Branch has used powers to increase the production of gas and critical materials, and to isolate and address supply chain issues. Simultaneously, state-level policy approaches have had to contend with previously established energy goals and critically evaluate clean technologies for renewable outcomes. Policy options employing renewable portfolio standards (RPS) or clean energy standards (CES) remain among the most popular.

There is widespread support for decarbonization at the state level, which can be seen by more than half the states adopting carbon emissions targets, renewable portfolio standards or clean energy standards (see Table 4), and the number of states that have released or are developing climate action plans (33 states released, eight updating, and one in development) (Center for Climate and Energy Solutions, n.d.a). The states adopting these plans tend to include three main regions including western coastal states, northeastern states (north of N. Carolina) and states surrounding the Great Lakes. An even more stark pattern of east vs. west coast states appears when looking at states adopting emissions trading systems (ETS), carbon pricing policies and cap and trade policies–which include 11 states in the Regional Greenhouse Gas Initiative as well as California and Washington, on the west coast.

Decarbonization programs at the state level are being promoted across sectors including efficiency standards for buildings and equipment, tax credits for energy efficiency and/or alternative energy sources, rebates for industrial or commercial energy savings programs and carbon offset programs. Some technologies are emerging as cost effectiveness studies and availability in the market are syncing with state incentives, as is the case with heat pumps. Due to large investments from DOE and state policy incentives in California, Connecticut, Massachusetts, Maine, New York, Oregon and Washington–experts are expecting increased uptake in this technology, especially in regions where building codes are requiring electric heating as well (Moore-Bloom, 2022).

Direct Air Capture (DAC) and Carbon Capture, Utilization, and Storage (CCUS) have been endorsed by states like Wyoming and Nebraska, as some states are pursuing a broader approach that encompasses several types of technology. However, despite massive investments in DAC at the federal level, the technology is years away from being a significant counterweight to the yearly global output of CO_2. While some states have continued to pursue solar and wind renewables, states with considerable investment in the fossil fuel industries have embraced DAC and CCUS rather than phase out their existing infrastructure (including Indiana, Nebraska, Oklahoma, Utah, Wyoming and West Virginia). The recent increase in coal demand due to natural gas prices and questions about coal plant closures for grid reliability seems to be renewing discussions on the need for this technology development. Given the lack of scalability and current technological inefficiency, it is unclear if DAC and CCUS have the staying power that other more conventional carbon-free energy resources have.

Nuclear Policies

The Inflation Reduction Act (IRA) provides multiple incentives to support the nuclear sector by ensuring energy security and cutting U.S. GHG emissions by 2030 (Office of Nuclear Energy, 2022). This legislation supports the existing nuclear industry by providing production tax credits and incentivizing new advanced nuclear deployment through technology-neutral production credits (Ibid). Further, the IRA provides funding for high-assay low-enriched uranium (HALEU) fuel supply chain development within the U.S., which is urgently required to deploy advanced reactors (Greene, 2022).

Another major piece of legislation supporting nuclear science is the CHIPS and Science Act. This law centers on boosting investment in university science and engineering infrastructure to expand the workforce and drive development of next generation technologies. This includes nuclear research reactors and the involvement of social sciences and law in nuclear investigations (Merrifield et al., 2022). The financing has already been impactful as the University of Illinois is planning for a construction permit in partnership with Ultra Safe Nuclear Corporation to site a microreactor at the Champaign-Urbana campus (McDermott, 2023). Penn State University has also signed a memorandum of understanding (MOU) with Westinghouse to collaborate on microreactor technology with an aim to build collaborations with steel and cement manufacturers regionally and decrease its carbon footprint. Additionally, Abilene Christian University and three partners with Natura Resources are exploring the process to build a molten salt research reactor (Ibid).

Recent national policy also reflects increasing support for nuclear innovation, funding technological developments and improving licensing/regulatory processes for advanced nuclear reactors (Swanek, 2019). Small modular reactors (SMRs) are a powerful focus of the nuclear sector that could allow for factory-fabricated and transported nuclear reactors capable of generating heat and power in previously more carbon-intensive sites. As energy prices increased in early 2022, states began to re-evaluate previous plans to phase out or decommission existing nuclear plants. Some also began to eye potential new construction and installation. For example, West Virginia repealed an article that had previously banned the construction of nuclear power plants. Ten states in 2022 passed legislation regarding the regulation of nuclear power plants, and more policies may be on the way. Even plants scheduled for decommissioning, like California's Diablo Canyon plant may be kept open to mitigate the effects of the energy crunch. This plant's operations have been approved to continue by the Nuclear Regulatory Commission as Pacific Gas & Electric seeks full approval to extend the plant's lifespan (Lopez, 2023).

In addition to carbon policies outlined above, Table 4 also summarizes recent nuclear policy developments from the past several years across the 50 states as well as extension support to keep existing nuclear plants operating. The state-by-state analysis highlights several policy trends which show a spectrum of nuclear support under development. As mentioned above in the carbon policy section, over half of the U.S. states have some sort of clean energy standard, renewable portfolio standard or carbon target, which includes a range of technologies to reduce carbon emissions. Recent policy changes are expanding definitions to incorporate nuclear technologies into zero-emission/carbon-free/clean energy definitions (CA, CT, ID, IL, IN, NJ, VA). Further, policy adjustments to repeal prohibitions on nuclear development or to update siting authority have reduced barriers to deploying advanced reactor technology (AK, CT, KY, MT, WI in addition to WV mentioned above). States like Nebraska and Wyoming have adopted policies that provide tax incentives or exemptions on property, electricity sales, and capital investment tied to nuclear development. These tax exemptions and advanced cost recovery mechanisms can support new reactor development. Several other states are exploring similar legislation. By doing so, the states recognize the need for financial support and for a workforce in regions without current nuclear plants, but have not successfully passed legislation to date.

Through policy direction and appropriations, many states or their leaders have directed task forces, academia, industry, or the public utilities commissions to collaborate and study nuclear potential. Some states are proposing or advancing studies of the potential for siting or permitting of new advanced reactors (MD, MI, NE, NH, PA, SC, VA).

The number and breadth of proposed and adopted policies, especially related to advanced nuclear technologies at the state level demonstrate an increased interest in including nuclear power as a carbon-free solution.

There are changes happening at the sub-state level that are difficult to capture in this type of analysis which focuses primarily on executive order, legislative mandate, RPS or carbon reduction standard. Market forces from customers, shareholders and investors have heavily influenced portfolio diversification for businesses, cities, and utilities in recent years. Given the sheer number and privacy (in some cases) of such investments, these would be difficult to track. However, utility industry analysts have demonstrated patterns of self-imposed carbon reduction plans and utility-adoption of other climate-related targets throughout the U.S., regardless of state policy.

Table 4. Summary of Carbon & Nuclear Policies in 50 States[g]

State	RPS/ CES	Nuclear Adoption/ Extension Support	Carbon Targets/ Related Policies	ETS	Other
Alabama					
Alaska	✓[1]	✓[2]			✓[3]
Arizona	✓[4]				✓[5]
Arkansas					
California	✓[6]	*See* Other	✓[6]	✓[7]	✓[8]
Colorado	✓[9]		✓[10]		✓[11]
Connecticut	✓[12]	✓[13]		✓[14]	
Delaware	✓[15]			✓[16]	
Florida					✓[17]
Georgia			✓[18]		✓[19]
Hawaii	✓[20]				
Idaho		✓[21]			
Illinois	✓[22]	✓[23]			✓[24]
Indiana	✓[25]	✓[26]	✓[27]		
Iowa	✓[28]				
Kansas	✓[29]				
Kentucky		✓[30]			
Louisiana					✓[31]
Maine	✓[32]			✓[33]	✓[34]

[g] ✓'s indicates State policies under development or enacted

State	RPS/ CES	Nuclear Adoption/ Extension Support	Carbon Targets/ Related Policies	ETS	Other
Maryland	✓[35]	✓[36]		✓[37]	✓[38]
Massachusetts	✓[39]			✓[40]	
Michigan	✓[41]	✓[42]			
Minnesota	✓[43]				
Mississippi		✓[44]			
Missouri	✓[45]				
Montana	✓[46]	✓[47]			
Nebraska	✓[48]	✓[49]	✓[42, 50]		
Nevada	✓[51]				
New Hampshire	✓[52]	✓[53]		✓[54]	
New Jersey	✓[55]			✓[56]	
New Mexico	✓[57]				
New York	✓[58]			✓[59]	
North Carolina	✓[60]	✓[61]			✓[62]
North Dakota	✓[63]				
Ohio	✓[64]				
Oklahoma	✓[65]		✓[66]		
Oregon	✓[67]		✓[68]		
Pennsylvania	✓[69]	✓[70]		✓[71]	
Rhode Island	✓[72]			✓[73]	
South Carolina	✓[74]	✓[75]			

State	RPS/ CES	Nuclear Adoption/ Extension Support	Carbon Targets/ Related Policies	ETS	Other
South Dakota	✓[76]				
Tennessee					
Texas	✓[77]				
Utah	✓[78]	✓[79]	✓[80]		
Vermont	✓[81]			✓[82]	
Virginia	✓[83]	✓[84]		✓[85]	✓[86]
Washington	✓[87]			✓[88]	
West Virginia		✓[89]	✓[90]		✓[91]
Wisconsin	✓[92]				✓[93]
Wyoming		✓[94]			

1. Alaska set a non-binding goal in 2010 to generate 50% of the state's electricity by 2025 and seeks to adjust this without increasing the overall cost of electricity to consumers. New bills were introduced in the 2022 legislative session. The RPS (SB179) scales required renewable energy shares for Railbelt power producers' net electricity sales: 20% by 2025; 30% by 2030; 55% by 2035; and 80% by 2040. The CES (HB301) requires 25% of net electricity sales to be from clean energy by 2027 on the Railbelt, then 55% 2040. The RPS does not include nuclear energy, and the CES does. See also Johnson and Wise, 2023.
2. A provision was added to 2021 AK S 177 that allows the legislature to approve nuclear and microreactor permits for "unorganized borough(s)" and creates a specific process for microreactor permitting. SB 177 was passed in May 2022, designating Department of Environmental Conservation to permit nuclear reactors, rather than the Legislature.
3. The Air Force selected Eielson Air Force Base to pilot its first microreactor (Szondy, 2021).
4. Arizona has a 2006 RPS requirement of 15% renewable energy by 2025.
5. Arizona has many pending legislative actions and updates, but nothing major for energy policy. Most notable are provisions regarding electric vehicle infrastructure and charging accessibility. (Pending) 2022 AZ S 1150 establishes minimum requirements for residential housing to be equipped with EV-charging accessible outlets. The 2023 AZ H 2241 electric vehicle, charging pilot program has been read in and is in committee.

6. California has GHG emission reduction goals: 40% below 1990 levels by 2030, and 80% below 1990 levels by 2050. It also aims to achieve 100% carbon-free electricity by 2045 and economy-wide carbon neutrality by 2045 (C2ES, n.d.b). 2021 CA S 596 requires the state board to develop a comprehensive net-zero strategy for California's cement sector "within the state as soon as possible, but no later than December 31, 2045." (Pending) 2021 CA A 1322 also states that on or before July 1, 2024, the state board shall develop a plan "to reduce aviation greenhouse gas emissions and help the state reach its goal of net-zero" emissions. Governor Newsom refused to sign this bill into law, recognizing this is already covered in the Low Carbon Fuel Standard.
7. "California's carbon cap-and-trade system is one of the largest, multi-sectoral emissions trading systems in the world" (C2ES, n.d.a). Revenues from the program supply the state's Greenhouse Gas Reduction Fund and are appropriated to state agencies to implement further GHG reduction initiatives. By law, 35% of the revenues are directed to environmentally disadvantaged and low-income communities. Since its inception, the program has produced $5B of total revenue. This program is connected with the Canadian province of Quebec's cap-and-trade system through the Western Climate Initiative (Ibid).
8. The future of Diablo Canyon Nuclear power plant is uncertain as its operational license application was rejected by the NRC and PG&E was told to submit a new application if they planned to continue operations past 2025. However, SB 846 authorized the state to provide a $1.4 billion loan guarantee to extend plant operations at Diablo Canyon Nuclear Power Plant through 2030.
9. Colorado's current RPS goal is 100% renewable energy production by 2050 (Ray et al, 2022). Colorado SB 18-003 (June 2018) required the Colorado Energy Office to work with utilities and stakeholders to promote clean energy sources, such as nuclear energy. 2022 CO S 118 also establishes provisions for the development of geothermal energy under the state's greenhouse gas pollution reduction roadmap, allowing for geothermal energy as a "renewable energy resource that qualifying retail utilities may use to achieve the electric utility sector greenhouse gas pollution reduction goals." This appears to allow geothermal to qualify under the state's RPS standard.
10. 2022 CO S 51 establishes "maximum acceptable global warming potential" for building materials, effective 2024 (*see* Section 1, 24-92-117), provides a tax credit for heat pumps (Sec 2., 39-22-545) residential energy storage systems (Sec 2., 39-22-546), and eligible decarbonizing building materials (Sec 4., 39-26-731).
11. In addition to considerable 2021 legislation, Colorado continues to pass policy incentivizing clean energy production, electric vehicle infrastructure, energy storage, and energy justice.
12. Connecticut's RPS standard has been updated to 45% renewable energy by 2030 and further updated to reflect, "not later than January 1, 2040, to a level of zero per cent from electricity supplied to electric customers in the state" (*see* 2022 CT S 10, Sec. 1, subsection (a), 22a-200a) (Ray et al, 2022).
13. The HB 5202's (2022) partial repeal of a nuclear moratorium, allows advanced reactor deployment within the footprint of existing nuclear facilities (NEI, 2023).
14. Connecticut is a member of the Regional Greenhouse Gas Initiative and joined in 2005.
15. Delaware has recently expanded its RPS to include new minimum levels of solar power production and increased minimum cumulative percentages of eligible energy resources from 2026 onward. Delaware's current standard is 40% renewable production by 2035 (*see* 2021 DE S 33, Section 1, subsection (a)) (Ray et al, 2022).
16. Delaware is a member of the Regional Greenhouse Gas Initiative and joined in 2005.

17. 2022 FL H 1411 encourages the implementation of floating solar facilities and establishes them as a "permitted use in the appropriate land use categories" of local planning. 2022 FL S 1764 created the Municipal Solid Waste-to-Energy Program that provides incentives for solid waste power production between municipalities and power vendors.
18. 2021 GA H 355 adds more specific language to the Georgia Carbon Sequestration Registry Act, including definitions of embodied carbon and global warming potential, and directs the Director of the State Forestry Commission to establish the Sustainable Building Material Technical Advisory Committee to "ensure the interoperability, general alignment, and compatibility of credits derived from the carbon sequestration results of building materials and embodied carbon results with global carbon credit and offset markets" (Ray et al, 2022).
19. As a non-policy, but important development, Georgia Power Co. will begin service for Vogtle Unit 3 & 4 in 2023 -- the first new nuclear reactors to be built in the US in more than three decades (Georgia Power, 2023).
20. Hawaii's RPS goal of 100% clean energy by 2045 remains unchanged from its 2015 standard.
21. Executive Order No 2018-07 supports continued promotion, advancement and deployment of advanced reactor technology, including SMRs. HB 591 (2018) supports tax exemptions for research and development associated with SMRs (NEI, 2023). HB 96 (2023), requested by the Leadership in Nuclear Energy (LINE) Commission - Nuclear Policy Working Group, passed both chambers and will be signed into law on March 23, 2023.
22. Illinois 2016 goal of 25% renewable energy by 2025 remains unchanged.
23. SB 2408, enacted in 2021, updates Illinois's renewable energy goals and establishes measures for zero-emissions credits for nuclear power plants and many other provisions for renewable and clean energy development. The policy itself is robust and requires further research. "Climate and Equitable Jobs Act" commits to keep the nuclear fleet online, even if that means paying during unprofitable times, but also agreed to cap earnings (for a plant owner) if energy prices rise. This paid off for customers in 2022 as there was a major fluctuation in energy prices due to the invasion of Ukraine. SB 18 (2021) established a zero-emission credit program for Byron, Dresden, and Braidwood nuclear facilities within the state, adding to the existing program (SB 2814, 2016) that developed the program for Clinton and Quad Cities facilities (NEI, 2023; Clifford, 2022).
24. Unrelated to policy, but important to mention is that the University of Illinois Champaign-Urbana is applying for a license to build and operate an UltraSafe microreactor on campus (McDermott, 2023).
25. Indiana has a voluntary clean energy standard for utilities to produce 10 percent of the electricity from renewable sources by 2025 (IC 8-1-37) (C2ES, n.d.b).
26. 2022 IN S 271 added provisions defining small modular nuclear reactors and updated the statute to reflect that qualifying SMRs are "clean energy projects" (see Section 1. 1C 8-1.8.5.12.1 and Section 2. IC 801-8.8-2, respectively). SB 271 also directs the state public utility company to develop rules regarding SMR construction at retiring coal and natural gas facilities. 2023 SB 0176 proposes changing the statutory definition of an SMR from 350 MW to 470 MW and provides other updates to the definition (pending) (Ray et al, 2022).
27. 2022 IN H 1209 provides processes for the underground storage of carbon dioxide, including permitting and easement regulations.
28. Iowa has the oldest operating renewable portfolio standard, first enacted in 1983, that requires the state's two investor-owned utilities to produce a combined 105 MW of renewable energy (Ray et al, 2022).

29. Kansas's voluntary RPS goal allows electricity producers to generate up to 20% of utility peak demand from renewable energy resources by 2025 (C2ES, n.d.b)
30. SB 11 in 2017 removed the moratorium on construction of new nuclear facilities (NEI, 2023).
31. LA S 110 establishes numerous provisions for the securitization of debt to finance certain energy transition costs, with the express aim of benefiting ratepayers, but the text fails to mention carbon and seems expressly designed with financialization and taxation in mind (see Section 2. Par VII-A, Chapter 9, Title 45, S.1271) (Ray et al, 2022).

    A critical development, though not directly related to policy is that Dow and X-energy plan to deploy an Xe-100 high-temperature gas reactor at one of Dow's Gulf Coast sites by 2030 through DOE's Advanced Reactor Demonstration Program. The two signed a joint development agreement March 1, 2023. Dow has multiple facilities in Louisiana and Texas (Patel, 2023).
32. Maine's RPS standard remains at the established (2018) 100% clean energy objective of 2050 and requires 80% electricity sales to come from renewable sources by 2030 (Ray et al, 2022; C2ES, n.d.b).
33. Maine is a member of the Regional Greenhouse Gas Initiative and joined in 2005 (Ibid).
34. Maine has been proactive in promoting carbon and clean energy targets and requirements for a variety of sectors. It uses different legislative metrics, such as 2021 ME S 143 expanding the powers available to the Main Clean Energy and Sustainability Accelerator to obtain and guarantee certificates and loans, and expands on what funds can capitalize the Accelerator (Ray et al, 2022).
35. Maryland's RPS was updated by SB 153, which increased the requirements for municipal utilities to source 20.4% of Tier 1 renewable sources. Maryland's current RPS goal is 50% clean energy by 2030 (Ibid).
36. SB 528 recognizes the critical role that nuclear power plays in the state's clean energy generation profile and established greenhouse gas emission reduction target (NEI, 2023).
37. Maryland is a member of the Regional Greenhouse Gas Initiative and joined in 2007 (Ray et al, 2022).
38. 2022 MD S 348 contains provisions providing for the Maryland Department of Agriculture to help foster development of organizations, contracts, and programs. It does so that facilitate "statewide or regional partnerships" for carbon offset markets and for "minimizing the costs and maximizing the benefits of voluntary enrollment of farmland in carbon offset market programs." (Section 1., 8-702, (C) and (D) (1) and (2)) (Ibid).

    Like other states, although not directly policy-related, it should be noted that the Maryland Energy Administration awarded grants to Frostburg State University and X-energy in June 2022 to evaluate the viability and benefits of installing an SMR at a retiring coal site (Tobar, 2022).
39. Massachusetts's update to its RPS remains unchanged in terms of the share at 35% by 2030. In 2017, Massachusetts adopted a CES requiring 80% of electricity sales to come from clean energy sources by 2050 (Ray et al, 2022; C2ES, n.d.b).
40. Massachusetts is a member of the Regional Greenhouse Gas Initiative and joined in 2007. Massachusetts also established a separate cap-and-trade program that runs in parallel to RGGI, covering its fossil fuel power plants in an effort to reduce aggregate CO2 emissions in response to a 2016 Supreme Court ruling (C2ES, n.d.b).
41. Michigan's RPS remains unchanged at the previously established goal of 15% renewable energy by 2021 (Ray et al, 2022).

42. Public Act 166 (2022) requires the Michigan Public Service Commission (PSC) hire an outside consulting firm to conduct a study on the future of nuclear power generation in Michigan. January 5, 2023, the Michigan PSC issued a call for proposals to evaluate and provide recommendations on: designs, environmental impacts, land/siting criteria, safety criteria, engineering/cost criteria, and many more components related to the social/economic aspects of planning. The report must be delivered to the Governor within 18 months of the enacted bill (Oct 2022) (Michigan PSC, 2023).
43. Minnesota's RPS (updated in 2018) sets requirements for Xcel Energy (31.5% by 2020), other investor-owned utilities (26.5% by 2025), and other utilities (25% by 2025) (Ray et al, 2022).
44. HB 863 exempts nuclear generating facilities from county, municipal and district ad valorem taxes, changing the requirement to a payment based on the assessed value of such nuclear generating plant (NEI, 2023).
45. Missouri's RPS remains unchanged at 15% renewables by 2021 for investor-owned utilities (Ray et al, 2022).
46. Montana's RPS remains unchanged at the previously established 15% renewables by 2015 (Ibid).
47. HB 273 (2021) removes a provision requiring the public to approve proposed nuclear facilities. Senate Joint Resolution 3 (2021) requires an evaluation of the economic feasibility or replacing coal facilities with advanced nuclear reactors (NEI, 2023).
48. Nebraska's utilities (the only state with 100% publicly owned utilities) have all committed to decarbonization goals, most recently with the 2021 decision of Nebraska Public Power District's non-binding 2050 decarbonization goal (Ray et al, 2022).
49. Nebraska is using pandemic aid to consider nuclear power for grid reliability (American Rescue Plan Act funding) and has begun a study for possible sites for SMRs in low-income communities affected by weather threats to grid resilience (Singer, 2023). L.B. 84 (2021) adds nuclear energy to qualifying renewable energy sources that are eligible for business tax incentives (NEI, 2023).
50. 2021 NE L 650 empowers the Nebraska Oil and Gas Conservation Commission to establish requirements and penalties under the Nebraska Geologic Storage of Carbon Dioxide Act, incentivizing the geologic storage of carbon dioxide in Nebraska (Ray et al 2022).
51. In 2019, Nevada moved from a non-binding RPS to a requirement that 50% of electricity sales in the state will come from renewable sources by 2030 (C2ES, n.d.b).
52. New Hampshire's RPS remains unchanged at the previously established goal of 25.2% renewables by 2025 (Ray et al, 2022).
53. 2021 NH H 543 (passed in 2022 session) establishes a "commission to investigate the implementation of nuclear reactor technology in New Hampshire." Advanced nuclear reactors, including SMR and breeder reactors, are to be investigated by the commission. Interim reports are to be sent December 2022, July 2023 and December 2023. Proposed: HB 616-FN adds Gen IV or later nuclear energy systems as a new class for the renewable energy portfolio after January 1, 2024 (Ray et al, 2022; NEI, 2023).
54. New Hampshire is a member of the Regional Greenhouse Gas Initiative and joined in 2005 (Ray et al, 2022; C2ES, n.d.b).
55. New Jersey's updated (2018) goal of 50% renewables by 2030 remains unchanged (Ibid).
56. While one of the original seven states to sign the "Regional Greenhouse Gas Initiative Memorandum of Understanding," New Jersey withdrew from the agreement in 2011, rejoining in 2018 by executive order (Ibid).

57. New Mexico updated its RPS in 2019, expanding its goal to 100% carbon-free sources by 2045 (Ibid).
58. New York's RPS goal of 100% zero emissions electricity by 2040 remains unchanged but did add an additional goal of 70% renewables by 2030 (Ibid).
59. New York is a member of the Regional Greenhouse Gas Initiative and joined in 2005 (Ibid).
60. North Carolina's goal of 12.5% by 2021 for investor-owned utilities remains unchanged (Ibid).
61. Docket No. E-100, Sub 179 (December 2022) requires Duke Energy Carolinas to pursue license extension for the existing nuclear fleet and authorizes the utility to incur project development costs associated with new nuclear generation. The company will provide updates through its integrated resource planning process (NEI, 2023).
62. NC H 951 authorizes performance-based regulation to effectuate a 70% reduction in emissions by electric public utilities (Ray et al, 2022).
63. North Dakota's non-binding objective of 10% renewable energy production by 2015 remains unchanged (Ibid).
64. In 2019, H.B. 6 reduced Ohio's previous RPS target of 12.5% to 8.5% by 2026 (Ibid).
65. Oklahoma's 2015 goal of 15% renewables production remains unchanged (Ibid).
66. 2021 OK S 1856 directs the Secretary of Energy and Environment to "create and administer a grant program for entities utilizing sequestration of carbon captured," effective November 1, 2022 (Ibid).
67. Oregon's RPS required that 50% of the electricity used by Oregonians be sourced from renewable resources by 2040 (State of Oregon, n.d.).
68. In 2021, Oregon's HB 2021 required 100% reduction of carbon emissions by certain electricity providers by 2040 (Ray et al, 2022).
69. Pennsylvania's RPS of 18% alternative energy resources by 2020-2021 remains unchanged (Ibid).
70. HR 238 (2022) the Joint State Government Commission was directed to conduct a holistic study on the benefits of nuclear energy and SMRs (NEI, 2023).
71. Pennsylvania was pending membership to the Regional Greenhouse Gas Initiative and is anticipated for full membership. Most recently, an injunction has been granted in one of several cases preventing Pennsylvania from joining RGGI, halting the membership process while the issue is litigated in the courts (Ray et al, 2022).
72. Rhode Island's RPS of 38.5% by 2035 was superseded by a new law that was signed June 30, 2022, greatly increasing the timeline for the state's energy production to be 100% offset by renewable energy by 2033 (Walton, 2022). The measure does not require renewable energy be the primary source of power generation, but demonstrates the state's commitment to renewable energy and its climate goals, alongside recent climate-oriented measures like H 5445 (known as the 2021 Act on Climate) and the recent approval of the offshore wind project, South Fork Wind (Ray et al, 2022).
73. Rhode Island is a member of the Regional Greenhouse Gas Initiative and joined in 2007 (Ibid).
74. South Carolina's voluntary RPS of 2% of aggregate generation capacity by 2021 remains unchanged (Ibid).
75. H. 4940 established the Electricity Market Reform Measures Study Committee to examine electricity market reform measures and recognized the benefits of nuclear power. The report was completed in January 2023 but is not available to the public yet (NEI, 2023).

76. South Dakota's non-binding objective of 10% renewable energy production by 2015 remains unchanged (Ray et al, 2022).
77. Texas's RPS goal of 10,000 MW by 2025 remains unchanged (and already achieved) (Ibid).
78. Utah's Renewables Portfolio Goal remains unchanged at 20% of retail sales by 2025, but utilities only need pursue cost effective renewables (Ibid).
79. Senate Concurrent Resolution 6 (2019) demonstrated support for and integration of advanced nuclear reactor technology. SB 24 (2019) amended state energy policy to promote nuclear generation technology (NEI, 2023).
80. 2022 UT H 244 establishes regulations, guidelines, and requirements for the geologic storage of carbon (Ray et al, 2022).
81. Vermont's RPS goal of 75% by 2032 remains unchanged (Ibid).
82. Vermont is a member of the Regional Greenhouse Gas Initiative and joined in 2005 (Ibid).
83. Virginia's 2020 update to its RPS leaves the share unchanged at 100% by 2045/2050 for Phase I and II utilities, respectively (Ibid).
84. 2022 VA H 894 directs the Department of Energy to study the development of small modular reactors in the state (Ibid). Senate Joint Resolution 60 (April 2020) encouraged the advancement of nuclear energy R&D and exploration of economic development opportunities tied to nuclear energy. HR 1303/SB 549 (April 2020) directed state agencies to coordinate with the Nuclear Energy Consortium Authority to develop a strategic plan for the role of nuclear energy in VA's progress towards carbon-free energy.
85. Virginia is a member of the Regional Greenhouse Gas Initiative and joined in 2021 (Ibid).
86. SB 828 (2020) and SB 817 amend the definition of carbon free and clean energy to include nuclear energy generation (NEI, 2023).
87. Washington's RPS of 100% clean energy by 2045 remains unchanged. The clean electricity standard (SB 5116, 2019) requires eliminating coal generation by 2025 (Ray et al, 2022; C2ES, n.d.b).
88. Washington passed SB 5126: Climate Commitment Act (2021) and the cap-and-trade program commenced January 1, 2023. The compliance periods have different targets, based on the state's existing GHG limits including 45% below 1990 levels by 2030, 70% below 1990 levels by 2040 and 95% below 1990 levels by 2050. The program focuses on large emitters while also working with businesses to cut greenhouse gases (WA Dept of Ecology, n.d.).
89. 2022 WV S 4 repeals the state's previous article banning construction of nuclear power plants (NEI, 2023).
90. 2022 WV H 4491 establishes a carbon dioxide sequestration program that aims to foster and develop regulations and underground sequestration facilities (Ray et al, 2022; C2ES, n.d.b).
91. The state is interested in leveraging federal funding to transition its fuel use from coal to nuclear, and is discussing the potential of siting a TerraPower advanced reactor at such sites (NEI, 2023).
92. Wisconsin's previously established RPS goal of 10% by 2015, with no reduction in renewable percentages at that time, remains unchanged (Ray et al, 2022).

93. An important non-policy related development for the state is that NuScale and the Dairyland Power Cooperative signed an MOU in February 2022 to evaluate the potential to deploy an SMR in Dairyland’s service territory, which covers Wisconsin, Minnesota, Iowa and Illinois (Davis, 2022).
94. 2022 WY H 131 updates provisions relating to advanced nuclear reactors and instates a tax exemption on qualifying reactors. HB 74 (2020) authorizes permits for SMRs to replace coal or natural gas-generating units as long as the rated capacity is not greater than 300 MW (NEI, 2023).

PART 5: BACKGROUND ON ENERGY IN ALASKA AND WYOMING

Energy System Change in Alaska and Wyoming

Alaska

Alaska, the largest US state (EIA, 2023), is known as a fossil fuel exporter, particularly for oil and gas. Alaska's Prudhoe Bay field is among the 10 largest oil fields in the nation (Ibid). However, the state is currently in an extended period of decline for oil production (Ibid) as shown in Figure 4. Ranked 4th in the country for proved reserves of oil and oil production in 2022, with roughly 4% of the national production in December 2022, most of Alaskan oil fields are mature (Ibid). Crude oil production in 2022 was roughly 160 million barrels, down from 587 million barrels in 1981 (EIA, 2023).

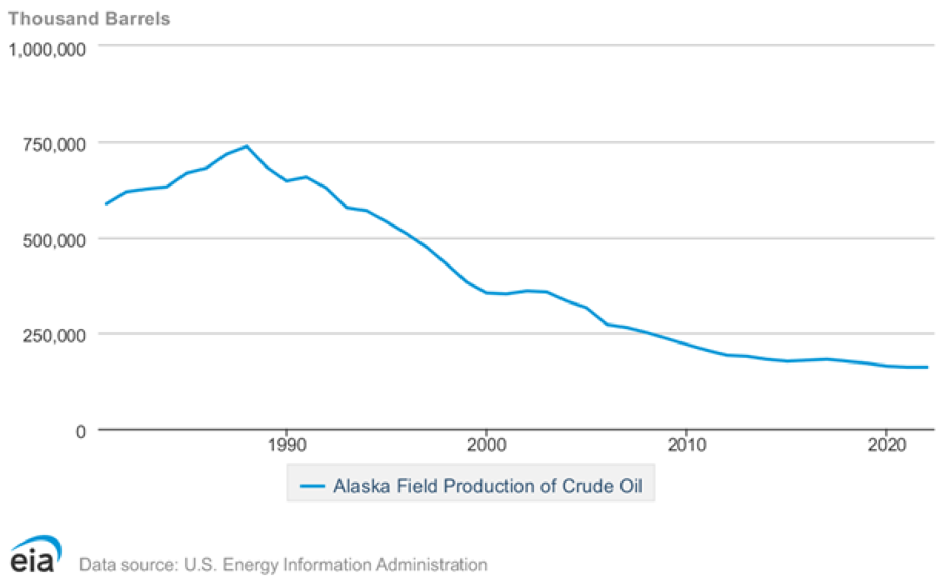

Figure 4. Alaska field production of crude oil (EIA, 2023).

Specific to natural gas (marketed production), the recent history is more mixed. Alaska has maintained fairly constant output between 1992 and 2021 onshore, at roughly 314,190 million cubic feet annually (EIA, 2022a). For offshore state production, there is a decline by more than a factor of 3 (Ibid). In terms of coal, there is one mine in operation, with Alaska ranked 18th in the country for production in 2021 (Ibid).

In 2022, Alaska generated about 32% of its electricity from renewables (EIA, 2023). Hydropower provided about 9/10ths of that (Ibid). Wind resources are strong along the coast, with wind power providing about 7% of the utility scale generation (Ibid). In contrast, natural gas fueled about 42% of electricity and coal fueled approximately 12% (Ibid). Numerous rural communities rely primarily on diesel for energy (Ibid). Broadly, the power market is highly heterogeneous and distributed with many microgrids (Interviews, 2022-2023).

Note: Since 1982, every eligible resident in the state is paid an annual dividend, based on the value of oil royalty revenue, from the Alaska Permanent Fund (EIA, 2023). The amount in 2022 was a record $3,284, almost 3 times the amount paid in 2021 (Ibid).

Wyoming

Wyoming has been a major energy producer and exporter of fossil fuels and electricity for years. In fact, it produces 13 times more energy than it consumes (EIA, 2022b). Policy and market changes have affected its status over this time.

At the national level, the passage of the Clean Air Act of 1970 to curb acid rain created favorable conditions for Wyoming coal, by requiring new coal-fired power plants to limit sulfur dioxide emissions. Amendments in 1990 expanded the scope, requiring all existing coal-fired power plants to reduce their emissions. The coal in the Powder River Basin of Wyoming was low-sulfur, unlike Appalachian and Midwestern coal that had a higher sulfur content (Better Wyoming, 2019). During the period, rail transport costs also improved, enabling Wyoming to become the nation's top coal producer by 1986 (EIA, 2022b). In 2021, Wyoming accounted for 41% of all mined coal in the U.S. (EIA, 2022c). The state continues to hold roughly 40% of the U.S. coal reserves at producing mines (Ibid).

A mix of energy pressures have impacted Wyoming's energy sector in recent years. The global recession of 2008-2010 together with the game change in unconventional oil and gas by way of horizontal drilling and fracking, plus rising cleaner energy interests, placed coal in a less favored position. Coal production peaked in 2008 and by 2021, production was roughly half that of 2008 (Pollack, 2023). For the same period, coal mining jobs dropped from 6,827 in the state to 4,567 (Ibid). During the coal production peak, the state earned roughly a billion dollars per year, strictly from coal (Ibid). Today, nearly half the state's annual income is derived from mineral extraction: approximately one-third each from coal, oil and natural gas; together with a smaller share from industries such as soda ash and bentonite (Ibid). See also Gerace et al, 2023.

The state shift aligns with a change in U.S. power production based on coal, declining from 48% to 22% for the same period (Ibid). In 2021, 96% of the State's coal was produced in Campbell County, the county where Gillette is based (*see* Case Study). Nine mines in the county still rank among the top 15 in the country, and all of them opened between 1972 and 1985 (Pollack, 2023).

Unlike coal production that was relatively stable before the 2010s and is done principally in the northeastern part of the state, oil and gas are extracted across the state and reflect boom-bust cycles tied to global markets. Wyoming's oil production in 2021 was down by a factor of 1.5 versus a peak in 1981. Its natural gas production peaked in 2009 and is now at par with levels from 1999 (EIA, 2022b, *see* also Figure 5 and Figure 6).

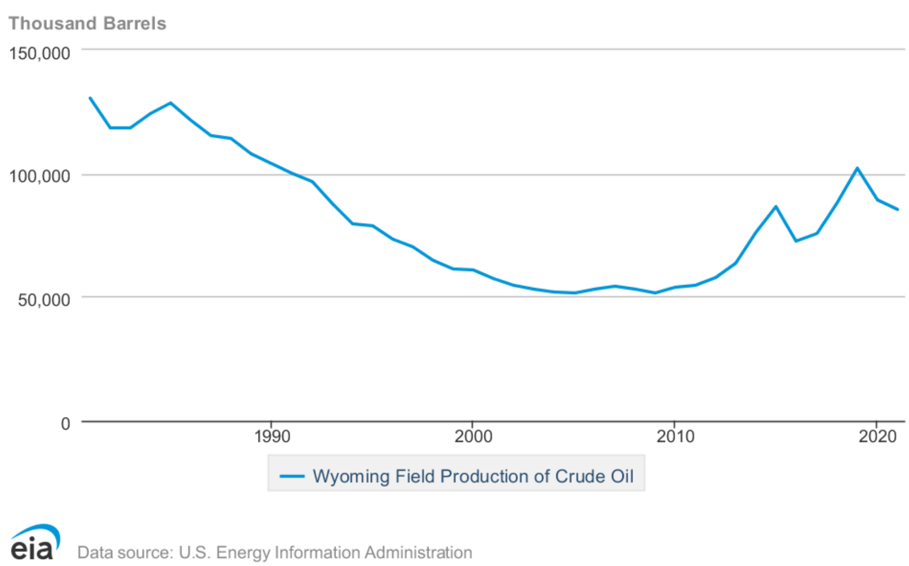

Figure 5. Wyoming field production of crude oil.

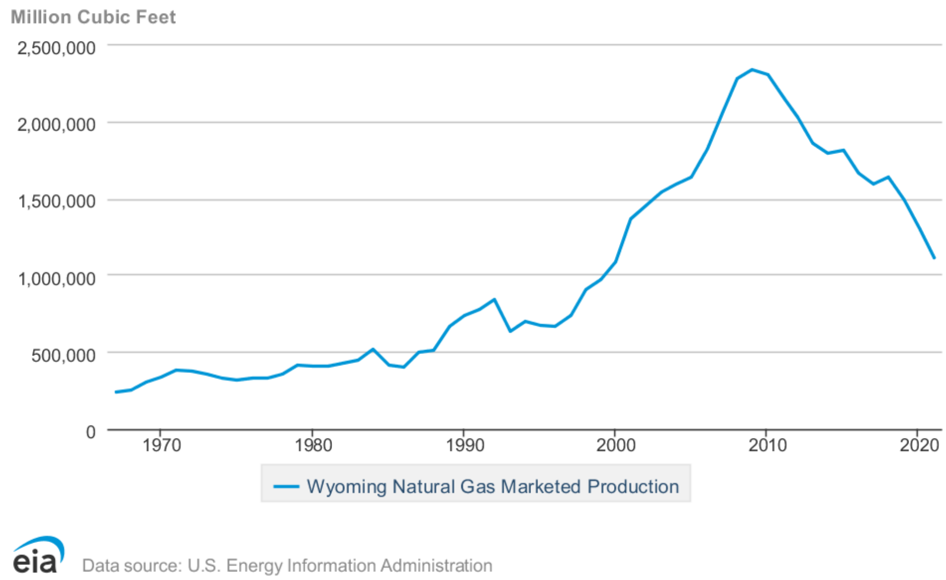

Figure 6. Wyoming Natural Gas Marketed Production

In terms of electricity, wind power in the state more than doubled since 2019, providing 19% of the electricity balance in 2021 (EIA, 2022b). Wyoming exported about 60% of its power in the period 2018-2021 (EIA, 2022d).

Note: A considerable portion of state revenue is provided by mineral royalties, severance payments, and related taxes (EIA, 2022b; *see* also Tax section).

Energy-intensive Developments in Alaska and Wyoming Associated with Microreactors

Alaska

Eielson AF Base was named as a military installation to site and demonstrate the feasibility of a microreactor. This is being done to demonstrate the capability of an MR to supply power in the event that the base's main source of power goes offline (Ellis, 2022). Currently, Eielson AF Base uses a 70-year-old, 15 MW coal-fired heat and power plant, with diesel fuel for back-up (Ibid). The request for proposals reflects a call for construction of a facility to accommodate an MR that would generate up to 5 MW and operate for 10 years, until its fuel is spent. "The plan calls for construction to begin in three years and for the reactor to begin generating power in 2027" (Ibid). The MR will be licensed by the U.S. Nuclear Regulatory Commission, and commercially owned and operated. This initiative reflects actions for the Microreactor Pilot Program that were initiated in response to the Fiscal Year 2019 National Defense Authorization Act requirement to construct and operate an MR by the end of 2027 (Sec. of the Air Force, 2022).

Alaska - Remote Communities, Studies, and Legislation

Alaska has unique energy needs, with remote communities reflecting considerably higher electricity costs. Compared to the December 2022 national average power cost of 15 cents/kWh, the weighted average residential rate before the Power Cost Equalization (PCE) Program support was paid in Alaska equaled 47 cents/kWh (EIA, 2023; AEA, 2023) (*see* also Nome Energy Overview for more discussion of PCE costs). These challenges have spurred communities and energy cooperatives in the region to look for more cost-effective solutions. In the early 2000s, the remote village of Galena studied the potential for installing a small nuclear reactor with Toshiba corporation, but the technology and regulation were not ready (Interviews, 2022-2023; Chaney et al. 2008). Since then, many new SMRs have been developed and are being examined as options across the U.S. and abroad. Copper Valley Electric Association near Glennallen, Alaska is exploring the possible deployment of a MR. The University of Alaska Fairbanks has been watching the development of the technology, especially availability to permit and deploy (Rhode, 2022). Copper Valley Electric has partnered with Ultra Safe Nuclear Corporation to assess the technical feasibility of a 10MW microreactor facility, considering cost, operations and social acceptance regionally (Ultra Safe Nuclear, 2022). In May 2022, Alaska also passed significant legislation through SB 177 which designated the Department of Environmental Conservation to permit nuclear reactors rather than the Legislature, in the hopes of helping Alaskan communities to reach net-zero carbon goals (Segall, 2022). (*See* also Policies Section).

Wyoming – Kemmerer

In November 2021, TerraPower announced Kemmerer, Wyoming as the site of the Natrium advanced reactor demonstration plant, supported by the U.S. Department of Energy and in partnership with PacifiCorp, the local utility company (TerraPower, 2021).

This followed a review of four candidate communities which included Gillette, Wyoming (Case study 2). The community of Kemmerer will transition infrastructure from the Naughton Power Plant, a coal facility scheduled to retire in 2025, for utilization with the new reactor. TerraPower planned to submit its construction permit to the NRC in mid-2023 but has announced up to a two-year delay due to a lack of HALEU supply chain outside of Russia (Stroka, 2022). TerraPower and PacifiCorp also announced a study to evaluate deploying five additional advanced reactors and integrated energy storage systems in the PacifiCorp territory by 2035–which includes Wyoming, among the additional sites. This study will focus on existing fossil fuel-fired generation sites, so the utility can continue to leverage infrastructure that is already in place (Clark, 2022).

PART 6: CASE PROFILE COMPARISON

The focus on Nome, Alaska and Gillette, Wyoming recognizes certain similarities. First, both are communities in major fossil fuel-producing states that are experiencing industry shifts tied to net zero priorities. Nome and Gillette are communities that were established around the beginning of the 20th century and have potential to diversify with new or renewed forms of mining of minerals that have national security significance. Nome and Gillette also have energy balances that reflect considerable use of fossil fuel. They are remote (Nome, is more so) and in regions with what can be considered extreme winter climates. Based on interviews, their communities appear to be tightly knit and resourceful. Sufficient housing is an articulated challenge for both.

Nome and Gillette also differ in important ways, as summarized in Table 5. The population of Gillette is roughly nine times larger than Nome, while its general fund (a pool including various sources of tax revenues) is about five times larger. The early commerce for the communities as well as that today also differ between them. Nome was established with gold mining before Alaska became a U.S. state. Today, Nome is a regional hub for the surrounding area, largely consisting of tribal/rural villages. Its population is diverse with indigenous and Caucasian members. Nome's port, airport and hospital are critical for the area. Gillette was founded as a rail town and is today part of what some refer to as the energy capital of the U.S., with strong ranching ties in the area. Gillette's community profile appears to be more homogenous, with a negligible tribal presence in its part of the state. Fishing and hunting are important for both communities, but may have stronger importance for Nome's subsistence living and cultural ties.

Table 5. Community comparison.

Profiles

	Nome, AK	Gillette, WY
Established	1901	1892
Pop size	~3,700 (2020)	~33,000 (2021)
Original commerce	Gold mining	Rail town
Today's economy	Mining, regional hub, fishing, hunting, tourism	Energy capital for fossil fuel, sports/tourism, rail, ranching
Energy today	High burden	Energy production capitol for fossil fuels; also has low-cost wind;
Current energy mix	All diesel/gasoline fueled (power, heat, transport), except 8% wind power in electricity mix and dog sleds	Power: Coal and natural gas Transport: diesel and gasoline Heating: primarily fossil
Unemployment %	10-13% (2017-2019)**	6.9% (2020, Campbell Co)
General fund – gov tax	$10,251,600 (2020)	$49,803,458 (2020)

Source: Authors' compilation, citing Alaska Department of Labor and Workforce Development, 2021; Kawerak, 2019; Campbell County Wyoming, 2021.

Case 1: Nome, Alaska

Nome, Alaska is a rural community on the western coast of the state. Located 2 degrees below the Arctic Circle, Nome is on the Norton Sound of the Bering Sea as shown in Figure 7. The Coty of Nome is recognized as a regional hub for the area villages, as it has regular boat and air traffic plus a major hospital. It is an isolated community without road access to the Alaskan Highway system. Nome's terrain and built environment, including pipelines, the grid, storage, etc. must account for regular permafrost changes.

As an unorganized borough, Nome has local governance in the form of a city mayor and city council. It does not have what may be construed as other municipal governance, but does offer public services with its school district and law enforcement.[h]

[h] Kotzebue, which is of comparable size and is an organized borough, collects taxes on area mines which support the local public services (NJUS Interview, 2022).

Figure 7. Map of Nome, Alaska.

Department of Community and Regional Affairs, 2023.

History

Community History

Malemiut, Kauweramiut, and Unalikmiut Eskimos have inhabited the Seward Peninsula since its early history, hunting caribou and fishing to support their diet in the harsh northern environment (Karewak, 2019). The city of Nome, established at the beginning of the 1900s, was once one of the most populated areas in Alaska (Interviews, 2022-2023). Founded following the discovery of gold in the area, Nome's location on the Bering Sea has led to it being exposed to natural disasters. 500 buildings were washed out to sea when a storm devastated the city in 1913, causing $1.5 million in damage (NYT, 1913). Most of Nome was later burnt down in 1934, with only the Government Wireless Station left standing (Time, 1934). In 1974, a 13-foot wave destroyed the city, causing over $30 million in damages (Johanson, 2011; Steever and Campbell, 2016).

In military history, Nome's geostrategic location allowed it to become a transfer point for lend-lease aircrafts from the U.S. to Russia in WWII. Between 1942-1945, nearly 8,000 planes came through Nome on the way to Russia for use in the war (Pitcher, n.d.).

Nome's population is a mixture of Inupiat and non-natives (Karewak, 2019). Subsistence activities remain central to many community members, which leaves employment opportunities in retail services, transportation, government, and medical services open (Ibid).

Industrial History

Gold deposits are said to have attracted the first people to what is modern Nome (Pitcher, n.d.). There have been many attempts to try and mine the offshore gold, with early attempts being largely unsuccessful due to machinery needs and other conditions. The area has other commodities such as silver and lead, and has great fishing waters, hosting one of the three fish processing plants in the Bering Sea.

Between 1898-1993, more than 4,800,000 ounces of gold were mined. The area has also produced more than 550,000 ounces of silver and small amounts of stibnite and scheelite. A significant amount of offshore gold remains at Nome. The total gold resource in the area is estimated to be approximately 1,000,000 ounces (Hawley and Hulson, 2000).

The growing trend of offshore gold mining in Nome has been enabled by the pre-existing fishing industry that provided vessels to be retrofitted into gold dredges. Mining has been key to the local economy by allowing for a longer economic season than fishing.

The Northern Bering Sea has experienced warming and thawing, and increased industrialization. Ship visits in Nome have increased from 34 in 1990, to 635 in 2015. The Dredge-mining fleet increased from 5 vessels in 2008, to more than 100 in 2016 (Rosen, 2021). "Bering Sea Gold", a Discovery Channel reality show set in Nome beginning in 2012, has helped industry growth. The Alaska Department of Natural Resources reports there were 5 active offshore gold-mining leases before 2011, and by 2020 the number had increased to 86 leases (Ibid). For the near-term, considerable change in the number of vessels to the Nome port is not anticipated with the enlargement of the port (U.S. Army Corp, 2020). Yet, the size of the vessels is expected to increase, incorporating added capacity and efficiency of delivery and supply.

Updated regulations have impacted industry in the area. In 2018, the International Maritime Organization approved a joint US-Russia plan, establishing "designated two-way traffic lanes and protective buffer zones for ships sailing the strait and the northern Bering Sea." The U.S. Coast Guard also has created new safety regulations. For example, since 2015, gold dredges have been classified as commercial vessels, not recreational vessels. The largest dredges are subject to mandatory inspections and must have "credentialed masters and chief engineers on board", with some of the safety regulations not applying to smaller dredges (Ibid).

Climate change has also impacted offshore mining in Nome. Conditions have expanded the open-water period and, therefore, the possibility of increased profits. However, global warming has weakened ice floats during the winter months, creating dangerous conditions for winter miners. From an environmental view, the impact of offshore mining on the seafloor habitat is inconclusive. Seabed mining is controversial in other parts of the country, with it being banned in Oregon state waters (Ibid). There can also be conflicts of interest between miners and local/Indigenous fishing and subsistence food harvests. There was pushback on a gold dredge project proposed along the coast near Nome in Safety Sound (Ibid). The Safety Sound wetlands area is vital for local wildlife, especially as there are endangered species there. The area is also an important source of wild food for Indigenous people.

Current Economic Development

The average income in Nome is $30,087, slightly higher than the national average of $28,555, however, the median income is $63,000 (Bestplaces.net, 2021). The area has been receiving investments to improve economic development. The Norton Sound Economic Development Corporation (NSEDC)[i] agreed to a $100,000 COVID relief fund for the city of Nome to support the improvement of community areas. The Nome Joint Utility System allocated this money towards Streetlight Safety Enhancements. The NSEDC is carrying out many projects in Nome to support its development.

Alaska had a Gross State or Domestic Product of $49.6 billion (IBIS World, 2022a).[j] The Gross State Product (GSP) growth rate on an annualized basis for the past five years to 2022 declined at a rate of 1.3%, ranking Alaska 50th of the 50 states (Ibid). As of 2022, Alaska had 114,911 businesses, with an average annual business growth of -0.7% for the years 2017-22. Table 6 depicts Alaska's top five Gross State Product sectors.

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[i] The corporation was set up in 1992 and, through the Individual Fishing Quote, earnings from fisheries in the region are given to the NSEDC to fund community development. In the 2021 NSEDC annual report money has been given to support schools, a thrift store and animal shelter. The water and sewer fund has given the City of Nome over $300,000 to improve its infrastructure. In 2021, the NSEDC provided incentives for people in the region to go to Nome and work through the Community Hire Program (NSEDC, 2021).

[j] Gross state product (GSP) and gross domestic product (GDP) are used interchangeably, with recognition that GSP is more relevant for state reporting.

Table 6. Alaska gross state product by sector.

Sector	GDP ($ thousands)	Growth 2022 (%)	Annualized Growth 2017-2022 (%)
Mining, quarrying, and oil and gas extraction	9,291,741	-8.8	-7.2
Transportation and warehousing	5,580,445	0.7	-1.0
Real estate and rental and leasing	4,572,095	-0.3	-0.3
Health care and social assistance	4,074,464	2.0	1.5
Retail trade	2,168,442	-1.1	-0.1

Source: IBIS World, 2022a

Looking deeper into statistics provided by the U.S. Bureau of Economic Analysis (BEA), Alaska, experienced modest, real GDP growth in all four quarters of 2021 (U.S. Bureau of Economic Analysis, 2022a). For the year 2021, as a whole, real GDP increased from 2020 in all 50 states and the District of Columbia, although Wyoming and Alaska reported the lowest increases at 1.1% and 0.3%, respectively (U.S. Bureau of Economic Analysis, 2022d).

Rare Earth and Critical Minerals

Alaska's Department of Natural Resources and partners have been assessing and documenting Rare Earth Elements (REE) and Critical Minerals (CM) in preliminary studies as well as discussing waste stream reuse strategies to help Alaska's REE-CM become economically competitive relative to imports (AK Department of Natural Resources, 2022). In August 2022, Alaska was awarded $6.75 million from the Bipartisan Infrastructure Law to conduct geologic mapping, airborne geophysical surveying and geochemical sampling in several high interest areas of Alaska to assess the mineral potential in these regions. The surveys will include arsenic, antimony, bismuth, cobalt, graphite, indium, platinum group metals, rare earth elements, tantalum, tellurium, tin and tungsten (USGS, 2022). The CORE-CM (carbon ore, rare earth and critical minerals) project will focus on existing mines for both coal and graphite, as researchers believe a REE mine could not be economical on its own in Alaska. The following section focuses on the potential of the Graphite Creek project, located near Nome.

Graphite One

The Graphite Creek flake graphite deposit, designated as the largest known graphite deposit in the United States (Junior Mining Network, 2022), is situated about 40 miles north of Nome in the Kigluaik Mountains on the Seward Peninsula.

Graphite is used in many technical applications due to its high thermal and electrical conductivity, high lubricity and light weight. The most beneficial uses are in anodes for batteries, fuel cells and capacitors–which are expected to ramp up as production of electric vehicle battery demand increases. The United States has not produced any graphite since 1990. Although many discussions surrounding electric vehicles are focused on the need for lithium, EVs use over 110 pounds of graphite per vehicle and graphite production will be critical to meeting demand globally (Graphite One, 2022a).

Vancouver-based company, Graphite One Resource, completed its prefeasibility study (PFS) for a prospective mine outside of Nome in 2022 and is moving forward with permitting and environmental assessments. The PFS estimated a pre-tax net present value (NPV) of $1.9B and post-tax NPV of $1.36B, before accounting for tax credits enacted by the U.S. Inflation Reduction Act of 2022, effective December 31, 2022 (Graphite One, 2022b). Graphite One aims to leverage a vertically-integrated approach from mine to material manufacturing. In doing so, it aims to "produce high-grade anode material for the lithium-ion Electric Vehicle battery market and Energy Storage Systems, with significant additional production for a range of value-added graphite applications" (Graphite One, n.d.).

The study assumes an operational life of 26 years with average production of 75,026 tonnes of advanced graphite products per year (Graphite One, 2022b). “Graphite Creek would be the country’s only operating graphite mine and give the U.S. a stake in the graphite market that has been dominated by Chinese mines for decades” (Brehmer, 2017).

Graphite One (2022b) expects to operate its mine for 23 years, supplying 100% of the natural graphite ore to a graphite manufacturing plant in Washington state. Its rationale for the export of raw material is based on prohibitively high energy costs in Alaska and low-cost electricity in Washington. The proposed mine would produce as much as 11,000 tons of ore per day (Mining.com, 2022; Lasley, 2022). The prefeasibility study estimated initial capital expenditures for the mine near $500 million with an additional $571 million for the manufacturing plant; however, the integrated project would be able to repay the debt in 5.1 years and would generate an estimated post-tax NPV of $1.4 billion (Mining.com, 2022).

Table 7 shows the company’s estimated resources, which are anticipated to increase with further exploration when mining is underway.

Table 7. Graphite One: Graphite Creek's drill tests and exploration potential.

Type	Tonnes	Grade	Cut-off	In-Situ Cg (graphitic carbon)
Measured	1.69MM	8%	5%	$135{,}171_t$
Indicated	9.26MM	7.7%	5%	$715{,}363_t$
Total Measured & Indicated	10.95MM	7.8%	5%	$850{,}534_t$
Inferred	91.89MM	8%	5%	$7{,}342{,}883_t$

Sources: Alaska Department of Natural Resources, 2022; and Graphite One, 2022a.
See also Energy Aspects of Select Economic Activity.

Deep Water Port

Development of the deepwater port of Nome is underway and in the first of three planned stages. In line with the National Defense Authorization WRDA 2022 - project cost sharing for this project will be 90% Federal and 10% State/Local until construction is complete (no cost share after construction). It is characterized as the only deepwater port in the U.S. Arctic and serves as a critical link for 60+ regional communities to the rest of Alaska. The development is being done as existing port facilities in the region are seen as overcrowded, with insufficient draft to accommodate larger, deep-draft vessel traffic. Energy for port operations is anticipated to be provided by the NJUS utility along with increased fuel for additional ships. Nome will be positioned better for global traffic (e.g., Northwest Passage melt, trade with Asia). The project is expected to improve the efficiency of buying/shipping costs; enable access for more industries in the Arctic; increase workforce needs for the Port and ancillary services; and will have upstream and downstream implications for banking, hotels, restaurants, tourism, etc. (U.S. Army Corps, 2020).

Nome Energy Overview

Nome Joint Utility System (NJUS) is the local, municipality-owned electric utility. In collaboration with area utilities, NJUS contracts for diesel oil shipments. Using competitive solicitations, they select a supplier on a 3-year contract basis with a minimum amount to be delivered at set rates (Interview, 2022).

Energy breakdown

- Power: diesel and wind.
- Transport: diesel, wind/water propulsion, animal power (dog sleds).
- Heat: Diesel, process heat, wood/biomass, other.

In 2022, 88% of Nome's power was provided by diesel oil and 12% by wind power (NJUS, 2023; *see* also Parsons, 2023). Nome's recent energy costs are indicated in Table 8.

Table 8. Nome energy costs.

Energy source	Spring 2022	Fall estimate 2022	RANGE Past 10 Years
Single phase electricity ($/kWh) (base rate + fuel surcharge before PCE)	$0.3574	$0.54	$0.3089-$0.4025
Home Heating oil ($/gallon)	$5.42/gallon	>$7.50/gallon	$4.41-6.28/gallon

Source: NJUS, 2022 and 2023. PCE refers to the Power Cost Equalization Program.[k]

The city of Nome's electricity grid is powered by an islanded wind-diesel microgrid with no current option to connect to a larger power grid (ACEP, n.d.1; Vandeer Meer and Mueller-Stoffels, 2014). Its current production is 32,500 MWh/year to meet community power needs (NJUS, 2022). This is fueled by approximately 1.8 million gallons of #2 diesel oil per year (Ibid). In 2021, the reported power load was approximately 2.7 MW to 5 MW (Ibid). Nome's baseload is experiencing average annual growth of 2% (Ibid).

Nome's grid has diesel generators as follows: two 5.2 MW Wartsila which alternate to supply power; a 3.6 MW Caterpillar for back-up; a 1.9 MW Caterpillar for back-up. It also has two 900 kW EWT wind turbines (NJUS, 2022). Total generation capacity is 16 MW, with a normal operating capacity of 10.4 MW (Ibid). Nome also has a reported 0.4 MW generator for black starts and peaking (Pike and Green, 2017). The Nome diesel generators are among the most efficient in Alaska, based on PCE data (NJUS, 2022). Since 2008, wind has contributed to Nome's energy mix, again currently at 8%. During peak periods, wind supplies 40% of electricity (NJUS, 2022).

The Nome electric utility system underwent considerable capital improvements in the late 2000s, including the addition of two new 5.2 MWe Wartsila generating units, upgraded fuel storage as well as substation equipment (NETL, 2008). Recovered heat is used to power and heat the city's power and potable water systems (Ibid).

Space Heating

Specific to heating, fuel oil is used to heat buildings and water at considerable cost. Heating costs per square foot for single family homes in Nome are 3+ times greater than costs in Anchorage and more than 2 times that of Fairbanks (NJUS, 2022, citing McKinley Research Group, 2022). Fuel suppliers deliver roughly 1,100 gallons of heating oil on average per building annually (NJUS, 2022). This translates to $8,300 per Nome household based on estimated costs of $7.50/gallon delivered in summer 2022 (Ibid). If Nome taps less expensive energy, more people may switch to electric heating, which other parts of Alaska do with cheaper electricity use (Ibid).

[k] The Power Cost Equalization Program "provides economic assistance to communities and residents of rural electric utilities where the cost of electricity can be three to five times higher than for customers in more urban areas of the state." The Alaska Energy Authority and Regulatory Commission of Alaska administer "the program that serves 82,000 Alaskans in 193 communities that are largely reliant on diesel fuel for power generation" (Alaska Energy Authority, n.d.).

Diesel uses for power and heating in Nome are estimated at 25% (electricity) and 75% (heating) (Alaska Energy Authority and NJUS interviews, 2022-2023). Fuel deliveries to Nome are lightered (transported by a smaller boat), given that the current Port lacks the depth necessary for direct tanker docking (*see* Port section). Nome's diesel tank farm storage is 3.3 million gallons (Interview, 2022-2023). It is located north of the Port on permafrost that is degrading (Ibid; NJUS, 2022). Currently, NJUS is completing design planning to relocate the tank farm to more stable ground (Interview, 2022-2023).

Potential Energy Pathways

Wind + Storage

Recent studies indicate that more wind could be added to the system at shares of 20+% and 40%. These are broken down in Table 9.

Table 9. Potential wind power expansion.

Location	Banner Ridge	Cape Nome
Projected specifications	2 × 1 MW EWT turbines would have an installed cost estimated at $14 million. If done with a Battery Energy Storage System (BESS) potentially paid for by the AK Energy Authority, this could increase Nome's power from renewables to over 20%.	4 × 1 MW wind turbines with a BESS would cost an estimated $44 million. This requires a line extension with considerable potential for expansion. It would increase Nome's wind power penetration to 40%.

Source: NJUS, 2022.

Penetration at 40% would necessitate controls for storage and/or curtailment. Use of an electric boiler or other option to convert excess wind to heat would be an economic option for Nome (Pike and Green, 2017; *see* also Araújo, 2014 and 2017).

Pilgrim Hot Springs 60 miles north of Nome with transmission expansion. A 2008 study of a 5 MWe installation indicated that Pilgrim Hot Springs could provide 41,600 MWh/year, which could cover nearly the entire power load (NETL). The estimated cost, including exploratory drilling, construction and transmission to connect to Nome, was determined to be $12,800/kW for a system lifetime of 30 years (Ibid). There may be an increase of two-line worker requirements with potential to realign current generation staff from the diesel system (Ibid). Operation costs are assumed to be primarily for staffing and supplies (Ibid). Adaptation is expected for water heating. Permitting is assumed for land only. Use of a binary power system without a steam phase would mean that CO2 and other gases would be reinjected. Costs for Nome power users were estimated to decline considerably with this option. However, questions existed over the capacity of the geothermal resources to cover expected needs (Ibid). One notable gain with geothermal energy integration from a utility vantage point is the opportunity to reduce the price volatility tied to diesel (Scott, 2015). For more in-depth study of geothermal resources and potential power output, *see* ACEP, 2015a and 2015b.

Microreactor – At the proposed mine with a microgrid or as part of NJUS with a transmission line addition

With planning underway for a microreactor (MR) at Eielson Air Force base, Nome has an opportunity to also gauge the applicability of an MR. In 2006, Toshiba evaluated permitting and the potential for a nuclear power plant in Galena. Around that time, Nome communicated with the NRC its interest and support for the Galena project (NJUS, 2022). Mine studies for Graphite One are also currently focused on the use of a microgrid, rather than extending transmission from Nome (Interviews, 2022–2023).

Other energy options

Recent energy assessments of natural gas and geothermal prospects for Nome indicate these options reflect unproven sources (NJUS, 2022). For hydropower, the resource is insufficient, and for solar, the resource could add incrementally to the Nome grid (Ibid).

Additional Energy Aspects of Select Economic Development in Nome

Graphite One

In production, year-round graphite mining, processing and haul activities would entail 200 employees and estimated monthly energy needs of 4-12 MW (NJUS, 2022). These numbers reflect more energy than NJUS can currently supply. Moreover, the anticipated load could be accommodated with a power line, but if power is to come from Nome, NJUS would not have the right equipment to provide that (Loewi, 2022). Mine studies for Graphite One are also currently focused on the use of a microgrid, rather than extending transmission from Nome (Interviews, 2022–2023).

Port Development (NJUS, 2022)

Preliminary analysis by NJUS considered primary use for electrical loading. This excludes Nome's power baseload and secondary development, such as the needs brought about by the buildings that might be built if the port expansion causes increased development in Nome. This assumed shore power provided to an Arleigh-Burke class destroyer, a cruise ship, power pedestals, lighting, water-sewer systems, etc. Estimated needs for December to April would be < .5 MW. For May-September would be <.5 to approximately 5.5 MW. October to November would require an estimated <.5 to approximately 3.5 MW. Incremental growth thereafter is anticipated.

In looking ahead to development opportunities, Nome's community power load and some estimated diversification paths are outlined next. Table 10 shows what is currently available and what would need to be expanded.

Table 10. Current and projected power load for Nome with various economic-energy system changes.

d Range (MW)	Current Community Baseload (MW)	Community Baseload + Arctic Deep Draft Port (ADDP) (MW)	Community Baseload + ADDP + Graphite One (MW)	Community Baseload + ADDP + Graphite One + Space Heating (MW)
Minimum	2.6	2.7	6.7	8.5
Average	3.7	5.2	13.2	20.1
Peak	5.0	9.4	21.5	34.4
—	Normal Operational Capacity		Exceeds Current Normal Operational Capacity	

Source: NJUS, 2022.

The perceived feasibilities of the following three energy paths were discussed in the elicitations: expanded fossil fuel (diesel), renewable energy (wind) + storage with some diesel, and nuclear (MR) to accommodate the above. *See* Part 7: Findings.

Case 2: Gillette, Wyoming

Gillette, Wyoming is located within the northeastern corner of Wyoming in Campbell County, between the Black Hills of South Dakota in the east and the Bighorn Mountains in the west. Campbell County was a hunting ground for the Sioux and Crow Tribes. In the 1880s, ranchers used the land for grazing longhorn cattle and sheep, which were then followed by homesteaders (Campbell County, n.d.). Today, ranching is the predominant land use in the county (Ibid). Campbell County has been described as one of the top 100 places to live in rural America (Ibid).

Gillette is the 3rd most populous city in the state out of 192 cities, with a population density of 2,396 people per square mile and a demographic breakdown reflecting 85% White and 10% Hispanic for the two largest groups (Wyoming Demographics, 2023; City Data, n.d.). The City's land area is 13.4 square miles at an elevation of 4,550 feet (City Data, n.d.). Gillette is a trade center for a region that produces grain, livestock, oil, uranium and coal (Brittanica, 2022). A large open-pit coal mine is nearby along with a state university agricultural experimental station (Ibid). In 2019, its population was 99% urban and 1% rural (City Data, n.d.).

History

Community History

In the late 1800s, Gillette (Figure 8) became a terminus point for the Burlington and Missouri River Railroad, allowing ranchers to ship cattle (Wyohistory, n.d.). The following year, Gillette was incorporated and developed to serve cowboys, ranchers and homesteaders (Gillette History, n.d.).

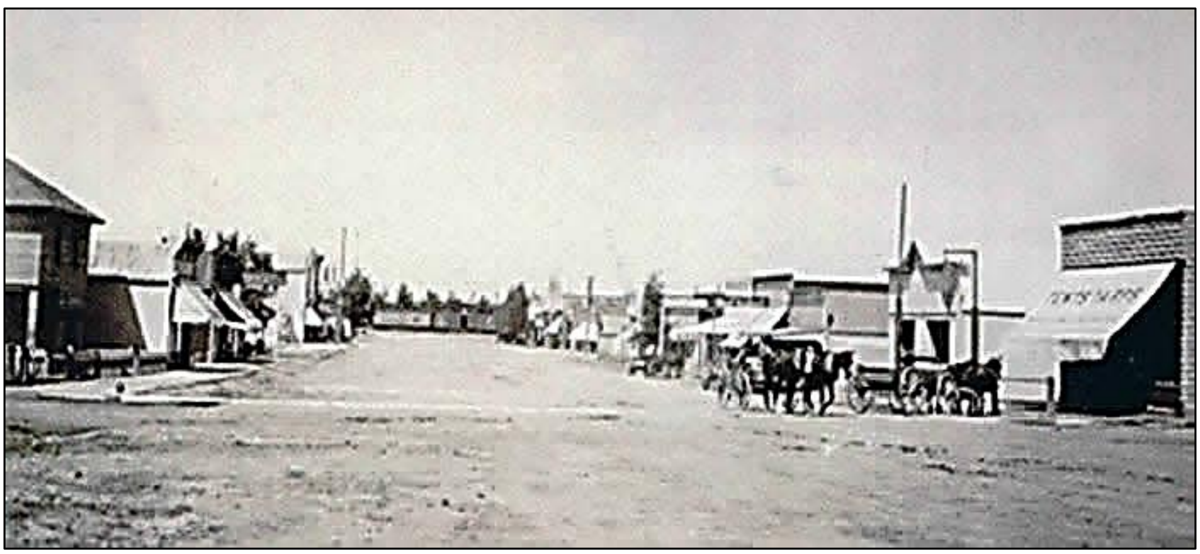

Figure 8. Early settlement photo of Gillette. Source: Rockpile Museum, Gillette, WY, n.d.

Industrial History

Early industries in Gillette included hotels, cafes, bars, stables, and blacksmiths providing services for travelers. Coal mining started as early as 1909 (Wyohistory, n.d.) The Wyodak Mine, which opened in 1923, runs today as the oldest operating coal mine in the U.S., despite workforce reductions by 40% in 2012 (Ibid; Interviews 2022-2023).

The first commercial discovery of oil in Campbell County occurred in 1948, followed by additional oil discoveries (Hein, 2014). Such energy development, together with that of coal, was a factor in the County's population doubling in the 1960s, followed by another near doubling the next decade (Ibid; Interviews, 2022-2023). Within Campbell County, Gillette's population alone grew by 69% from 7,194 in 1970 to 12,134 in 1980 (Ibid). These boom and (later) bust cycles have been dubbed the 'Gillette Syndrome', referring to a range of pressures including demands for water and sewer systems, rising property prices and competition for labor in the local community (Hein, 2014).

The 1973 OPEC oil embargo catalyzed interest in producing greater domestic energy supplies (Araújo, 2017). During this time, the Powder River Basin which surrounds Gillette increased coal output and, by the 1980s, had seven of the ten largest coal mines in the U.S. (Gaudet, 2019). By 2010, Black Thunder Mine in Campbell County was the top U.S. coal producer, supplying 116.2 million tons of coal (Hein, 2014). In 2013, nine coal mining companies were located in the County, along with eighteen oil and gas producers in the region (Ibid).

Largely due to coal production, Campbell County in 2012 was the richest county in Wyoming with an assessed valuation of $5.8 billion (Ibid). Campbell County has traditionally brought in more revenue than any other county in the state, with revenue from taxes on the energy industry being used for the city, schools and other services (Mills and Hershman, 2017).

More broadly, the Powder River Basin now produces ~40% of America's coal (Wyoming Mining Association, 2023). However, as shown in Figure 9, the industry is experiencing longer term decline. In 2016, roughly 500 miners were laid off in one day, drawing widespread attention to the disruption (Propp, 2017; Interviews, 2022-2023). Patrick Hladky, who (with his brother) manages Cyclone Drilling, an oil rig company started by their father, indicated "Natural gas is in competition for power generation … [t]he downturn in coal was less to do with regulation by the federal government and more to do with the price of natural gas" (Mills and Hershman, 2017).

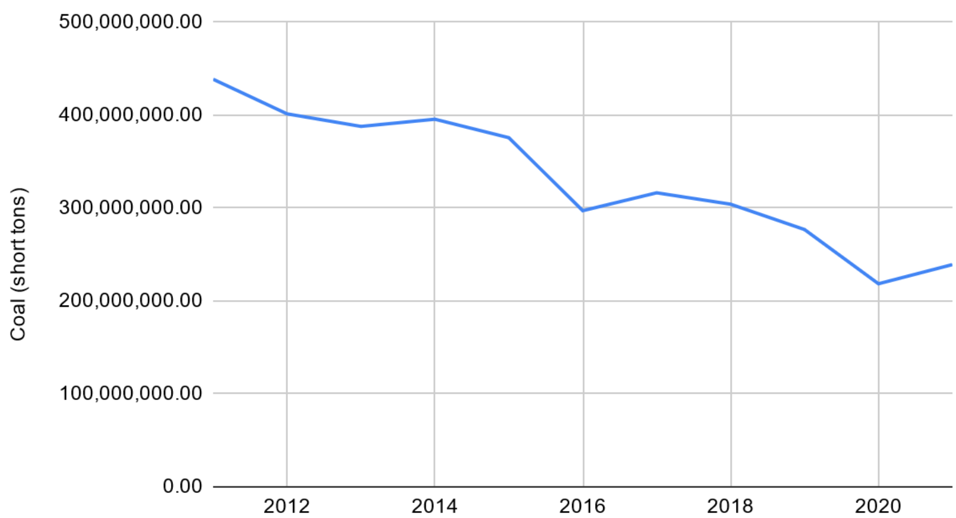

Figure 9. Wyoming coal production. Source: Wyoming State Geological Survey, 2022.

Alongside the above challenges for coal, railroad capacity constraints in the Powder River Basin have also been highlighted as currently constraining Wyoming coal output (Interviews, 2022-2023). Travis Deti, Executive Director of the Wyoming Mining Association stated that with increases in demand and pricing, but an absence of sufficient rail transport Wyoming lost an estimated $60 million dollars in state revenue, or 12.5% of annual coal production in 2022 (Bleizeffer, 2021).

In line with the above conditions, it is widely accepted in the community of Gillette that the economy needs to adapt (Interviews, 2022-2023). As part of the new economy, PacifiCorp recently opened a 520 MW wind farm an hour and half south of Gillette (Sutter, 2021). Atlas Carbon is also making activated coal for use in water filters such as with Brita or Piore, as well as huge chemical filters for water and air that remove pollutants such as mercury from coal in power plants (Mills and Hershman, 2017). The local Dry Fork Station, one of the newest coal-fired power plants in the country, runs on local coal and uses activated carbon to clean up its emissions (Ibid).

For over half a century, uranium mining has also been an important industry in Wyoming. The federal government established the Atomic Energy Commission (AEC) in 1946, which provided incentives for uranium mining (Larsen, 2019). In the 1950s, the Lucky Mc company began mining uranium in the Shirley basin area of Wyoming, alongside a number of other mining companies. By 1960, the AEC recognized that stockpiles were growing too large, so presented the mining companies with two options: continue with the current contract until 1967 and no guarantee of price afterwards, or produce 50% more by 1970, but at a reduced price (Ibid). The situation triggered bankruptcies and scale-backs (Ibid). Following this period, four major uranium producers remained in Wyoming: Western Nuclear, Lucky Mc, Federal American Partners, and Globe/Union Carbide (Ibid). The fuel crisis of the 1970s spurred uranium price increases and demand growth for use in nuclear power (Ibid). As most of the country struggled with the energy crisis, Wyoming thrived due in part to its uranium production (Ibid; Interviews, 2022-2023). The Three Mile Island nuclear accident brought a swift end to the uranium boom in 1979, as companies cancelled plans for nuclear power plants and regulations increased surrounding nuclear power (Ibid).

Current Economic Development

In 2016, the average income for Campbell County was $54,654, 2% below Wyoming's per capita income ($56,081) and 14% above the U.S. per capita earnings (Campbell County Board of County Commissioners, 2017). Notably, the population of Campbell County is relatively young, compared to other locations (Ibid).

In 2022, Wyoming reported a Gross State Product of $36 billion, with a declining annualized growth rate of -0.7% for the years 2017-2022 (IBIS World, 2022b). This GSP/GDP growth rate ranked Wyoming 48th among all 50 states. As of 2022, there are 86,201 businesses in Wyoming, with an annualized business growth rate of 2.1% for the years 2017-2022 and a state growth rank of 36th for the same period (IBIS World, 2022b). Table 11 outlines Wyoming's top five GSP or GDP sectors.

Table 11. Wyoming gross state product by sector.

Sector	GDP ($Thousands)	Growth 2022 (%)	Annualized Growth 2017-22 (%)
Mining	7,093,873	-5.4	-4.6
Real estate and rental and leasing	3,601,583	-1.0	-1.6
Manufacturing	3,549,062	4.4	7.7
Transportation and warehousing	2,336,080	-5.7	-3.8
Retail trade	1,922,390	-1.0	-0.5

Source: IBIS World, n.d.b.

The average unemployment rate in Wyoming is 3%. Campbell County has one of the highest rates in the state at 3.3% (DOE, 2022). The total number of people working in Wyoming decreased by -5.1% between 2019 and 2021, from 354,815 to 336,824 (WY Dept of Workforce Services, 2022). **50% of Wyoming's general revenues for public goods come from the "three-legged stool" of coal, oil, and natural gas** (Ibid). Therefore, public services have been hit by the reduction in output. The state's school systems have also been impacted, as coal revenue is by far the most prominent source of education funding. Policymakers in the past used this model of coal-heavy funding for education due to the non-cyclical nature of coal production, compared to oil and natural gas which experience greater price fluctuation, but are now facing challenges as coal reliance is waning (Godby, 2021). When all the coal revenue streams are added together, the amount roughly equaled $567,227,776 in 2020, which is a significant decrease from 2012's total coal revenue of $1,263,851,007 (Godby et al, 2015; Wyoming Mining Association, 2021). The lay-offs will continue as more coal stations are set to close in the near future (Interviews, 2022-2023). Therefore, there may be an available workforce primed for a new industry.

Energy Redevelopment

While the region around Gillette has been producing fossil fuels for years, decarbonization goals and competitive rates of other fuels have been driving decline in recent years. Projects such as those on carbon capture feasibility, activated coal, and non-thermal uses of coal are being conducted to align with net zero carbon emission targets and refocus the region as a carbon management hub (Interviews, 2022-2023; *see* also Part 7).

Tourism and Recreation

The city of Gillette has been diversifying its economy into non-energy sectors. This is accomplished by building venues such as the Energy Capital Sports Complex and Cam-Plex aimed to increase tourism and recreational opportunities in the area (Bleizeffer, 2021; *see* also Part 7).

Innovation

The U.S. Department of Commerce has invested $3.4 million to "Support Business Development and Job Growth in Campbell County, Wyoming" (U.S. Dept of Commerce, 2022). Of this total, roughly $2.8 million is allocated toward infrastructure improvements at the Pronghorn Industry Park, a site set to explore the future of carbon technology in the U.S. (Ibid). The Wyoming Innovation Center was opened in Gillette in 2015. The center's first tenant is planned to be the National Engineering Technology Laboratory (NETL) and the University of Wyoming is expected to be a partner, offering opportunities for students and graduate students to get involved in tests on novel technologies (Cook, 2022).

Uranium Mining Potential

Wyoming contains the largest known uranium ore reserve in the U.S. and, in the past, was ranked number one in uranium production (WY State Geological Survey, 2022b). Since the 1950s, more than 200 mines have been sited in Wyoming and experts estimate more than 200 million pounds of uranium ore remains economically recoverable (Ibid).

Uranium is highly valued, but mining, especially in Wyoming, only occurs when market prices make mining viable or when strategic investments make sense to maintain a federal uranium reserve. Production of yellowcake was dramatically lower over the past decade or so due to international market conditions, but forecasters are expecting conditions to improve.

As the primary feedstock for nuclear power plants and nuclear-powered submarines, uranium is now more fully seen as a mineral of national/energy security importance (Powers & Rubin, 2022). At its peak global production in the 1980s, the U.S. produced over 40 million pounds per year (Cook, 2022). Travis Deti, the Wyoming Mining Association's Executive Director, does not see why the U.S. couldn't reboot, with western state mines producing 10-20 million pounds per year (Ibid). Uranium production had a steep decline after 2016 and, though prices rose in spring 2022 to $60/pound, Wyoming Consensus Revenue Estimating Group (CREG) estimates prices will need to be sustained between $60-80/pound in order for operations to restart (CREG, 2022). Current uranium concentrate pricing is at $40-50/pound.[1] CREG forecasts uranium production will increase in coming years as the U.S. focuses on the establishment of a domestically produced uranium stockpile (Ibid).

The U.S. has not been producing uranium domestically because it is less expensive to import from other countries, and options remain such as with Canada and Australia which have large reserves (EERE, 2022). Furthermore, all commercial conversion of uranium currently occurs outside the U.S., though the ConverDyn/Honeywell plant is expected to come back online in 2023 (WNN, 2021). State-owned Russian and Chinese conversion operations have dominated the global market with over 40 percent of capacity in the supply chain (Ibid). Experts assert it is difficult for independent companies to compete with state-owned enterprises, but it will be necessary for the U.S. to strengthen each section of the supply chain to continue competing in nuclear technology globally. This is an argument for industrial policy.

The COVID-19 pandemic disrupted supply chains, transportation and global operations which constricted uranium supply. U.S. uranium production is the lowest it has been since the 1940's which has left the nuclear industry reliant on foreign imports (Barrasso, 2021). To be more self-sufficient and improve energy security, the government is looking to invest in the nuclear supply chain in the US. In 2021, Congress provided $75 million to the DOE in the $1.9 T pandemic relief bill to acquire domestically mined and converted uranium (Ibid; Powers & Rubin, 2022). Russia, Kazakhstan, and Uzbekistan provide nearly half of U.S. supplies for nuclear fuel–causing concern over whether a national uranium reserve should be created and if uranium should be listed as a critical mineral under existing circumstances (Powers & Rubin, 2022). Concerns remain over the environmental risks from expanded uranium production in the U.S. As global supply chains continue to be disrupted, uranium suppliers and political supporters have encouraged Congress to act in development of a domestic uranium supply chain, including both mining and enrichment operations.

Currently Russia is the only commercial producer of HALEU uranium which is required for advanced nuclear reactors. The U.S. is focused on a growing number of advanced reactor projects to move energy portfolios toward carbon neutral futures. Therefore, the DOE is looking to include HALEU and standard low-enriched uranium in its uranium strategy (WNN, 2022a). Energy security is at the forefront of policy makers' minds, as well as the possible economic and job impacts such a facility could bring (Ahn et. al., 2022). DOE released a request for information in December 2021 seeking public input on its plans to create a new HALEU program in the U.S. to demonstrate the potential for commercial deployment of advanced reactors, leveraging funding from the Infrastructure Investment and Jobs Act (Office of Nuclear Energy, 2021). Comments submitted to the RFI assert establishment of a supply chain domestically is necessary for commercial investment into the advanced reactor technology to ensure a steady demand of HALEU production (WNN, 2022b).

[1] Wyoming has removed severance tax on the production of uranium when spot prices are lower than $30/lb but the severance tax will increase incrementally to 4% when spot prices exceed $60/lb (CREG, 2022).

Specific to Wyoming, the uranium industry and related exploration have been a part of the mining playing field as far back as the mid-20th century (Cook, 2022). Since then, the industry has undergone boom-and-bust cycles, with cheaper uranium produced in countries, as noted above. According to Scott Melbye, Executive Vice President of Uranium Energy Corp., and President of the Uranium Producers of America, he has “never been more optimistic about the prospects for nuclear energy and also what that means for uranium mining and the supply and demand of uranium (Ibid).” Today, all of Wyoming's uranium mines are in-situ operations (in contrast to open-pit mining), resembling oil and gas wells (Ibid). Operations that are on standby or fully licensed and ready to move are where the focus can be expected. Wyoming’s congressional delegation is prioritizing that the fuel cycle needs for advanced reactors can be met domestically (Ibid).

Importantly, with the announced plan for Wyoming to adopt its first nuclear plant using small modular reactor technology to replace a retiring coal plant in Kemmerer, public discussions have expanded around nuclear technology and uranium. According to interviews, a questioner in one public discussion about the Kemmerer project asked whether the plant would use Wyoming-sourced uranium (Interviews, 2022-2023). The answer currently is no. As noted earlier, the plant opening has been pushed back roughly 2 years by TerraPower to 2030 (Tan, 2022), given that HALEU is currently only sourced from Russia, a country under major sanctions. Brian Muir, the city administrator of Kemmerer indicated, “I think this might actually give our Wyoming uranium industry a little more time to put things together to provide that uranium (Ibid).” In December 2022, Senator Barrasso of Wyoming and other senators urged the Senate Committee on Appropriations to include funding in Energy & Water Development for the U.S. nuclear fuel security consistent with section 8103 of S.A. 5499, the FY 2023 National Defense Authorization Act (U.S. Senate, 2022).

Wyoming Taxes

Wyoming applies a gross products tax in lieu of a tax on the land, unlike other states which often tax mineral properties based on reserves in the ground Wyoming only taxes a mineral once–when it is produced (WY Leg, 2015). The fair market value of the mineral being produced is assessed and taxed after mining or production and the gross product tax is assessed to be given to counties and the severance tax is imposed for state projects and taxation purposes (Ibid). Though Wyoming’s mineral severance tax is a central source of revenue for the state, the percentage taxed does not differ much from other mineral rich states such as North Dakota and Texas (5-7%) but has been criticized for not following a more state-focused model like Alaska which takes 35% of net production value (NCSL, 2018; Western, 2008).

Wyoming has been providing minimal reductions to severance tax for coal in hopes of increasing overall production (severance from 7 to 6.5%). Recent Wyoming nuclear legislation also provides tax exemptions for the production of electricity from advanced nuclear reactors that use at least 80 percent uranium mined in the U.S. (WY HB0131, 2022).

Wyoming currently has a $1/MWh tax for wind and increases to this tax have been discussed for over a decade (Thompson, 2010). As Wyoming contemplates the transition away from fossil fuels, the state continues to look for ways to fund state programs and budgets. These discussions have required tax advocates to balance the desire to increase the production tax on wind projects without undermining the potential for project development as an economic diversification strategy, especially when compared to wind potential and economics of projects in surrounding states (Cook & Godby, 2019). Under current tax policy conditions and economics, Wyoming is fourth in western states for its low tax rate–but the cost differences between Montana (#2) and Colorado (#3) estimates are less than 3% when a 20 to 30-year project life is assumed (Ibid). This highlights the competitiveness of these projects across states, which could likely be impacted by any changes to tax incentives.

Gillette/Campbell County Energy Overview

Coal makes up 98.44% of the fuel used for electricity in Campbell County, offset by only 1.42% natural gas, and less than 1% of each distillate fuel oil and waste oil (Reese, 2022).

The City of Gillette is represented in electricity by a municipal utility that serves residential, commercial and industrial electric customers. The city provides electricity from two generation facilities, including partial ownership of the 100 MW WyGen III coal plant and full ownership of a 40 MW simple-cycle gas-fired combustion turbine as well as bilateral purchases from regional utilities. The utility has also secured future resources to meet increasing energy needs through a long-term contract (2054) for 3-4 MW of hydroelectricity from Western Area Power Administration, a power purchase agreement with Black Hills Wyoming to purchase 5 MW additional power from Wygen I (beginning in 2023), and a regional peaking contract (City of Gillette, 2021).

The municipal utility serves 15,576 customers, including 13,081 residential, and 2,495 commercial customers as of December 31, 2020. The City of Gillette is a summer peaking system, which experienced an all-time peak demand of 77.8 MW during summer 2017, but demand and energy consumption has leveled off over the past several years (City of Gillette, 2021). Gillette's average residential electricity rate is 11.48 cents per kilowatt hour, which is 3.51% higher than Wyoming's average rate of 11.09 cents (Reese, 2022). Campbell County is the fourth highest electricity generating county in Wyoming, but due to the large energy-producing sector and small population the state has one of the highest per capita energy consumptions in the U.S. (EIA, 2022c).

Energy adaptations for uranium mining and other economic development are conceptual at this point and will be reviewed in terms of perceived outlooks in Part 7. The options that are examined include ramping fossil fuel, a microreactor, and use of wind plus storage.

PART 7: FINDINGS

This section distills the findings from the elicitation, case analysis and literature reviews.

1. **What economic developments, including mining of graphite (Alaska) or uranium (Wyoming), are likely in the communities of focus for the next 5-10 years?**

Nome, Alaska

Nome's traditional economic activity in gold mining and fishing/hunting has several areas of prospective growth.

Graphite One Mine

Development of the Graphite One mine outside of Nome is an option that is quite likely to occur, barring any surprises in the later stages of feasibility assessment and permitting.

Graphite One has been engaging with communities near the proposed mine, including Teller, Brevig Mission, Mary's Igloo and Nome to discuss the project and provide updates (Interviews, 2022-2023). The proposed mine is located in a remote location and would require a crew of up to 200 people to live onsite year-round. Initial processing of graphite is expected to take place at the site before transporting it by truck to Nome and sending it by barge to the final processing destination in Washington (Gannon, 2022; Interviews, 2022-2023).

The strong mining history and culture of the region provide a certain level of familiarity for community acceptance. (However, a recent failure with Nova Gold's Rock Creek Mine in the area is acknowledged in community discussions, so there is a mix of expectations.)

Current activity at the proposed Graphite One mine site is being fueled by diesel that is brought in by helicopter. Modeling by Graphite One is based on assumptions that indicate diesel will be the fuel source. However, they are open to considering nuclear. Some reservations were voiced that combining new mining in the location with nuclear power generation, such as that from an MR, presents a twin challenge for stakeholders who may be concerned. Ancillary services can be expected (trucks, port, repairs, components, etc.) with this economic development.

Deep Water Port

Development of the deep-water port is already underway with the Army Corps of Engineers and the City of Nome. Agreed funding (90:10, federal-local) is outlined up through the construction. Three stages were broken out to allow for more staging around funding. The Award for Phase 1 competitive bids is expected in 2023, with Phase 2 – 2025 and Phase 3 – 2027.

Energy and economic implications are expected to be notable, with planning underway for workforce development, discussions about housing, and electric utility planning.

Additional Economic Development Potential

Other areas of development that were raised include the possibility of a Coast Guard base installation and increased tourism. With the addition of a Coast Guard facility, the currently limited housing market will need to be expanded. There is also some concern that prices will be skewed from a military installation, with the federal government covering whatever is needed for service families, displacing the local residents. With respect to tourism, there was an increase prior to the pandemic, which seemed in line with greater adventure-based destinations.

Gillette, Wyoming

Gillette self-identifies as the energy capital of the U.S. and is positioned, as shown in Figure 10, to continue building on these strengths.

Figure 10. Gillette, WY as the Energy Capital of the U.S. Source: High Country News, Luna Anna Archey and Jonathan Thompson. Reprinted with permission.

Uranium Mining

Wyoming has a considerable history in uranium mining. While more than 200+ mines have operated in the State since the 1950s, with more than 200 million pounds of uranium ore still deemed to be economically recoverable (WY State Geological Survey, 2022b), closures in previous decades were noticeable, as the global uranium markets shifted toward a less costly supply that was available from countries like Russia, Kazakhstan, and Canada. The U.S. is now reconsidering its domestic supply strategy to fuel its nuclear fleet as geopolitics placed Russian imports out of bounds. While the global market is constricted, the U.S. is no longer buying from Russia, and prices increased, low-cost sources remain (Canada, Kazakhstan, etc.). This raises credible questions for U.S. policymakers on whether the U.S. will move past pure global, market conditions and spur a domestic supply chain for security reasons.

According to those in the uranium industry, global prices need to be at $60/pound or higher and remain there, for the domestic industry to want to restart and scale.

Wyoming is well positioned to restart uranium mining operations in Cambell County as well as Casper, Sweetwater and Freemont Counties (more southwestern in Wyoming). In Campbell County, one mine is on standby, and others are permitted to restart and ready to go if uranium pricing hits and stays above $60/pound or if policies shift toward strengthening a domestic supply.

Compared to coal mining and other fossil fuel extraction, the skill, expertise and infrastructure requirements are not as considerable and do not directly correlate in a 1:1 job substitution opportunity. Campbell County's uranium mining is based on in situ recovery which functions more like oil and gas wells, as opposed to open pit or underground mining that pertains to coal. However, interest was stated during industry interviews in Gillette and/or the Powder River Basin becoming part of an emerging supply chain for the nuclear industry and, where possible, to mine and process uranium for Wyoming plants, as well as those operating elsewhere in the U.S.

Notably, Gillette currently has many other highly paid jobs available in the fossil fuel industry, so uranium mining is less visible. Nonetheless, Campbell County has the capabilities and readiness to (re)start uranium mining and processing.

Energy-based Entrepreneurial Eco-system Centered on Low-carbon Adaptations of with Fossil Fuel and Rare Earths

The community and industries of Gillette are deeply rooted in the production of coal, oil, and natural gas, with many public services and venues supported through taxes and other aspects of these industries. They also recognize that decarbonization is underway globally, and there is a long-term downward trend with coal, with short-term uptick from global market flux.

Looking ahead, Gillette appears to be focusing on innovation/entrepreneurship and education to advance with the changing playing field, such as with non-thermal use of coal (e.g., bricks), direct air capture, and alternative carbon value streams.

- **Wyoming Innovation Center**: WIC is an incubator space to commercialize carbon products using coal and coal by-products. It also focuses on rare earth element processes. Its first tenant is the National Energy Technology Lab with R&D for commercialization of rare earths.
- **Integrated Test Center**: ITC is a test site for carbon capture, utilization and sequestration (CCUS); with demonstration at the Dry Fork Power Plant.
  To date, it has been involved with the UW Carbon X Prize, a competition for best CO2 utilization; and Carbon Safe, currently in Phase III with Site Characterization and CO2 Capture Assessment.

- **Gillette Technical Center/Gillette College** – Gillette College is currently completing the accreditation process as it spun off independently from Sheridan College. This modern campus has state-of the art equipment, including augmented reality/virtual simulation that is suited for training a new workforce on safety needs, and other industry requirements. Gillette College is also well positioned for industry adaptation with numerous industry-specific advisory boards.
- **Wyoming Innovation Entrepreneurs** – This group is designed to mentor, advise and innovate with business opportunities that focus on Wyoming advances, by leveraging local resources and business insights.

  The energy and workforce needs will depend on what emerges for new industry.

Additional Economic Diversification

Gillette is actively retooling itself to be an events and tourism destination. A signature development to watch is its Cam-plex venue that is designed for conferences/conventions, theater, dance, trade shows, livestock shows and rodeos, horse racing, RV events, and Scout as well as religious gatherings.

2. What considerations were raised for a microreactor vs. another alternative form of energy vs. continued reliance on fossil fuel, if economic development were to scale up due to new mining and/or other development for the respective communities?

Nome, Alaska

Specific to mining of graphite by Graphite One, the company staff does not see MR technology readiness as mature enough to align commercially with a planned operational start for the mine around 2028. They also see the social license for mining + an MR as a dual challenge.

In technical feasibility terms, an MR could serve as the basis for a microgrid that produces power and heat at the mine. An MR could also be installed with Nome electric utility NJUS, displacing some diesel, and requiring a transmission line to be added. Renewables in the form of wind plus storage could be added to a mine-based microgrid or NJUS. This option is not being considered at the mine, but is under consideration for integration by NJUS in its system.

In terms of other economic development beyond graphite mining, with the port plus other activities, the addition of an MR to displace some/most diesel, or the scale-up wind (plus storage) to 40% of the power mix appears to be a plausible option for further study.

Gillette, Wyoming

In terms of uranium mining, there is natural synergy and interest expressed by the community in using an MR. Many (not only in uranium mining) see Wyoming as very well suited to stand up a nuclear hub for the fuel cycle, nuclear technology supply and ancillary services. In fact, a number of people in industry expressed strong ambition to contribute to the global nuclear build-out with Wyoming as a hub.

Gillette's economic activity around fossil fuels does not appear to have an immediate point of opportunity for an MR. However, if rare earth extraction ramps up, or more advanced carbon management occurs with CCUS or hydrogen production, an MR appears to be a candidate fuel source.

Gillette's tourism and events activity do not naturally lend themselves to choices for or against an MR. Yet, Wyomingites value nature and tourism, and could conceivably replace some fossil-based generation with an MR and use tourism as a way to educate visitors about the state's carbon management hub (aim).

Across many discussions, renewables, such as wind power, were dismissed either because the resource is stronger in another part of the State or it was not seriously pictured, despite Wyoming doubling its share of wind power since 2019 to 19% in 2021 (EIA, 2022b).

The cultural focus seems to be more centered on new nuclear if Gillette is to move past fossil fuels.

3. **How would greater economic development in the next 5-10 years translate in terms of industry/infrastructure, environmental sustainability, and community/workforce development?**

Nome, Alaska

Graphite mining with an MR or renewables on a microgrid is not currently being considered by Graphite One. If instead, an MR were included in electric utility NJUS's supply, a transmission line would need to be built to the mine, along with an already anticipated road build-out. If an MR were sited in the area, additional consideration will be needed to account for regular permafrost shifts in the terrain. For this reason, an MR may need to be sited above ground or in areas of thaw-stable permafrost (previously mined areas that are primarily gravel).

Access roads and infrastructure will be needed for the mine, as the deposit site is about 10 miles from spur-road access to that region's Taylor Highway.

Transmission line expansions will have land use implications. Ancillary activity/services are expected (trucks, port, repairs, components, etc.) with such economic development.

In environmental sustainability terms, some asked what would happen with an MR in terms of nuclear waste. Others noted that increased economic activity (in any form) will likely displace wildlife, which matters, especially for subsistence hunters. Specific to the community and workforce development, a number of people noted that local expertise would be needed for an MR, especially given the remote nature of Nome.

Looking next at the same question with wind and storage, the transmission build-out is seen to have the same implications for land use and wildlife. There was not notable concern about environmental sustainability aspects of renewables scaling or community and workforce concern. Historic issues with older, misaligned wind turbines were occasionally mentioned, yet there is also recognition that the larger modern EWTs function noticeably better.

Gillette, Wyoming

Wyoming is quite focused on diversifying its economy. Gillette especially is leveraging state and federal funding to build out projects to commercialize carbon products to maintain economic development from its wealth of mineral resources. The coal economy has been central to Wyoming's general fund and continues to support most of Gillette's central and ancillary services. Thus, considering economic development outside of fossil fuels that could provide high-paying jobs consistently over time may be difficult.

Business developers and local leadership estimated that the most important first steps for Gillette would be to obtain properties ready for industrial and commercial development to attract new companies to the area. The region currently has plenty of fossil-fuel powered electricity, but is constrained in the infrastructure for natural gas. Residents recognize carbon policy could quickly limit the economic and technical viability of coal mining and their operating coal plants, and a shift to nuclear, especially advanced nuclear could be a next step. Gillette was one of four sites being considered for the Natrium reactor, sited in Kemmerer, and its existing coal infrastructure could be leveraged for a nuclear reactor if another one was sited locally.

Gillette is currently a hub for coal/natural gas/methane drilling and mining technicians and machinists, internationally. Some members of the industry see themselves as flexible and available to adapt the nuclear workforce to support with manufacturing, assembling, transporting, or working on aspects of the fuel supply chain. Companies and individuals stated interest in exploring participation in the fuel supply chain in greater depth.

Residents do not appear to have any major concerns with the environmental sustainability of proposed development projects. Currently, oil and gas traffic and open pit coal mining have significant air, water and vegetation abatement plans. The level of proposed uranium mining, especially in-situ would require much less of a footprint or traffic than other types of mining. There have been discussions regionally about wind development and wildlife habitat including sage grouse and large game animals, but Wyomingites seem confident that adequate measures are being taken to protect the environment, balanced with development.

The Gillette Community College and Tech Center are points of interface with different industries and are able to provide community development through educational opportunities. Their structure is much more nimble than traditional educational institutions and able to provide training and certificate programs in a range of technical careers, necessary to the energy ecological system. Employers and community members indicate that the community college, in partnership with industry, will play a key role in workforce development, but it will need to find fast pathways to credentials or micro-credentials in the right fields. If Gillette is going to build a nuclear workforce and strengthen the existing pool of skilled workers, it needs to improve linkages to engineering schools/internships which bring talented workers who will stay in Gillette. Residents see opportunities to learn from the experience of Kemmerer and possibly bridge the workforce digitally, as PacifiCorp has expressed its intent to site as many as five reactors across its territory.

4. What are the opportunities and barriers for MRs in these communities?

Nome, Alaska

If cost estimates are seen as credibly firmed up and show improved competitiveness with existing diesel, there is general interest in exploring new options for Nome. There is also widespread interest in following what occurs with Eielson Air Force Base and in terms of learning more. There is recognition that MRs are still under development and adoption may be 10 or so years out. Those who are interested in thinking through MR adoption also see that planning needs to begin soon to be in the ‘pipeline’.

If an MR were installed, for instance in the electric utility NJUS’s market, the utility would need to consider whether to buy and train its staff or lease the technology in such a manner that expert maintenance would be handled by the owner.

More broadly for Alaska, some see a regional industrial hub opportunity for the state with multiple MRs along the rail belt and as an MR hub.

In relation to security, Nome’s proximity to Russia was noted. With current hostilities, there is some acknowledgement of a security risk in having a nuclear plant installed. Here, one simply can look to the Russian firing upon the Zaporizhzhia Nuclear Power Station in southwestern Ukraine. However, generally speaking, this was not a widely raised concern.

Those who are less interested in MRs mentioned national waste management issues and alternative opportunities with renewables. Others don’t see the current, costly diesel dependence as a problem. Permafrost is an environmental condition that would affect siting as it currently affects diesel tank storage.

Gillette, Wyoming

Unlike Alaska, the driver to find and adopt a cheaper source of electricity is not an express goal in Wyoming at this time, especially in Gillette where so much of the economy depends on coal. Gillette residents recognize their community as the energy capital for U.S. fossil fuel production and a technological hub for future energy development. Due to this identity, businesses and individuals would like to participate in the buildout of the advanced nuclear economy, identifying general community acceptance of industry and resource utilization as readiness to build competencies in this area. The community seems to be looking at the disruptive potential of the nuclear industry as a whole rather than siting just one nuclear reactor in the community—and would like to understand the viability of the technology.

Like Alaska and the Eielson Air Force Base MR, Gillette is watching closely as the Natrium Reactor is sited on the other side of the state to understand the social, technical and economic barriers such a process might take. However, at the same time, some companies are more broadly considering how they might participate in different components of the MR economy. Transportation strategists are considering how rail and trucking routes could be utilized to move MR components across the US.

There are currently six operating coal plants in Gillette. These are likely both opportunities and barriers to nuclear in Wyoming. Since the Gillette economy is largely based on coal mining and coal-fired power generation, community members and industry will continue to run these plants as long as economically feasible. Some community members noted the current economics of coal are likely preventing longer term investments in other economic opportunities and, more importantly, hiding the oncoming bust. This is particularly impactful because there seems to be funding for communities in crisis, but little for those transitioning on the precipice of crisis. The opportunity in repurposing the large amount of infrastructure following coal-plant closures is credible. As in Kemmerer, and discussed in other locations, existing infrastructure could be leveraged for the nuclear build.

Given that uranium mining has taken place in Wyoming and specifically near Gillette for decades, community members seem comfortable with nuclear technology and waste—though, as in Alaska, they believe having a permanent nuclear storage solution would help the nuclear case.

PART 8: LIMITS

As with all research, it is important to acknowledge limits.

The policies portion of the study drew from national and state-level resources that reflect diverse timelines for policy changes and published updates. This report represents a distilled snapshot of available information that we were able to access for the period of this study.

Specific to the interviews, we continue to see more people who would be valuable to engage in the subjects that we examined. We also found there were perspectives that were not able to be included, either because of availability or interest. For Nome, it would be beneficial to engage more voices from the indigenous communities. Similarly for Gillette, it would be beneficial to engage more voices from the power sector. Across both communities, it would be insightful to engage with school superintendents and hospital administrators as they represent key community voices and are also point people for prime energy users. In the case of Gillette, schools are also seen as beneficiaries of energy/mineral tax money. Further, to improve our understanding of the workforce potential, demographics, and general ideas about transient worker populations in each location, we could engage with more people in technical training/education on how they are planning for boom/bust expansion/contraction.

PART 9: DISCUSSION AND FUTURE RESEARCH

Interviews and case analysis revealed that both states produce considerable natural resources that are exported out of state for higher value refining or processing. If low carbon energy could be scaled more fully in both states at competitive costs for **advanced manufacturing, the state economies have considerable potential for added depth and breadth of existing and new industries.**

This study also showed that the Nome and Gillette are forward-looking communities that anticipate palpable economic change in the next 5-10 years. They are strategically asking how they can adapt to leverage inherent strengths which align with community interests.

Workforce development priorities are at the foreground of discussions in both locations. As substantial economic choices are still dependent on studies, demonstrations or shifting market developments (e.g., Graphite One mine; uranium mining restarts; carbon management build-outs), workforce educators need more clarity in order to anticipate the need gaps and timing. The remote and less dense nature of the community populations presents opportunity for innovative adaptations in virtual, augmented reality and other forms of training that the State and federal government could support. Moreover, there is interesting potential for learning across the two communities.

In terms of **prospective regional energy choices, increased information sharing** was commonly voiced as important for both communities. This suggests that public officials and industry should work with educators through public meetings and other planning activities to inform on needs, prospective options and tradeoffs as well as **more engaged decision-making**.

Specific to nuclear energy, consistent questions were raised about how spent nuclear fuel (SNF)/nuclear waste would be handled. Given that some microreactor designs envision 'plug and play' technology, planning will need to factor for microreactor SNF/waste being shipped back to a manufacturer or another designated site with fuel intact for refueling or replacement. In such cases, **regulations that are under development need to account for transport of a microreactor + SNF/waste via a plane or ship** (Law of the Sea) in addition to more conventional transport (Shropshire et al, 2021; Black et al, 2022). For microreactor technology that can refuel on site, the States may wish to consider **State-Federal agreements on nuclear waste management or new consent-based siting calls**.

Thinking about microreactor challenges across groups, the limited numbers on expected costs for adopters and pre-commercialization status of the technology were voiced as areas that need to be more mature for prospective adopters to think more seriously about the technology. Likewise, recognition of specialized workforce needs presents an opportunity for deeper discussion in community planning.

More broadly, shifting policies and perceptions around decarbonization are impacting energy diversification conditions. Pathways and timelines to decarbonization at state and federal levels will heavily influence Nome and Gillette communities, as both locations depend on fossil fuels in varying ways and energy economics will trickle down into community projects and workforce.

This report identified high-level tax policies and the significance of mineral taxes to the economies of both states. A more in-depth analysis of the **tax and mineral schemes with a review of relevant peer models** could provide decision-makers with a comparative baseline for adaptation to leverage new opportunities. Additional analysis of a range of **critical minerals and rare earths or materials of national security significance** could be completed to shed light on expanded market potential in each state.

Specific to land ownership, access and rights of way, these may well present barriers to energy and economic development. In states like Wyoming and Alaska, which have considerable state and federal lands, projects can face obstacles due to the complexity of jurisdictional boundaries and necessary assessments. Further, transmission and roads may need to cross private lands and require additional permissions and permitting. Contextualizing and evaluating these possibilities would be important considerations regarding siting energy in these locations.

Alongside decarbonization, tax-minerals policies and land rights, the policy playing field has clearly been evolving in recent years across multiple jurisdictions, as the federal government, Tribes, and states have seen increased needs to develop flexible regulations and procedures for regional diversification and infrastructure, as well as jobs. A more in-depth assessment of **interjurisdictional oversight in each case location would be beneficial to understand the intersecting authorities tied to land use, permitting, mineral rights and mining, port oversight, energy and the environment**. This would be especially relevant in Alaska, considering the numerous Tribal organizations.

Finally, Nome, Alaska and Gillette, Wyoming have provided important natural resources to their regions and the U.S. economy. Amidst shifting priorities tied to decarbonization and national security, their communities now face important choices for energy and economic strategies. Both communities have histories of navigating booms and busts with natural resource markets. They are preparing for transitions that present unique opportunities to develop new industries from existing resources. Both are well-suited for establishing innovation hubs that leverage natural strengths. We recommend that the stakeholders work through community-informed planning measures to discuss concerns and opportunities, while developing locally-relevant approaches to address the coming changes.

REFERENCES

Ahn, Alan, Josh Freed and Ryan Norman. 2022. “Developing Domestic HALEU Supply Spells Freedom from Russian Dependency,” Third Way, April 6, 2022. https://www.thirdway.org/memo/developing-domestic-haleu-supply-spells-freedom-from-russian-dependency.

Alaska Center for Energy and Power (ACEP). n.d.a. Nome Power Integration Options, https://acep.uaf.edu/projects-(collection)/nome-power-integration-options.aspx, Accessed November 1, 2022. See also, https://acep.uaf.edu/media/134658/Nome-Power-Integration-Options-Snapshot-final.pdf.

Alaska Center for Energy and Power (ACEP) n.d.b. Pilgrim Hot Springs Geothermal Exploration, https://acep.uaf.edu/projects-(collection)/pilgrim-hot-springs-geothermal-assessment.aspx.

Alaska Center for Energy and Power (ACEP). 2015a. Nome Energy Storage and Geothermal Exploration, June 26, 2015, https://acep.uaf.edu/media/158030/Nome-Energy-Storage-6-26-15.pdf.

Alaska Center for Energy and Power (ACEP). 2015b. Pilgrim Hot Springs Geothermal Exploration, Report, https://acep.uaf.edu/media/174877/pilgrimFinal-report_Final.pdf.

Alaska Department of Labor and Workforce Development, 2021. “2020 Census Data for Redistricting,” https://live.laborstats.alaska.gov/cen/2020-census-data.html.

Alaska Department of Natural Resources. 2022. “Bringing Alaska’s carbon ore, rare earth and critical minerals potential into perspective,” https://dggs.alaska.gov/energy/core-cm.html, Accessed 16 December 2022.

Alaska Energy Authority (AEA). n.d. "About the Power Cost Equalization Program," https://www.akenergyauthority.org/What-We-Do/Power-Cost-Equalization, Accessed February 1, 2023.

Alaska Energy Authority (AEA). 2023. Power Cost Equalization Program, https://www.akenergyauthority.org/Portals/0/Power%20Cost%20Equalization/FY22%20PCE%20Community%20Report.pdf.

Araújo, Kathleen. 2023a. "The Evolving Field of Energy Transitions." In: Routledge Handbook of Energy Transitions, edited by Kathleen Araújo. Routledge: London, UK.

Araújo, Kathleen. 2023b. "A Roadmap for Concepts and Theory of Energy Transitions." In: Routledge Handbook of Energy Transitions, edited by Kathleen Araújo. Routledge: London, UK.

Araújo, Kathleen. 2017. Low Carbon Energy Transitions: Turning Points in National Policy and Innovation. Oxford University Press: New York, NY.

Araújo, Kathleen and David Shropshire. 2021. "A Meta-Level Framework for Evaluating Resilience in Net-Zero Carbon Power Systems with Extreme Weather Events in the United States," *Energies*, 14(14), 4243; https://doi.org/10.3390/en14144243.

Barrasso, John. 2021. "Barrasso: We Must Ensure American Technologies are Leading the Global Expansion of Nuclear Energy," [Video], https://www.youtube.com/watch?v=qpc4O7tJlQQ, Accessed 15 November 2022.

Benoit, D., Pike, C., and Holdmann, G., 2014a. The Pilgrim Thermal Anomaly, *Geothermal Resources Council Transactions*, 38:470–486.

Benoit, D., Pike, C., and Holdmann, G., 2014b, Fluid-entry Temperatures, Depths, and Water Chemistry at Pilgrim Hot Springs, Alaska, *Geothermal Resources Council Transactions*, 38: 487–495.

Bestplaces. n.d.a. Nome, Alaska, https://www.bestplaces.net/economy/city/alaska/nome, Accessed March 9, 2023.

Bestplaces. n.d.b. Gillette, Wyoming, https://www.bestplaces.net/economy/city/wyoming/gillette, Accessed March 9, 2023.

Better Wyoming. 2019. "Federal Regulations Created Wyoming's Coal Industry," https://betterwyo.org/2019/09/11/federal-regulations-created-wyomings-coal-industry/.

Bleizeffer, Dustin. 2021 "Gillette, Campbell County Plan for Post-coal Economy." WyoFile, https://wyofile.com/gillette-campbell-county-plan-for-post-coal-economy/, Accessed August 31, 2022.

Bleizeffer, Dustin. 2022. "Looming rail strike threatened Wyoming economy, coal Industry," WyoFile, https://wyofile.com/looming-rail-strike-threatens-wyoming-economy-coal-industry/, Accessed February 14, 2023.

Black, Geoffrey, David Shropshire, Kathleen Araújo, and Aliki van Heek. 2022. "Nuclear Microreactors: A Review of the Technology, Economics and Regulatory Considerations," *Nuclear Technology*, 209 (1) S1-S20. https://doi.org/10.1080/00295450.2022.2118626.

Brehmer, Elwood. 2022. "Nuclear Power Industry Targets Alaska for Small Reactors," Governing. https://www.governing.com/next/nuclear-power-industry-targets-alaska-for-small-reactors, Accessed August 29, 2022.

Brehmer, Elwood. 2017. "Graphite prospect near Nome holds big potential," Alaska Journal of Commerce, https://www.alaskajournal.com/2017-02-08/graphite-prospect-near-nome-holds-big-potential, Accessed February 14, 2023.

Britannica, The Editors of Encyclopedia. "Gillette". Encyclopedia Britannica, 14 Feb. 2022, https://www.britannica.com/place/Gillette. Accessed February 26, 2023.

Campbell County. n.d. "About the County" https://www.campbellcountywy.gov/316/About-the-County, Accessed February 5, 2023.

Campbell County Board of County Commissioners. 2017. A Campbell County Profile: Socioeconomics.

Campbell County Wyoming. 2021. Campbell County Wyoming Government—Annual Report 2020/2021.

Center for Climate and Energy Solutions (C2ES). n.d.a. "California Cap and Trade System," https://www.c2es.org/content/california-cap-and-trade/, Accessed February 16, 2023.

Center for Climate and Energy Solutions (C2ES). n.d.b. "State Climate Policy Maps," https://www.c2es.org/content/state-climate-policy/.

Chaney, R., Colt, S., Johnson, R., Wies, R. and White, G., 2008. "Galena Electric Power: A Situational Analysis," prepared for the National Energy Technology Laboratory, Final Report, DE-FC26-06NT41248, https://digital.library.unt.edu/ark:/ 67531/ metadc931151/m2/1/high_res_d/963353.pdf.

City of Gillette. 2021. "2020 Integrated Resource Plan," https://www.gillettewy.gov/home/showpublisheddocument/40838/637606382036070000.

City Data. n.d. "Gillette, Wyoming," https://www.city-data.com/city/Gillette-Wyoming.html, Accessed February 1, 2023.

Clark, Kevin. "TerraPower, PacifiCorp to evaluate 5 advanced nuclear reactors." Power Engineering, Oct 28, 2022, https://www.power-eng.com/nuclear/terrapower-pacificorp-to-evaluate-5-advanced-nuclear-reactors-in-western-u-s/#gref.

Clifford, Catherine. "Keeping Illinois nuclear plants open is saving some customers $237 a year on average," CNBC, May 18, 2022, https://www.cnbc.com/2022/05/18/keeping-illinois-nuclear-plants-open-saving-some-customers-237-a-year.html.

Cook, Benjamin and Robert Godby. 2019. Estimating the Impact of State Taxation Policies on the Cost of Wind Development in the West, Center for Energy Economics and Public Policy Report, https://www.wyoleg.gov/InterimCommittee/2019/03-20190708EstimatingtheImpactofStateTaxationPoliciesontheCostofWindDevelopmentintheWest-3-8-2019-corrected.pdf.

Cook, Hugh. 2022. "The Wyoming Innovation Center seeks to explore the different uses of coal." Wyoming Public Media, https://www.wyomingpublicmedia.org/natural-resources-energy/2022-06-15/the-wyoming-innovation-center-seeks-to-explore-the-different-uses-of-coal, Accessed 15 June 2022.

Davis, John. 2022. "Dairyland Power Cooperative considers adding nuclear power to its energy portfolio," Wisconsin Public Radio, March 8, 2022, https://www.wpr.org/dairyland-power-cooperative-considers-adding-nuclear-power-its-energy-portfolio.

Deign, J. 2021. Nuclear: These Countries Are Investing in Small Modular Reactors, World Economic Forum, January 13, www.weforum.org/agenda/2021/01/buoyant-global-outlook-for-smallmodular-reactors-2021.

EERE. 2022. "Nuclear Energy," U.S. Department of Energy, https://www.energy.gov/sites/default/files/2022-02/Nuclear%20Energy%20Supply%20Chain%20Report%20-%20Final.pdf, Accessed November 29, 2022.

Eielson Air Force Base. 2021. "Eielson AFB Announced as Site for Air Force Micro-Reactor Pilot," https://www.eielson.af.mil/News/Article-Display/Article/2812077/eielson-afb-announced-as-site-for-air-force-micro-reactor-pilot.

Ellis, Tim. 2022. Pentagon Asks for Proposals to Build Small Nuclear Power Plant at Eielson Air Force Base, Alaska Public Org, October 2, 2022, https://alaskapublic.org/2022/10/02/pentagon-asks-for-proposals-to-build-small-nuclear-power-plant-at-eielson-air-force-base/.

Energy Information Administration (EIA). 2022a. "Alaska: State profile and energy estimates," Feb 17, 2022, https://www.eia.gov/state/?sid=AK.

Energy Information Administration (EIA). 2022b. "Wyoming: State profile and energy estimates," April 21, 2022, https://www.eia.gov/state/?sid=WY#tabs-3.

Energy Information Administration (EIA). 2022c. "FAQs," November 8, 2022, https://www.eia.gov/tools/faqs/faq.php?id=69&t=2.

Energy Information Administration (EIA) 2022d. "Electricity Data Browser, Retail sales of electricity (million kilowatt hours)," Wyoming, Annual, 2018-21.

Energy Information Administration (EIA) 2023. Alaska State Energy Profile, https://www.eia.gov/state/?sid=AK, Accessed March 21, 2023.

Erickson, Camille. 2022. "Uranium buyers, Ukraine Crisis Drives Spot Price to 10-Year High," S&P Global Market Intelligence, March 11, 2022. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/uranium-buyers-ukraine-conflict-drive-spot-price-to-10-year-high-69251651.

European Commission. 2022. "REPowerEU," May 18, 2022, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en, Accessed December 10, 2022.

Gannon, Megan. 2022. "Graphite One Fields Questions as Mine Exploration Progresses," The Nome Nugget, http://www.nomenugget.net/news/graphite-one-fields-questions-mine-exploration-progresses, Accessed December 16, 2022.

Gaudet, Joseph. 2019. "The Energy Capital of the World: A History of Grass, Oil, and Coal in the Powder River Basin," PhD dissertation, University of Michigan.

Georgia Power Company. 2023. "Vogtle 3 & 4," https://www.georgiapower.com/company/plant-vogtle.html.

Gerace, Selena. 2022. "Wyoming Residents' Perspectives, Desires, and Values related to Nuclear Energy in Wyoming" Emerging Energy Markets Analysis Initiative, Report, University of Wyoming.

Gerace, S., Holubynak, E., and Righetti, T. "Wyoming Carbon Policy Sensitivity Analysis," Emerging Energy Analysis Initiative, Report, University of Wyoming, February 2023, also Appendix B in Aumeier, S., Shropshire, D., Araujo, K., Koerner, C., Bell, C., Fauske, G., Johnson, R., Parsons, J., Walsh, B., Gerace, S., Holubynak, E., Righetti, T., Microreactor Applications in U.S. Markets: Evaluation of State-Level Legal, Regulatory, Economic and Technology Implications, Report, Idaho National Laboratory, prepared for the U.S. Department of Energy, INL/RPT-22-02756, March 2023.

Gillette History. n.d. "Gillette History - Campbell County, WY," https://www.campbellcountywy.gov/DocumentCenter/View/509/Gillette-History?bidId=, Accessed September 9, 2022.

Godby, Robert, Roger Coupal, David Taylor, and Tim Considine. 2015. “The Impact of the Coal Economy on Wyoming,” Report, University of Wyoming Center for Energy Economics and Public Policy, https://legacy-assets.eenews.net/open_files/assets/2016/04/13/document_gw_11.pdf, Accessed November 28, 2022.

Godby, Robert. 2021. “Wyoming’s Energy Economy in Transition, with Robert Godby.” Resources Radio, https://www.resources.org/resources-radio/wyomings-energy-economy-in-transition-with-robert-godby/, Accessed November 28, 2022.

Graphite One. n.d. “Overview: Pre-feasibility study report,” https://www.graphiteoneinc.com/pfs/#overview.

Graphite One. 2022a. “Alaska Graphite: Tech Materials for Global Ingenuity,” Presentation to: UAF/DGGS CORE CM Stakeholders, https://dggs.alaska.gov/energy/download/core-cm/08-foo-graphite-one.pdf, Accessed December 16, 2022.

Graphite One. 2022b. “Preliminary Feasibility Study Technical Report,” prepared by JDS Energy & Mining Inc., https://www.graphiteoneinc.com/wp-content/uploads/2022/10/JDS-Graphite-One-NI-43-101-PFS-20221013-compressed.pdf.

Greene, Stephen S. “The Inflation Reduction Act reinforces nuclear energy’s role as a climate solution,” Atlantic Council: Energy Source, August 10, 2022, https://www.atlanticcouncil.org/blogs/energysource/the-inflation-reduction-act-reinforces-nuclear-energys-role-as-a-climate-solution/.

Grubler, Arnulf. 1998. Technology and Global Change. Cambridge University Press: Cambridge, UK.

Hawley, C.C., and Travis Hulson. 2000. “Nome Offshore Placer Deposits,” USGS, https://mrdata.usgs.gov/ardf/show-ardf.php?ardf_num=NM253, Accessed September 8, 2022.

Hein, Rebecca. 2014 “Campbell County, Wyoming,” https://www.wyohistory.org/encyclopedia/campbell-county-wyoming, Accessed August 31, 2022.

Herz, Nathaniel. 2018. “Nuclear power in Alaska? Experts say it’s not as far-fetched as you think,” Alaska Public Media, Nov 21, 2018, https://alaskapublic.org/2018/11/21/nuclear-power-in-alaska-experts-say-its-not-as-far-fetched-as-you-think/.

Holdmann, G., Fay, G., Witmer, D., Williams, F., Schwoerer, T., Pride, D., & Stevens, R., 2011. Small-Scale Modular Nuclear Power: An Option for Alaska? Report, Alaska Center for Energy and Power, University of Alaska, Fairbanks.

Holdmann, G., Roe, G., Colt, S., Merkel, H., & Mayo, K., 2021. Small-Scale Modular Nuclear Power: An Option for Alaska? Update. Alaska Center for Energy and Power, University of Alaska, Fairbanks.

Homeland Security Newswire (HSN) 2019. “Exploring Options for Microreactors in Alaska”, Homeland Security Newswire.

IBIS World. n.d.a. Alaska – State Economic Profile, https://www.ibisworld.com/united-states/economic-profiles/alaska/#EconomicOverview, Accessed February 25, 2022.

IBIS World. n.d.b. Wyoming – State Economic Profile, https://www.ibisworld.com/united-states/economic-profiles/wyoming/, Accessed February 25, 2022.

Intergovernmental Panel on Climate Change (IPCC) 2022. IPCC Sixth Assessment Report: Impacts, Adaptation and Vulnerability, www.ipcc.ch/report/ar6/wg2.

International Energy Agency (IEA) 2022. Emergency Measures Can Quickly Cut Global Oil Demand by 2.7 Million Barrels a Day, Reducing the Risk of a Damaging Supply Crunch, http://www.iea.org/news/emergency-measures-can-quickly-cut-global-oil-demand-by-2-7-million-barrels-a-day-reducingthe-risk-of-a-damaging-supply-crunch.

International Energy Agency (IEA) 2021. Net Zero by 2050: A Roadmap for the Global Energy Sector, May 2021, www.iea.org/reports/net-zero-by-2050.

International Energy Agency (IEA) and Nuclear Energy Agency (NEA) 2020. Projected Costs of Electricity 2020, http:// www.iea.org/reports/projected-costs-of-generating-electricity-2020.

James, Alexander. and Watson, Brett. 2022. Regional Economic Effects of Energy Investments and Transition: A Review, Emerging Energy Markets Analysis Initiative, University of Alaska.

Johanson, Mark. 2011 "Alaska weather: Similar Alaskan storm hit Nome in 1974," International Business Times, https://www.ibtimes.com/alaska-weather-similar-alaskan-storm-hit-nome-1974-367434.

Johnson, R. and Wise, N. "Perspectives on Microreactor Adoption in Alaska: Industrial Energy in the Interior and Alaska State Policy Review," Emerging Energy Analysis Initiative, Report, University of Alaska, also Appendix C in Aumeier, S., Shropshire, D., Araujo, K., Koerner, C., Bell, C., Fauske, G., Johnson, R., Parsons, J., Walsh, B., Gerace, S., Holubynak, E., Righetti, T., Microreactor Applications in U.S. Markets: Evaluation of State-Level Legal, Regulatory, Economic and Technology Implications, Report, Idaho National Laboratory, prepared for the U.S. Department of Energy, INL/RPT-22-02756, March 2023.

Junior Mining Network. 2022. "U.S. Government Cites Graphite One's Graphite Creek as the Largest Graphite Deposit in the United States," , Accessed Aug 31, 2022.Kawerak, Inc. 2019. "Bering Straits Comprehensive Economic Development Strategy, 2019-2024," https://www.commerce.alaska.gov/web/Portals/4/pub/ARDORs/2020%20report/Bering%20Strait%20CEDS.PDF.

Koerner, C. "Wildfire and electric grid: Crisis requires long-term planning rather than rapid response." The Hill, August 11, 2022. https://thehill.com/opinion/energy-environment/3594389-wildfire-and-electric-grid-crisis-requires-long-term-planning-rather-than-rapid-response/.

Larsen, Zachary. 2019. "In Defense of the Modern Company Town: Wyoming's Uranium Communities." Master's Thesis, Utah State University.

Lasley, Shane. 2022. "Graphite One builds momentum into 2022," North of 60 Mining News, https://www.miningnewsnorth.com/story/2021/12/31/news/graphite-one-builds-momentum-into-2022/7131.html, Accessed December 16, 2022.

Lazard. 2021. "Levelized Cost of Energy, Levelized Cost of Storage, and Levelized Cost of Hydrogen," October 28, 2021, http://www.lazard.com/perspective/levelized-cost-of-energy-levelized-cost-of-storage-andlevelized-cost-of-hydrogen.

Loewi, Peter. 2022. "Governor Visits Nome, Listens to Report on Energy," Nome Nugget News, August 11, 2022. http://nomenugget.net/news/governor-visits-nome-listens-report-energy.

Lopez, N. "Feds allow Diablo Canyon to stay open while seeking 20-year extension," Cal Matters, March 2, 2023, https://calmatters.org/environment/2023/03/diablo-canyon-nuclear-power-plant/.

Macdonald, R. and Parsons, J.E., 2021. "The Value of Nuclear Microreactors in Providing Heat and Electricity to Alaskan Communities," MIT Center for Energy and Environmental Policy, Research Working Paper 21-018, November.

McDermott, Jennifer. 2023. "Nuclear Microreactors may be a game changer," Real Clear Markets, February 13, 2023. https://www.realclearmarkets.com/2023/02/13/nuclear_microreactors_may_be_a_game_changer_881240.html.

Merrifield, Jeffrey S., Craig J. Saperstein, Sidney L. Fowler, and Nicole Steinberg. 2022. The CHIPS and Science Act Offers Support to Advanced Nuclear and Fusion Industries, Pillsbury Insights, August 24, 2022. https://www.pillsburylaw.com/en/news-and-insights/chips-science-act-supports-nuclear-fusion-industries.html.

Michigan Public Service Commission. "MPSC issues request for proposals for study on future of nuclear power generation in Michigan," January 5, 2023, https://www.michigan.gov/mpsc/commission/news-releases/2023/01/05/mpsc-issues-request-for-proposals-for-study-on-future-of-nuclear-power-generation-in-michigan.

Mills, E. and Hershman, H. "Gillette, Wyoming: Industry and politics in coal country, "Marketplace, March 10, 2017, https://www.marketplace.org/2017/03/10/gillette-wyoming-industry-and-politics-coal-country/.

Mining.com. 2022. "Graphite One prefeasibility outlines $1.2bn capex for Alaska mine and Washington state plant," https://www.mining.com/graphite-one-prefeasibility-outlines-1-2bn-capex-for-alaska-mine-and-washington-state-plant/, Accessed December 16, 2022.

Moore-Bloom, Ruby. 2022. "Policies Could Jumpstart Heat Pump Adoption," Clean Energy Transition Institute, June 20, 2022, https://www.cleanenergytransition.org/post/policies-could-jumpstart-heat-pump-adoption.

National Conference of State Legislatures. 2018. "State Oil and Gas Severance Taxes," https://www.ncsl.org/energy/state-oil-and-gas-severance-taxes#:~:text=Tax%20Type%3A%20Energy%20Minerals%20Severance,percent%20to%20State%20General%20Fund.

National Energy Technology Laboratory (NETL). "Nome Region Energy Assessment," Report, DOE/NETL 2007/1284, March 2008.

New York Times (NYT). 1913. "Storm sweeps away 500 houses at Nome; famous Alaskan camp nearly destroyed – damage will be $1,500,000." New York Times, https://www.nytimes.com/1913/10/07/archives/storm-sweeps-away-500-houses-at-nome-famous-alaskan-camp-nearly.html, Accessed December 16, 2022.

Nichol, M. and Desai, H., 2019. "Cost competitiveness of micro-reactors for remote markets," Nuclear Energy Institute, Washington, DC.

Nome Joint Utility Systems (NJUS). 2022. "Nome Community Energy Today and Tomorrow", Report, NJUS.

Nome Joint Utility Systems (NJUS). 2023. Load Data, NJUS.

Norton Sound Economic Development Corporation (NSEDC). 2022. "2021 Annual Report," https://www.nsedc.com/wp-content/uploads/2021-NSEDC-AR-Web.pdf.

Nuclear Energy Institute. "State Legislation and Regulations Supporting Nuclear Energy," January 2023.

OECD. n.d. "Managing Environmental and Energy Transitions for Regions and Cities," www.oecd.org/greengrowth/energy-environment-transition.htm, Accessed September 1, 2022.

Office of Nuclear Energy. 2021. "U.S. Department of Energy Seeks Input on Creation of HALEU Availability Program," https://www.energy.gov/ne/articles/us-department-energy-seeks-input-creation-haleu-availability-program, Accessed November 29, 2022.

Parsons, J. "Evaluating the Cost Competitiveness of Microreactors," Emerging Energy Analysis Initiative, Report, MIT, March 2023, also Appendix D, in Aumeier, S., Shropshire, D., Araujo, K., Koerner, C., Bell, C., Fauske, G., Johnson, R., Parsons, J., Walsh, B., Gerace, S., Holubynak, E., Righetti, T., Microreactor Applications in U.S. Markets: Evaluation of State-Level Legal, Regulatory, Economic and Technology Implications, Report, Idaho National Laboratory, prepared for the U.S. Department of Energy, INL/RPT-22-02756, March 2023.

Patel, Sonal. 2023. "X-energy and Dow Will Deploy a 320-MWe Xe-100 Nuclear Facility at Gulf Coast Site," Power Magazine, March 1, 2023, https://www.powermag.com/x-energy-and-dow-will-deploy-a-320-mwe-xe-100-nuclear-facility-at-gulf-coast-site/.

Pike, Chris and Nathan Green. 2017. "Nome Wind-Diesel System Overview," Draft Technical Report, ACEP, November 1, 2017. https://acep.uaf.edu/media/288908/Pike-Green_Nome_Wind-Diesel_Final.pdf.

Pitcher, Don. n.d. "A Brief History of Nome, Alaska," https://www.moon.com/travel/trip-ideas/a-brief-history-of-nome-alaska, Accessed September 6, 2022.

Pollack, Nicole. 2023. "Demand for Wyoming coal is collapsing. Seismic changes are ahead for the state," Casper Star Tribune, Updated Feb 14, 2023, https://trib.com/business/energy/demand-for-wyoming-coal-is-collapsing-seismic-changes-are-ahead-for-the-state/article_c1c779b4-8de4-11ed-8e53-a76dd4b949a4.html.

Powers, Mary and Debra K. Rubin. 2022. "Biden, Senate Committee Push to Expand U.S. 'Critical Minerals' Mining," Engineering News-Record, https://www.enr.com/articles/53878-biden-senate-committee-push-to-expand-us-critical-minerals-mining, Accessed November 29, 2022.

Propp, Alan. 2017. "Beyond the Coal Boom: Powder River Basin Residents Look to a Diversified Future." & the West, Stanford University, https://andthewest.stanford.edu/2017/beyond-the-coal-boom-powder-river-basin-residents-look-to-a-diversified-future/, Accessed September 9, 2022.

Rankine, Alex. 2022. "Why Europe Could be Heading for a 'Nuclear Renaissance' with Energy Prices at Record Highs", Money Week, April 15, 2022, https://moneyweek.com/investments/commodities/energy/604701/why-europe-could-be-heading-for-a-nuclear-renaissance-with.

Raven, Rob, Suzanne Van den Bosch, and Rob Weterings. 2010. "Transitions and Strategic Niche Management," *International Journal of Technology Management*, 51(1): 57-74.

Ray, Aaron, Daniel Shea, Christopher McMichael, and Austin Ingleheart. 2022. "2021 Legislative Energy Trends," National Conference of State Legislatures, last update April 25, 2022, https://www.ncsl.org/research/energy/2021-legislative-energy-trends.aspx.

Reese, Nick. 2022. Campbell County, Wyoming Electricity Rates & Statistics, https://findenergy.com/wy/campbell-county-electricity/.

Rhode, Scott. 2022. "Nukes of the North: Copper Valley Electric Association studies micro modular reactor," Alaska Business, Feb 4, 2022, https://www.akbizmag.com/industry/energy/nukes-of-the-north-copper-valley-electric-association-studies-micro-modular-reactor/.

Rogers, Everett. 1995. Diffusion of Innovations (4th ed.). Free Press: New York, NY.

Rosen, Y. 2021. "For fortune hunters dredging Alaska's Bering Sea floor for gold, old mining traditions blend with new realities," Arctic Today, https://www.arctictoday.com/for-fortune-hunters-dredging-alaskas-bering-sea-floor-for-gold-old-mining-traditions-blend-with-new-realities/, Accessed September 6, 2022.

Schot, Johan and Frank W. Geels. 2008. "Strategic Niche Management and Sustainable Innovation Journeys: Theory, Findings, Research Agenda, and Policy," *Technology Analysis & Strategic Management*, 20(5): 537–554. https://doi.org/10.1080/09537320802292651.

Scott, A.G., 2015. Fuel Oil Volatility – Complications for Evaluating a Proposed Power Purchase Agreement for Renewable Energy in Nome, AK, Innovating Energy Access for Remote Areas: Discovering Untapped Resources, 89.

Secretary of the Air Force. 2022. "Request for Proposal Released for Eielson Air Force Base Micro-Reactor Pilot Program," September 26, 2022, https://www.safie.hq.af.mil/News/Article-Display/Article/3169035/request-for-proposal-released-for-eielson-air-force-base-micro-reactor-pilot-pr/.

Segall, Peter. 2022. "Dunleavy signs microreactor bill at sustainable energy conference," Juneau Empire, May 24, 2022, https://www.juneauempire.com/news/dunleavy-signs-microreactor-bill-at-sustainable-energy-conference/.

Shropshire, David, Geoffrey Black, and Kathleen Araújo. 2021. "Global Market Analysis of Microreactors," Report, INL/EXT-21-6314, DOE Microreactor Program.

Singer, Stephen. 2023. "Nebraska utility reviews sites for small modular nuclear reactors using U.S. pandemic aid," Utility Dive, January 18, 2023, https://www.utilitydive.com/news/nebraska-nppd-nuclear-small-modular-reactor-smr-study/640554/.

State of Oregon. N.d. "Renewable Portfolio Standard," https://www.oregon.gov/energy/energy-oregon/pages/renewable-portfolio-standard.aspx, Accessed March 16, 2023.

State of Wyoming: Consensus Revenue Estimating Group (CREG). 2022. "Wyoming State Government Revenue Forecast Fiscal Year 2023 – Fiscal Year 2028," https://www.wyoleg.gov/budget/CREG/Reports/Oct2022CREGReport.pdf.

Steever, Bill and Mike Campbell. 2016. "From the storm that destroyed Nome to vicious volcanic ash, here are 10 of Alaska's biggest wind events," Anchorage Daily News, https://www.adn.com/alaska-life/we-alaskans/2016/10/23/from-the-storm-that-destroyed-nome-to-vicious-volcanic-ash-here-are-10-of-alaskas-biggest-wind-events/, Accessed December 16, 2022.

Stoellinger, Temple, Steve Smutko, Selena Gerace, and Nita Tallent. 2022. "Clean Energy Hub Stakeholder Identification," Emerging Energy Markets Analysis Initiative, White Paper, University of Wyoming.

Storrow, Benjamin. 2022. "Rhode Island passes bill to go 100% renewable," EnergyWire, June 16, 2022.

Stroka, Mary. 2022. "TerraPower: Natrium reactor plant delayed due to limited HALEU," Oil City News, December 15, 2022, https://oilcity.news/community/energy-community/2022/12/15/terrapower-natrium-reactor-plant-delayed-due-to-limited-haleu/.

Sutter, John. 2021. "Opinion: This town powered America for decades. What do we owe them?" CNN, https://www.cnn.com/2021/01/23/opinions/biden-climate-change-gillette-wyoming-coal-sutter/index.html, Accessed September 9, 2022.

Swanek, Thaddeus. 2019. "President Signs Bipartisan Bill to Modernize Nuclear Regulation," Nuclear Energy Institute, https://www.nei.org/news/2019/president-signs-bill-to-modernize-nuclear.

Szondy, David. 2021. "US Air Force to install nuclear micro-reactor at Alaskan base." New Atlas, October 23, 2021, https://newatlas.com/military/us-air-force-nuclear-micro-reactor-alaska/, Accessed 6 March 2023.

Tan, Caitlin. “The Opening of TerraPower’s Nuclear Plant in Kemmerer will be Delayed by Two Years,” Wyoming Public Radio, December 14, 2022, https://www.wyomingpublicmedia.org/natural-resources-energy/2022-12-14/the-opening-of-terrapowers-nuclear-plant-in-kemmerer-will-be-delayed-by-two-years.

TerraPower. 2021. “TerraPower selects Kemmerer, Wyoming as the preferred site for advanced reactor demonstration plant,” November 16, 2021. https://www.terrapower.com/natrium-demo-kemmerer-wyoming/.

Time. 1934. “Nome no more.” Time. https://content.time.com/time/subscriber/article/0,33009,930524,00.html, Accessed December 16, 2022.

Thompson, Jonathan. “Thumbs up on Wyoming’s Wind Tax,” High Country News, Feb 25, 2010, https://www.hcn.org/blogs/goat/thumbs-up-for-wyos-wind-tax.

Thompson, Jonathan. “How the West’s Public Lands Fared in 2022,” High Country News, December 22, 2022. https://www.hcn.org/articles/landline-how-the-wests-public-lands-fared-in-2022/print_view.

Thompson, Jonathan. “Wyoming’s Coal-fired Economy is Coming to an End,” High Country News, December 4, 2019, https://www.hcn.org/issues/51.21-22/coal-wyomings-coal-fired-economy-is-coming-to-an-end/print_view.

Tobar, Christine. 2022. "Could a Md. coal plant house a small nuclear reactor?” Maryland, The Daily Record, July 25, 2022, https://thedailyrecord.com/2022/07/25/study-examines-whether-md-coal-plant-could-house-small-nuclear-reactor/.

Ultra Safe Nuclear. 2022. “Copper Valley Electric Partners with Ultra Safe Nuclear Corporation,” Feb 2, 2022, https://www.usnc.com/copper-valley-electric-partners-with-ultra-safe-nuclear-corporation-to-perform-feasibility-study-of-a-micro-modular-reactor-mmr-r-energy-system-in-alaska/.

United Nations. n.d. “Climate Action,” http://www.un.org/en/climatechange/net-zero-coalition, Accessed December 15, 2022.

University of Alaska, Center for Economic Development. 2020. “Microreactors in Alaska, Use Case Analysis,” October, https://static1.squarespace.com/static/59f6b60bcf81e02892fd0261/t/60189ac2d4aab87fb9b3211a/1612225233302/Use+Case+Analysis_Complete.pdf.

U.S. Army Corps of Engineers. 2020. “Integrated Feasibility Report and Final Environmental Assessment.” Port of Nome Modification Feasibility Study, Nome, Alaska, https://www.poa.usace.army.mil/Portals/34/docs/civilworks/publicreview/portofnome/FinalNomeIFREA29May2020signed.pdf?ver=2020-06-02-192545-533.

U.S. Department of Commerce, Economic Development Administration. 2022. “U.S. Department of Commerce Invests $3.4 Million in American Rescue Plan Funds to Support Business Development and Job Growth in Campbell County, Wyoming,” Sep 13, 2022, https://www.eda.gov/archives/2022/news/press-releases/2022/09/13/campbell-county-wy.htm.

U.S. Department of Energy. 2018. “U.S. Dept. Energy Report Explores U.S. Adv. Small Modular Reactors to Boost Grid Resiliency.” U.S. Department of Energy.

U.S. Department of Energy. 2022. “Wyoming Unemployment Falls to 3.0% in July 2022,” Wyoming Department of Workforce Services, Research and Planning, https://doe.state.wy.us/lmi/news.htm, Accessed August 22, 2022.

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. n.d. “Wyoming 80-Meter Wind Resource Map,” https://windexchange.energy.gov/maps-data/142.

U.S. Department of State and Executive Office of the President. "The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050," November 2021, https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf.

U.S. Economic Development Administration. 2022. "U.S. Department of Commerce Invests $3.4 Million in American Rescue Plan Funds to Support Business Development and Job Growth in Campbell County, Wyoming," September 13, 2022, https://www.eda.gov/news/press-release/2022/09/13/us-department-commerce-invests-34-million-american-rescue-plan-funds, Accessed 9 February 2023.

U. S. Geological Survey. 2022. "Bipartisan Infrastructure Law helping Alaska map critical mineral resources," https://www.usgs.gov/news/national-news-release/bipartisan-infrastructure-law-helping-alaska-map-critical-mineral.

U.S. Office of Nuclear Energy. 2022. "Inflation Reduction Act Keeps Momentum Building for Nuclear Power," https://www.energy.gov/ne/articles/inflation-reduction-act-keeps-momentum-building-nuclear-power.

U.S. Senate, Letter to Chair Feinstein and Ranking Member Kennedy, December 22, 2022, https://www.barrasso.senate.gov/public/_cache/files/37129c65-848e-445c-a968-ebd1c8b11564/12.08.2022-ltr-rqsting-funding-for-us-nuceal-fuel-security.pdf.

Vandeer Meer, Jeremy and Marc Mueller-Stoffels. 2014. "Wind-Geothermal-Diesel Hybrid Microgrid Development: A Technical Assessment for Nome, AK," U.S. DOE DE SC0004903 and DE EE 0002846.

Walton, R. "Rhode Island governor signs 'most aggressive renewable energy standard in US, targets 100% offsets by 2033, Utility Dive, June 16, 2022.

Washington Department of Ecology. n.d. "Climate Commitment Act," https://ecology.wa.gov/Air-Climate/Climate-Commitment-Act#:~:text=The%20Climate%20Commitment%20Act%20(CCA,path%20to%20lower%20carbon%20emissions.

Western, Samuel. 2008. "Does Wyoming Get Enough for Its Mineral Riches? Severance Tax Reform in the Cowboy State," WyoFile, February 8, 2008, https://wyofile.com/does-wyoming-get-enough-for-its-mineral-riches-severance-tax-reform-in-the-cowboy-state/.

Wise, Nathan, Kris Koski and Tara Righetti. 2022a. "A Summary of Western Interconnection State Renewable and Clean Energy Standards," Emerging Energy Markets Analysis Initiative, Memo, University of Wyoming.

Wise, Nathan, Kris Koski and Tara Righetti. 2022b. "An analysis of the conditions under which a microreactor could be considered a qualifying facility under PURPA," Emerging Energy Markets Analysis Initiative, Memo, University of Wyoming.

Wise, Nathan, Kris Koski and Tara Righetti. 2022c. "An overview of the regulatory framework for nuclear microreactor applications in Wyoming," Emerging Energy Markets Analysis Initiative, Memo, University of Wyoming.

WNN. 2021. "U.S. conversion plant gears up for next 40 Years," World Nuclear News, https://www.world-nuclear-news.org/Articles/US-conversion-plant-gears-up-for-next-40-years, Accessed November 29, 2022.

WNN. 2022a. "DOE working on its uranium strategy – Granholm," World Nuclear News, https://www.world-nuclear-news.org/Articles/DOE-working-on-its-uranium-strategy-Granholm, Accessed November 15, 2022.

WNN. 2022b. “Certainty of demand key to HALEU supply, says Orano,” World Nuclear News, https://www.world-nuclear-news.org/Articles/Certainty-of-demand-key-to-HALEU-supply-Orano, Accessed November 29, 2022.

Wyoming Demographics. 2023. “Gillette,” https://www.wyoming-demographics.com/gillette-demographics, Accessed February 10, 2023.

Wyoming Department of Workforce Services: Research & Planning. 2022. “Wyoming Labor Force Trends,” https://doe.state.wy.us/lmi/trends/0922/0922.pdf, Accessed November 28, 2022.

WY HB0131. 2022. Nuclear power generation and storage-amendments, State of Wyoming 67th Legislature, https://www.wyoleg.gov/Legislation/2022/HB0131.

Wyoming Legislative Interim Committee. 2015. “Wyoming Mineral Taxation: Constitution, Statutes and Concepts,” Presentation to Attorney General, https://www.wyoleg.gov/InterimCommittee/2015/SMTPresentationAG-DoR.pdf.

Wyoming Legislative Interim Committee. 2015. “Wyoming Mineral Taxation: Constitution, Statutes and Concepts, Presentation to Attorney General, https://www.wyoleg.gov/InterimCommittee/2015/SMTPresentationAG-DoR.pdf.

Wyoming Mining Association. 2021 “Concise Guide to Wyoming Coal,” http://www.wyomingmining.org/wp-content/uploads/2022/02/2021-22-Concise-Guide-to-Wyoming-Coal.pdf, Accessed November 28, 2022.

Wyoming Mining Association. 2023 “Coal,” https://www.wyomingmining.org/minerals/coal/, Accessed February 28, 2023.

Wyoming State Geological Survey. 2022a. “Coal Production and Mining: Quarterly Coal Production,” Report.

Wyoming State Geological Survey. 2022b. “Critical Minerals in Wyoming,” Report, Wyoming State Geological Survey, https://www.wsgs.wyo.gov/products/wsgs-2022-critical%20minerals-summary.pdf, Accessed 29 November 2022.

APPENDIX

Interviewee Affiliations

Alaska

- Alaska Dept of Environmental Conservation
- Alaska Department of Transportation
- Alaska Energy Authority (multiple)
- Alaska Mining Association
- Bering Straits Native Corporation
- Denali Commission
- Consultant - Mining
- Consultant - State energy
- Geological Survey
- Graphite One (multiple)
- Kawarek, Inc
- Kotzebue Elec Association
- Marine Exchange, Alaska
- Nome City (multiple)
- Nome City Council
- Nome Joint Utility Services (multiple)
- Port of Nome (multiple)
- Sierra Club
- Sitnasuak Native Corporation
- University of Alaska (multiple)

Wyoming

- Campbell County (multiple)
- Cyclone Drilling
- Earthwork
- Energy Capital Economic Development Entrepreneur (multiple)
- Gillette Community College
- Journalist
- L&H Industrial
- Powder River Basin Resource Council
- Resident
- University of Wyoming (multiple)

- Uranium Energy Corporation
- Wyoming Business Council
- Wyoming Department of Workforce Services
- Wyoming Economic Development Association
- Wyoming Energy Authority (multiple)
- Wyoming Innovation Partnerships
- Wyoming Mining Association
- Wyoming Workforce Development Council

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Appendix B

UW Wyoming Carbon-Policy Sensitivity Analysis[m]

Wyoming Carbon Policy Sensitivity Analysis

University of Wyoming
School of Energy Resources
Selena Gerace, Eugene Holubynak, Tara Righetti

February 16, 2023

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I. Introduction

This project aims to better understand the potential value chain for industrial microreactor applications in Wyoming. Our research explores whether and why Wyoming industries are motivated to decarbonize and their level of openness to microreactors as a potential solution. We focused on industries that are either currently prevalent or have high potential to be developed in Wyoming and the Rocky Mountain Region and which require a great deal of energy for their operations. Based on these criteria, we chose four industries to analyze: *Trona Mining and Processing*, *Hydrogen Production*, *Direct Air Capture* (DAC), and *Digital Economies (including cryptocurrency mining and data and computational centers)*. We commenced this study with an analysis of the potential markets for microreactors to understand the market context and economic incentives in each industry. We then conducted a series of interviews with industry representatives to gain insights about the specific motivations of different companies, the decisions they're making regarding decarbonization, and their openness to microreactors.

II. Potential Markets for Microreactors in Wyoming

This portion of the study identifies initial market profiles for Wyoming industries that might use microreactors. This preliminary analysis includes industry size and growth potential, current workforce, locations, energy needs, access to global export markets, and other potentially relevant factors.

Wyoming is a net energy producer. The state is a leading producer of fuel resources including coal, oil, and natural gas. In addition, the sustainable resource and energy production portfolio is growing in Wyoming due to changes in energy consumption policies in the neighboring states and favorable policy and regulatory frameworks for Carbon Capture Utilization and Storage, hydrogen, and mineral extraction. The state's high energy literacy, demographics, and the relative remoteness of many communities within the state makes it a potentially attractive market for the introduction of nuclear microreactors (MRs).

Based on interviews with industry leaders and a review of relevant literature, we identified several industries as potential users of microreactors: trona mining, hydrogen, direct air capture (DAC), and digital economies (including data centers and cryptocurrency mining). Each of these industries includes a component which is tied to Wyoming's geology and natural resources, including is trona resources, natural gas necessary for cryptocurrency mining, and production of hydrogen using steam methane reforming (blue hydrogen), and the subsurface geologic storage capacity for hydrogen and DAC. The growth of these industries may therefore result in economic development and increased use of Wyoming's natural resources. A summary of the market potential for microreactors is provided in Table 12.

Table 12. Summary of market potential for Microreactors in Wyoming.

	Data Centers	Digital Economies	Trona	Hydrogen	DAC
Global market size	\$80B	\$5B	\$2.7B	\$130B	\$0.2B
Global market growth potential 2030	\$240-800B	\$10B	\$4.0B	\$1300B	\$12B
Global energy consumption	292 TWh	120-240 TWh	216 TWh	\$4,200 TWh	1,200 MWh
Median energy consumption per unit	150 MW	20 MW	20 TWh	8 TWh	1-1,200 MWh
Size of Wyoming industry	\$1.5B	\$0.25B	\$0.9B	\$2.5B	\$0B

	Data Centers	Digital Economies	Trona	Hydrogen	DAC
Wyoming industry growth potential 2030	$5B	$0.5B	$1.4B	$25B	$2B
Current Wyoming energy consumption	600 MWh	350 MWh	72 TWh	4 TWh	0 MWh
Wyoming energy consumption growth potential 2030	2400 MWh	800 MWh	107 TWh	40 TWh	12 TWh

Most of these sectors are either new or growing. This presents both opportunities and challenges for the use of MRs in these sectors. Because new ventures are still figuring out operational routines and identifying potential ways for optimization, it can be difficult to determine precise energy needs. Additionally, the industries may not have sufficient information on their operational costs or facility design to comprehensively evaluate the use of microreactors. However, the interviews clearly articulate a demand for sustainable power sourcing in these new industries. MRs therefore present a great opportunity to decarbonize and optimize energy and resource production operations.

a. Trona Mining

The mining industry accounts for 10 percent of world energy consumption. The U.S. mining industry (excluding oil & gas) consumes approximately 1,246 trillion Btu/year (BSC Incorporated, 2007). Wyoming has the world's largest deposit of trona, supplying about 90% of the nation's soda ash (WMA website, 2022). Wyoming mines produced over 17.4 million tons of trona and employed 2,225 people in 2018.

The U.S. trona market size was valued at $1.33 billion in 2019 (GVR Report, 2020) and it is expected to register a compound annual growth rate of 1.7% from 2020 to 2025. The market is anticipated to be driven by increasing demand for trona from animal feed, air pollution control, and soda ash industries. Trona is primarily used to manufacture soda ash, by heating it to a very high temperature and converting it to sodium-carbonate.

Trona is mined underground using heavy equipment such as continuous miners, most of which are electric. The use of energy by the trona industry is estimated at 72 TWh. To reduce the carbon footprint and provide flexibility of power supply, some trona companies are currently considering alternative supply sources for heat and power.

b. Hydrogen

The International Energy Agency's (IEA) World Energy Outlook 2022, provides a 2050 net-zero scenario, envisioning the deployment of clean (low-carbon) hydrogen at a rapid pace. By 2050, the IEA projects clean hydrogen sources to account for at least 10% of global energy consumption, which entails a 300% scale-up of clean hydrogen production by 2030 and a staggering 1,500% by 2050.

At 10 Mt of hydrogen produced per year, the United States trails China and several other European and Asian countries in terms of total hydrogen production. In the United States, production of clean hydrogen has generally been slow to achieve pace with essential climate targets due to complex policy barriers, lack of infrastructure, and the high costs associated with production. However, a new suite of climate-friendly legislation, policy, and appropriations—such as the Infrastructure Investment and Jobs Act (IIJA), the Inflation Reduction Act (IRA), and the Department of Energy's (DOE) "Earthshots" Initiative—have energized ambitions for domestic production of clean hydrogen with promises to turbo-charge development via incentives such as direct funding as well as production tax credits for qualified "clean" hydrogen production. The IIJA, for instance, allocates a total of $9.5 billion USD in appropriations for clean hydrogen, a substantial portion of which is dedicated to the development of four or more hydrogen hubs across the country. In 2022, the IRA subsequently added significant tax incentives to encourage the development of clean hydrogen in the United States. Notable additions included a new Section 45V of the tax code, which creates a two-tier, inflation-adjusted, 10-year production tax credit for clean hydrogen produced after 2022 at a qualified facility on which construction is initiated before 2033. The main objective of the incentives provided by the U.S. DOE is to grow hydrogen economy and ecosystem within the U.S. to ten times the present production.

Wyoming has the resources and policy necessary to support development of new hydrogen projects. Blue hydrogen is produced from natural gas, with resulting emissions managed through carbon capture and storage (CCS). The successful and efficient production of blue hydrogen requires a unique blend of geology, infrastructure, policy, and incentives. It requires proximity to feedstock, geologically appropriate formations for carbon sequestration, and extensive transportation infrastructure—all within a jurisdiction that has passed favorable CCS policy. As a national leader in energy innovation and production, Wyoming ranks among the top ten states for both natural gas reserves and production and has a vital interest in securing the long-term viability of its fossil fuel economy and taking advantage of its extensive subsurface pore space for CCS. The state has supported a decade of research to determine the feasibility and safety of geologic storage and has enacted a leading-edge legal regime that clarifies the requirements of CCS projects, including laws to allocate pore space ownership and liability and establish injection certification and permitting procedures. Wyoming received primacy from US EPA for UIC Class VI in 2020. Its existing energy transport network includes both extensive rail, pipeline, and interstate highway systems that have evolved in correlation with Wyoming's export of energy to high-demand markets across the West Coast to the Midwest. Each of these features make Wyoming an ideal location for a blue hydrogen economy.

With the tremendous growth potential in mind, there are several applications of nuclear MRs for hydrogen ecosystems. These include mobile technologies based on hydrogen in combination with use of the nuclear microreactors for both civilian and military NATO operations (Gryz et al., 2021), the use of mobile Haber-Bosh applications for ammonia production (Ganley, Seebauer, Masel, 2004), and the use of sustainable nuclear power for hydrogen production during steam methane reforming or autothermal reforming processes that that operate at relatively high pressures and temperatures. Although this section of the report focuses on hydrogen production, the potential for ammonia production in the state is currently being assessed and represents a potential area for further study.

c. Direct Air Capture (DAC)

There are currently 18 DAC plants operating worldwide, capturing almost 0.01 Mt CO2/year. A 1 Mt CO2/year capture plant is in advanced development in the United States. In the Net Zero Emissions by 2050 Scenario, DAC is scaled up to capture almost 60 Mt CO2/year by 2030 (IEA, 2022). Several DAC companies are looking to develop sequestration hubs in Wyoming at present due to its favorable geology and geologic sequestration legal and regulatory frameworks.

It takes around 1,200 kilowatt-hours to remove a ton of carbon from the atmosphere using DAC. Because the economic viability of DAC relies exclusively on carbon-based incentives such as 45Q and voluntary carbon markets which take into account lifecycle net-CO_2 removals, sustainable energy production is critical for this industry. U.S. DOE has recently funded a study that examines the use of DAC combined with dedicated long-term carbon storage and coupled to existing low-carbon energy (U.S. DOE, 2022a). Microreactors could play a role in this new and growing industry.

d. Cryptocurrency Mining

Cryptocurrency mining has grown into a substantial industry over recent years, with fluctuating valuations that exceed trillions of U.S. dollars. Mining involves an energy intensive process of verifying blocks of transactions on the blockchain known as "hashing." The size of the market of the energy consumption for this industry globally is often compared to the power consumption by a small size European country and is estimated between 120 and 240 billion kilowatt-hours per year (OSTP, 2022).

The global cryptocurrency market was valued at $4.25 billion in 2021 and is expected to expand at a compound annual growth rate of 12.2% from 2022 to 2030 (GVR Report, 2022). According to IP addresses from people involved in Cryptocurrency mining, in 2020, the countries that mine the most Cryptocurrency are closely related to cheap energy prices, (Cambridge Centre for Alternative Finance 2022).

The sizes and power capacities for cryptocurrency mining operations vary widely from below 1 MW to hundreds of MWs (OSTP, 2022). The medium size of crypto mining operation is in the tens of MWs. Due to the young age of this industry, the process of operational optimization has not been complete yet. Also, the remoteness of the location for the cryptocurrency mining operation is playing a smaller role with the availability of reliable internet access. Some of these operations are currently looking to use methane emissions from oil and gas production operations (Hall, 2022) in various basins across the USA. The pressure to use sustainable power sources for operations and openness to new technologies makes this industry a potential pilot candidate for nuclear MRs. The scalability of the operations and modular nature creates an opportunity to scale the operations to the power source.

Wyoming's crypto-friendly legislation (WY SF0125; Long, 2019) provides more consumer protection and investment security, as well as an easier means of acquiring digital assets. These regulations give crypto companies a better understanding of their legal status and it will decrease operational risk and uncertainty (Aspan, 2021; Alford, 2021). With the industry projected to grow in Wyoming, sustainable power generation options will be required. In 2022, Black Hills Energy, a publicly traded utility, announced (Ligon, 2022) that it will deliver up to 75 MW of power to a new mining operation in Cheyenne. There are other crypto mining companies (Fugate, 2022) that operate or are planning to operate in Wyoming soon. The energy consumption by the industry ranges from 5 to 75 MW.

e. Data and Computational Centers

The demand for data and computational centers is expected to grow in the coming years. Some studies (Andrae & Edler, 2015; Andrae, 2019; Andrae, 2020; Koot & Wijnhoven, 2021; Hintemann & Hinterholzer, 2019) estimate the market will grow 3 to 10 times from the current capacities by 2030, with the current market size estimated at around $80B. Data and computational centers help to solve the growing need to process data for various applications, that include direct data storage, video streaming, communication technology's needs, monitoring information on industrial processes, artificial intelligence, and machine learning. User behavior increases data center energy needs from 292 TWhs in 2016 to 353 TWhs in 2030 (Koot & Wijnhoven, 2021). Although datacenter workloads continue to grow exponentially, due to implementation of energy use optimization strategies, the demand for power use by datacenters has decoupled from the exponential trend (Shehabi, 2018). The power supply needs of individual data centers are variable. There is no standard configuration. While data centers are increasingly requiring energy capacity of close to 100 MW of power or more, there are many data centers requiring less than 1 MW of power as well. The size of future data centers may depend on the availability of power supplies.

There are estimations relative contribution of greenhouse gas emissions by data centers could grow from roughly 1–1.6% in 2007 to exceed 14% of the 2016-level worldwide by 2040, accounting for more than half of the current relative contribution of the whole transportation sector (Belkhir & Elmeligi, 2018). Therefore, many new construction facilities carefully select development sites based on many criteria, including sustainable power generation availability, such as hydro or renewable generation. With the expansion of the internet network capacities and capabilities, the value proposition of data center construction in remote locations with available power supplies is becoming more viable. This may create a market opportunity for the use of nuclear MRs. For example, Kohler Power Systems (Miller, 2022) is running 120MW data center in Illinois on nuclear power and is excited about the potential for nuclear power generation capabilities for data centers “within perimeter” that becomes a possibility with nuclear MRs.

Currently, there are four data centers in Wyoming in Afton, Casper, Cheyenne, and Sheridan (Data Center Map, 2022). For example, Microsoft operates a datacenter in Cheyenne, Wyoming. The power sources for the facility are Cheyenne Light, Fuel and Power Company and Black Hills Energy and the estimated energy consumption is 237 MW. In 2015, the expansion was expected to bring the company's total investment in the data center to $750 million and employment to 50 full-time jobs. Among considerations for building the data center in Wyoming were available cheap energy and cool climate that makes data center operations more efficient (per Microsoft representative). Between 30% to 55% of a data center's energy consumption goes into powering its cooling and ventilation systems (Rong, 2015).

III. Carbon Policy Sensitivity Analysis: Interviews with Industry

To better understand the potential value chain for the use of industrial microreactor applications in Wyoming, industry motivations to decarbonize, and industry openness to microreactors, we conducted a series of interviews with representatives of each of these four industries: *Trona Mining and Processing* (2 interviews), *Hydrogen Production* (2 interview), *Direct Air Capture* (DAC) (3 interviews), and *Digital Economies* (2 interviews for *Cryptocurrency Mining* and 1 interview for *Data Centers)*. We focused our study specifically on companies currently operating in Wyoming or considering developing project in Wyoming to gain insights about the specific needs, opportunities, and limitations presented by the state's geography, infrastructure, regulations, and markets.

We found and selected our interviewees by reaching out to UW School of Energy Resources' current network of connections in the energy industry. We also requested assistance from project partners in identifying potential representatives in these organizations. Lastly, we used the snowball sampling method of asking interviewees to make connections to other people in their industries. As such, this report represents a situation assessment of the current energy needs and motivations of these industries—an assessment aimed at informing future research and next steps. It does not, however, represent a comprehensive simple random sample of the industry, nor should it be considered statistically significant. The sample size of our study, while naturally limited due to the limited number of market participants in Wyoming, is sufficiently representative of these industries in the state for the purposes of informing future research.

We asked interviewees a series of questions aimed at understanding their needs and motivations related to energy sources. Specifically, we asked questions about: 1) the current energy sources they are using, 2) what is motivating them to decarbonize their energy sources (if indeed they are feeling motivated to decarbonize), 3) the timeframe in which the plan to decarbonize, 4) their preference for decarbonized energy from the grid vs. developing their own decarbonized source of energy, 5) their openness to considering microreactors as a source of low carbon energy, 6) what other sources of decarbonized energy they are considering adopting, and 7) what attributes are most important to them in an energy source.

It's important to note that each of these industries has different needs and constraints around energy, different relationships to decarbonized energy and the clean energy 'ecosystem' and are at different stages of their operations—with some being well-established companies that have been operating for decades and others being companies that are still in the project development phase and have not begun operations yet. It is helpful to consider these industries in two different categories: 1) DAC and Hydrogen Production which are industries specially operating in the decarbonization space (either to provide low-carbon energy or to provide decarbonization services), 2) Trona and Digital Economies which may participate in decarbonization, but the primary product they are producing is something else (e.g., soda ash, data services, or cryptocurrency). As such, we adapted questions slightly to fit the context of the industry representative we were interviewing.

Also, of note, while interviewees were asked about the views on microreactors (MRs) as a potential energy source (e.g., if they would consider it and why, and if they had concerns about it), many didn't have specific views about MR technology or specific knowledge about the potential benefits or costs of MRs. However, all were familiar with the concept of small-scale, advanced nuclear reactors in general and most took the opportunity to discuss their views on small modular reactors (SMRs) and nuclear energy more broadly.

Below is an analysis of the major findings from the interviews. To ensure confidentiality, we have kept all interviewees and the companies they represent anonymous and have not reported any identifying details. Towards this purpose, interviewees are referred to using the pronouns "they" whereas companies are referred to as "it."

a. Findings from Interviews

Trona

Current energy sources:

Both trona industry representatives who were interviewed reported that their companies have co-generation systems on their coal and natural gas boilers that produce heat (which is used to generate the necessary steam that is used in processing trona) and electricity. Both also said their companies purchase electricity from Rocky Mountain Power (RMP). One representative specified that their company used some diesel fuel as well. CO_2 emissions are generated from all of these energy sources, including the fossil fuels burned on site and the purchased electricity from RMP which is generated with a mix of fossil and non-fossil energy resources. CO_2 is also released during the processing of trona into soda ash.

Motivations to decarbonize:

When asked if they feel pressure to decarbonize, the answer was a resounding *yes* from the trona industry representatives. "We feel an incredible amount of pressure," said one representative. When asked where this pressure is coming from, both representatives listed several drivers. These include:

The impending demise of coal: One representative said that part of this pressure is simply due to the impending demise of coal. As more coal-fired power plants are scheduled for closure, the coal mines that supply their coal could also close. Those are the same coal mines that supply the coal for the trona industry. As such, the industry is anticipating that it could become increasingly difficult to have a reliable and cost competitive supply of coal to run boilers.

Market/customer demand: Both representatives said pressure is coming from customer demand. "Customers are asking for decarbonized energy," said one representative, and customers care about the carbon footprint of the product they purchase. This representative attributed this to the customers' own concerns about meeting sustainability goals and their Environmental, Social, and Governance (ESG) scores. Interestingly though, even though the trona industry representatives reported feeling pressure from their customers to decarbonize, they also said that this has not yet translated into a decrease in demand for their companies' products. One representative attributed this to the absence of a lower emissions alternative. The only alternative for natural soda ash is synthetic soda ash which has 20% more greenhouse gas emissions. But still, as one representative said, "Customers are saying that what we're doing isn't good enough and want to know what we're going to do to reduce emissions further." If synthetic trona producers were to decarbonize so as to produce advantaged products, that could increase consumer choices.

Peer pressure: One trona industry representative said that part of the pressure they feel to decarbonize comes from concern that other trona industry companies will decarbonize first. If that were to happen, the trona produced with a lower carbon footprint may be more competitive on the market. However, the representative also said their company doesn't want to adopt costly decarbonization systems that would increase its operating costs and make it not cost competitive with others in the industry. The company is threading a needle between not being the first to go all in on decarbonization and not being left behind.

Reputation: One representative cited the long-term future reputation of the company as a motivation, saying that community sentiment and perspectives are important, including the perspectives of the local community, the investor community, as well as the perspectives of employees and potential employees. The people it is hiring want to know about the company's emissions profile and want to work for a company that values and embodies sustainability practices. As such, the representative said, if the company wants to attract the best employees, it needs to be responsive to this desire.

Regulation and policy: Neither representative cited regulation nor policy as a major driver of pressure to decarbonize. They considered it a potential future source of pressure and something to keep up to date on, but currently, there were no specific policies motivating the immediate drive toward decarbonization. One representative said there were some potential tax subsidies or carbon credits the company could take advantage of depending on the type of decarbonized energy it switches to, but said it isn't clear how much these subsidies or credits will do to offset the cost of decarbonation.

Timeframe to decarbonize:

One representative said that their company's timeline to reduce carbon emissions from its' operations was clearly defined. A company-wide goal was set for reducing greenhouse gas emissions by 30% by 2030. The other representative indicated that the timeline was not well defined yet, saying that the company doesn't have a goal established and is still in the stage of understanding what the available options and costs are and determining what will be possible. "We want to take a bottom-up look and see what is feasible," the representative said.

Preference for decarbonized grid vs. developing own source of decarbonized energy:

We asked interviewees if they had a preference between purchasing decarbonized energy from the grid (if it were available), developing their own decarbonized source of energy, or if they would consider relocating to a state that offered a decarbonized option. Trona industry representatives said they would definitely be interested in a decarbonized option offered by the state if that were available. However, since it's not, both said their companies are looking into their own decarbonized energy systems. Since trona mining and soda ash production are tied to the location of the natural resource, relocating to an area with lower cost clean energy is not a viable option.

Openness to and concerns about MRs/SMR/nuclear energy:

Both trona industry representatives expressed openness to and interest in small-scale, advanced nuclear reactor technology. They cited the benefits of it being a carbon-free source of energy that is reliable and has a small footprint. One representative said that SMRs are also appealing because they can generate both heat (for producing steam) and electricity (of which, any that is unused, could be sold back to the grid).

However, both representatives also said they have concerns about SMRs and nuclear energy more generally. They both expressed concerns about how long it would take to implement an SMR system due to uncertainty about the technology being ready for adoption today and due to the rigorous and prolonged permitting process for nuclear energy. Costs were also mentioned as a concern with one representative saying their company would consider SMRs more concretely "once the regulatory hurdles are out of the way, the costs more defined, and the industry proven."

Additionally, concerns were expressed by both representatives about the public perceptions of nuclear energy. One representative said that while they believe current nuclear technology is safe and will be an important energy source in the future, they are concerned that the broader public does not yet seem to have this perspective. The representative continued, "If we want to be truly carbon-free, we have to embrace nuclear. The success of the Natrium plant will be critical to our society's view of nuclear power."

Other decarbonization options being considered:

When asked about the type of decarbonized energy system they're considering, both representatives said their companies were considering a variety of options in addition to their interest in nuclear technology. These options included:

Natural gas: Both representatives said that converting the company's coal boilers to burn natural gas instead is the most viable option for reducing greenhouse gas emissions in the short term. Both said natural gas is appealing because it has a *lower-carbon* intensity, is readily available, and is reliable. However, both expressed some concerns about natural gas, as well. One representative said that natural gas isn't *as reliable* as coal because it's not possible to stockpile it on site and have guaranteed energy reserves. Additionally, the other representative expressed concerns about the rising cost of natural gas.

CCS: Both representatives said they have considered Carbon Capture and Storage (CCS) to decarbonize their current energy sources and operations, but each has some concerns about this option as well. These concerns included the lack of widespread adoption of CCS systems currently and the high costs of adopting the technology and building the necessary infrastructure.

Hydrogen: Hydrogen was also mentioned by one representative as an option being considered. While this representative said that the hydrogen infrastructure isn't developed enough yet for it to be an option right now, the company would consider it in the future.

Notably, both representatives said they have looked into, but cannot feasibly consider, wind or solar. Neither representative considered them to be viable options because of the intermittent nature of their energy generation which means back-up power must be purchased from the grid at an elevated price, and because these renewable resources don't produce thermal heat for generating the necessary steam for trona processing.

Also notably, one representative again pointed out the nuanced challenge of balancing the benefits and costs of adopting decarbonized energy, saying that if costs of decarbonization are too high, the company would become uncompetitive and lose market share. This could, paradoxically, result in a net increase in global emissions if producers outside the U.S. who have higher emissions pick up that market share.

Importance of different attributes of energy types:

When asked to rank the relative importance of *timing* (i.e., how long it would take to implement the decarbonized energy), *cost*, and *reliability* when choosing an energy source, both trona industry representatives agreed that *reliability* is paramount. The only forms of decarbonized energy their companies are considering are those that will provide reliable energy. Their companies have eliminated wind and solar as possible options due to the unreliable nature of those resources. Likewise, *timing* was also identified as a key consideration for the industry. Both representatives indicated the need to make plans to decarbonize imminently and the challenge of doing this if a technology that isn't commercially available yet or if the permitting process could be lengthy. While *cost* was mentioned several times throughout both interviews as an important consideration due to the need to remain cost-competitive, it was also acknowledged that if the market incentives demand decarbonization, the increased costs would be worth it.

Digital Economies--Cryptocurrency Mining

Current energy sources:

Energy sources differ between cryptocurrency miners. One of the cryptocurrency mining representatives that we interviewed said they currently use vented gas to power the machines used for mining. Because the company is small, the energy requirements are relatively low-- approximately 1 MW of energy. Because vented gas would otherwise be flared or released, using it for energy does not increase greenhouse gas emissions over the status quo. The other cryptocurrency representative, who does not currently operate in Wyoming, said their company uses primarily nuclear and hydroelectric, and some solar and wind. It purchases all its energy from the grid and sets up agreements with the local utilities in different project locations to ensure it is getting its desired clean energy mix. When necessary, some of the grid power the company purchases are generated from natural gas, but it purchases carbon offsets for the carbon intensity of this energy.

Motivations to decarbonize:

Social responsibility: Both cryptocurrency mining representatives said using decarbonized energy was important to them and their companies as a value and as important for society. One representative attributed this value to a drive towards advancing society and believes reliable decarbonized energy is essential for the long-term progress of society and our ability to continue to evolve as a species. The other representative said that "It's the right thing to do. The climate emergency is real and large purchasers of energy have the opportunity to facilitate the energy transition through a market-based approach." Elaborating on this, the representative said that the more demand cryptocurrency miners create for low-carbon energy, the faster the transition to low-carbon energy will happen. This representative said their company pays more for low-carbon energy but believes that what it gets in return is 'largely in the form of good will" from the communities in which it operates.

ESG: One cryptocurrency mining representative also said that the cryptocurrency mining industry overall is feeling the pressure of ESG reporting standards. The representative said that while this is less of a concern for small companies, it is a considerable concern for publicly traded companies. The carbon intensity of the energy source cryptocurrency miners use has a direct impact on ESG scores which can impact the ability to attract investors. This is especially challenging because it can be difficult to find decarbonized sources of energy that are cost competitive in many locations.

Timeframe to decarbonize:

One cryptocurrency mining representative said that their company is currently in the process of formalizing timelines to completely decarbonize but its goal is to operate on 100% clean energy. The other cryptocurrency mining representative said that the timeframe is largely not in their company's power to determine. Speaking specifically about cryptocurrency mining in Wyoming, this representative said that the limitation is the availability of decarbonized energy for miners to purchase. A major hurtle cited is that independent power providers can't sell excess energy they produce unless they sell to a utility or are regulated as a public utility in Wyoming. This is a significant disincentive for potential developers of decarbonized energy that could provide energy to cryptocurrency miners. It also means that cryptocurrency miners are left with few options for energy sources in Wyoming. The representative said, "If there was more nuclear and access to purchase renewable power it would be easy to bring miners here."

Preference for decarbonized grid vs. developing own source of decarbonized energy:

One cryptocurrency mining representative said that as an industry, they would love to purchase decarbonized energy from the grid if possible, however, purchasing any energy from the grid has been a challenge in Wyoming. The representative said that when helping to do site selection for large mining companies, they have had to move projects out of the state because the energy isn't available. Indeed, there is significantly more demand for energy in Wyoming from cryptocurrency miners than there is availability. When Black Hills Energy issued an RFP for cryptocurrency mining companies, they got requests for over 1.2 gigawatts of energy from 15 companies, but it only entered into an agreement with one cryptocurrency company to supply 45 megawatts. The representative also said that setting up power purchase agreements (PPA) with Rocky Mountain Power is cost prohibitive and attributes this to the higher prices Rocky Mountain Power can get by selling their energy out of state. This lack of available energy is a huge barrier for cryptocurrency mining companies to establish themselves in Wyoming, said the representative. And cryptocurrency mining is unique in that miners are highly mobile—they can go to where the energy sources are. So, if it's not available here, they'll go somewhere else.

This cryptocurrency mining representatives also said that some other mining companies are open to investing in building their own energy infrastructure and have the financial means to do so. But, again, there are disincentives to doing this because to sell any of this energy, they would either need a power purchase agreement with the utility or would be regulated as a public utility which would have high costs associated with it. As such, there is a greater trend towards energy companies becoming miners, rather than mining companies becoming energy providers.

The other cryptocurrency mining representative said they purchase all their energy from the grid (for projects outside of Wyoming) and the availability of energy is a determining factor in siting projects. They said that when deciding where to site projects, their company considers if there is power available, if that power is available at a price that allows it to make money, and if that power is produced from low-carbon sources. However, this representative also said there are many disincentives to purchasing grid power, such as fees to hook up to the grid. As such, they believe it could be economical to develop their own source of power.

Openness to and concerns about MRs/SMR/nuclear energy:

Both cryptocurrency mining representatives were strongly supportive of nuclear energy in general, seeing huge potential for it to be used to power mining. One representative stated a preference for it as an energy source for their company's mining operation. This representative expressed some national safety concerns related to commercial-scale nuclear reactors but was highly supportive of small reactors (around 500 MW). The representative also expressed some concerns about the cost of nuclear technology being prohibitive. Overall, though, this representative believes more availability of nuclear energy would not be beneficial because it would attract more cryptocurrency miners to Wyoming, and also believes nuclear energy is necessary and important for the future of human civilization. "Nuclear is best for humanity," said the representative and expressed a desire for more public outreach and education to combat what was characterized as a fear-based campaign against nuclear.

The other representative also expressed strong interest in nuclear energy, saying that their company was very in favor of it. This representative said, "In order to electrify everything, we have to use nuclear or it's not going to happen."

Other decarbonization options being considered:

Wind and solar: One cryptocurrency mining representative expressed interest in both wind and solar as a source of decarbonized energy, but also recognized limitations and tradeoffs related to those resources. Wind and solar have high land-use requirements, and the intermittent nature of them incentivizes a massive buildout of renewables, which creates an even larger footprint on the landscape. The other representative said their company has also considered developing its own solar array as a power source.

Geothermal: One representative expressed some interest in geothermal and thought it could be a good match for cryptocurrency mining but recognizes that it's not an option that is currently available.

Hydroelectric: One representative also mentioned hydroelectric as an affordable and reliable source of energy, but acknowledged that, due to the environmental concerns with building new hydroelectric dams, it probably has limited potential to provide energy for cryptocurrency mining.

Gasifier: One representative said that their company has a patent on a gasifier and thinks there could be opportunities in using it to convert waste to a power source for mining. However, the limitation is finding a consistent waste stream.

<u>Importance of different attributes of energy types</u>:

Because of the extreme competitiveness of the cryptocurrency mining industry, one representative asserted that *cost* is the most important consideration. Because the costs and prices related to mining fluctuate greatly, including costs of the machines and the prices of the commodity, the margins are often very small for being profitable as a miner. "It's probably one of the most competitive industries in the world. If you're paying $0.07 per kw hour for energy, you're barely breaking even," said the representative.

This representative also said that reliability is extremely important because it has a direct impact on profits as well. The machines used to mine cryptocurrency are expensive so it's ideal to have as much *uptime* (time when they are running) as possible. 98% uptime is ideal, this cryptocurrency mining representative said. Any downtime (when the machines aren't running) is expensive because it means that large capital investment isn't generating revenue.

However, it's part of some cryptocurrency miners' business model is to generate revenue from providing grid services in the form of demand flexibility. For example, during times of peak demand, cryptocurrency miners can shut off their mining operations, so they aren't consuming power and will receive subsidies in the form of demand response payments. Miners also can ramp up their mining operations to consume excess renewable energy generation.

The other cryptocurrency miner said simply that the most important attribute to their company is whether the energy is low-carbon. After that *cost* is most important and then *timing.*

<u>Digital Economies--Data Centers</u>

<u>Current energy sources</u>:

The data center representative we interviewed represents a data center project in Wyoming that is in the process of being constructed. When Phase I of the project is completed, it will require 30 MW of electricity. The company has a contract in place with Rocky Mountain Power to supply all of this electricity from a nearby wind farm (with back-up power off the grid to provide reliable electricity when the wind resources are not generating power). It also has developed a liquid cooling system that will require 95% less energy than other cooling systems. This will translate into the data center requiring 50% less energy and will make it one of the most energy efficient data centers in the U.S. The cooling system works by pulling cold water (55 degrees F) out of an aquifer that is just below the water table. This cool water is used for cooling the data center, then the heat from the warmed water will be used to supply heat to an indoor farming operation. The company is also planning to use diesel generators as a backup energy source.

The eventual, planned full build-out of the data center will be considerably larger and will require 120 MW. The company has a strong preference that all its power will be from renewable or low-carbon sources of energy, whether that comes from contracting renewable energy from Rocky Mountain Power or developing their own source of decarbonized energy. It is communicating with a microgrid developer that could develop a solar array near the data center and provide the necessary power.

Motivations to decarbonize:

Policy Incentives: The data center representative said current policies are providing financial incentives that are motivating their company to use decarbonized energy. The company plans to claim investment tax credits (ITCs) for geothermal energy (for its cooling system). Since it is also considering a solar microgrid to supply power for its planned full buildout, it could also be eligible for the ITC for microgrid controllers.

Investor demand: The data center representative said that being eligible for these tax credits for low-carbon energy is also very attractive to investors. Because the full project buildout will be around a $180 million investment, obtaining the necessary investor commitments is challenging, but investors are more willing to invest if the expected project costs are partially offset by the tax credits.

Profitability: The representative also said that profitability and economics are driving their motivation towards decarbonized energy, asserting that carbon emissions have an associated cost, and by reducing the company's carbon footprint, it will also be reducing costs. The example of this mentioned was the indoor farming operation which will transform waste heat from the liquid cooling systems into another profitable output—the farming of local produce. This produce will in turn be sold locally, thus replacing some of produce that is currently transported to Wyoming from California, and offsetting the CO_2 emissions generated during transportation.

Timeframe to decarbonize:

Ideally the data center will run on completely decarbonized energy from the time it becomes operational through its lifespan, said the representative. However, this is partially dependent on the energy mix that is supplied from the grid by Rocky Mountain Power which cannot come solely from wind due to the intermittent nature of wind resources. The representative is hopeful that the proportion of decarbonized energy on the grid will be increasing soon due to the TerraPower facility that is scheduled to be operational by 2030 and will supply energy to the grid.

Preference for decarbonized grid vs. developing own source of decarbonized energy:

The data center representative said the choice between purchasing decarbonized energy from the grid vs. developing the company's own source of decarbonized energy largely depends on price. While it is currently planning to purchase energy from the grid, the company is also considering working with a microgrid developer to build a solar array to supply energy to the data center. If it can get lower energy prices from such a microgrid, it will choose that option. However, the representative also mentioned that grid energy is appealing due to its reliability. Even when renewables are producing energy, the grid has an energy mix that will still provide consistent power. The representative noted that the development of the TerraPower facility would make that grid energy still more appealing because the company would get all the reliability of the grid and a greater proportion of the energy mix would be decarbonized.

Openness to and concerns about MRs/SMR/nuclear energy:

The data center representative expressed openness to nuclear energy several times. As mentioned above, nuclear energy's ability to supply both reliable and decarbonized power is appealing and the data center representative is supportive and enthusiastic about the planned TerraPower reactor being sited in Kemmerer, Wyoming. The data center representative is also familiar with microreactors specifically from having worked with people who have operated them in the United States Navy where microreactors have been used for decades. Through this connection, the representative understands microreactors to be safe and reliable and would be open to using them when they are available and cost effective. The only concerns expressed about microreactors (outside of potential costs) were related to the time it would take to adopt a microreactor system due to current regulation in the U.S. Despite these concerns, the data center representative sees opportunities for microreactors to be a power source for the data center, especially as backup generation that could replace the backup diesel generators they are planning to use.

Other decarbonization options being considered:

Solar Microgrid: The data center is also considering working with microgrid developers to develop a large-scale solar array near the data center that would operate as the power source. This solar array would not be connected to the grid, but would use grid-scale batteries to manage the intermittent solar energy supply.

Hydrogen: The data center mentioned hydrogen as a potential energy source they would consider in the future. However, because it is not available now, and probably won't be for many more years, hydrogen is not a strong consideration currently.

Importance of different attributes of energy types:

The data center representative said that, of course, *timing*, *cost*, and *reliability* are all important. But *timing* is of the utmost importance right now because the company is looking to complete construction of Phase I of the data center within 15 months of breaking ground. This relatively short construction timeline is possible because it has created a modularized building approach in which different components of the data center are constructed off site and then shipped. This system decreases costs and is more appealing to investors. However, it also means that for this modular installation, the company will need a power source that can be operational soon.

Hydrogen Production

Current energy sources:

Hydrogen production in Wyoming has not yet been developed and operators are still determining their system designs and energy uses. One hydrogen industry representative, speaking about several blue hydrogen (hydrogen produced from natural gas with CCS technology used to mitigate CO_2 emissions) generation projects the company is currently developing, said the main sources of energy their company plans to use are methane (decarbonized using CCS) and renewables (both wind and solar). The amount of each will vary depending on many factors related to where the projects are sited, such as the availability of renewable resources and their costs, etc. The company estimates that 95% of the greenhouse gas emissions associated with any methane used to generate heat and power as well as those the process of generating hydrogen from natural gas will be captured and stored through CCS. The other hydrogen industry representative, speaking about several green hydrogen (hydrogen produce through electrolysis in which the power sources are renewable energy sources) generation projects that are either in operation now or in development, said that their company uses a variety of renewable energy sources depending on what's available at a given project location. The company primarily uses wind, solar, and hydropower. It also uses grid energy for backup and for times when adequate amounts of renewable energy are not available. Any of this grid energy that is not from renewable sources is offset through the purchase of renewable energy credits (RECs).

Motivations to decarbonize:

As is evident by their current choices of energy sources, both the blue and green hydrogen production companies are already motivated to use decarbonized energy. Low-carbon emissions are a part of their business model. While the green hydrogen representative said their company is committed to only using decarbonized energy (or purchasing RECs to offset any carbon-emitting energy sourced from the grid), the blue hydrogen representative reported that their company does not feel "pressure" to further decarbonize beyond its current plans and would only decarbonize further if there were clear incentives to do so. The factors motivating the hydrogen representatives decarbonization efforts include:

Market/customer demand: Both hydrogen representatives said that customer demand was a major motivator to use decarbonized energy. The green hydrogen representative said that its customers want hydrogen that is 100% green, meaning that it is produced from 100% renewable energy. The blue hydrogen representative said that customers for blue hydrogen are already purchasing the product for its low-carbon intensity, and some customers *have* expressed interest in further decarbonization. This representative indicated that if customers are willing to pay, and market prices reflect this demand, the company will invest in more decarbonization, saying "These things end up being an affordability issue. It's a matter of looking at what the market would pay per ton of additional CO_2 mitigated."

Investor demand: The blue hydrogen representative also said that a significant part of their motivation to decarbonize is from investors. "Investors," said the representative "have a lot of appetite" for decarbonization.

Responsibility and values: The blue hydrogen representative also indicated that, as a company, they feel a sense of responsibility to provide affordable energy to communities, bringing up that increases in cost associated with additional CO_2 mitigation are often borne by communities. However, the representative also said that reducing greenhouse gas is an important company value and it feels responsible to do so. "It feels good," said the representative, "We believe in conducting business in a way that has positive externalities. And it benefits the company positively, as well."

Profitability: The green hydrogen representative said that part of their company's business model is transporting and selling hydrogen (not just producing it). The representative noted that it's cheaper to produce green hydrogen than to purchase grey hydrogen (hydrogen produced from natural gas using steam methane reform without capturing the carbon emissions). The company believes this is the future of the market as well and sees the costs of renewables continuing to come down while the costs of grey hydrogen will continue to increase due to volatility in the oil and gas markets.

Policy: The green hydrogen representative also pointed to the regulation as a motivation to use decarbonized energy, saying that the hydrogen production tax credit offered through Inflation Reduction Act means that the company could be eligible for a tax credit up to $3 per kg of hydrogen. "That's huge," said the representative, "It's a big driver."

<u>*Timeframe to decarbonize*</u>:

The blue hydrogen representative didn't cite a specific company goal for further decarbonization, but said their company expects deeper decarbonization in the latter part of the decade (2027-2030), saying that this timeframe for decarbonization of the energy space is becoming a reality more broadly. For this to happen though, the representative said, the technology needs to mature, the supply chain needs to transition, and the infrastructure needs to be developed. The representative also brought up the massive scale of the challenge of managing the quantity of CO_2 that will be produced from a widespread buildout of blue hydrogen production. Irrespective of the energy source used, CO_2 is produced through the process of generating hydrogen from natural gas and, even if all the CO_2 is captured, there is still the issue of where to store it. While some of it may be stored geologically, there are limitations to the space available in geologic formations with the necessary properties for long-term storage. This is, said the representative, a *huge* issue to be solved. "It will take money, time, and coordination to figure it out." The green hydrogen representative said that their company goal is to produce and sell 100% green hydrogen by 2025 (currently they purchase some grey hydrogen which they ship and sell to their customers).

Preference for decarbonized grid vs. developing own source of decarbonized energy:

The blue hydrogen representative said that for the time being their company plans to develop its own sources of decarbonized energy because it is currently the most cost-competitive option. While indicating openness to connecting to a decarbonized grid, the company didn't have a specific preference for it. The representative noted that since power costs are a significant part of the operating costs, the company would consider any option for decarbonized power that is more affordable. The availability of affordable, decarbonized energy is an important in siting their projects.

The green hydrogen representative said that when siting new energy projects, the availability and cost of low-carbon energy are at the forefront of their decision making. Other than demand and access to a distribution network, energy cost and availability are the most important factors in a sitting decision. The developer reported that the company is open to this energy coming from the grid, developing its own energy source, or, if necessary, buying carbon-emitting energy and purchase RECs.

Openness to and concerns about MRs/SMR/nuclear energy:

The blue hydrogen representative said they have not considered nuclear technologies like SMRs or MRs in a robust way. While voicing broad support for small-scale, advanced nuclear technology that can provide energy without carbon emissions, the representative thought that for the quantity of power needed for pink hydrogen generation, SMRs would be not able to produce it affordably. The hydrogen representative suggested that microreactors could be an option in the future. The representative reported that while they did not have any safety concerns if adequate protocols are in place, they had concerns about technology readiness and the complicated and lengthy permitting process for nuclear energy. Practically, said the representative, the company has to be responsive to customer demand for decarbonization in a timely manner.

The green hydrogen representative expressed openness to nuclear energy. While it doesn't currently use any nuclear energy, it has considered including nuclear as part of the energy mix and it would be open to purchasing nuclear energy from the grid as a reliable source of low-carbon energy. And, though the company hadn't specifically considered MRs, the green hydrogen representative said it would definitely consider microreactors when they become available, saying: "If we could have reliable, low-carbon power, let's go build it." The representative expressed some concerns about what the costs would be but also acknowledged that costs would likely come down. In talking about the small footprint of a MR, the representative was enthusiastic that it would require so much less land than solar fields require, especially considering the additional buildout required to make up for the intermittent nature of solar. "Nuclear could be a solution," said the representative.

Other decarbonization options being considered:

As mentioned above, the blue hydrogen representative said that their company is planning to use wind, solar, and methane with CCS. The methane may be reformed into hydrogen and then used as an energy source or may be combusted in natural gas turbines. Either way, CCS will be used to decarbonize the energy. No other options we mentioned as being considered.

The green hydrogen representative said that their company may consider other options in the future, but for the time being it wants to make sure that its energy sources meet the standards for green hydrogen. Currently there is a wide spectrum of which energy sources are technically considered acceptable to qualify as green hydrogen, but the company is being conservative in its choices to make sure its customers accept its product as 'green' hydrogen.

Importance of different attributes of energy types:

Again, like representatives in all other industries, the blue hydrogen representative said *timing*, *costs*, and *reliability* are interconnected factors in determining what energy sources to choose. This representative pointed out that *cost and reliability* are directly impacted by each other, saying that a company could pay more to get more reliability, so it's a matter of determining the value of additional reliability for your business model. *Timing* was pointed out as being the most important factor because it is essential that they have energy sources in place for projects to become operational.

The green hydrogen representative said that *cost* and *timing* are interconnected, and they are jointly the most important. "Cost," said the representative, "is hugely important". *Reliability* is also important, but there are ways they can manage issues of reliability. For example, the company's hydrogen plants can run off solar during the day and then use grid power (offset by RECs) at night. Similarly, the company produces hydrogen which it uses as buffer storage (meaning they produce excess when they have the energy and then use the hydrogen as energy storage). This, said the representative, is currently cheaper than using batteries to store energy.

Direct Air Capture

Current energy sources:

The DAC industry is unique in that the product it sells *is* carbon removal. The business model of all three companies interviewed is to geologically store the captured CO_2 and sell carbon removal credits based on the net amount of CO_2 captured and permanently sequestered. DAC operations also require a substantial amount of energy and, as such, the DAC companies interviewed are highly motivated to have low-carbon energy sources so their total emissions, based on a lifecycle analysis (LCA), are low and they can maximize the carbon removal credits they can generate and sell.

Two of the DAC representatives we interviewed said their companies are using renewable energy (primarily generated from solar and geothermal) and waste heat which both can be carbon-free. One of these representatives said their company is also considering building behind the meter renewables backed up by purchasing low-carbon energy from a regulated utility through a power purchase agreement (PPA). The third representative's company was also considering a PPA through a local utility as their primary source of energy. Additionally, two of these companies are also considering a new oxy-fuel combustion technology (an innovative power generation system in which natural gas is reacted with pure oxygen and all the carbon dioxide formed is captured as part of the process resulting in reliable, near-zero-emissions electricity). However, one of these representatives expressed concern about purchasing energy from the public utility because the utility's energy mix may not be low-carbon and said that this option would be a short-term solution and could only be extended into the long-term if the utility fully built out their renewable capacity.

Two DAC representatives also expressed concern about the negative public perception that DAC projects will use low-carbon energy that could be used to generally decarbonize the grid instead. One of these representatives believes this is shortsighted because developing and de-risking DAC technology today will allow the technology to be ready for when it is needed by mid-century. However, due to this concern, both representatives said that in the long-term their companies will most likely choose the new oxy-fuel combustion technology and cited the benefits that it can produce both near-zero emissions electricity and heat.

Motivations to decarbonize:

Developing a sustainable business: All DAC representatives said their companies' motivation to decarbonize their energy sources is to develop a sustainable business while providing a climate solution the world needs. A part of developing a business that can survive and grow is about generating revenue, which DAC companies do by selling carbon removal credits. The number of credits a DAC company can sell is based on how much CO_2 it removes which is calculated based on a LCA of their total emissions. If the emissions from the company's energy source are high, it can't generate or sell as many carbon removal credits, potentially leading to an unsustainable business.

Market/customer demand: While related to developing a sustainable business, two of the DAC representatives specifically called out customer demand as a driving factor in the desire to decarbonize. They said that their companies' customers highly value carbon removal as a unique service that actually removes carbon from the atmosphere and stores it permanently underground. Other credits that are on the market are mostly carbon offsets which often do not actually represent carbon *removal* but are essentially just carbon *reductions*. Carbon removal credits are far more valuable in terms of climate change mitigation and customers are willing to pay a premium for them. According to the representatives, these customers care a lot about the type of energy source that is being used to power this carbon removal. "Such a customer does not want an energy source that is not pure," one DAC representative said.

Preference for decarbonized grid vs. developing own source of decarbonized energy:

All DAC representatives said their companies would be open to and interested in connecting to a decarbonized grid if it were available. One DAC representative said it would simplify their company's operations significantly to not have to develop and operate its own energy source. However, because that isn't an option that is widely available, all are planning to develop (or have already developed) their own systems. Even the DAC representative who said that their company was considering a PPA with a utility, said that because the energy mix of the grid is largely not decarbonized, it's limiting the company's ability to consider that as a long-term viable option.

Openness to and concerns about MRs/SMR/nuclear energy:

All DAC representatives expressed openness to nuclear energy broadly. One representative said that their company currently has a policy against using nuclear, but is considering reevaluating it. This representative also said they have considered taking waste heat off of a nuclear reactor, but said that if the company does this, it would become part of the cooling system. Because this is an important component of the safety protocol for the reactor, the company has reservations about it. Another representative said their company is interested in SMRs, has considered them as an energy source, and while it wouldn't want to operate one itself, the company would consider working with an SMR provider. This representative expressed the belief that the SMR technology would be inherently safe and indicated that it could be something the company would consider further in the future when costs decrease. Another concern raised by two of the DAC representatives was the public perception of nuclear energy among their customers. One of these representatives said that while they believe nuclear energy is a part of the clean energy future, as a company they are concerned that there could be community backlash related to the use of nuclear energy, and that the company would want to ensure community support before investing in it.

Other decarbonization options being considered:

All DAC representatives expressed openness to all sources of decarbonized energy, in general. While one had a strong preference for non-fossil options only, others were open to anything as long as it provided reliable, low-carbon energy and was accepted by their customers, investors, and the general public. In fact, another representative also said that their company is currently pursuing a fossil generation system coupled with carbon capture and storage. No other options were specifically mentioned as being considered.

Importance of different attributes of energy types:

Similar to the representatives interviewed in other industries, the DAC representatives said that it is difficult to tease out the relative importance of *timing*, *cost*, and *reliability* because the factors are all interconnected. One representative said that, while it's hard to definitively prioritize one over the other, *timing* is essential because their company needs the energy source to be available for the project to operate. Reliability was mentioned by the same representative as a top priority because it's not feasible (or profitable) to have a system that only operates intermittently. To overcome the reliability issues associated with renewables, this representative said that their company is considering a PPA with a utility for back-up power or battery storage. Another representative said that the relative importance of these attributes changes over time. In the short term, the company may be willing to pay more for an energy source because it's available and reliable immediately. But, in the long term, there may be other options available which would allow the company to prioritize costs more.

b. Opportunities and Challenges for Microreactor Applications

The information obtained through these interviews and the above analysis suggests several opportunities for MR adoption by the industries studied. It also suggests some challenges.

Opportunities

Industries are motivated to decarbonize: Representatives from all of the interviewed industries affirmed a desire to decarbonize. Digital economies and those industries working specifically in the decarbonization space--DAC and hydrogen—have already substantially decarbonized their energy sources. The Trona industry is still actively considering potential sources of low carbon energy. Even among the companies that have relatively low carbon emissions currently, all expressed openness (even eagerness) for other low-carbon energy sources, especially those that could be cost effective, reliable, and readily available.

General openness to and enthusiasm for nuclear options: Representatives of all industries expressed openness to nuclear energy options, especially small-scale, advanced nuclear technologies. While some expressed concerns, none had ruled out nuclear as an energy source and some expressed strong enthusiasm. In particular, the cryptocurrency mining representatives reiterated several times the conviction that nuclear energy from small reactors would be an ideal solution for the mining industry due to nuclear energy as a reliable source of energy that doesn't emit greenhouse gases or have other negative environmental impacts such as the large footprint of wind or the ecosystem disturbances associated with hydroelectric. The data center representative was also strongly in support of nuclear energy.

Strong desire for reliable energy: While timing seemed to be the attribute of energy sources that was the most important to most industry representatives we interviewed, reliability was mentioned many times as an essential attribute. In particular, representatives of the trona industry would not consider any energy source that wasn't exceedingly reliable, hesitating to accept anything that was less reliable than a stockpile of coal on site. As a result, hybrid systems that incorporate microreactors with other sources of generation may be a preferable alternative for the trona industry. Data centers may also have redundancy requirements that could require hybrid systems.

Many concerns about other decarbonized energy options: For each industry, there was a variety of other decarbonization options that representatives were considering. However, each presented distinct challenges and tradeoffs, such as the cost and complexity of adopting CCS technology, the intermittent nature of wind and solar, the large footprint of solar developments, the lack of availability or development of the industry of hydrogen or geothermal, and the lack of available decarbonized energy available on the grid. This suggests there is very much a need for a reliable, cost-effective option for decarbonized energy that MRs could provide.

Interest in decarbonized grid-scale energy: Most industry representatives expressed interest in grid-scale decarbonized energy if available. The general sentiment was that it would simplify operations to not develop their own energy source and, if grid-scale decarbonized energy was available at a competitive cost, they would seriously consider this option.

Challenges

Lack of knowledge about MRs: Perhaps the most immediate challenge is that many industry representatives do not have specific knowledge about MR technology. Many seemed generally aware (and some very aware) of SMRs or microreactors, and many were interested, but thought that these were options for the future. This is a challenge because many of these industries view decarbonization as something that needs to happen imminently and are developing plans. If industries invest in decarbonized energy systems now, they may be committed to them for the foreseeable future and may forego the opportunity to invest in MRs in the future. It will be important to understand potential lock-in, including costs of a transition and compatibility of system design and to provide potential industry users with information about the output, cost, and availability of MR systems.

Concerns about the time it will take to implement: Almost all representatives expressed strong concerns about how long the permitting process for a nuclear energy system would take. Representatives cited this as a significant hurdle that would prevent their companies from pursuing SMR/MR technology as a viable option. Additionally, there were concerns about when the technology would be commercially available and proven. Almost unanimously, representatives from all industries said their companies need decarbonized energy that is ready now.

Concerns about costs: Many representatives interviewed had concerns about the costs of a small-scale, advanced nuclear system. Many perceived nuclear power to be expensive relative to other options. We didn't ask specific questions to determine where that belief originated. Developing information that compares nuclear with the cost of these industries' current energy sources and the other decarbonization systems they are considering would be helpful.

Concerns about public perceptions: Likewise, several industry representatives brought up the negative public perceptions of nuclear energy and said it could dissuade their companies from pursuing a nuclear-based energy system. Even though none of the representatives themselves said they believed advanced nuclear technologies to be unsafe (and many stated their believe that they are quite safe), the fear that using nuclear energy would harm their companies' reputation with customers, investors, or the public was a significant deterrent for some representatives including one in the trona industry and two in the DAC industry. While not deterred by the negative public perceptions, one cryptocurrency mining company representative expressed strong concerns that the public perceptions could hold back the industry and needed to be promptly addressed. Concerns about nuclear power among ESG investors may also be a factor for some industries.

Concerns about policy: One cryptocurrency mining representative specifically called out challenges with Wyoming State policy that limits the ability of independent power providers to sell energy without being regulated as a public utility. Citing interconnection costs and other factors, this representative thought that policy was significantly limiting the availability of energy for cryptocurrency miners to operate in Wyoming. Addressing this concern through legislation could greatly incentivize the cryptocurrency mining industry to develop in Wyoming.

Uncertainty regarding the classification of microreactors within carbon credit markets or as part of federal tax credit processes also discourages use of MR technology. Companies working in the decarbonization space are very attentive to life cycle analysis and net carbon relative to cost. Agency guidance that clarifies how nuclear would be considered for purposes of claiming sequestration and hydrogen tax credits could help address these concerns.

IV. Areas for Future Research

Based on these findings, there are several areas where further research is warranted. These include:

The specifics of energy systems. A better understanding of the specific energy systems and needs of each of the studied industries would be beneficial in understanding challenges or opportunities related to MR technologies. These may differ significantly among market participants based on facility size, location, and other details. Because MRs would need to be right-sized to a specific facility, additional research is needed to determine the specific capacity needs and system design of potential users. Details about energy systems that would be helpful include:

- More specifics about the types and relative quantities of energy needed (heat, electricity, etc.)
- Requirements for the energy source to be mobile
- Any other specific demands placed on the energy system such as redundancy requirements
- If reactive power is needed
- Geographic constraints such as transmission capacity

The cost constraints: Knowing the energy cost constraints of different industries, and the potential costs of microreactor systems, could help inform cost-based decision making. This includes what each industry's current energy costs are, as well as target energy costs in the future.

Value in a demonstration? Demonstrations to specific industries may help potential users of microreactors better understand how MRs could work within their companies' energy systems.

Identify strategies for low-carbon energy transition: Considering that MRs are not currently commercially available, engagement now can help industries understand whether nuclear will be a variable option for them in the future and to design systems that prevent lock-in. Where companies are using backup power from the grid or diesel generation, microreactors could potentially replace these sources even if the primary energy source of the facility was unchanged. Many of these industries are adopting low-carbon technologies now. Future research should explore how locked in these industries will be to their current decarbonatization choices and how lock-in to these choices could be avoided. It should also address a transition strategy for switching it MRs in the future and what those timeframes would be.

Explore public perceptions of nuclear energy: Many industry representatives identified concerns about public perception as a potential determinant to MR adoption. These industries are concerned about the impact a microreactor could have on perception of their businesses or products, including access to capital. Better understanding of public perceptions could help inform industry evaluations of microreactors. The white paper *Wyoming residents' perspectives desires, and values related to nuclear energy in Wyoming* is an initial analysis of existing literature related to this issue. However, deeper analysis of what the specific public concerns might be related to MR is an important next step.

Explore other markets: Future research could explore the potential for the use of microreactors in conventional mining, oil and gas, carbon refining, ammonia production, and other industries. This research should also consider the ability of other energy-consuming industries to relocate for proximity to hydrogen or ammonia facilities and into infrastructure constraints to development of such industries in Wyoming including transportation and access to markets.

Next steps for policy/regulatory concerns: Regulation features prominently in industry members' concerns about use of microreactors. Cost, availability, and market access are all impacted by policy and regulation. For instance, some interviewees expressed interest in contracting for zero-carbon electricity from microreactors but were not interested in developing or operating their own power production facility. Other interviewees were interested in developing power production capabilities but were concerned about access to and interconnection with the grid or the ability to sell excess power into deregulated markets. Nearly all respondents who expressed openness to operating their own power production, were concerned about the potential time and risk associated with licensing a facility and thus were evaluating more immediately available alternatives.

References

Alford, K. 2021. "Wyoming House Bill Further Defines a Digital Asset." NCS. https://www.ncscredit.com/education-center/blog/wyoming-house-bill-further-defines-a-digital-asset/ [https://perma.cc/ZJ8B-APWZ].

Andrae, A., and Edler T. 2015. "On Global Electricity Usage of Communication Technology: Trends to 2030." Challenges. https://doi.org/10.3390/challe6010117.

Andrae, A. 2019. "Comparison of several simplistic high-level approaches for estimating the global energy and electricity use of ICT networks and data centers." Int J Green Technol, 5, pp. 50-63.

Andrae, A. 2020. "Hypotheses for primary energy use, electricity use and CO2 emissions of global computing and its share of the total between 2020 and 2030." WSEAS Trans Power Systems, 15, pp. 50-59.

Aspan, M. 2021. "How Caitlin Long turned Wyoming into crypto country." Fortune. https://fortune.com/2021/07/29/caitlin-long-wyoming-crypto/ [https://perma.cc/59HB-SQE5].

Belkhir, L., and A. Elmeligi. 2018. "Assessing ICT global emissions footprint: trends to 2040 & recommendations." J Clean Prod, 177 (2018), pp. 448-463, https:doi.org/10.1016/j.jclepro.2017.12.239.

BSC Incorporated. 2007. "U.S. Mining Industry Energy Bandwidth Study." https://energy.gov/sites/prod/files/2013/11/f4/mining_bandwidth.pdf.

Data Center Map. "Wyoming Data Centers." Accessed Nov 10, 2022. https://www.datacentermap.com/usa/wyoming/Grand View Research Report. 2020. "U.S. Trona Market Size, Share & Trends Analysis Report By Application (Soda Ash, Animal Feed, Air Pollution Control), By End-use (Power, Glass, Steel, Cement, Oil & Gas), and Segment Forecasts, 2020 – 2025, 2020." Report ID: GVR-2-68038-724-7. https://www.grandviewresearch.com/industry-analysis/us-trona-market.

Fugate, Valeria. 2022. "Crypto-Knight officials opens its facility on Friday." Wyoming News Now. https://www.wyomingnewsnow.tv/2022/05/16/crypto-knight-officals-opens-its-facility-friday/.

Ganley, J.C., E.G. Seebauer, and R.I. Masel. 2004. "Development of a microreactor for the production of hydrogen from ammonia." Journal of Power Sources, Volume 137, Issue 1, 2004, Pages 53-61, ISSN 0378-7753, https://doi.org/10.1016/j.jpowsour.2004.05.032.

Grand View Research. "U.S. Trona Market Size, Share & Trends Analysis Report By Application (Soda Ash, Animal Feed, Air Pollution Control), By End-use (Power, Glass, Steel, Cement, Oil & Gas), And Segment Forecasts, 2020 – 2025." Accessed November 14, 2023. https://www.grandviewresearch.com/industry-analysis/us-trona-market.

Gryz, J., K. Król, A. Witkowska, M. Ruszel. 2021. "Mobile Nuclear-Hydrogen Synergy in NATO Operations." Energies. 14(23):7955. https://doi.org/10.3390/en14237955

Hall, Joseph. 2022. "Bitcoin could become a zero-emission network: Report." Cointelegraph. https://cointelegraph.com/news/cryptocurrency-could-become-a-zero-emission-network-report.

Hintemann, R. and Hinterholzer, S. 2019. "Energy consumption of data centers worldwide: How will the internet become green?" CEUR Workshop Proc.

Huigui Rong, Haomin Zhang, Sheng Xiao, Canbing Li, Chunhua Hu. 2016. "Optimizing energy consumption for data centers." Renewable and Sustainable Energy Reviews. Volume 58, 2016, Pages 674-691, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2015.12.283.

IEA. 2022. "Direct Air Capture." IEA, Paris. https://www.iea.org/reports/direct-air-capture.Grand View Research Report. 2022. "Cryptocurrency Market Size, Share & Trend Analysis Report By Component, By Hardware, By Software, By Process (Mining, Transaction), By Type, By End-use, By Region, And Segment Forecasts, 2022 – 2030." Report ID: GVR-4-68039-979-9. https://www.researchandmarkets.com/reports/5665123/cryptocurrency-market-size-share-and-trend

Koot, M. Wijnhoven, F. 2021. "Usage impact on data center electricity needs: A system dynamic forecasting model." Applied Energy, Volume 291, 116798, ISSN 0306-2619. https://doi.org/10.1016/j.apenergy.2021.116798

"Largest Bitcoin Mining Farms in the World." Sunbird. Accessed November 14, 2023. https://www.sunbirddcim.com/infographic/largest-cryptocurrency-mining-farms-world

Ligon, Cheyenne. 2022. "Black Hills Signs Deal to Power Cryptocurrency Mining in Wyoming." CoinDesk. https://www.coindesk.com/business/2022/06/21/publicly-traded-utility-company-inks-deal-to-power-cryptocurrency-mining-in-wyoming/.

Long, Caitlin. 2019. "What Do Wyoming's 13 New Blockchain Laws Mean?" Forbes. https://www.forbes.com/sites/caitlinlong/2019/03/04/what-do-wyomings-new-blockchain-laws-mean/.

Majkut, J., Jane Nakano, and Mathias Zacarias. 2022. "Making Hydrogen Hubs a Success." Center for Strategic and International Studies. https://www.csis.org/analysis/making-hydrogen-hubs-success. See H.R.5376 § 13204; 42 U.S.C. 7545(o)(1).

Miller, Rich. 2022. "Are Nuclear-Powered Data Centers on the Horizon?" Data Center Frontier. https://www.datacenterfrontier.com/energy/article/11427510/are-nuclear-powered-data-centers-on-the-horizon.

Shehabi, A., S.J. Smith, E. Masanet, and J. Koomey. 2018. "Data center growth in the United States: decoupling the demand for services from electricity use." Environmental Research Letters, 13, Article 124030. https://www.researchgate.net/publication/328620851_Data_center_growth_in_the_United_States_Decoupling_the_demand_for_services_from_electricity_use.

Sidley Tax and Energy Update. 2022. "Inflation Reduction Act: Overview of Energy-Related Tax Provisions—An Energy Transition 'Game Changer'." Sidley. https://www.sidley.com/en/insights/newsupdates/2022/08/inflation-reduction-act-an-energy-transition-game-changer.

State of Wyoming Legislature. 2019. "SF0125 - Digital assets-existing law." Accessed November 14, 2022. https://www.wyoleg.gov/Legislation/2019/sf0125.

The White House Office of Science and Technology Policy. 2022. "Climate and Energy Implications of Crypto-Assets in the United States." Washington, D.C. https://www.whitehouse.gov/wp-content/uploads/2022/09/09-2022-Crypto-Assets-and-Climate-Report.pdf.

The White House Office of Science and Technology Policy. 2022. “The White House Fact Sheet: Climate and Energy Implications of Crypto-Assets in the United States.” https://www.whitehouse.gov/ostp/news-updates/2022/09/08/fact-sheet-climate-and-energy-implications-of-crypto-assets-in-the-united-states/.

US Department of Energy. 2022a. “Selections for Funding Opportunity Announcement 2560: Direct Air Capture Combined with Dedicated Long-Term Carbon Storage, Coupled to Existing Low-Carbon Energy.” https://www.energy.gov/fecm/articles/selections-funding-opportunity-announcement-2560-direct-air-capture-combined.

US Department of Energy. 2022b. “DOE Establishes Bipartisan Infrastructure Law’s $9.5 Billion Clean Hydrogen Initiatives. https://www.energy.gov/articles/doe-establishes-bipartisan-infrastructure-laws-95-billion-clean-hydrogen-initiatives.

Wyoming Energy Authority. “Hydrogen.” Accessed November 14, 2022. https://www.wyoenergy.org/wp-content/uploads/2022/07/WEA_WyomingHydrogenRoadMap-FINAL.pdf.

Wyoming Mining Association. n.d. “Trona.” Accessed November 15, 2022. https://www.wyomingmining.org/minerals/trona/.

“Wyoming’s Pro-Blockchain Laws Tame The Wild West of Crypto.” Sygna. U.S. Crypto Regulations, Blog. Accessed November 14, 2023. https://www.sygna.io/blog/wyomings-pro-blockchain-laws-tame-cryptos-wild-west/.

Appendix C

UA Perspectives on Microreactor Adoption in Alaska: Industrial Energy in the Interior and Alaska State Policy Review[n]

DAVID E. SHROPSHIRE

Executive Summary

Small-scale, advanced nuclear energy has been proposed as technology solution to provide clean, carbon free baseload heat and power for energy markets across Alaska, including small microgrids, mining installations, and other industrial energy users with large, base-load power needs. This white paper was developed by the University of Alaska Center for Economic Development as part of the Idaho National Laboratory Emerging Market Analysis program for the Micro Reactor Program to examine the potential market and policy drivers for small scale nuclear adoption among industries in the state with a focus on the Interior region.

This paper uses a qualitative lens to address three questions and is, therefore, divided into three sections discussing each question:

1. Examining the energy market in Interior Alaska, how do the basic economic sectors in the region utilize heat and power and what do economic projections for those industries mean for energy consumption?
2. Focusing specifically on the mining industry in the Interior, how do current energy solutions meet industries' future goals and how might small-scale nuclear technologies address needs or create challenges?
3. How do current and proposed Alaska State policies enable or impede nuclear energy adoption?

Key findings include:

- Energy is a core pillar of the Alaska economy as the state is both a producer and a high per capita consumer of energy. Access to plentiful and affordable energy, a vital consideration for industrial development, is seldom a given in the state. In some areas, energy for consumption is readily available, like Southcentral Alaska with its plentiful natural gas reserves. However, in other areas of the state, local energy sources are less abundant, and residents and industry must rely on imported sources, like heating oil, propane, diesel, and other fuels, for heat and power production.

[n] This work has been performed with funding support through contract No. 226920 from Idaho National Laboratory, operated by Battelle Energy Alliance, LLC, for the United States Department of Energy.

- In the Interior region of the state, industry has historically been fueled by with coal and diesel . Despite long-held plans for constructing a natural gas pipeline, access to lower emission fuels is limited or logistically challenging. This is a growing concern as future industrial climate and emission legislation become more likely.
- Alaska is home to notoriously energy-intensive industries. The state is ranked the second highest in per capita energy consumption. Approximately 57% of that energy consumption is by industrial users. Historically, many of these industries have exported all refining and value-added manufacturing outside of Alaska due to the cost of conducting those activities in the state: a function of the cost of energy, but also logistics, labor, economies of scale, and other variables.
- The Interior Alaska economy is largely concentrated around four core energy intense industries: the military, oil and gas, higher education, and mining. The military and mining industries, specifically, are expecting growth in the coming decade primarily due to federal policies.
- The Interior mining industry is clearly feeling both external and internal pressures to decarbonize operations. Both hard rock mines in the region have set clear ESG goals which explicitly target energy production and consumption. At a different level, pressure from the federal policies to penalize carbon intensity or incentivize industrial decarbonization is becoming increasingly probable and will likely impact operational costs (Araújo and Koerner 2023). From a separate angle, the market is likely moving toward finding ways to value the environmental impact of commodities. First movers are finding ways to position themselves to be competitive from many angles.
- For grid connected mines, self-producing power is constrained by the remaining mine life which limits the feasibility of capital-intensive energy projects. However, in Interior Alaska mines are often at the end of the grid. From a resiliency perspective this can be a concern for continuous mining operation. From a utility perspective, integrating generation resources at mine sites generates concerns about stranded resources. Flexibility and mobility in the technology might balance this risk—both of which may be attributes of microreactors which might otherwise be factored into rates.
- Access to, and utilization of, a heat resource is a valuable element of an alternative energy technology like nuclear. To fully utilize this resource co-location at a mine would be required. However, the value of the heat resource must be balanced with the cost of infrastructure to utilize the heat.
- As an emerging technology, the advanced nuclear industry needs to consider federal, state, and local policies. Policies impact both the likelihood of communities and industries choosing nuclear technologies and the logistics of permitting, constructing, and operating a nuclear project.
- Alaska State Statutes and Regulations support a host of energy subsidies and project funds designed to lower the cost of power for rural residents and to support energy capital projects. While none of these programs explicitly call out nuclear energy, each may interact with the adoption of microreactors.
- During the 2022 legislative cycle the Alaska State Legislature considered two bills proposing the adoption of a Renewable Energy Standard or Clean Energy Standard, each with explicit definitions of clean energy. HB301 clearly includes nuclear energy in its definition of clean energy, while SB179 does not include nuclear in the basket of qualifying energy sources.
- In spring 2022, the Governor of Alaska signed into law legislation revising Alaska’s statutes and regulations around nuclear energy. The legislation exempts microreactors from certain state-level siting requirements for nuclear reactors and modifies regulations to accommodate advanced reactor technologies.

- Recently established regulations around electric reliability organizations (EROs) introduce a new actor to the energy playing field in urban Alaska. EROs are tasked with conducting integrated resource planning for interconnected utility grids in the state. While this legislation effectively creates another gate for nuclear energy projects to pass through, it also requires the evaluation of the full range of possibilities for the grid when conducting planning, including nuclear technology.

The following sections examine each of these topics in greater detail by focusing first on the Interior Alaska energy markets, then focusing on the mining industry in the region specifically. The subsequent section provides a review of Alaska statutes and regulations.

Section I: Interior Alaska Energy Market Overview

Interior Alaska has been the traditional lands of the Athabaskan people for thousands of years. The city of Fairbanks, the largest city in the region, began as a gold rush town in the 1900's, quickly becoming a supply center for the region. Since its establishment, the Fairbanks area has been a hub of economic activity for the oil industry, mining industry, military, university, transportation services, tourism, and more.

This analysis defines the "Interior" region to include the Fairbanks North Star Borough, Denali Borough, Yukon -Koyukuk Census Area, and Southeast Fairbanks Census Area, to be consistent with the economic data defining the region. However, it should be noted that the Yukon-Koyukuk Census Area is more remote, has a smaller population, and has a significantly different economy than the rest of the region. Discussions of the region's economy focus primarily on urban areas of the Interior Region.

Approximately 111,300 people live in the Interior (State of Alaska 2021). Power on the road system is largely produced using locally-sourced coal from Usibelli Coal Mine, diesel, purchased power from other Railbelt utilities, and a mix of wind and solar. Heat is generated through a patchwork of sources: a distributed steam heat system in downtown Fairbanks, wood or heating fuel to local houses, and coal-to-steam heat on the University of Alaska Fairbanks campus.

The local power utility, Golden Valley Electric Association (GVEA), is largely reliant on two coal-fired power plants for the bulk of their local generation, as shown in Figure 11, one of which is scheduled for retirement in 2024. The utility is rapidly pursuing alternative energy sources: purchased power from other utilities, wind, solar, and a battery system. However, viable replacement of generation infrastructure to support the baseload power provided by coal generation is still undetermined in the long run.

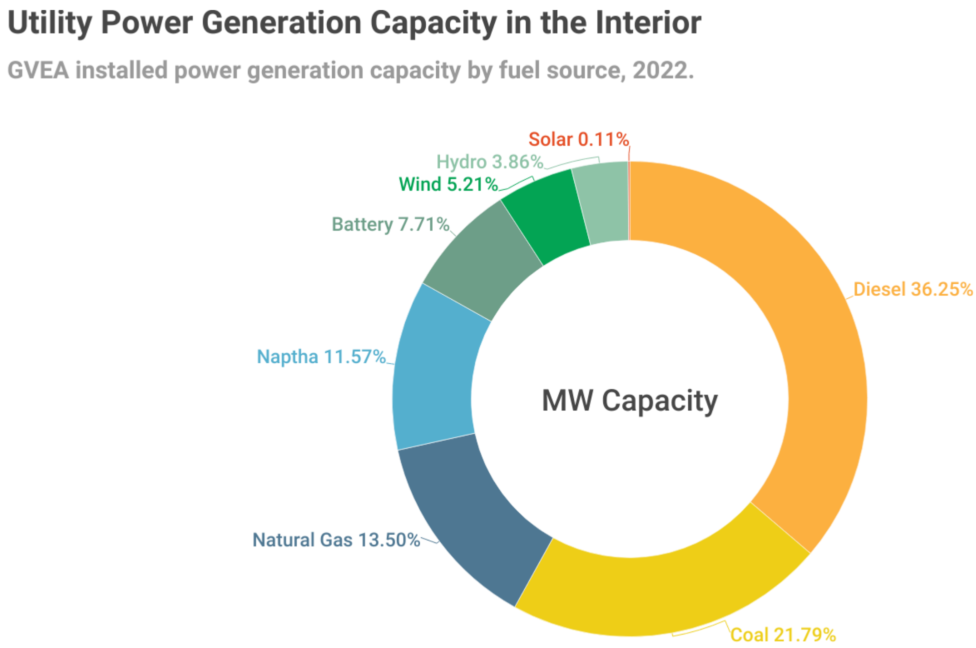


Figure 11. GVEA installed power generation capacity by fuel source. Source: GVEA, 2022.

The region struggles with the impacts of local inversion in the Tanana Valley, severely impacting air quality in the area tied to residential wood burning, fuel oil used for heat, and other sources (State of Alaska, N.D.). Forest fires have also burned through the region in recent years (Voiland 2022). The growing impacts of climate change are the concern of a growing grass root climate movement in the region, pushing the adoption of clean energy resources.

Economic Overview

The three boroughs and census areas discussed above are part of the Interior Economic Region as shown in Figure 12, including the Fairbanks North Star Borough, Southeast Fairbanks Census Area, Denali Borough, and Yukon-Koyukuk Census Area. The Interior Economic Region was used to define the geographic region to expand data availability While it is the largest sub-region in the Interior by area, the Yukon-Koyukuk Census Area is sparsely populated and made up of remote communities off the road system.

This analysis utilizes the larger region—including the Yukon-Koyukuk Census Area—to define the regional economy. However, it does not focus on the more rural areas, as most of the region's economic activity is focused on the road system. It's also important to note that the Yukon-Koyukuk Census Area includes 147,805 square miles or the size of Montana while having a population of approximately 6,500 (State of Alaska, N.D.).

Figure 12. Alaska Economic Region. Source: Alaska Department of Labor and Workforce Development.

Across the Interior Economic Region there were 42,700 jobs in 2021, as shown by industry sector in Figure 13. Over the last decade, employment in the region has dropped by 9% (State of Alaska 2021). This decline in jobs began in 2013, well before the pandemic. However, as with other areas of the state with large tourism sectors, the economic impacts of the COVID-19 pandemic hit the local economy hard, resulting in job losses, decline in government revenues, and business closures. In the Leisure and Hospitality industry alone, 31% of jobs were lost between 2019 and 2020 (State of Alaska 2021).

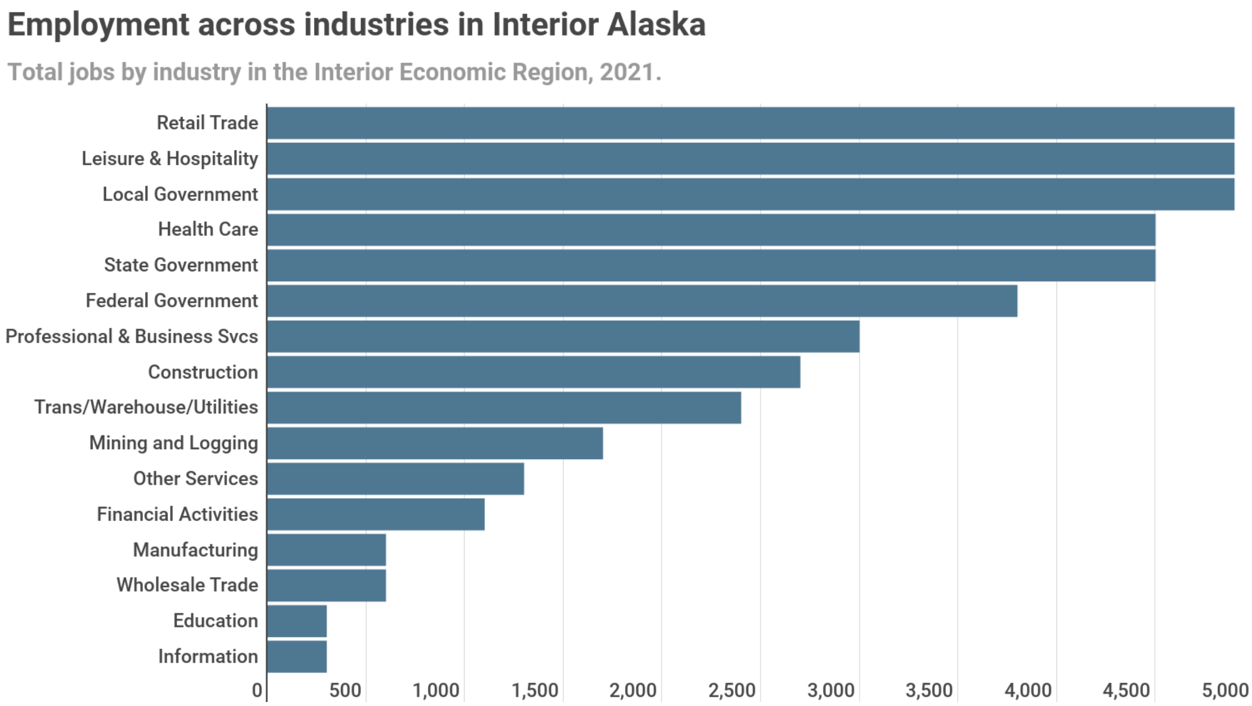
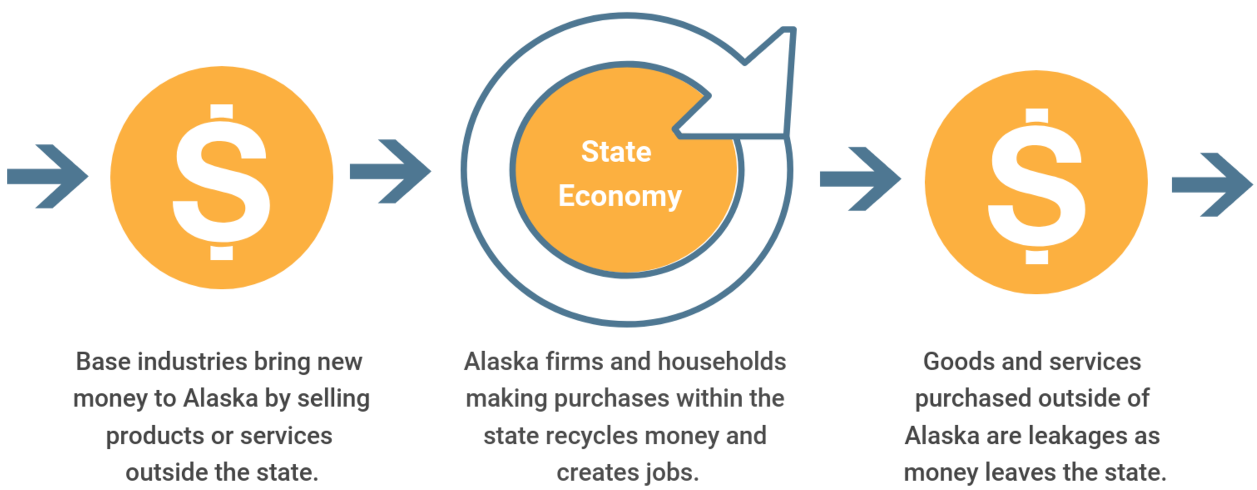


Figure 13. Total jobs by industry in the Interior Economic Region, 2021. Source: Alaska Department of Labor and Workforce Development.

The economy in the Interior centers around a handful of key industries: military, mining, university, transportation, and tourism (Fairbanks North Star Borough 2022). While other sectors like healthcare, retail, and local government are large employers and are important drivers of a healthy economy, they do not provide a base of new wealth generation that brings new money into the region. Instead, those industries support residents' quality of life and retain value in the local economy.



Interior Core Energy-Consuming Industries

The analysis below provides an overview of the economic impact and energy usage of four core energy-consuming industries in the Interior region: the military, mining, oil refining, and higher education. This includes a discussion of factors that may influence future energy usage of these industries, including—to the extent possible—quantifying projected energy consumption.

Military

Interior Alaska hosts four defense installations: Eielson Air Force Base, Fort Wainwright, Fort Greely, and Clear Space Force Station. In Fiscal Year 2021, 12,250 Department of Defense personnel were residing in the Interior, accounting for approximately 11% of the total population in the region (U.S. Department of Defense 2022). Defense spending generates an enormous amount of economic activity through defense contracting. Between Fiscal Year (FY) 2017 and FY2019, defense spending in the Interior region averaged $738 million (UACED 2021). It is estimated that 1 in 3 jobs in the Interior are tied to the defense industry (UACED 2021).

Each of the defense installations maintains its own power and heat generation capabilities; however, each is also tied to the GVEA grid. On-site generation is used for CHP (Table 13), as well as backup generation and responding to gaps in demand when GVEA's intertie is unable to provide sufficient power.

Table 13. Installed Power Production Systems at Interior Defense Installation. Source: University of Alaska Center for Economic Development, 2020, and U.S. Government Accountability Office, 2014.

Installed Power Production Systems at Interior Defense Installations			
Installation	System Type	Installed Capacity (MW)	Fuel Type
Fort Wainwright	CHP	20	Coal
Fort Greely	CHP	7.4	Diesel
Eielson A.F.B.	CHP	15	Coal
Clear Space Force Station	CHP	22.5 (Closed)	Coal/Diesel Backup

The local economy in Interior Alaska is closely tied to developments at the defense installations, following fluctuations in base staffing closely. In 2005, Eielson A.F.B. was the focus of the Base Realignment and Closure Commission (BRAC) efforts, with Eielson one of the installations listed for closure. The move would deeply impact the local economy; however, the base was eventually saved from closure.

In more recent years Eielson A.F.B. has been the source of a growing amount of activity both on and off base. In April 2022, the Air Force completed the bed down of 54 F-35A aircraft permanently assigned to the base. The assignment of the aircraft to Alaska required a large-scale base expansion, including the construction of 36 new buildings and 54 shelter units for the aircraft. With this, approximately 3,500 new active-duty personnel and dependents are relocating to the Fairbanks North Star Borough and surrounding areas. The base expansion signals a growth in energy consumption tied to a larger population and increased activity on and off base.

Oil and Gas

Fairbanks serves as a hub for activity for the Trans-Alaska Pipeline System (TAPS), which stretches from the North Slope to Valdez and moves North Slope crude oil to market. Strategically positioned along the pipeline corridor, the Fairbanks North Star Borough community of North Pole is the home of one of Alaska's three refineries, producing heating fuel, kerosene, diesel, jet fuels, and asphalt base oil (State of Alaska Division of Oil and Gas 2016). The refinery also produces turbine fuels for power generation in partnership with Copper Valley Electric Association and GVEA.

The refinery hosts a 22,000-barrel-per-year capacity. Petroleum refining is an energy intensive process, with crude oil distillation ranked as one of the largest energy consuming processes in the refining industry (Wang, Lee, Molberg 2004). The North Pole Petro Star refinery uses throughput from TAPS as a feedstock and refinery fuel source, utilizing approximately 25% of the feedstock it draws from the pipeline and reinjecting the remainder (State of Alaska Division of Oil and Gas 2016).

There is limited data on current or historical energy consumption at the Petro Star North Pole refinery, making it difficult to project future energy needs at the site. However, long-range fuel forecasts for Alaska predict a slow but steady decline in demand for petroleum products (McDowell Group 2020). Figure 14 shows the projected statewide fuel consumption of distillate (diesel fuel) and jet fuel, two of the primary products manufactured at the refinery in the North Pole.

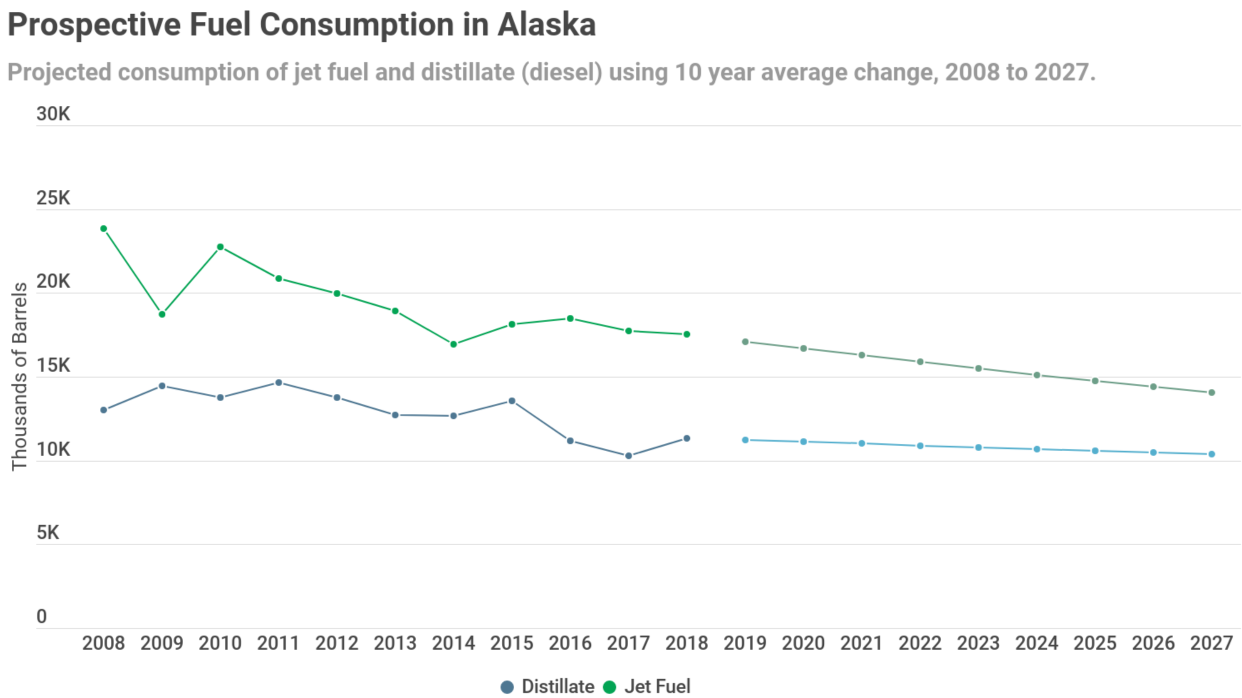


Figure 14. Projected consumption of jet fuel and distillate (diesel) using 10-year average change, 2008 to 2027. Source: McDowell Group.

It should be noted that while this is the most recent fuel consumption projection, some factors have already occurred which could change these projections, such as the F-35 transfer to Eielson. A handful of variables could push projections of long-range consumption in Alaska either up or down.

- **F-35 transfer to Eielson Air Force Base.** Petro Star North Pole refinery provides jet fuel for Eielson A.F.B. In 2016 it was announced that two squadrons of F-35As would be transferred to Eielson, a total of 54 jets and 1,300 military personnel. The aircraft became fully operational at the base in 2022 (354th Fighter Wing Public Affairs 22). These new aircraft will likely increase jet fuel consumption at the military base.
- **Growth in air cargo at Fairbanks International Airport.** The COVID-19 pandemic instigated a dramatic growth in air cargo in Alaska. In 2020 Ted Stevens Anchorage International Airport was ranked the 1st for cargo in the U.S. by volume (Federal Aviation Administration 2021). Future growth in commercial air traffic in Anchorage and Fairbanks primarily, but also statewide, indicates a corresponding increased demand for commercial jet fuel.

- **Decline in fuel oil consumption for heating.** Throughout much of Alaska, diesel fuel #2, or heating oil, is used for space heating. Across the state use of fuel oil is projected to decrease (State of Alaska 2020); however, this trend could deviate in the Interior due to population growth stemming from activity at Eielson. Given the growing focus on reducing the use of carbon intensive fuels and air quality issues in Fairbanks, it is also likely that decreases in heating fuel use in the region may occur more rapidly than predicted through energy efficiency improvements or the adoption of alternative heating fuels like natural gas.

Higher Education

The University of Alaska Fairbanks (UAF) campus is one of the three main campuses of the University of Alaska System. In Fall 2021, the campus employed approximately 2,100 (793 faculty and 1,588 staff) (University of Alaska Fairbanks 2022). As an employer and educational institution, UAF plays a large role in the local economy.

UAF serves as an important research and development institution in the Interior region and statewide, including the home for federal programs like the Department of Energy Arctic Energy Office and the Cold Climate Housing Research Center. The UAF campus alone managed a total of $136 million in research expenditures in FY21 (University of Alaska Fairbanks 2022).

UAF is Alaska's land grant university and manages 10,189 acres of land between its main campus and satellite campuses. On the main campus, UAF operates a coal-fired combined heat and power plant, which provides power and steam for heat and hot water to the campus. The newest steam generator has a 17 MW nameplate capacity and became operational in 2020 (U.S. Energy Information Administration 2021). The campus also operates a backup 9.6 MW diesel generator and can purchase or sell power from/to GVEA. UAF electricity rates are variable year-to-year as shown in Figure 15.

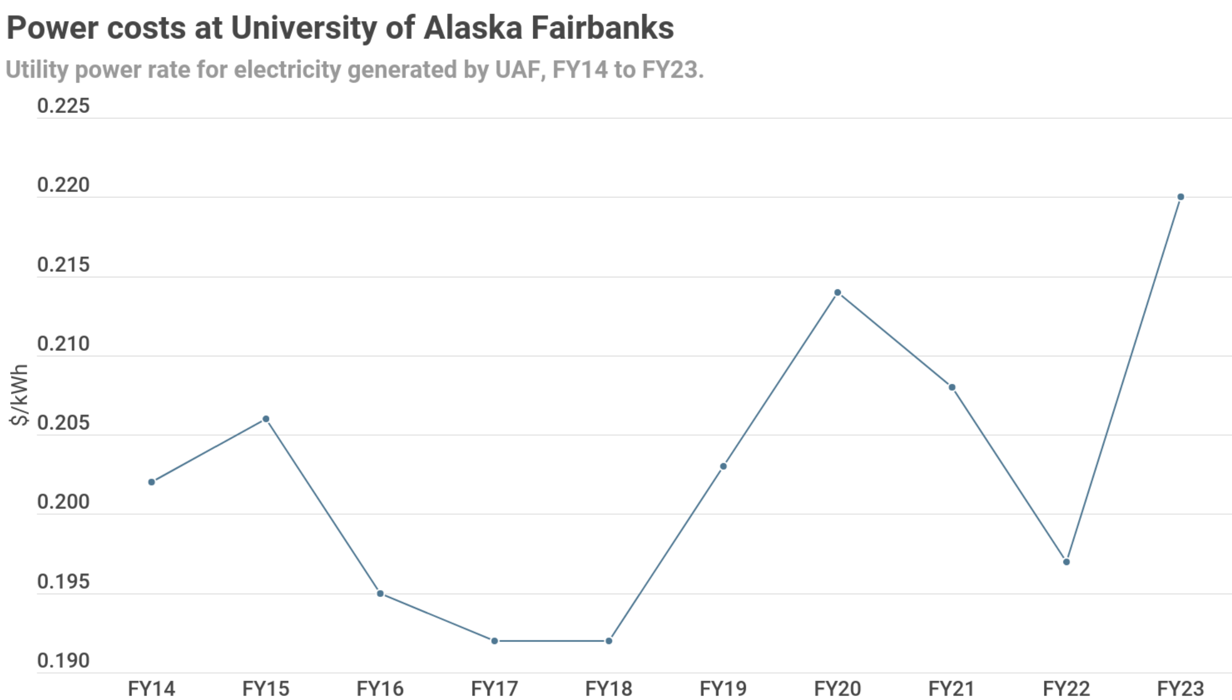


Figure 15. Utility power rate for electricity generated by UAF, FY14 to FY23. Source: UAF.

A district heat system serves the campus using steam produced by the coal power plant. In FY23, the utility rate for that steam was $13.30 per 1,000 pounds. As seen in Figure 16, the cost of steam heat to the campus was rising from FY17 through FY21. However, prices dropped in FY22 and have since begun to increase (University of Alaska Fairbanks, N.D.).

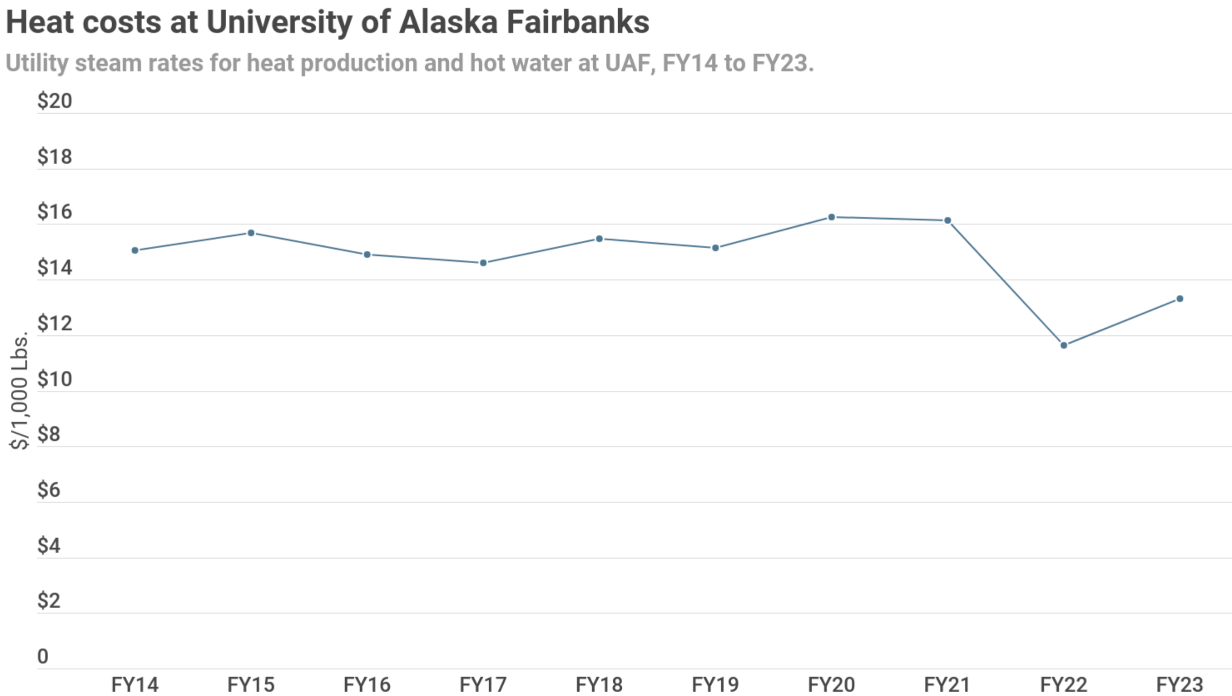


Figure 16. Utility steam rates for heat production and hot water at UAF, FY14 to FY23. Source: UAF, 2022.

Fuel for the coal-fired energy system is sourced from Usibelli Coal Mine and costs UAF $67.08 per ton (University of Alaska Fairbanks, N.D.).

The coal plant was brought online in 2020 and is anticipated to have a long life with the ability to support growth on UAF's campus until 2045 (Alaska Business 2019). Factors that may impact growth in power consumption on campus include:

- **Funding Sources.** Funding for the University of Alaska systems includes a blend of State of Alaska unrestricted general funds (30% in FY 2021), receipts from vocational programs and general university programs (27%), federal receipts (27%), and other funds (17%) (University of Alaska Fairbanks 2022). Between FY2013 and FY2021 the percentage of the budget funded by general funds has shrunk by 30% due to the overall state fiscal situation. Budgetary uncertainty in the future may restrict investment in the university (a restriction felt statewide) and limit growth.
- **Enrollment.** Student enrollment at the UAF campus was 7,478 in the Fall of 2021. Enrollment trends are an indicator of growth or investment in a university. UAF's enrollment declined by 24% between the fall of 2013 and 2021.

- **Research Activities.** UAF is working towards obtainment of an R1 research classification and houses not only university research institutes, but also larger non-academic programs, from the Alaska Center for Unmanned Aircraft Systems Integration to the Cold Climate Housing Research Center. Between the fall of 2016 and 2021, research expenditures grew by 33%. With renewed interest in the Arctic from the federal government and new investment in research and development in the region (The White House 2022), research expenditures at UAF are likely to continue increasing, encouraging growth at the campus.

Mining

The Interior region of Alaska is home to three large operating mines and numerous deposits under exploration. One mine, Usibelli, extracts coal to generate power and heat across the Interior. The other two mines, Pogo and Ft. Knox, are hard rock gold mines. This analysis will focus on Pogo, Fort Knox, and other hard rock mines in the permitting/exploration stages.

Collectively, Pogo and Fort Knox employ an estimated 1,005 people (Watson, Loeffler 2022). Across Alaska, 74% of the individuals employed by the mining industry are Alaskan residents (McKinley Research Group 2022).

Mining is an energy-intensive industry. The cost of power and heat are both key to the profitability of a project. In some cases, whether or not a mine can access an economic energy source will determine whether that mine is developed.

- **Pogo.** The mine is owned and operated by Northern Star Resources, LLC. The site hosts an underground gold mine and mill, which produces an average of 3,000 tons per day, requiring 15 MW of power production to facilitate mining and milling operations. Power is supplied to the mine through a 13.8 kV transmission line connected to the GVEA grid. Power usage at the mine primarily comes from underground electric drilling activities and milling. The site’s power requirements include pumps, water treatment, and above-and-underground lighting (Sumitomo Metal Mining Pogo 2017).
- **Fort Knox.** Fort Knox Mine is an open pit gold mine, mill, and heap leach facility owned and operated by Kincross Gold. The gold mine produces an average of 50,000 tons of low-grade ore per day. Power requirements for the site range between 32 and 35 MW. Power is supplied to the site from an intertie with the GVEA grid. The mine consumes approximately 200,000 and 300,000 MWh annually, primarily for milling purposes. The energy requirements include extraction activities (diesel equipment), transportation of materials (diesel equipment), milling (power), site offices and man camp facilities (power and diesel heat) (Sims 2018).

Both mines have impending retirement dates: 2027 and 2024 for Fort Knox and Pogo, respectively, however significant exploration continues adjacent to Pogo. Losing the load of either mine would be a significant downshift in the industrial power load GVEA supports, and could significantly impact the utility’s finances. For example, in 2021, the power sales to Fort Knox alone represented 19% of GVEA kWh sales and 14.6% of the utility’s revenues (State of Alaska 2022). Power utilities utilize economies of scale to drive the cost of power down.

While it remains possible that both mines could further develop additional adjacent resources at their mine sites, neither has published significant plans to do so. Pogo has conducted significant exploration of an adjacent deposit at Good Pastor and is investing in infrastructure upgrades and operational capabilities to extend the life of the mine (Northern Star Resources Limited 2022).

However, the Interior is a mineral rich region and there are other mine prospects in the region, as shown in Table 14. A 2022 report published by the University of Alaska Anchorage Institute for Social and Economic Research analyzed future scenarios for mineral development in Alaska, based on the expected lifespans of current mines and likelihood of known deposits being developed. The report divides mine prospects in the region by those within 30 miles from the road systems and those farther than 30 miles from the road system. Six mines within 30 of the road system in the Interior are more developed prospects. A further five are more than 30 miles from a highway (Watson, Loeffler 2022).

Table 14. Currently Operating and Later Stage Mining Prospects in Interior Alaska. Source: Watson and Loeffler, 2022.

Currently Operating and Later Stage Mining Prospects in Interior Alaska		
Project Name	**Status**	**Type**
Interior Prospects within 30 of the Highway		
Fort Knox	Operating	Hard Rock
Golden Summit	Preliminary Economic Assessment	Hard Rock
NAOSI	Exploration: Significant	Hard Rock
Manh Choh	Permitting	Hard Rock
Livengood	Pre-Feasibility	Hard Rock
DELTA	Exploration: Moderate	Hard Rock
LMS	Exploration: Moderate	Hard Rock
Interior Prospects more than 30 miles from highway		
Pogo	Operating	Hard Rock
Nixon Fork	Development	Hard Rock
Vinasale	Exploration: Significant	Hard Rock
Illinois Creek	Exploration: Significant	Hard Rock
Red Mountain	Exploration: Moderate	Hard Rock
Lakeview	Exploration: Moderate	Hard Rock

Mine developments have long timelines, however, so it remains unclear how imminently any of these mines may be operational and what their energy requirements will be. Several prospects in the region are in the moderate to significant exploration stages and depending on the deposit, site conditions, mineral prices, and other variables could reflect significant timeline changes.

The timeline for development of a mine is dependent on many factors. Ore grade, tonnages, recovery challenges, infrastructure, and cost can all impact if and when a deposit moves through the development phases. Metal prices, infrastructure and access improvement, and new technologies can create further pivot points for mine feasibility (McKinley Research Group 2022). A 20-year span from exploration to development as an operating mine is not unusual.

Of the mines in the exploration, feasibility, and permitting stages in the Interior, two are in the advanced stages and could potentially begin operation in the next decade: Manh Choh and Livengood.

- **Manh Choh.** Perhaps the most advanced prospect in the region, Manh Choh is located southeast of Fairbanks near the village of Tetlin. The mine plans include the development of a small open pit mine with an operating life of four to five years, utilizing the mill at Fort Knox. This will require trucking ore 240 miles to the Fort Knox mill. Supplying between an estimated 2,800 to 6,500 t/day to the mill on average and requiring an estimated 200,000 to 300,000 kWh of power supply annually (Kincross, N.D.). Kinross estimates it will employ 400-600 individuals at the mine and will require 3,500 MWh per year of power from the local utility—Alaska Power and Telephone—to operate at the mine site (McKinley Research Group 2022).

- **Livengood.** Still in the feasibility and permitting stages, Livengood is a proposed conventional open pit with milling and processing on site. The mine will have an estimated operating life of 23 years, employing 331 individuals. The site is expected to host a mill with a processing capacity of 52,600 t/day. The operator expects to purchase power from GVEA with an estimated peak power demand of 55 MW (43 MW for just the process plant). Livengood estimates its cost per ton milled will be $12.95. On site heat will be provided by liquified natural gas (Hardie et al 2021). The estimated development timeline could still change dramatically.

When looking at energy prospects into the future, mines in the Interior must balance the feasibility of self-producing power and heat versus purchasing power from the local utility. Self-producing power on site comes with the benefit of decreased infrastructure costs to interconnect to the grid; however, it adds a layer of logistics to site operation which could translate to higher costs. Connecting to the grid can require large amounts of infrastructure spending to connect to the local grid but removes the logistical hurdle of operating a small power plant. Depending on the energy resources utilized by the local grid, interconnection can also help mines meet emissions goals. Projected needs for electricity in the Interior Alaska mining sector are provided in Figure 17.

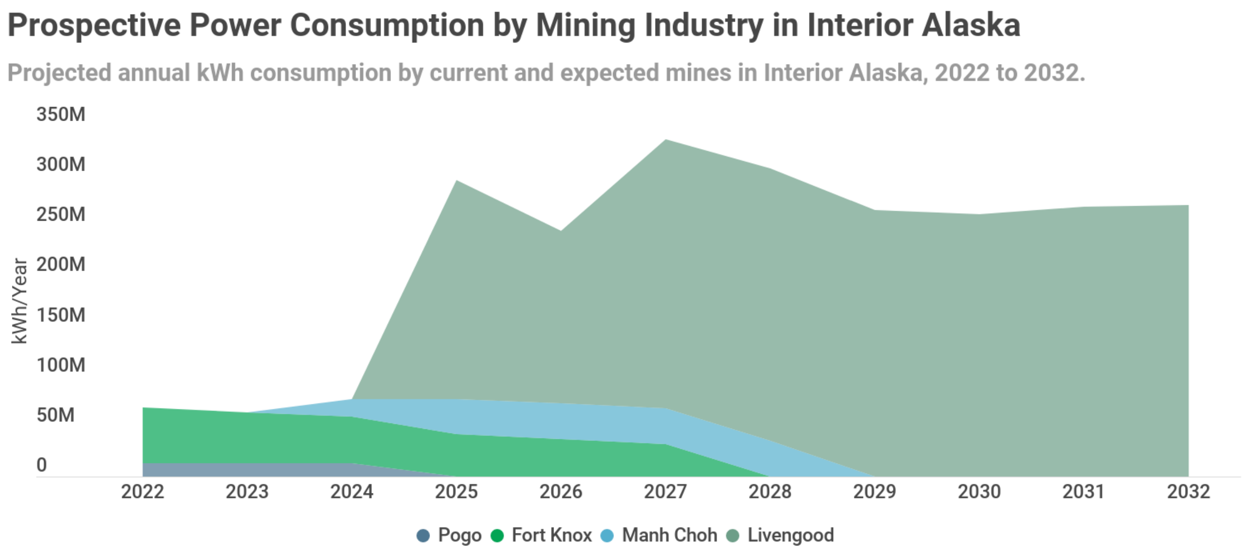


Figure 17. Projected annual kWh consumption by current and expected mines in Interior Alaska, 2022 to 2032. Source: CED calculations.

Conclusion

Given the energy intensity of the majority of the Interior's basic industries, the cost and availability of energy –both heat and power—are intrinsically tied to economic growth in the region. With mines, refineries, military installations, the industrial load that GVEA serves deviates significantly from other utilities in the state. However, energy in the region is at a crossroads between decarbonization and fuel availability. How energy develops into the future could impact economic growth in the area. The following white paper will explore how industrial energy users make technology decisions by focusing on the mining industry in Interior Alaska.

Section II: Mining Case Study

Industrial developments can be challenging to launch in Alaska. Energy cost is often one of key barriers to project development, whether that project is a building construction on a university campus or a mine development (McKinley Research Group 2021).

When the cost of energy impacts the feasibility of an industrial development, it can be a significant hurdle for economic development—the difference between new jobs creation or nothing. On the opposite side of that coin, plentiful and affordable heat and power can be an economic driver, attracting industry to a specific geography and enabling value-added product development.

In Alaska, the cost of energy across most of the state, including on the Railbelt, results in most industrial development—such as manufacturing or value-processing—being shipped out-of-state or overseas (State of Alaska 2022). Energy, both power and heat, is just one variable among many which industries struggle with in Alaska, including but not limited to:

- Access and cost of labor,
- Cost of supplies and supply chain challenges,
- Access to specialized services.

Across Alaska, the cause of these challenges is often remoteness. Even in Anchorage or Fairbanks, the state is often characterized as “being at the end of the supply chain” (Johnson et al 2021). In remote areas of the state--off of the road system and only accessible by plane or boat—the challenge of providing energy at industrial sites has been mostly solved by using diesel fuel for heat and power production. Examples of these sites across Alaska include remote mines and seafood processing plants.

In more urban areas of the state, colloquially called the “Railbelt” large-scale energy users have more options and access to a large, distributed energy grid, driving down the cost of power. Industrial or large-scale energy users have the option to connect to the grid and the benefits of economies of scale that come with it or co-generate their own heat and power. Most have chosen to connect to the grid.

Small scale nuclear energy has been examined as an option for remote energy users to decarbonize and stabilize costs. However, while energy costs in remote areas make alternative energy sources, like nuclear, an attractive option, the remoteness, access to capital and workforce, supply chain remoteness, etc. make operating early-stage technologies challenging (Alaska Energy Authority 2022). Urban Alaska, on the other hand, enjoys improved access to project capital, a larger labor pool, and a more robust supply chain. However, complementing those operational benefits is a lower cost of power and heat which makes adopting new technologies technically easier but economically more difficult.

> In the Chugach Electric Association services area—which serves Anchorage the average residential rate for power is $0.21/kWh. Across rural areas of the state the weighted average residential rate was $0.46/kWh in Fiscal Year 2021 (State of Alaska 2022).

The drive to examine alternative energy sources, renewables and nuclear, has become increasingly relevant for industrial energy users as they are motivated to improve emissions and environmental impacts. In the future these environmental impacts may have a very real cost impact if/when climate driven taxes credits or penalties become more prevalent (The White House 2022, and Araujo and Koerner 2023).

How and Why Firms Make Energy Decisions

Using any number of lenses, cost is one of the primary drivers of how and why companies make decisions. For large industrial companies which consume significant amounts of energy, energy costs can be one of the most important cost variables.

However, energy cost is a complex variable to unpack. It can be tied to many other goals; such as, sustainability, environmental impacts, ensuring continuous operations, etc. Firms also must respond to internal pressures as well as external, such as government oversight, ethical standards, and environmental responsibility.

For a large industrial energy user, energy operations can be a decision between self-producing power and heat or purchasing power from a local utility or contracting with a power producer. This decision is often predominantly influenced by geography.

A decision-making matrix for self-generation and utility interconnect is provided in Table 15.

Table 15. Energy Operations Decision Making Matrix.

Energy Operations Decision Making Matrix				
Operation Model	**Regulatory**	**Transmission**	**Generation**	**Heat**
Self-Generation	Regulatory burden falls on the operator. Is the site in a utility area? Depending on the energy source, are FERC or NRC permitting required?	Construction of transmission infrastructure limited to onsite.	Local installed generation capacity to serve site power needs. Owned, operated, and maintained by the site.	Depending on the power source, combined heat and power production can be used for space heating or process heat.
Utility Interconnect	Regulatory burden predominantly falls on the utility.	Often requires significant investment in transmission infrastructure, built and maintained by the industrial user.	None, or limited backup generation.	Heat production not tied to power production.

When large-scale energy users are weighing their options between self-generating versus other options they balance cost, reliability, resiliency, and ESG goals as shown in Table 16.

Table 16. Market Drivers for Energy Choices by Large-Scale Energy Users. Source: UACED, 2020.

Market Drivers for Energy Choices by Large-Scale Energy Users	
Cost	
High Cost	As a component of business expenses, high energy costs can dramatically impact whether a business or organization is breaking even or profitable.
Variable Cost	Variability in energy costs makes budgeting and business planning difficult. Fluctuations in oil costs between 2020 and 2022 is a good example of how extreme and unpredictable swings in fossil fuel costs can be.
Reliability	
Supply Guarantee	In any organization, reliable provision of energy is key to keeping the lights on and business going. Continuous energy supply enables businesses to plan operations schedules and ensure consistent supply of products or services.
Resiliency	
Fuel Supply Disruptions	Resiliency speaks to an organization's ability to weather unexpected disruptions. In the energy space, one common variable is fuel supply disruptions, either from transportation, supply shortages, or other causes.
Transmission Disruptions	Transmission lines are a critical point of weakness for energy infrastructure. Downed or damaged lines can interrupt power supply and interrupt operations.
ESG Goals	
Environment	Environmental goals are increasingly prevalent in the public and private sector. In some ways, they can be a tool to benefit or attract customers. However, environmental impacts have a growing monetary cost with penalties for contamination and emissions.
Social	Social responsibility, accountability to the community, and fair labor practices are just a handful of examples of social variables which organizations track and set goals around. Most can intersect with energy production operations.
Governance	Ethical governance practices include the accurate and transparent accounting, ethical and diverse leadership practices, and accountability to stakeholders.

Added on top of these variables is the regulatory structure that the energy user exists within. Energy production, especially power production, is a heavily regulated industry. Navigating the operational and legal nuances of a regulated industry can be difficult and costly—one reason why many industrial energy users choose to purchase power from the utility.

For industries or organizations in the Interior, most power production falls within GVEA's service area (Golden Valley Electric Association 2018, 1). For grid-tied industrial energy users to produce power and sell it to the grid, they would be required to go through the relevant federal and state regulatory processes.

Some energy users may choose to contract with an independent power producer (IPP) which would require managing the relationship between the IPP and the utility, and the relevant federal and state regulations. This is the model being deployed by the Air Force at Eielson Air Force Base for its Microreactor Pilot Program.

For this reason, while there are benefits to collocating alternative energy sources like microreactors at industrial sites to utilize heat production in addition to power generation, it may be more effective to think of power production in terms of the regional system as a whole.

One aspect of the Interior power ecosystem not well considered, is heat production. Across the region, there is a patchwork of co-generation assets, the primary purpose of which is to produce heat for industrial processes or distributed heat systems. These systems generate power as a secondary purpose. That power is used internally, and excess is sold to the grid.

The University of Alaska Fairbanks operates a coal-fired combined heat and power system which produces heat, hot water, and power for the university campus. Excess power production is sold to the grid and power is purchased from the grid when necessary.

Focusing on hard rock mining in the Interior

Fast Facts about Mining in the Interior

- Three operating mines in the region – 1 coal and 2 hard rock gold mines (1 open pit – Fort Knox- and 1 below ground - Pogo).
- The two hard rock mines in the region are approaching their end of life. However, a handful of prospects (Manh Choh and Livengood) are in the advanced stages of development and could begin operations in the near term.
- Pogo reported consuming approximately 1.06 million GJ in gross energy in Fiscal Year (FY) 2022 across purchased power, heating fuel, and transportation (Northern Star Resources 2022).
- Fort Knox represented 19% of Golden Valley Electric Associations total kWh sales in FY2021, approximately 241,800,441 kWh purchased by the mine.
- Mining in the region employs approximately 1,200, and an additional 800 jobs are supported through the upstream and downstream supply chain effects (Watson, Loeffler 2022).

The case study discussed here examines one example of large-scale energy users in the Interior. The mining industry makes up a cornerstone of the Interior economy, the base upon which jobs and businesses in the region are built.

There are three operating mines in the Interior (one coal mine and two hard rock mines). More prospects are in the exploration, permitting, and development stages across the Interior, many with access to the road system and the local energy grid.

The mining industry in the region is part of a larger ecosystem of businesses and services in the region as illustrated in Figure 18. It is also deeply tied to the university and other workforce programs. This supply chain feedback loop supports approximately 800 jobs in the region in addition to the roughly 1,200 mining jobs at active mines in the region (Watson, Loeffler 2022).

Figure 18. Interior Gold Mining Industry Cluster. Source: IMPLAN, 2022.

Even narrowing in on the energy industry as a component of the mining industry supply chain, the three currently active mines play an integral role as both energy consumers and suppliers. The industry consumes heat (often heating oil) and power (grid tied utility purchases) for mine operations and producing fuel for power production by the grid (coal).

Many areas of Interior Alaska have struggled with air quality issues related to wood burning and heating oil usage for heat. The two hard rock mines in the region have actively been pursuing methods for reducing emissions and minimizing environmental impacts including investigating electrification or alternative fuels for the mine fleet and improving the energy efficiency of mining processes. The companies which own Pogo and Fort Knox have both implemented robust ESG plans, as shown in Table 17.

Table 17. Interior Hard Rock Mining Companies' Stated ESG Goals. Source: Northern Star Resources, N.D., and Kincross, 2022.

Interior Hard Rock Mining Companies' Stated ESG Goals	
Pogo	**Fort Knox**
• 2030 Emissions Reduction Targets of 35% reduction in Scope 1 and Scope 2 Emissions. • Net Zero operational emission by 2050. • FY25 commissioning approximately 20 MW of renewables at Pogo Operations, either via grid or non-grid renewable energy (wind and battery resource potential).	• Goal 1: Incorporating energy-efficient and renewable energy projects into operations and development projects. • Goal 2: Partnering with equipment manufacturers, energy suppliers, and innovation organizations to reduce GHG emissions and energy use. • Goal 3: Embedding climate change considerations into strategic business decisions. • Goal 4: Maintaining robust governance and transparent reporting. • Goal 5: Enhancing the business' resiliency to climate change.

From current actions and policies to explicit goals, it is clear that for the mines in the Interior the energy transition is already here. However, weighing an energy transition requires first addressing the current needs of the mine operations and balancing the benefits and challenges of a shift from the status quo. Using the example of the two operating hard rock mines, Table 18 lists some drivers and detractors that could influence an energy transition.

Table 18. Drivers and Detractors for Alternative Energy Adoption.

Drivers and Detractors for Alternative Energy Adoption in the Mining Industry	
Opportunities	**Challenges**
• Meeting environmental goals and outside decarbonization pressures. • Access to potential incentives and tax credits associated with decarbonization. • Goodwill or perception benefits in community from emission reduction. • If energy costs are lower, expand current revenue streams or develop new revenue streams (new value-added processing, carbon capture, hydrogen production, etc.). • Access to a carbon free heat source.	• Operational burden of new energy technology adoption—learning curve (whether utility operated, self-operated, or contracted). • Balancing new capital cost with remaining mine life and revenue stream. • Regulatory burden associated with nuclear energy on an already heavily regulated industry. • Public perception surrounding technology. • Technology readiness and supply-chain certainty of new energy technologies.

While the potential opportunities of a targeted energy transition at a mine site does create new economic opportunity, reduction of usage of coal and diesel will have economic consequences to the businesses supplying fuel, many of which are locally owned firms. If a mine leverages a new energy technology to shift to a new fuel source for transportation, transportation operators, repair and maintenance providers, and other services tied to the mine might be impacted. A reduction in sales or a business model shift means lower revenues which can often translate to job losses and loss of income.

While it is outside of the scope of this paper to estimate the economic impact of that trade-off, it is important to recognize the effect the energy transition will have to plan early to mitigate and compensate for potential losses.

Thinking about the system as a whole

As was previously mentioned, while it can be useful to simplify the question of de-carbonization of the mining industry in Interior to a decision made by the mine operator, in reality the energy demands at the mines function as part of a greater ecosystem in the region.

Looking alone at the regional power system, Fort Knox alone represented 19% of the kWh sales for GVEA in 2021 (Golden Valley Electric Association 2022). GVEA itself is examining an energy transition in terms of retirement of the Healy 2 coal plant. Long-term retirement and replacement of coal heat and power generation assets in the region reveals a broader need for baseload power replacement which supports the adoption of renewable assets like wind and solar (Ellis 2022).

> In many ways Healy, Alaska, is a traditional coal community. The area supports both Usibelli Coal Mine and GVEA's generation assets Healy 1 and Healy—both coal plants. With the retirement of many coal-fired energy assets in the region, Healy could see a decline employment at the mine and the power plant. Both Usibelli and GVEA are considering long-term options for preserving employment and economic stability in the region.

On a broader scale, the decline in natural gas production in the Cook Inlet—the primary source of fuel for power generation and heat in South Central Alaska—signals a growing concern about the cost of power and power availability for wheeling across the Railbelt system (DeMarban 2022).

One solution to both GVEA's challenge around coal replacement is adoption of a more distributed generation system, with generation assets collocated with at key demand sites or at end points on the grid where there otherwise might be stranded assets. Done in partnership with a large power/heat user this could support power needs and support the larger grid while providing access to a heat source at the site. This model could have benefits for both the utility and industrial sites like a mine, including:

- Access to heat production from excess power produced or thermal sources. Heat could be used for space heating, to support current industrial processes, or to develop new lines of business, like hydrogen production.
- Grid support for adoption of renewables. Baseload power support for the grid, co-located with large-power users could moderate the adoption of renewable, intermittent assets. Intermittent renewable technologies require the grid to have some capacity to fill valleys when power from renewable sources is unavailable. Traditionally, this need has been met with batteries, fossil fuel generation, or other flexible energy technologies. To support wider adoption of renewable resources while meeting clean energy goals a clean energy technology capable of serving as a "battery" will likely be needs. Small nuclear reactors may be one option.
- Flexible or temporary asset positioning. To support existing mines with short- to mid-term life spans, temporary energy systems deployed by the utility but capable of being relocated elsewhere may be beneficial. To support new, grid-tied mine developments, distributed energy systems capable of rapidly scaling up or down to accommodate mine production cycles may be beneficial.

Impact of disconnection

One option discussed here for energy production at the mines was for a mine to disconnect from the grid (or choose not to connect at the onset of development) and self-produce power. While this option seems unlikely given the added operational complexity for mine operators, it is still worth mentioning the impact that would have on the regional energy system and the utility's economy of scale.

Generally speaking, power utilities operate using economies of scale to manage costs. They spread costs across a predictable number of kWh sales. When generation temporarily scales up or down to meet demand utilities incur new variable costs, but usually fixed costs remain the same. In the short term this generally does not cause an impact on rates. However, more permanent fluctuations in demand—like a large power user choosing to operate its own energy system—could have an impact on rates if managed incorrectly.[o]

Utilities manage demand projections and resources needs closely, however. Large power users going offline is not often a change that happens suddenly. Utilities like GVEA manage relationships with large customers closely to project long-term changes to the system and control costs. The effect of this is minimal impact on rate payers when large shifts in the system can be anticipated and managed appropriately.

One option which is becoming more prevalent for large grid-tied industrial users is a sleeved PPA, where the utility or Independent Power Producer, owns and operates the energy installation with an agreement from the customer to purchase power for the lifetime of the technology. This model serves a distributed energy system, where industrial customers might need access to a heat source. The sleeved PPA model also moves the regulatory and capital burden from the energy users and onto the utility/power producer, leveraging their comparative advantage (U.S. Environmental Protection Agency, N.D.).

Findings

By looking at the example of the mining industry in Interior Alaska, there are clear drivers for decarbonization of the industry's energy sources. Almost all of these variables boil down to the cost competitiveness of the industry. Some include:

- The Interior mining industry is clearly feeling both external and internal pressures to decarbonize operations. Both hard rock mines in the region have set clear ESG goals which explicitly target energy production and consumption. At a different level, pressure from the federal level to penalize carbon intensity or incentivize industrial decarbonization is becoming increasingly probable and will likely impact operational costs. From a separate angle, the market is likely moving toward finding ways to value the environmental impact of commodities. First movers are finding ways to position themselves to be competitive from many angles.
- For grid connected mines, self-producing power is constrained by remaining mine life which limits the feasibility of capital-intensive energy projects difficult. In addition, the flexibility of a grid intertie reduces the operational complexity of mine operations while limiting the operational capability of the mine to the capacity of the intertie.
- In Interior Alaska, mines are often at the end of the grid. From a resiliency perspective this can be a concern for continuous mining operation. From a utility perspective, integrating generation resources at mine sites generates concerns about stranded resources. Flexibility and mobility in technology might balance this risk, which might otherwise be factored into rates.

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[o] All grid connected large power users operate under either a tariff or special contract with the utility. This often sets out the terms and conditions for asset ownership, operations and maintenance, allowable kWh sales, rates, and whether independent power production and excess sales back to the grid are allowable. If a customer chooses to disconnect from the utility grid and seek alternate generation capabilities, terms are also often set out with penalties to the customer.

- Access to, and utilization of, a heat resource is a valuable element of an alternative energy technology like nuclear. To fully utilize this resource co-location at a mine would be required. However, the value of the heat resource must be balanced with the cost of infrastructure to utilize the heat.
- Value-added production would likely benefit the mine and the regional economy, supporting local jobs. However, expanding that capability within the region is unlikely unless it is cost competitive. Energy cost is one of the largest variables limiting the feasibility of value-added production from mines in the Interior.

Section III: Alaska Energy and Nuclear Policy Review

Alaska's high-power costs and dependence on fossil fuels have driven a suite of energy policies and programs set out in the state's statutes and regulations. How these policies function is an important consideration for communities and energy stakeholders considering adopting new energy technologies.

This section is intended to serve as a detailed review of existing state-level policies potentially affecting nuclear energy production at the state level in Alaska. The primary focus is on climate and energy policies. It also reviews new or proposed legislation which may be relevant to nuclear energy production, including proposed Renewable Portfolio Standards and recently passed advanced nuclear specific legislation.

As an emerging technology, the advanced nuclear industry needs to consider federal, state, and local policies. Policies impact both the likelihood of communities and industries choosing nuclear technologies and the logistics of permitting, constructing, and operating a nuclear project. Alaska's statutes and regulations host many energy policies some of which are targeted at nuclear energy and others which may, non-explicitly, impact nuclear development.

Funding programs and subsidies make up the bulk of Alaska's energy policies, some of which could have implications for nuclear energy projects.

Power Cost Equalization Program. In its simplest form, the Power Cost Equalization (PCE) program is a state subsidy designed to equalize the cost of power in remote areas to urban Alaska (Railbelt). The subsidy is targeted at residential power customers and community facilities and calculated using a formula based on the utilities qualifying fuel and non-fuel costs. The program is targeted at reducing the cost of diesel-fueled power and there has been debate over whether it disincentivizes the adoption of other generation technologies, including potential nuclear projects.

Power Project Fund. The Power Project Fund is a loan fund appropriated by the legislature which may be used by electric utilities to pay for a variety of energy project costs: directly for the construction or improvement of small power facilities or for non-construction purposes; such as, studies, applications for necessary licenses and permits, engineering, and designing of projects. The fund does not clearly include or exclude specific technologies and could potentially finance nuclear projects.

Southeast Energy Fund. The Southeast Energy Fund is a State energy project fund created to support energy projects in Southeast Alaska specifically. However, while the fund exists in statute, it lacks funding, making it effectively defunct.

Renewable Energy Grant Fund. The Renewable Energy Grant Fund provides grant funding for renewable energy projects in Alaska. In state statute, the program excludes nuclear energy projects from the types of projects allowable to receive funding. While this does not explicitly create a barrier for nuclear energy projects by preventing the development of nuclear projects, incentivization of other non-nuclear energy sources creates a pull in the energy market away from nuclear technologies as projects are more likely to align technologies with funding sources.

Recently adopted legislation in Alaska has the potential to impact future nuclear energy projects.

Non-Binding Renewable Energy Goal. Alaska currently has a non-binding renewable energy goal of generating 50% of its power through renewable or alternative energy sources by 2025. This goal, while not specifically addressing nuclear energy, lacks any teeth to incentivize adoption of alternative energy sources and is, therefore, unlikely to affect movement toward decarbonization.

Nuclear-Specific Statute. In spring 2022, the Governor of Alaska signed into law legislation revising Alaska's statutes and regulations around nuclear energy. The legislation exempts microreactors from certain state-level siting requirements for nuclear reactors and cleans up regulations to accommodate advanced reactor technologies.

Electric Reliability Organizations. Recently established regulations around electric reliability organizations (EROs) introduce a new actor to the energy playing field in urban Alaska. EROs are tasked with conducting integrated resource planning for interconnected utility grids in the state. The legislation also gives the Regulatory Commission of Alaska the power to approve the construction of large energy facilities. While this legislation effectively creates another gate for nuclear energy projects to pass through, it also requires the evaluation of the full range of possibilities for the grid when conducting planning, including nuclear technology.

New energy policies are developing quickly in the current physical and economic climate. There is a growing push in the policy realm toward de-carbonization of energy sources through renewable and clean energy sources across the globe, and across the U.S. states are adopting clean energy or renewable energy portfolio standards. Alaska is no different in this space, with two new bills introduced in the Alaska State House and Senate during the 2022 legislative session. Neither have passed, but they signal a future shift in Alaska's energy mix.

House Bill 301. HB301, would create a binding Clean Energy Standard (CES) of 25% of net electricity sales be from clean energy by the end of 2027 on the Railbelt, before increasing that requirement to 55% by the end of 2040. The proposed CES clearly includes nuclear energy in its definition of clean energy.

Senate Bill 179. SB179 would create a binding Renewable Portfolio Standard (RPS) requiring Railbelt power producers to use renewable energy resources to supply their net electricity sales in the following percentages: "(1) 20 percent by December 31, 2025; (2) 30 percent by December 31, 2030; (3) 55 percent by December 31, 2035; (4) 80 percent by December 31, 2040." The proposed RPS does not include nuclear in the basket of qualifying energy sources.

Existing Policies

Power Cost Equalization Program

In 1985, the state of Alaska established the PCE program in an effort to mitigate the significantly higher rates electric customers in rural Alaska were paying compared to those in urban areas. The program was enacted as part of a compromise to the investments made in power infrastructure on the Railbelt, which lowered the cost of power in urban areas. The aim of the program is to ensure that electric customers across the state pay for electricity at a rate similar to the rates paid by customers in Alaska's three largest cities.

> *"Eligible electric utilities" are entitled to receive assistance from the PCE's main fund. An eligible electric utility is "a public, cooperative, or other corporation, company, individual, or association of individuals" that meets three conditions: 1) the entity "owns, operates, manages, or controls" a facility that generates, transmits, or distributes electricity for public consumption; 2) in 1983, the entity had a residential consumption level of less than 15,000 megawatt-hours if it served multiple communities or less than 7,500 megawatt-hours if it served only one community, thereby making it eligible for assistance in that year under former statutes; and 3) in 1984, the facility used diesel generators to produce more than 75% of the utility's electrical consumption. Certain electric utilities are expressly excluded from eligibility for the PCE program. According to the AEA, these include utilities serving the Railbelt, the utility in Juneau, and utilities that receive their electricity from the "Four Dam Pool facilities."*

PCE assistance is available for both "community facilities" and "residential customers." As a general requirement, utilities must use sound management practices to minimize costs in order to qualify for PCE assistance, and are required to work with state agencies to introduce "energy conservation measures" and explore alternatives to diesel generation. PCE assistance may only be provided for such costs between a base amount established by the Regulatory Commission of Alaska ("RCA") and one dollar. That base amount is updated annually by an order of the RCA. For fiscal year 2023, the RCA has established a base amount of 19.58 cents, making PCE assistance available for costs per kWh between 19.58 cents and one dollar.

Electric utilities pass PCE assistance onto their customers by subtracting the utility's PCE level per kilowatt-hour sold from customers' rates. This subtraction is only made up to the regulatory limits for community facilities and residential customers.

In addition to lowering electricity bills in rural communities, PCE funding has an additional purpose of funding grants for utility improvements. The AEA is authorized to make grants from the main PCE fund for a "small power project that will reduce the cost of generating or transmitting power to the customers of the utility." Any such grant may only fund up to 75% of a project's cost, and only three percent of the main PCE fund may be allocated to such grants in a fiscal year. A small power project must either generate less than 1.5 megawatts of power or "provide a metering system, transmission system, distribution system, or bulk fuel storage facility that has an estimated cost of less than $3,000,000."

The PCE program is seen by many as essential (Kohler 2020). The program is important for rural electric customers in that it reduces their electric rates so that they are comparable to rates in urban areas despite these communities' reliance on expensive diesel fuel (Alaska Energy Authority, N.D.). For example, the average cost of residential electricity in Dillingham, a larger rural community, was $0.45 per kWh for residential service in Fiscal Year 2021 before the PCE subsidy. With the PCE subsidy the effective residential electric rate was $0.32 per kWh (Alaska Energy Authority 2022). Comparatively, the residential power rate in Anchorage was $0.20 per kWh in the same period (Chugach Electric Association 2022).

Functionally, the PCE program acts as a subsidy for diesel-generated electricity and can make it difficult to introduce new generation sources such as nuclear into the mix (Sorrell 2021). This is because the program specifically subsidizes costs associated with diesel generation. However, some utilities have effectively manipulated the calculation to include costs associated with renewable production (i.e., purchased wind in Sand Point).

As long as the program remains sufficiently funded, eligible electric utilities are able to continue to rely on expensive fuel sources like diesel to provide electricity with minimal financial impact. It is true that as a condition of receiving PCE funding, utilities must consider diesel alternatives. However, a 2019 report by the AEA indicated that not only was diesel a major continuing source of electricity in rural Alaska, but that the AEA was actively working to improve current diesel generation systems rather than replace them (Alaska Energy Authority 2019). The subsidies thus potentially diminish incentives to explore new technologies like microreactors, which have been projected to begin supplying electricity at costs that are competitive with those of diesel generators before later dropping to levels that are consistently cheaper than diesel generators (Nuclear Energy Institute 2019).

A microreactor project could potentially receive a utility improvement grant under the PCE program, although the amount of such grants issued in any given year is limited and a microreactor would have to both reduce generation costs and meet the minimum construction cost or generation requirements laid out in regulation.

Other Funding Programs

Alaska has several other sources of funding to assist in various energy-related projects. These funding programs range from loans to grants, and vary in whether or not they favor a particular generation source or group of sources. This subsection provides an overview of programs that may be relevant to nuclear energy production and analyzes the barriers and opportunities they collectively and individually pose to nuclear energy projects in Alaska.

Power Project Fund

The Power Project Fund is a loan program which provides loans to qualifying applicants for the development, expansion, or upgrade of electric power production facilities. Funds may be used for distribution, transmission, efficiency or conservation, bulk fuel storage, and waste energy projects.

The fund can be capitalized by appropriations by the legislature, proceeds from selling loans appropriated by the legislature, and loan repayments and interest. Loans are issued from the fund by the AEA to:

- Electric utilities;
- Regional electric authorities;
- Municipalities;
- Regional and village corporations;
- Village councils; and,
- Independent power producers.

These loans may to be used to pay directly for the construction or improvement of “small-scale power production facilities” (less than 10 megawatts) or various other types of facilities. Loans may also be used for non-construction purposes to pay for studies, applications for necessary licenses and permits, engineering, and design of projects.

The AEA is prohibited from making a loan for a “major project” without prior legislative approval. A major project is one where “the cumulative state monetary involvement, through loans, grants, and bonds, is at least $5,000,000 or a project for which a loan of more than $5,000,000 has been requested.”

Southeast Energy Fund

The Southeast Energy Fund was established to ensure equity in funding of energy projects in Southeast Alaska during a period when funding for large energy projects in other areas of the state was expected. However, the large energy projects never moved forward in other regions of the state and the Southeast Energy Fund has never received appropriations to balance out funding (Robert Venables, email correspondence, July 30, 2022).

The program can be composed of funding from four sources: 1) legislative appropriations to the fund; 2) gifts, other contributions, and federal money; 3) interest earned on the balance of the fund; and 4) investments made by Alaska's Department of Revenue using the fund.

The AEA is authorized to make grants from the fund to various public and private entities for projects serving Southeast Alaska, including:

- Power projects
- Repayment of loans
- Payments on bonds for hydroelectric projects and electrical transmission lines or interties.

The term "power project" is broadly defined and likely encompasses most generation facilities, including nuclear facilities.

While this fund appears to have the potential to significantly affect energy investments in Southeast Alaska, it is not currently being utilized. In 2010, the fund's statute was amended to include more funding sources and to be available to more recipients. At that time, however, no money had been transferred to the fund for over ten years. Since then, no grants from the fund have been made. However, until the statute is sunset, the mechanism exists for the program to be funded in the future.

Renewable Energy Grant Fund and Recommendation Program

The Renewable Energy Grant Fund is a state program designed to fund renewable energy projects across the state. The program appropriated $257 million in funding for wind, biomass, solar, energy storage, hydroelectric, and other projects.

The Fund is managed by the AEA and is comprised of funding from four sources: (1) legislative appropriations; (2) gifts, other contributions, and federal money; (3) interest earned on the balance of the fund; and (4) investments made by Alaska's Department of Revenue using the fund.

Funding for each project individually appropriated by the legislature. In the past, the program has received large amounts of funding, with up to $26.6 million appropriate to projects in State Fiscal Year (FY) 2011. In more recent years, funding for the program has been variable or nonexistent. It was put on ice from FY 2016 through 2018, appropriations were made in FY 2019, then defunded in FY 2020 and 2021; however, funding was restored in FY 2022 and 2023, with $15 million in funding appropriated to energy projects in FY 2023 (Alaska Energy Authority, N.D.).

An "eligible applicant" to the program is:

- An electric utility
- Independent power producers
- Local government
- Other governmental utility, including a tribal council and housing authority.

AEA further provides that an eligible applicant must demonstrate that the applicant will own the project, control the site where the project is located, and operate and maintain the project for its economic life. The third of these requirements is conditional in that ownership or operation of a project may be conveyed if AEA determines that "the conveyance protects the public interest in and benefit from the grant."

Project eligibility requirements vary depending on the type of project. Renewable energy projects, in order to qualify for a grant under the program, must not have been in operation on August 20, 2008 (or be an addition to an existing project operating before that date) and must be:

- Either a hydroelectric facility or directly utilize renewable energy resources
- A power generation facility which uses hydrogen fuel cells derived from renewable resources or natural gas
- A facility that generates energy from renewable energy resources.

"Renewable energy resources" are defined as:

- Wind, solar, geothermal, waste heat recovery, hydrothermal, wave, tidal, river in-stream, or hydropower
- Low-emission nontoxic biomass based on solid or liquid organic fuels from wood, forest, and field residues, or animal or fish products
- Dedicated energy crops available on a renewable basis
- Landfill gas and digester gas.

Natural gas projects can qualify for a grant under the program only if they benefit a community with a population of 10,000 or less and that does not have "economically viable renewable energy resources" at its disposal. Finally, transmission and distribution infrastructure may qualify for a grant under the program if it links a renewable energy or natural gas project to the infrastructure.

The program was initially created in 2008 and set to expire in 2013. However, in 2012, the legislature extended the program for ten years. This extension set a new expiration date of June 30, 2023, at which point the statute governing the program is to be repealed. This leaves less than a year from the time of this writing before the program expires, leaving the future of the program undetermined.

How do These Funding Programs Affect Nuclear Energy Production?

Some aspects of these programs may not complement the development of nuclear energy production in Alaska. Instead, they often provide incentives to maintain fossil fuel production or incentivize renewable energy projects.

The Renewable Energy Grant Fund could represent a barrier to nuclear energy production, as it excludes nuclear from eligibility. Precluding nuclear from being considered "renewable" is typical of many state laws favoring renewable energy, despite nuclear energy generally being considered "clean" because it does not emit carbon. The program does allow for natural gas, which is not renewable, to be used in a funded project under certain conditions, but no similar provision is made for nuclear. By funding other generation sources, the program could disincentivize future nuclear projects. Whether this program presents an actual barrier to nuclear energy generation depends on whether its life is extended past its current 2023 expiration date, and as such, the legislature's activity in this area is worth monitoring.

Other aspects of grant and loan programs represent potential opportunities for nuclear energy production. Loans under the Power Project Fund appear to be available to nuclear projects, provided certain conditions can be met. While microreactors range from one to 50 megawatts in capacity, only 10 megawatt and smaller facilities would be eligible under the program (Idaho National Laboratory, N.D.). Loans from Power Project Fund are also available for non-construction uses, including applications for licenses and permits. This could be particularly helpful for nuclear facilities, which require a license from the United States Nuclear Regulatory Commission (NRC).

The Southeast Energy Fund initially appears as though it would be an opportunity for nuclear energy production in Alaska. Based on the broad definition of "power project," a grant could likely be awarded under the fund for the construction of a nuclear facility. In 2010, after the most recent amendment to the statute creating the fund, an opinion by Alaska's Attorney General expressly stated that nuclear energy projects would be eligible for grants from the fund (May 2010). Presently, however, it does not appear that the fund will be of any use to nuclear projects.

Other Energy Policies in Alaska

Alaska's Non-Binding Renewable Energy Goal

Many states have responded to energy and climate-related concerns by stating goals toward emission reductions or renewable energy adoption, often non-binding. Some states have created a renewable portfolio standard (RPS) which generally requires utility providers within a state to supply gradually increasing percentages of the total electricity with renewable energy. As of the date of this memo, Alaska does not have an RPS in place. The state does, however, have a declared energy policy, passed in 2010, which establishes a non-binding goal of supporting energy efficiency and conservation, promoting economic development through energy development, supporting energy research and development, and coordinating government functions. The policy does not explicitly state a goal for renewable or alternative energy production.

Though it is not included in the codified version of the policy, the original bill includes an expression of legislative intent which states that "the state receive 50 percent of its electric generation from renewable and alternative energy sources by 2025." No definition is provided in the bill for "renewable energy sources" or "alternative energy sources." The codified declaration of policy contains many other provisions related to energy conservation, economic development, education and research, and the coordination of government functions. Relevant to nuclear energy is the policy of encouraging economic development by "promoting the development, transport, and efficient use of nonrenewable and alternative energy resources, including natural gas, coal, oil, gas hydrates, heavy oil, *and nuclear energy*, for use by Alaskans and for export."

These policies, while directly addressing nuclear energy and other energy sources, are not likely to have a tangible impact on nuclear energy production. Neither the legislature's intent nor the codified policies are binding, and thus there is no legal or economic incentive to carry out these policies. The codified policies are especially unlikely to affect nuclear energy because they use generic language to set broad goals which are difficult to meaningfully assess.

The statement of legislative intent is more specific in terms of its goals but fails to define a "renewable energy source" or "alternative energy source." Nuclear energy is generally not considered to be renewable under state RPS laws, but without a direct statement as to what qualifies as "renewable," any attempt at defining the term is speculative. Furthermore, the inclusion of "alternative energy sources" in the goal complicates things even further, as the term could reasonably be expected to include sources beyond those that are "renewable," but is similarly unclear as to its meaning. Alaska's energy policy thus does not create any threats to nuclear energy production, but also creates few opportunities.

Alaska's New Microreactor Legislation

In May 2022, a new bill was signed that would exempt microreactors from certain state-level siting requirements for nuclear reactors. A microreactor is defined by the bill as "a nuclear utilization facility that is a nuclear fission reactor consistent with the definition of 'advanced nuclear reactor' in 42 U.S.C. 16271 and capable of generating not more than 50 megawatts of capacity." While federal licensing requirements still remain in place in any case, the bill eases the overall siting process by relaxing state law in this area.

The bill eliminated a significant state requirement regarding nuclear energy for microreactors specifically. Prior legislation required that each nuclear reactor constructed within the state receive a permit from Alaska's Department of Environmental Conservation (DEC) to construct the reactor on land designated by the legislature for such construction. The new bill leaves the DEC permitting requirement in place, but eliminates the need for siting approval by the legislature. An additional requirement left in place by the bill prohibits the DEC from issuing a permit "until the municipality with jurisdiction over the proposed facility site has approved the permit." For sites located in an "unorganized borough," the legislature must approve the permit before it is issued by the DEC.

The bill further eliminates the requirement that various state regulatory bodies continually conduct studies in order to determine whether the presence of nuclear facilities within the state would require changes in current laws and regulations. Under the bill, these studies are no longer required for microreactors. In place of these studies, the DEC is to collect comments from these agencies upon notification that an entity has applied with the NRC to operate a microreactor within the state, with such comments addressing "the [NRC] licensing process specific to the microreactor."

Overall, the new bill is a step toward modernizing Alaska's nuclear laws by carving out specific recognition for newly developing nuclear technology, improving the viability of bringing microreactors into the state. Under a more streamlined process, prospective microreactor project developers in Alaska have their requirements eased at the state level, with the updated requirements recognizing this new technology as distinct from conventional nuclear technology. This is especially helpful for nuclear energy's viability considering that nuclear projects are already subject to an extensive siting and licensing process by the NRC, making any reduction in legal and regulatory burdens welcome news to project developers.

Electric Reliability Organizations

An Electric Reliability Organization (ERO) is an organization that was created to establish and enforce reliability standards on bulk power systems, like the Railbelt in Alaska. EROs can oversee a variety of duties, including:

- Participating in the planning and development of power grids
- Enforcement of equitable review of generation and transmission
- Defining and enforcing reliability standards.

Alaska passed new legislation in 2020 to ensure that interconnected utilities in the state are served by an ERO. These organizations, once certified by the RCA, are in charge of overseeing certain aspects of coordination between utilities that are not currently monitored by the RCA under its ratemaking and related powers (Poux 2022). In practice, this legislation was specifically designed to apply to utilities located within the Railbelt (State of Alaska 2020).

The legislation was seen by some as a long time coming. Benefits that will result from the legislation, according to Renewable Energy Alaska Project, include lower electricity costs and more public involvement in the development of large-scale electricity projects. The legislation is generally designed to encourage collaboration between utilities in the Railbelt, and overall seeks to create greater efficiency in a practical and realistic manner, as advocated by the RCA in a 2015 recommendation to the legislature:

> *If the Railbelt electrical system were a blank slate today and the current institutional facts on the ground didn't exist, a single utility owning and operating all of the generation, transmission, and distribution assets would probably be the most efficient and effective system. That is not the situation we have today. It is not realistic to believe some form of a public power entity will be created with public dollars to purchase the Railbelt electric utilities' assets. Purchase of all of the Railbelt electric utilities' assets by an investor-owned utility is also unlikely given the governing structures and debt encumbrances. The State of Alaska's serious financial constraints make significant state contributions to the Railbelt's unfolding electric transmission needs a highly improbably scenario. Our recommendation to the legislature has been shaped by a clear view of our current reality and by a desire to identify a path forward that is actually attainable and that benefits ratepayers in the Railbelt (State of Alaska 2015).*

In requiring more formal cooperation among electric utilities, stakeholders seek to create greater reliability and lower electricity costs while eliminating waste and inefficiency (Poux 2022).

EROs have four main responsibilities created by statute. First, an ERO must "develop reliability standards that provide for an adequate level of reliability of an interconnected electric energy transmission network." An ERO must also develop integrated resource plans.

Integrated resource plans are submitted to the RCA and must include:

- An evaluation of the "full-range" of cost-effective options including additional generation, transmission, battery storage, and conservation across the entire grid
- Considerations for how to meet customer needs while providing the greatest value regardless of location or ownership of facilities or conservation actions.

Another noteworthy provision of ERO legislation is the requirement that the RCA must approve the construction of "large energy facilities" by a utility served by an ERO. The most relevant of these types of facilities for nuclear energy projects (and generation facilities in general) is "an electric power generating plant or combination of plants at a single site with a combined capacity of 15,000 kilowatts or more with transmission lines that directly interconnect the plant with the transmission system." In order to approve such construction, the RCA must determine that the facility is necessary to the interconnected electric energy transmission network to which it would be interconnected, that the facility complies with the ERO's reliability standards, and that the facility would meet the needs of a utility it serves in a cost-effective manner.

The RCA has established regulations guiding how an ERO should operate; including creating standards for nondiscriminatory open access transmission and interconnection. Regulations state that EROs must demonstrate that their criteria for interconnection is not discriminatory or preferential . . ." This is key when considering the mix of energy developers, technology types, and fuel sources. The regulation requires that interconnection of energy sources and transmission be considered according to equal criteria across the Railbelt.

The Railbelt utilities have begun the process of forming an ERO, but the RCA docket is still ongoing. On March 25, 2022, the Railbelt Reliability Council ("RRC") filed an application to be certified as the ERO for the Railbelt. According to the Alaska Power Association, "[t]he RRC will provide a forum and structure for six interconnected Railbelt utilities, along with seven non-utility stakeholders, to work together to address Railbelt-wide regional electric system issues to ensure grid resilience and reduce long term costs." As of this writing, the RRC has not yet been certified.

The establishment of an ERO is likely to affect the energy landscape within the Railbelt (Alaska Business 2022). Integrated resource planning would make it so that electricity needs within the Railbelt are evaluated considering the region's circumstances collectively. It is difficult to say with any precision exactly what this could mean for nuclear energy, but it would make decisions regarding nuclear energy subject to a wider variety of input, at the very least.

Standards for nondiscriminatory interconnection and open access transmission could potentially have a positive effect on nuclear energy generation. Renewable Energy Alaska Project describes these provisions as being particularly friendly toward renewable energy (REAP 2020). Although these requirements likely are positive for renewable energy projects, in reality, they are helpful for any small and independent power producers. This could include developers of microreactors, which may additionally be incentivized for use in independent power production under federal law.

Perhaps most significantly for nuclear energy generation, EROs may come to play an important role in a future renewable portfolio standard or clean energy standard. This potential legislation, discussed below, is being debated in Alaska as of this writing and would certainly affect nuclear generation within the state. Currently proposed bills would implement such legislation depending on whether or not electric utilities are served by an ERO, making EROs and their jurisdiction potentially even more impactful than they already are under current law.

Proposed Legislation

Proposed Clean Energy Standard and Renewable Portfolio Standard

Clean Energy Standards (CES) and Renewable Portfolio Standards (RPS) are policy tools that some states have begun to implement to encourage the adoption of renewable energy systems or diversification of a grid. The difference between a CES and an RPS stems from how policies define technologies as "renewable" versus "clean."

In 2022, two new bills were introduced in Alaska's legislature that would create either a Clean Energy Standard (CES) or a Renewable Portfolio Standard (RPS) for the state. The most noteworthy difference between the two bills is that the house bill, in one version, would impose a CES, which is nuclear-inclusive, while the senate bill would impose a RPS, which is nuclear-exclusive. Each of these bills, if passed, would likely have significant effects on the potential market for nuclear energy in Alaska.

House Bill 301

HB 301 would create a CES in Alaska. This type of standard would impose requirements for some utility providers to supply customers with "clean energy" as opposed to strictly requiring "renewable energy." The bill defines a "clean energy resource" using the following list:

- Wind, solar, geothermal, waste heat recovery, hydrothermal, wave, tidal, river in-stream, or hydropower
- Low-emission nontoxic biomass based on solid or liquid organic fuels from wood, forest and field residues, or animal or fish products
- Dedicated energy crops available on a renewable basis
- Landfill gas and digester gas
- Nuclear.

Because nuclear energy would count toward meeting the standard proposed by the bill, HB 301 could represent a major opportunity for nuclear energy in Alaska if passed.

The first section of HB 301 states that the bill's purpose "is to establish a clean energy standard that requires certain regulated electric utilities to derive increasing percentages of the utility's sales from clean energy resources in order to minimize costs to consumers, increase stability for economic development, maximize grid resiliency, and minimize the state's carbon emissions." Various provisions within the bill would amend the recently-passed legislation regarding EROs discussed above. One such provision would add the requirement that an ERO's integrated resource plan "include options to meet the clean energy standard . . ." The bill also adds an additional requirement for the RCA to approve construction of a large energy facility, requiring that the facility is not detrimental to a utility's ability to meet the CES.

The most impactful section of the bill is its sixth section, which would establish the actual CES requirements. The CES would first require any load-serving entity subject to the standards of an ERO to supply 25% of net electricity sales with clean energy by the end of 2027, before increasing that requirement to 55% by the end of 2040. A second CES requirement would jointly apply to all of the load-serving entities subject to the standards of an ERO. This would require "the aggregate net electricity sales for all load-serving entities on the interconnected electric energy transmission network [to] include 80 percent of sales from clean energy resources by December 31, 2050."

Load-serving entities subject to the CES would be required to submit an annual report to the RCA. This report will document the entity's progress toward meeting the CES in the previous year, including a demonstration of compliance using documentation of the entity's net electricity sales from that year. RCA regulations implementing the reporting requirement would minimize the burden placed on a load-serving entity.

The CES legislation would also establish a system of "clean energy credits" which could be used to satisfy the CES. A clean energy credit is defined by the bill as follows:

> *"clean energy credit" means one credit equal to the generation attributes of one megawatt hour that is generated from capacity built on or after July 1, 2022, that generates electrical energy derived from a clean energy resource; where fossil and clean fuels are co-fired in the same generating unit, the unit is considered to generate clean electrical energy in direct proportion to the percentage of the total heat input value represented by the heat input value of the clean fuels.*

Load serving entities would be permitted to "trade, sell, or otherwise transfer" their credits. Clean energy credits could be used only once, and load-serving entities would be responsible for demonstrating that a credit is derived from a clean energy resource in Alaska and that the credit has not already been used.

Ultimately, the passing of a CES like the one currently proposed would be positive for nuclear energy generation in Alaska, especially in contrast to the challenges a more traditional RPS could create. Although the CES would only apply to load-serving entities within the Railbelt at this point in time, including nuclear in its list of generation sources that satisfy a CES could make nuclear a more attractive option in the region. This could provide a boost for nuclear generation within the Railbelt, as the region does not have the same incentive of high, variable diesel costs to explore nuclear as the state's more remote areas. The Railbelt is also a large region, home to about two-thirds of Alaska's population. This larger market could not only allow for more nuclear projects, but more variation in technology. While microreactors may be particularly well-suited for smaller off-grid communities, small modular reactors (SMRs), which are larger than microreactors but share many of their technological advantages over conventional nuclear technology, may allow an area like the Railbelt to decarbonize while still providing on-demand electricity. SMRs have also been lauded for their potential to harmonize with renewable energy resources by providing reliable backup power for energy sources like wind and solar, the energy output of which can be subject to uncontrollable factors. A CES for Alaska would thus allow for wider application of nuclear technology in the state.

Senate Bill 179

A bill in Alaska's Senate, in contrast to the House bill described above, would create an RPS rather than a CES. The bill's expressed purpose is very similar to that of the CES bill, except that it focuses on renewable energy as opposed to clean energy. The bill ultimately requires utilities to supply electricity using renewable energy resources in a very similar manner that clean energy sources would be required under the CES bill. "Renewable energy resources" are defined by the bill as follows:

> *"renewable energy resource" means a resource that naturally replenishes over a human, not a geological, time frame and that is ultimately derived from solar power, water power, or wind power; a "renewable energy resource" comes from the sun or from thermal inertia of the earth, minimizes the output of toxic material in the conversion of energy and*
>
> . . .
>
> *does not include . . . nuclear . . .*

Therefore, while many of the mechanics of each bill operate in the same way, the bills are drastically different in what they would mean for nuclear energy generation.

There are several ways that the RPS bill operates exactly like the CES bill. The RPS bill would require that an ERO's integrated resource plan "include options for each load-serving entity to meet the renewable portfolio standard . . ." The bill would also require that approval of a large energy facility be made by the RCA only if accompanied by a finding that the facility "is not detrimental to a load-serving entity's ability to meet the renewable portfolio standard . . ." Reporting requirements and noncompliance penalties (and waiver of such penalties) are also largely the same under the proposed RPS as they are under the proposed CES. The RPS bill also establishes a system of renewable energy credits much like the clean energy credit system described above, but it differs slightly in that renewable energy credits, to count toward compliance with the RPS, must originate "from generation located within a load-serving entity's service area or from generation connected to the interconnected electric energy transmission network that serves a load-serving entity's customers."

The bills differ most significantly in terms of their actual energy standards. While the most noteworthy and obvious difference is that the RPS bill requires utilities to supply electricity with renewable energy resources, there are several other significant differences. First, the RPS bill would require a much higher percentage of renewable energy resources over time than the CES bill would require of clean energy resources, at least for individual load-serving entities. The RPS would also reach its maximum percentage requirement a decade sooner than the CES. Under the RPS bill, load-serving entities served by an ERO would be required to use renewable energy resources to supply their net electricity sales in the following percentages: "(1) 20 percent by December 31, 2025; (2) 30 percent by December 31, 2030; (3) 55 percent by December 31, 2035; (4) 80 percent by December 31, 2040."

The RPS bill also, unlike the CES bill, does not have an express standard that applies jointly to all load-serving entities served by an ERO. Although a joint RPS applying to all load-serving entities is not expressly created, the aggregate performance of load-serving entities would still be of significance under the exemption provisions of the proposed RPS. The exemptions section provides that, if aggregate sales of electricity among all load-serving entities subject to the ERO meet the RPS requirements, all load-serving entities are "exempt" from the RPS; in other words, if the entire group collectively meets the RPS, the requirements are satisfied and individuals are not assessed. In the event that the targets are not met by the group as a whole and individual entities are subject to evaluation, a load-serving entity will receive an exemption for its first instance of noncompliance with the RPS. Both exemptions, however, may not be granted after December 31, 2040, when the final RPS increase would initiate.

The proposed RPS, if passed, would ultimately create a fairly significant barrier for nuclear energy generation in Alaska. Not only would the potential advantages for nuclear generation under a CES not be recognized, but nuclear generation would directly suffer under the RPS, at least within the Railbelt. Opportunities for microreactors in isolated grids would still most likely exist if the RPS were passed, but the possibility of a more diverse array of nuclear technology being deployed within the Railbelt would certainly be called into question, as the RPS would restrict nuclear energy to, at most, a 20% share of the electricity market, a portion for which it would still have to compete with all other generation sources.

Findings

Alaska has many laws and regulations, both currently in force and proposed for the future, which could affect nuclear generation within the state. An understanding of how each of these laws operate, along with their potential effects is crucial for high level planning surrounding any potential nuclear projects.

Funding programs play a significant role in Alaska energy markets. Perhaps the most noteworthy of these is the Power Cost Equalization Program. This program, though in many respects essential for rural Alaskans, effectively subsidizes diesel fuel and creates little incentive to initiate the large-scale infrastructure changes that would likely be required to change primary fuel sources. Other funding programs offering both loans and grants for the development of energy projects could also be important in shaping nuclear energy’s viability in the state. Funds that assist in the continued use of diesel or incentivize the expansion of renewable energy may indirectly disincentivize nuclear generation by encouraging other generation sources. The Power Project Fund, on the other hand, could be very helpful for potential nuclear developers, as the funds can be used for constructing small nuclear facilities, as well as be put toward the costs of “license and permit applications.”

Alaska’s current non-binding renewable energy policy, though inclusive of nuclear energy, is unlikely to affect nuclear generation in any significant way. The policy’s lack of enforcement mechanisms, its lack of clarity in defining its essential terms, and the abstract nature of its goals make it unlikely to have any measurable effect on the way electricity markets within the state operate. Even if the policy were to have some kind of influence, it would be difficult or impossible to assess, as there are no reporting requirements or continued studies to assess the ongoing progress toward meeting these goals. Finally, the policy may soon be displaced if either Alaska’s proposed RPS or CES is passed, either of which would likely render the energy policy all but irrelevant.

Of direct importance to nuclear energy’s future in Alaska is the state’s microreactor bill that passed in 2022. This bill would exempt “advanced nuclear reactors” from certain aspects of state-level nuclear siting requirements. Although permitting and licensing would still be required at the state and federal levels, and some local input would be necessary as well, the bill would ease burdens placed on nuclear developers by cutting down on the required permits and approvals. This easing of regulatory burdens could be key to enabling nuclear energy production within the state, as the nuclear industry nationwide is regulated very heavily, producing great costs to market participants in terms of both time and money.

Electric reliability organizations are sure to change the way all energy sources are regulated within Alaska’s Railbelt, and thus will necessarily affect prospects of nuclear energy in the region. Many of the duties of EROs do not pertain specifically to nuclear energy, but rather affect the high-level planning of planning of energy projects and their various aspects in a more general sense. One provision that may be particularly important to nuclear, though, is the requirement that EROs provide “standards for nondiscriminatory open access transmission and interconnection.” This provision presents a significant opportunity for microreactors, which have a low generation capacity and may be utilized by small and independent power producers who could interconnect and sell energy from a microreactor as a secondary function in addition to a microreactor’s primary function of providing electricity and heat to industrial facilities or other specialized uses.

A final important consideration regarding nuclear policies in Alaska concerns two proposed bills, HB 301 and SB 179. The former would create a clean energy standard, and could have an extremely positive impact on nuclear generation's viability within the state. SB 179, on the other hand, creates a renewable portfolio standard that would, by 2040, an 80% share of electricity sales to come from *renewable* rather than *clean* energy resources. This small change of wording drastically changes the bill's effects, as nuclear fuels are explicitly excluded from the definition of "renewable energy resources." Under this bill, nuclear energy would only have access to 20% of the market, which could hurt its chances of becoming truly prevalent in the region. Though the CES and RPS bills would mean drastically different things for nuclear energy, it should be noted that either would only apply within the Railbelt unless another region comes to be served by an ERO, potentially reducing their effects.

Overall, nuclear energy remains an interesting prospect for development in Alaska. While some state policies directly or indirectly discourage nuclear energy production, others encourage it or at least provide incentives for engaging in such production. Equally important as current policies is the consideration of proposed policies, which could have some of the most profound effects on nuclear energy's ability to penetrate markets within the state.

Section IV: Summary and Path Forward

Opportunities and Challenges

In many ways, Alaska can be considered a first-mover state for advanced nuclear energy, with numerous use cases for microreactors specifically. In terms of policy, Alaska has made early revisions to state statutes on nuclear siting, and nuclear energy has featured in ongoing discussions around new policy at the state level, like with the recent bills proposing renewable portfolio standards.

The discussion in this document unpacks some of the opportunities and challenges around microreactor adoption in the interior of the state and, using a broader lens, how state policies might interact with small-scale nuclear adoption.

Opportunities

Movement toward diversified energy systems. In urban Alaska, the power system is undergoing a transition. Moving toward greater adoption of renewables, decreased access to local natural gas, adoption of a more distributed resource grid, and a push to decarbonize. These variables are mostly favorable for alternative energy adoption, presenting an opportunity for microreactors or small-scale nuclear energy technology to provide base load power, support renewable adoption, or fill in gaps where there might be resiliency concerns. Grid endpoints or supporting large industrial loads are two examples of this.

Need for decarbonization. Policy signals like the proposed Alaska Renewable Portfolio Standard and industry ESG (Environmental, Social, and Governance) goals are just two examples of political and market movement toward decarbonization of energy systems in Alaska. While renewables technologies are increasingly cost-competitive and are being more widely adopted, they are unlikely to fully replace fossil fuel extraction and consumption in Alaska, potentially leaving space in the market for nuclear technology.

High cost of power driving innovation. Historically, the high cost of energy across Alaska has driven innovation. The adoption of new technologies and testing and product development in the state continues to be a rich space for startup activity. However, this must be balanced by the need for reliability and resiliency on the many power grids across the state.

Early interest in nuclear energy. Nuclear energy has a long history in Alaska, starting at Fort Greely with the SM-1A power plant. Today energy producers across the state are engaged in ongoing discussions around advanced nuclear energy. Technical understanding and awareness of microreactors among energy experts are likely higher than average.

Need for heat. While heat often receives less attention than power, demand for heat across Alaska is high and of critical importance to health and safety. In most areas, heat is produced by burning fossil fuels, leaving a rich space for decarbonization. Industrial heat is one potential opportunity for microreactor technologies with large, constant, and central heat demand.

Decarbonization of other systems. Decarbonization of transportation systems is another area of opportunity for microreactors. Constant, affordable heat and power may enable the implementation of electric or hydrogen-fueled vehicles. Looking at the mining space, fleet electrification, or alternative fuel adoption will aid mines to meet their ESG goals.

Favorable microreactor siting policy. Alaska's recent revision of nuclear siting statutes, and current drafting of microreactor regulations, signal a favorable policy environment in Alaska for siting microreactors. It also presents an opportunity for Alaska to model legislation to other states to revise or adopt policies specific to microreactors and learn from others making similar revisions.

Challenges

Cost competitiveness. Across the board, energy costs in Alaska are high; however, costs can also be variable across the state. Rural areas experience some of the highest costs but could have the most to lose from adopting early-stage technologies and often have lower local technical capacity. More urban areas experience lower costs but have greater technical capacity to manage unforeseen circumstances. All are sensitive to costs. Microreactors are initially expected to be a high-cost energy technology and will compete against other, potentially lower cost options.

Concern over public perception. Energy experts in Alaska appear to have some technology awareness and comfort with microreactors; however, concern remains around understanding, awareness, and comfort across the broader population. Little is known about nuclear public perception in Alaska, especially around microreactors or other advanced nuclear technologies.

Fixed asset amortization. Focusing on the industrial energy space, the mining industry specifically has raised points about matching the cost of a large energy asset to the remaining life of mine development. Operators voiced concerns over spreading the cost of a microreactor across limited revenues anticipated for existing mines. Opportunities do exist for small modular reactors that could be moved between mining locations.

PCE (Power Cost Equalization) subsidy impacts. It remains unclear how adopting a microreactor in a rural community might affect a community's PCE subsidy. Perceptions around the reduction impacts of PCE may present a hurdle for a microreactor project in a community participating in the program.

Areas for Future Research

Based on these findings and other ongoing work in Alaska, there are several areas where further exploration is warranted. Many of these proposed future areas of work could interest other funders for a shared effort. These include:

- Utilization of a microreactors heat resource:
  - Examining and developing business models for utilization of heat from a microreactor under a handful of use cases such as an industrial heat and power user, community distributed heat system or electric heating.
- Microreactor Supply Chain:
  - Mapping the microreactor supply chain cradle to grave, including the relationship with national security concerns and new business development opportunities, inclusive of manufacturing.
    - Advance work with the Alaska Innovators and Entrepreneurs group working to address supply chain needs through business development awareness seminars.

- Comparing (State-by-state) tax and other incentive packages for manufacturers, and related business developers. Exploration of other forms of resources necessary to aid business entry into the energy service sector inclusive of ancillary service or product providers in the microreactor space.
- Workforce training and associated jobs analysis. Identification of where the jobs are now and a forecasting of the jobs of the future. What skills and occupations are present within the nuclear industry now, and how do these crosswalks to the needs of a micronuclear industry sector. Identification of resources in and out of state to stage workforce development - just-in-time training.

- Arctic and Alaska:
  - Exploring the incorporation of microreactors into existing oil and gas extraction operations to address heat and power needs at industrial enclaves and lengthen the economic viability timeframe of existing fields.
  - Understanding permafrost considerations given nuclear heat and power solutions–using a case study approach. Exploring how Canada addresses district heat solutions while avoiding impacts on permafrost.
    - Conducting an economic impacts analysis of Northwest passage opening—assessing the economic opportunities to communities in the Alaskan Arctic, including how energy availability plays a role in the economic potential.
    - Modeling a use case analysis of emergency management and disaster response and how the use of microreactors can be incorporated.
    - Conducting an analysis of critical mineral extraction and refining (mapping deployment use scenarios). This is a long-term strategy related to the CHIPS Act.
- Public Policy
  - Identifying points of public acceptance and resistance. Drafting op-ed or short white paper that can be utilized between states.
    - Exploring Dow Chemical small modular reactor use case in Mexico. What lessons can be gleaned and how is the case study comparable to AK, WY.
  - Identifying how the work of EMA to date can help influence public policy decision making. Explore what tools are still necessary. Identify how entities such as the Ted Steven's Center and Ted Steven's archives could benefit from this work.
  - Modeling different use cases, conduct an economic analysis inclusive of replacement costs for investment in renewables or reinvestment in renewables versus investments in microreactors or small modular reactors. Exploration of how UAA could establish a nuclear energy institute
  - Establishing a new industry sector is a complex endeavor – not many examples to readily learn from. Begin to map all the elements that need to occur and what stakeholders need to engage.

References

2019. "UA Coal-Fired Power Plant Wins Power Magazine Top Plant Award." *Alaska Business.* August 14, 2019. https://www.akbizmag.com/monitor/ua-coal-fired-power-plant-wins-power-magazine-top-plant-award/

2022. "National Strategy for the Arctic Region." *The White House: Washington.*

354th Fighter Wing Public Affairs. "Eielson AFB celebrates F-35 beddown completion." Air Force. May 19, 2022. https://www.af.mil/News/Article-Display/Article/3036523/eielson-afb-celebrates-f-35-beddown-completion/#:~:text=Eielson%20AFB%20has%20a%20total,for%20fifth%2Dgeneration%20aircraft.%20(.

Alaska Energy Authority. 2022. "Power Cost Equalization Program: Statistical Report FY2021." https://www.akenergyauthority.org/What-We-Do/Power-Cost-Equalization/PCE-Reports-Publications.

Alaska State Legislature. House of Representatives. An Act relating to the establishment of renewable portfolio standard for regulated electric utilities: and providing for an effective date. HB 301, 32d Leg., Reg. Sess. 2022. https://www.akleg.gov/basis/Bill/Detail/32?Root=hb%20301.

Alaska State Legislature. Senate. *An Act relating to nuclear facility siting permits: and relating to microreactors.* SB 177, 32d Leg., Reg. Sess. 2022. https://www.akleg.gov/basis/Bill/Detail/32?Root=sb%20177.

Alaska State Legislature. Senate. An Act relating to the establishment of a renewable portfolio standard for regulated electric utilities; and providing an effective date. SB 179, 32d Legislature, Reg. Sess. Introduced in Senate February 4, 2022. https://www.akleg.gov/basis/Bill/Detail/32?Root=SB%20179.

Alaska Statute. 2022. § 42.05.

Alaska Statute. 2022. § 42.45.

Alaska Statute. 2022. § 44.99.

Araújo, Kathleen and Koerner, Cassie. 2023. "An Assessment of Policies and Regional Diversification with Energy, Critical Minerals and Economic Development in Emerging Markets." Report Prepared for the U.S. Department of Energy.

DeMarban, Alex. "Hilcorp warns Alaska utilities about uncertain Cook Inlet natural gas supplies." *Anchorage Daily News.* May 17, 2022. https://www.adn.com/business-economy/energy/2022/05/17/hilcorp-warns-alaska-utilities-about-uncertain-cook-inlet-natural-gas-supplies/.

DeMarban, Alex. 2022. "Gov. Dunleavy Signs Bill Streamlining Effort to Bring Nuclear Microreactors to Alaska Villages." *Anchorage Daily News*. May 24, 2022. https://www.adn.com/business-economy/energy/2022/05/24/gov-dunleavy-signs-bill-streamlining-effort-to-bring-nuclear-microreactors-to-alaska-villages/.

Ellis, Tim. 2022. "GVEA changes course, Oks Healy 2 shutdown, Healy 1 upgrade." *KUAC.* June 28, 2022. https://fm.kuac.org/2022-06-28/gvea-changes-course-oks-healy-2-shutdown-healy-1-upgrade

Energy Information Agency. 2021. "Form EIA-860 Data." https://www.eia.gov/electricity/data/eia860/.

Energy Information Agency. N.D. "Alaska: State Profile and Energy Estimates." https://www.eia.gov/state/?sid=AK.

Fairbanks North Star Borough. 2022. "Comprehensive Economic Development Strategy Update: 2022-2027." https://fnsbceds.com/wp-content/uploads/2022/10/09-30-22-FNSB-CEDS-Full-CEDS-Adopted.pdf.

Federal Aviation Administration. 2021. "CY2021 Qualifying Cargo Airports, Rant Order, and Percent Change from 2020." https://www.faa.gov/airports/planning_capacity/passenger_allcargo_stats/passenger/cy21_cargo_airportshttps://www.faa.gov/airports/planning_capacity/passenger_allcargo_stats/passenger/cy21_cargo_airports.

Johnson, N., Erickson, K. S., Ferguson, D. B., Jager, M. B., Jennings, L. L, Juan, A. R., Larson, S., Smythe, W. K. S., Strawhackers, C., Walker, A., Carroll, S. R. 2021. "The impact of COVID-19 on food access for Alaska Natives in 2020." *NOAA Arctic Report Card OAR ARC.* 21-15. DOI: 10.25923/5cb7-6h06.

Johnson, Richelle. 2020. "Microreactors in Alaska: Customer Discovery and Perception." *University of Alaska Center for Economic Development.* https://static1.squarespace.com/static/59f6b60bcf81e02892fd0261/t/60189afcbc397811525aca24/1612225286635/Customer+Discover+and+Perception+Analysis.pdf.

Johnson, Richelle. 2020. "Microreactors in Alaska: Use Cases." *University of Alaska Center for Economic Development.* https://static1.squarespace.com/static/59f6b60bcf81e02892fd0261/t/60189ac2d4aab87fb9b3211a/1612225233302/Use+Case+Analysis_Complete.pdf.

Kincross Gold. 2021. "Kincross Gold 2021 Climate Report." https://s2.q4cdn.com/496390694/files/doc_downloads/2022/07/6849_Kinross_2021_Climate_Report.pdf.

Kincross. 2022. "Kincross Gold: 2021 Sustainability Report." https://s2.q4cdn.com/49639069.4/files/doc_downloads/2022/05/6838_Kinross_SR-2021_May_10-(1).pdf.

Klouda, Nolan, Johnson, Richelle, and Mills, Ian. 2021. "Alaska's Military Supply Chain: An Analysis." *University of Alaska Center for Economic Development.*

Kohler, Meera. 2020. "Defunding Power Cost Equalization Would Gut a Lifeline for Rural Alaska." *Alaska Village Electric Cooperative.* https://avec.org/2020/11/12/defunding-power-cost-equalization-would-gut-a-lifeline-for-rural-alaska/.

McDowell Group. 2020. "Statewide and Port of Alaska Long Range Fuel Forecast." *Port of Alaska.* https://www.portofalaska.com/wp-content/uploads/Alaska-PoA_Fuel_Forecast_Nov2020.pdf.

McKinley Research Group. 2022. "The Economic Benefits of Alaska's Mining Industry." Accessed December 8, 2022. http://www.alaskaminers.org/_files/ugd/beae26_58eaa908926f41a18a2d4cf5d74bad4b.pdf.

McKinley Research. 2021. "Alaska's Renewable Energy Economy: Progress and Possibility." *The Nature Conservancy.* https://www.nature.org/content/dam/tnc/nature/en/documents/AlaskaRenewableEnergy2021.pdf.

Northern Star Resources Limited. 2022. "Pogo Site Visit Presentation: September 2022." https://www.nsrltd.com/investor-and-media/asx-announcements/2022/september/investor-presentation-pogo-site-visit

Northern Star Resources, Ltd. 2021. "Sustainability Report." Accessed January 8, 2023. https://www.nsrltd.com/sustainability.

Northern Star Resources. N.D . “Environmental Stewardship.” Accessed January 8, 2023. https://www.nsrltd.com/sustainability/environmental-stewardship.

Nuclear Energy Institute. 2019. “Cost Competitiveness of Micro-Reactors for Remote Markets.”

Poux, Sabine. 2022. “There’s No Organization Uniting the Alaska Railbelt’s Electrical Utilities. One Group Just Applied to be the First.” Alaska Public Media. April 4, 2022. https://alaskapublic.org/2022/04/04/theres-no-organization-uniting-the-railbelts-electrical-utilities-one-group-just-applied-to-be-the-first/.

REAP. 2020. “Four Things You Should Know About Alaska’s New Electric Reliability Organization, or “ERO” Apr. 8, 2020. https://alaskarenewableenergy.org/4-things-you-should-know-about-alaskas-new-electric-reliability-organization/.

Sims, John. 2018. “Fort Knox Mine Fairbanks North Star Borough, Alaska, USA: National Instrument 43-101 Technical Report.” *Kincross.* Accessed December 11, 2022. https://s2.q4cdn.com/496390694/files/doc_downloads/2018/Fort-Knox-June-2018-Technical-Report.pdf.

Sorrell, Evelyn. 2021. “Tensions in Renewable Policy Development in Alaska.” Kleinman Center for Energy Policy. Accessed July 31, 2022. https://kleinmanenergy.upenn.edu/news-insights/tensions-in-renewable-policy-development-in-alaska/.

State of Alaska. 2016. “Preliminary Best Interest Finding and Determination for the Sale of Alaska North Slope Royalty Oil to Petro Star Inc.” *Division of Oil and Gas Alaska Department of Natural Resources.* https://aws.state.ak.us/OnlinePublicNotices/Notices/Attachment.aspx?id=104610.

State of Alaska. 2021. “Population Estimates.” *Department of Labor and Workforce Development. https://labor.alaska.gov/.*

State of Alaska. 2022. “Alaska Statewide: Comprehensive Economic Development Strategy 2022-2027.” *Alaska Department of Commerce, Community, and Economic Development.* https://www.commerce.alaska.gov/web/Portals/0/pub/CEDS/Final%202022-2027%20Alaska%20Statewide%20CEDS.pdf?ver=2022-11-14-103449-430.

State of Alaska. 2022. “Golden Valley Electric Association, Inc. and Subsidiary: Consolidated Financial Statements and Supplementary Information, and RUS Report.” *Regulatory Commission of Alaska.* https://rca.alaska.gov/RCAWeb/ViewFile.aspx?id=CEFA5B28-B152-436B-A3C9-DDC567D9A69D.

State of Alaska. 2023. “Tariff Action Memo: Chugach Electric Association: Cost of Power Adjustment and Small Facility Power Purchase Rate.” *Regulatory Commission of Alaska.*

State of Alaska. N.D. “Fairbanks PM2.5 Data.” *Division of Air Quality: Monitoring and Quality Assurance.* https://dec.alaska.gov/air/air-monitoring/community-data/fnsb-fairbanks-pm25-data/.

State of Alaska. N.D. “Interior economic region total Nonfarm employment, percent change 2012 to 2021. *Department of Labor and Workforce Development. https://labor.alaska.gov/.*

Sumitomo Metal Mining Pogo. 2017. “2017 Pogo Plan of Operations: Revision 1.”Accessed December 11, 2022. https://dnr.alaska.gov/mlw/mining/large-mines/pogo/.

The White House. 2022. “Inflation Reduction Act Guidebook: Clean Energy.” https://www.whitehouse.gov/cleanenergy/inflation-reduction-act-guidebook/.

U.S. Department of Defense. 2022. “Defense Spending by State – Fiscal Year 2021.” *Office of Local Defense Community Cooperation.* https://oldcc.gov/dsbs-fy2021.

U.S. Department of Defense. N.D. “Micro-Reactor Pilot Program.” *Eielson Air Force Base: Deploy.* Accessed November 10, 2022. https://www.eielson.af.mil/microreactor/.

U.S. Environmental Protection Agency. N.D. "Utility Green Tariffs." *Green Power Markets.* Accessed January 8, 2023. https://www.epa.gov/green-power-markets/utility-green-tariffs.

University of Alaska Center for Economic Development. N.D. "Economic Impacts of the Military in Alaska." https://infogram.com/economic-impacts-of-the-military-in-alaska-1hdw2jp8x0nwd2l?live.

University of Alaska Fairbanks. "UAF Fuel Cost for Steam and Power." Accessed November 10, 2022. http://pecanpi.uaf.edu/utilitiesweb/powercost.jpg.

University of Alaska Fairbanks. N.D. "FS Utility Rates." Accessed November 10, 2022. https://facilities.alaska.edu/uaf/fsweb/utilityRates.cfm.

University of Alaska Fairbanks. N.D. "Fact Sheet." *Planning, Analysis, and Institutional Research* Accessed November 10, 2022. https://www.uaf.edu/pair/factsheet/index.php.

Voiland, Adam. 2022. ""A Smoky Summer in Alaska." *NASA.* https://earthobservatory.nasa.gov/images/150056/a-smoky-summer-in-alaska.

Wang, Michael, Lee, Hanjie, Molburg, John. 2004. "Allocation of Energy Use in Petroleum Refineries to Petroleum Products: Implications for Lifecycle Energy Use and Emission Inventory of Petroleum Transportation Fuels." *International Journal of Lifecycle Assessment.* 9 (1): 34-44. http://dx.doi.org/10.1065/lca2003.07.129.

Watson, Brett, Loeffler, Robert. 2022. "The Economic Potential of Alaska's Mining Industry." *Institute of Social and Economic Research, University of Alaska Anchorage.*

Appendix D

MIT Evaluating the Cost Competitiveness of Microreactors[p]

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SUMMARY

The purpose of this study is to assess opportunities and barriers for microreactors in emerging energy markets. This analysis employees cost optimization modelling to evaluate economic tradeoffs for microreactor applications. A generic microreactor is studied for operation at: (1) a utility located at a remote location (i.e., Nome, Alaska), and (2) a hypothetical institution on the central Alaskan railbelt operating a district heating loop. Results will provide insights into the economics of microreactors that cogenerate electricity and heat. The study begins with a survey of prior research on the cost competitiveness of microreactors in Alaska.

INTRODUCTION

Chaney et al. (2008) evaluated installation of a microreactor at the small city of Galena in central Alaska along the banks of the Yukon river. The city's incumbent utility system relied exclusively on diesel. The evaluation considered a variety of generation technologies, but ultimately focused on comparing the cost of three main alternatives: (i) continued reliance on diesel, including capacity for back-up, (ii) a shift to primary reliance on coal generation, with diesel units for back-up, and (iii) a shift to primary reliance on a microreactor, also with diesel back-up. The study found that the nuclear system provided the lowest cost power for consumers. A key driver of this result was that the vendor offered to fully subsidize the capital cost of the new microreactor, so that the only cost incurred by the city utility would be the staffing and other operating costs, including fuel costs. When an estimated capital cost is included, the nuclear alternative was no longer the lowest cost. Another key driver was that the microreactor system included expanded provision of heat, in particular district heating to the nearby air station. This offset some of the costs, thereby lowering the cost of electricity charged to customers. The study did not evaluate the ability of the other alternatives to provide this same heating service.

Holdmann et al. (2011) from the Alaska Center for Energy and Power (ACEP) compares the Levelized Cost of Electricity (LCOE) for five small reactor designs to diesel- and natural gas-fueled alternatives across ten differently situated communities. The study explores how the results vary depending upon assumptions on the capital cost of the reactors and upon assumptions about fossil fuel prices and carbon prices. The communities differ in size, which impacts the suitability of the reactors relative to the load: many of the communities were too small relative to reactor capacity. The communities also differ in the availability of natural gas and the delivered cost of diesel. The span of projected fossil fuel costs drove the comparison, so that in the low forecast the small reactors were more costly than the fossil fuel alternatives regardless of the capital costs, while in the medium and high forecasts, the microreactor would become the less costly in certain communities at some time horizon. The low range of carbon prices considered did not significantly impact the analysis. In the case of one community—Eielson Air Force Base (AFB), the study included the possibility of supplying a district heating system and found that this had a significant impact on the residual cost of electricity.

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Nichol and Desai (2019) describe a range of possible LCOEs for microreactors and how this range may fall as deployment proceeds. They then describe a range of LCOEs for differently situated Alaskan communities and customers facing different delivered cost of diesel or other fuels—with remote Arctic communities facing the highest cost, remote defense installations the next highest, island communities and remote mines the next, followed by the Alaskan Railbelt and then, at the low-cost end, by the lower 48 U.S. grid. These two ranges overlap significantly, so that microreactors appear initially competitive in the high diesel cost locales and potentially becoming competitive in other locales, depending upon the realized cost of microreactors.

Holdmann et al. (2021), in an update to ACEP's 2011 study, identified subsequent changes in key drivers in the cost comparisons. Notably, the Railbelt region where a reactor was most potentially competitive, had undergone significant investment in new efficient gas-fired capacity, possibly foreclosing an economic rationale for investment in reactor capacity. It noted the exceptions of Eielson AFB and Fort Wainwright which continued to rely on aging coal-fired CHP plants. Also, new gas delivery contracts in the Railbelt locked in prices substantially below those used in the 2011 study, compounding the competitiveness challenge in that region. Third, oil prices had fallen, lowering diesel costs throughout Alaska. On the other hand, if the Nichol and Desai (2019) microreactor cost range is accurate, this could make reactors competitive outside of the Railbelt, at small hub communities. Finally, the study reiterated the possibility of providing district heating to an existing system as an important factor in evaluating cost competitiveness.

More context about the various communities and potential customers for reactors in Alaska beyond the cost comparisons discussed above can be found in a report by the University of Alaska's Center for Economic Development (2020).

Macdonald and Parsons (2021) build on this earlier work by moving from minimizing LCOE to minimizing system cost. They evaluate a microreactor's inclusion as a part of a portfolio of equipment on a system using a capacity expansion and dispatch model that minimizes 'system cost', which is the total capital and operating cost of the full set of generation and heating equipment used to serve loads. For simple systems employing only one technology, the LCOE and the system cost analysis will be the same. However, once a system deploys multiple technologies to serve a load, the results of the two evaluations may differ. This is because the microreactor may not displace a single technology one-for-one: rather, the inclusion of a microreactor may lead to a reshuffling of the reliance on a combination of technologies making the required comparison more complex. Moreover, the realized duty cycle of the microreactor depends upon the types of other equipment on the system, which is a second factor to include in the correct cost comparison. Without a full system model, it can be difficult to identify the right combination to compare against the microreactor. For example, Macdonald and Parsons show that a microreactor installed on a remote mine to substitute for a diesel generator may operate at a greater capacity factor than one installed in the Railbelt to substitute for an efficient gas generator. As shown below, where the microreactor is used to supply heat, seasonality in the heat demand and the daily cycles in electricity demand may mean that occasionally some heat is produced as bypass heat, lowering the quantity of electricity supplied. However, this is done where the value of electricity is less, using capacity installed to serve other hours when the value is high.

This report discusses the application of the system cost approach in more detail, focusing on two specific contexts. In doing so, it highlights key drivers for analysis. The first context is a small, off-grid community centered on Nome, Alaska. The second is a large institution in the Alaskan Railbelt which operates a district heating loop, based on candidates in the Fairbanks region. This work is preliminary to additional studies in each context, incorporating priorities and options detailed by the local communities and utilizing input assumptions appropriate to each context. Laying out the methodology as we do here facilitates the process leading towards future studies.

SYSTEM COST DRIVERS IN NOME CONTEXT

An earlier appendix in this report, Appendix A, provides a more comprehensive overview of Nome and the provision of its energy. Heating demand constitutes three-quarters of its energy services and electricity one-quarter. However, almost all the heating is supplied at individual households where diesel fuel is a convenient option and a microreactor cannot readily be a substitute. Therefore, our initial focus is on the electricity demand served by the Nome Joint Utility Services (NJUS). Later we discuss further analysis including heat.

Current System

Figure 19 shows Nome, Alaska's hourly electric load in 2022. Overlaid on it are the monthly average loads. In addition to the seasonality flagged with the monthly averages, the load has the typical daily cycle, with an afternoon peak on average 14% above the daily mean and an early morning minimum 13% below the daily mean.

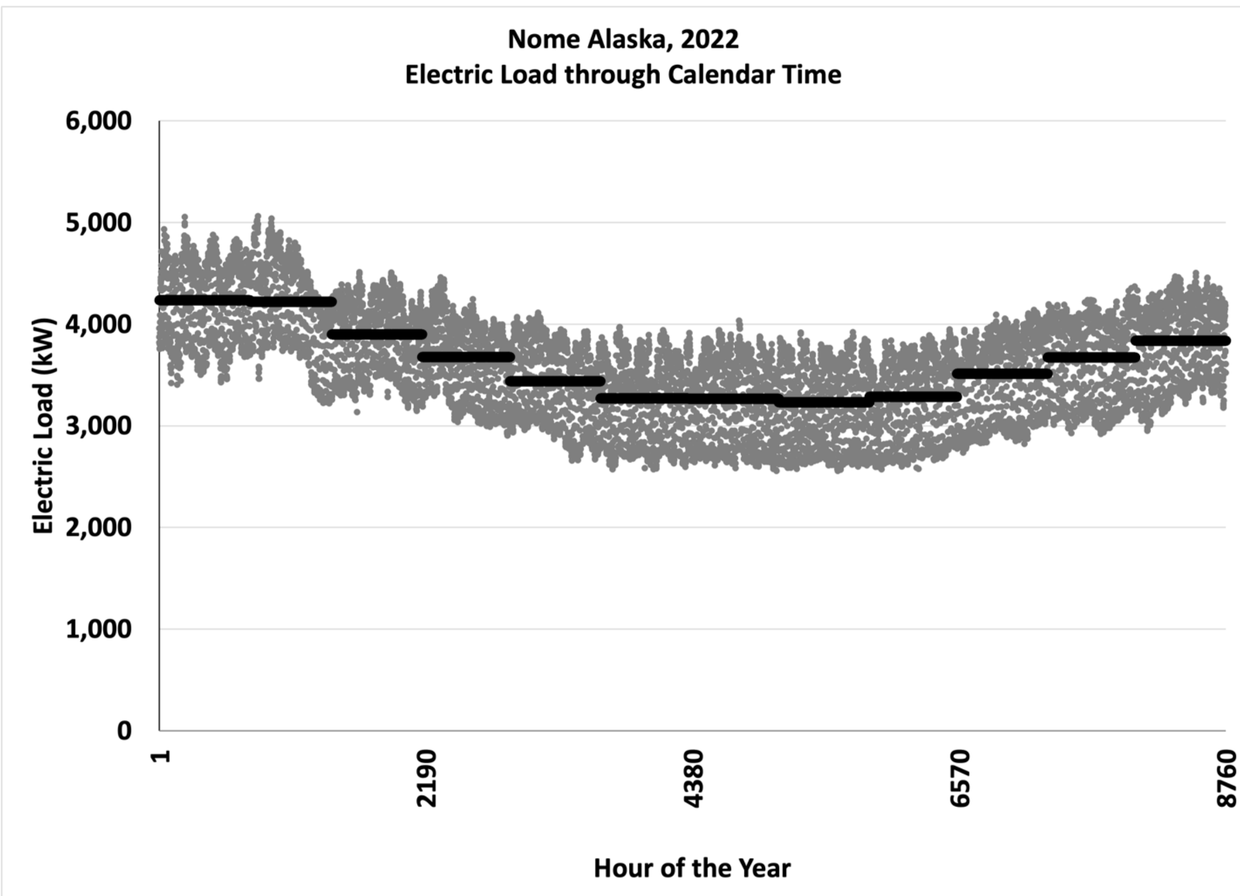

Figure 19. Hourly electric load, 2022. Source: Nome Joint Utility Services. Data for a few hours has been adjusted where generation constrained reported load.

The load shape matters because it imposes requirements on the system. For example, Nome's average hourly load in 2022 was 3,628 kilowatts (kW). However, its peak load was 5,063 kW. The local utilities company must maintain a portfolio of capacity that can reliably supply this peak load, not just the average load. Therefore, a common industry metric is the load factor, which is the ratio of the average load to the peak load. A constant load has a load factor of 1.0, and the peakier the load, the smaller is the load factor. For Nome, the annual hourly load factor is 0.72.

NJUS currently serves this load using four diesel generators and two wind turbines. Pike and Green (2017) provide a detailed analysis of the operation of the system using a year of data from July 2015-June 2016. The utilization currently seems to still conform to their descriptions. "NJUS operates with two Wärtsilä 5.211-megawatt (MW) diesel generators, which alternate to supply power. A 3.660 MW Caterpillar generator is used during the off-peak summer hours when demand is low, and a 1.875 MW Caterpillar generator is used to augment peak loads during winter afternoons. A 0.4 MW diesel generator is used as a black start unit in case of a black out and can support lower temporary peaking requirements." The wind (W) turbines each have a capacity of 0.900 MW, and total generation equals approximately 12% of load in 2022, although reports for earlier years have shown an 8% share. Currently wind generation is often curtailed—according to Pike and Green (2017), nearly a third of the potential generation is lost to curtailment. The curtailment is necessary to limit the share of load supplied by wind and thereby maintain sufficient spinning reserve to maintain power quality on a microgrid without sophisticated control equipment.

Alternative Supply Options for Current Load

NJUS (2022) outlines a variety of options for Nome's future energy supply. These include further installation of Emergya Wind Technologies (EWT) in combination with a Battery Energy Storage System (BESS), which together could expand wind's contribution up to more than 20% or even 40% of electric load depending upon the scale of turbines added. Table 19 lists the equipment in the current system (Option A) alongside the equipment in these two expanded wind options (Options B and C). The table also shows a further Option D which substitutes a microreactor (MR) for one of the large diesel generators.

Table 19. Alternative equipment options to serve current load.

Equipment in Alternative System Options			
Option A Current System	Option B Additional Wind & BESS	Option C Expanded Wind & BESS	Option D Microreactor
Existing Diesel	Existing Diesel	Existing Diesel	Existing Diesel
Wärtsilä 5.211 MW	Wärtsilä 5.211 MW	Wärtsilä 5.211 MW	~~Wärtsilä 5.211 MW~~
Wärtsilä 5.211 MW	Wärtsilä 5.211 MW	Wärtsilä 5.211 MW	Wärtsilä 5.211 MW
Caterpillar 3.660 MW	Caterpillar 3.660 MW	Caterpillar 3.660 MW	Caterpillar 3.660 MW
Caterpillar 1.875 MW	Caterpillar 1.875 MW	Caterpillar 1.875 MW	Caterpillar 1.875 MW
Existing Wind	Existing Wind	Existing Wind	Existing Wind
EWT 0.900 MW	EWT 0.900 MW	EWT 0.900 MW	EWT 0.900 MW
EWT 0.900 MW	EWT 0.900 MW	EWT 0.900 MW	EWT 0.900 MW
	Additional Wind & BESS	Expanded Wind & BESS	Microreactor 5MW
	EWT 1 MW	EWT 1 MW	
	EWT 1 MW	EWT 1 MW	
	BESS	EWT 1 MW	
		EWT 1 MW	
		BESS	

Table 20 provides summary data on how each of these systems might operate when optimally dispatched over a year. These numbers are illustrative only to help show the system cost calculation, and are not calculated from a dispatch model. Consistent with historical experience, for the current system, Option A, the two wind generators are shown providing a combined 8% of load. Per Pike and Green (2017) a significant share of the potential wind generation is curtailed to maintain system stability—in the illustration, this is about a quarter of their potential and is responsible for the capacity factor being only 16%. Most of the load is supplied from the two large diesel generators, which alternate services on the system. The two smaller generators provide occasional supplements when needed.

Table 20. Illustrative system inputs (capacity) and system outputs (generation) for four options.

Option A

	Input Capacity MW	Output Generation MWh	Output Capacity Factor
D1	5.211	13,744	30%
D2	5.211	13,744	30%
D3	3.660	585	2%
D4	1.875	1,170	7%
W1	0.900	1,271	16%
W2	0.900	1,271	16%
Total		31,784	

Option B

	Input Capacity MW	Output Generation MWh	Output Capacity Factor
D1	5.211	11,490	25%
D2	5.211	11,490	25%
D3	3.660	585	2%
D4	1.875	1,170	7%
W1	0.900	1,694	21%
W2	0.900	1,694	21%
W3	1.000	1,882	21%
W4	1.000	1,882	21%
BESS	1.000		
Total		31,886	

Option C

	Input Capacity MW	Output Generation MWh	Output Capacity Factor
D1	5.211	9,684	21%
D2	5.211	9,684	21%
D3	3.660	585	2%
D4	1.875	1,170	7%
W1	0.900	1,694	21%
W2	0.900	1,694	21%
W3	1.000	1,882	21%
W4	1.000	1,882	21%
W5	1.000	1,882	21%
W6	1.000	1,882	21%
BESS	1.000		
Total		32,038	

Option D

	Input Capacity MW	Output Generation MWh	Output Capacity Factor
MR	5.000	20,615	47%
D2	5.211	6,872	15%
D3	3.660	585	2%
D4	1.875	1,170	7%
W1	0.900	1,271	30%
W2	0.900	1,271	30%
Total		31,784	

The values shown for Options B and C reflect the assumption that the addition of the BESS reduces curtailment of the wind turbines. As a result, their capacity factors increase from 16% to 21%. Total wind generation in Option B is 7,152 megawatt-hour (MWh), which is an increase of 4,610 MWh over the current system, Option A. As a consequence, diesel generation falls by 4,508 MWh. The difference between the increase in wind generation and the decrease in diesel generation is due to round-trip losses in utilization of the battery.

The addition of a further two wind turbines in Option C increases wind generation by an additional 3,764 MWh, and decreases diesel generation by 3,612 MWh.

Looking to the assumed generation for Option D, with a microreactor, we should understand that a critical determinant of the system cost is the amount of time that the microreactor is offline for maintenance. In constructing Table 20, we assumed that the microreactor is offline for one quarter of the year. During this period the large diesel generator carries most of the dispatchable load. The other two diesel generators continue to provide occasional peaking capability, just as they do in the current system.

System Cost Comparisons

Table 21 shows a set of cost assumptions for the equipment used in these various options. Table 22–Table 25 shows the system cost of each option. These are all ‘greenfield’ calculations, meaning that each system includes a complete set of new equipment. Table 26 collects the total cost number from each option. For the set of assumptions made here, the four options all have approximately the same unit cost, \$0.42–\$0.45 per kWh.

Looking at the cost categories, Option D with the microreactor has the largest capital expense and the lowest fuel cost.

Table 21. Cost assumptions.

	Capex $/MW	Fixed O&M $/MW/y	Variable O&M $/kWh	Diesel Fuel Cost $/gal	Efficiency kWh/gal	Nuclear Fuel Cost $/MWh	Life y	Annuity Factor 7%
D	1,900,000	82,000	0.121	4.59	15.8		20	0.0944
W	6,000,000	88,260					20	0.0944
BESS	1,400,700	32,500					10	0.1424
MR	12,500,000	115,000	0.010			60	30	0.0806

Table 22. System cost for Option A.

Option A

	Annual Cost ($/y)				
	Capex	Fixed O&M	Variable O&M	Fuel Cost	Total
D1	934,575	427,302	1,663	3,992,578	5,356,118
D2	934,575	427,302	1,663	3,992,578	5,356,118
D3	656,408	300,120	71	169,897	1,126,496
D4	336,275	153,750	142	339,794	829,960
W1	509,722	79,434			589,156
W2	509,722	79,434			589,156
Total	3,881,277	1,467,342	3,538	8,494,848	13,847,005

Table 23. System cost for Option B.

Option B

	Annual Cost ($/y)				
	Capex	Fixed O&M	Variable O&M	Fuel Cost	Total
D1	934,575	427,302	1,390	3,337,934	4,701,201
D2	934,575	427,302	1,390	3,337,934	4,701,201
D3	656,408	300,120	71	169,897	1,126,496
D4	336,275	153,750	142	339,794	829,960
W1	509,722	79,434			589,156
W2	509,722	79,434			589,156
W3	566,358	88,260			654,618
W4	566,358	88,260			654,618
BESS	199,428	32,500			231,928
Total	5,213,420	1,676,362	2,993	7,185,558	14,078,333

Table 24. System cost for Option C.

Option C

	Annual Cost ($/y)				
	Capex	Fixed O&M	Variable O&M	Fuel Cost	Total
D1	934,575	427,302	1,172	2,813,328	4,176,376
D2	934,575	427,302	1,172	2,813,328	4,176,376
D3	656,408	300,120	71	169,897	1,126,496
D4	336,275	153,750	142	339,794	829,960
W1	509,722	79,434			589,156
W2	509,722	79,434			589,156
W3	566,358	88,260			654,618
W4	566,358	88,260			654,618
W5	566,358	88,260			654,618
W6	566,358	88,260			654,618
BESS	199,428	32,500			231,928
Total	6,346,135	1,852,882	2,556	6,136,346	14,337,919

Table 25. System cost for Option D.

Option D

	Annual Cost ($/y)				
	Capex	Fixed O&M	Variable O&M	Fuel Cost	Total
MR	5,036,650	575,000	206	1,236,916	6,848,773
D2	934,575	427,302	831	1,996,289	3,358,998
D3	656,408	300,120	71	169,897	1,126,496
D4	336,275	153,750	142	339,794	829,960
W1	509,722	79,434			589,156
W2	509,722	79,434			589,156
Total	7,983,352	1,615,040	1,250	3,742,897	13,342,538

Table 26. System cost across four options.

	System Cost	
Option	($/y)	($/kWh)
A	13,847,005	0.44
B	14,078,333	0.44
C	14,337,919	0.45
D	13,342,538	0.42

These cost calculations have not internalized the damage from greenhouse gas and other harmful emissions. Looking back at Table 20, we can see that the volume of diesel generation declines as we move from Option A to Options B, C and D. A careful analysis of emissions would have to evaluate the exact duty cycle each Option imposed on the diesel equipment, reflecting the varying efficiency level with the changing capacity utilization, as well as the impact of start-ups.

Expanded Load Options

NJUS (2022) discusses how Nome's load may evolve in the future. The potential drivers are discussed in Appendix A. Some of the drivers likely involve load shapes that are different from the current shape, and so may significantly alter the relative cost of different portfolios of generating equipment, including portfolios that incorporate a microreactor. The literature for microreactors in Alaska has emphasized the potential value in delivering heat alongside power generation. The next section will analyze how cogeneration may or may not increase the competitiveness of a microreactor in Alaska's Railbelt. Based on the work in Macdonald and Parsons (2021) and the calculations in the next section, the opportunities for expanding the use of cogenerated heat in Nome deserves further exploration.

SYSTEM COST AND COGENERATION IN THE RAILBELT

As mentioned in the introduction, there are several sites in the Alaskan Railbelt that could be good candidates for a microreactor because they have district heating systems that can make use of the microreactor's waste heat. Most of these are in the Fairbanks region and fuel their systems with coal. Holdmann et al. (2021) noted that several drivers had shifted in recent years, making it more difficult for a microreactor to be cost competitive. One of these is the increased penetration of natural gas into the region. Macdonald and Parsons (2021) suggested that a microreactor could potentially be cost competitive if it could make sufficient use of its waste heat, and if the reduction in emissions were given a significant value. Although natural gas is generally a cleaner fuel than coal, its combustion results in greenhouse gases and criteria pollutants.

The Value of Cogeneration

Natural gas-fired generators are very efficient and pose a very strong competitive challenge to microreactors for the electricity market, especially when emissions are unpriced. Natural gas-fired boilers are very efficient and pose a similarly strong competitive challenge to microreactors for the heat market. However, when electricity and heat are cogenerated, the competitive position of microreactors improves. In the modeling of Macdonald and Parsons (2021), microreactors produced 2 units of waste heat for every 1 unit of electricity, equivalent to a thermal efficiency of 0.33. In comparison, the ratio was 0.35 for a natural gas combined cycle plant (NGCC) and 0.44 for open cycle gas turbines (OCGT). For diesel generators, the ratio is 1 to 1, or thermal efficiency of 0.50. The ratio is low for NGCC generation because it very efficiently converts fuel to electricity, leaving relatively little energy for waste heat recovery.

The value of this cogeneration is going to depend significantly on the structure of the heat demand relative to the electricity demand. Electricity can be sourced across a grid, so the exact location of the demand may not matter. Heat cannot be easily transported long distances, so it is not possible to serve regionally aggregated demand. Moreover, only some local heat demand will be aggregated in a district heating system. So, the question becomes whether a particular local district heating system demand has a profile that can make efficient use of a microreactor's waste heat.

Figure 20 and Figure 21 show annual time profiles of electricity and local heat demand for two hypothetical institutions. Table 27 provides some summary statistics for these two profiles. The two profiles have been constructed to have the same aggregate heat load. For Institution A, the annual heat load is 3.7 times the electric load, on a MW basis, whereas for Institution B, the annual heat load is only 25% larger than the electric load. More important to the system cost calculation, however, is the shape of the heat load. The range between the minimum and maximum for Institution B is nearly four times the range for Institution A. The annual hourly heat load factor for Institution A is 0.57 and for Institution B is 0.197. This load factor suggests that a microreactor is going to be less competitive in serving Institution B as compared to Institution A.

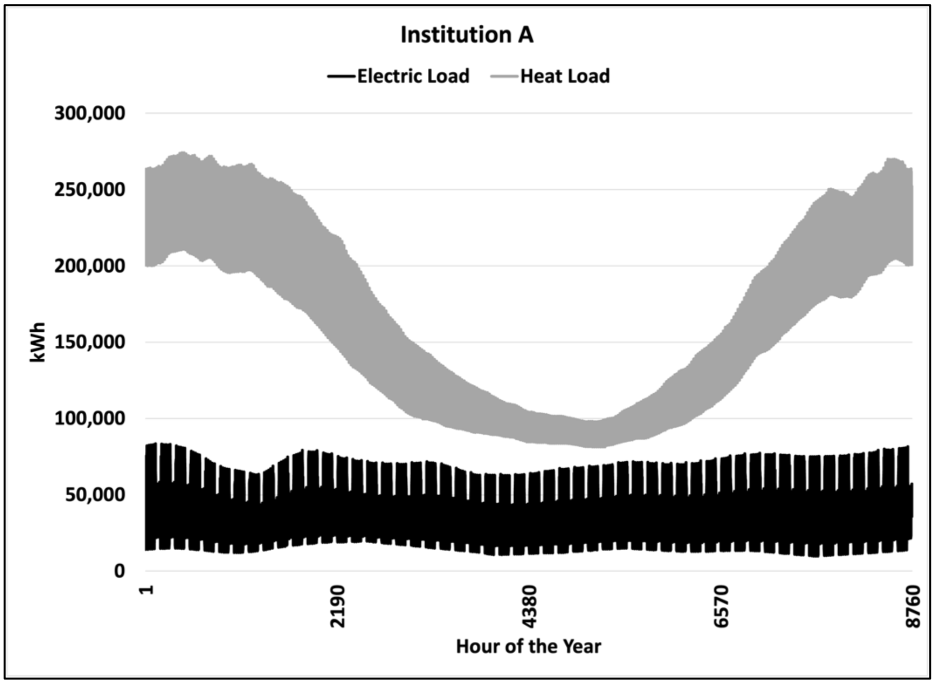

Figure 20. Electric and heat load for hypothetical Institution A on the Railbelt.

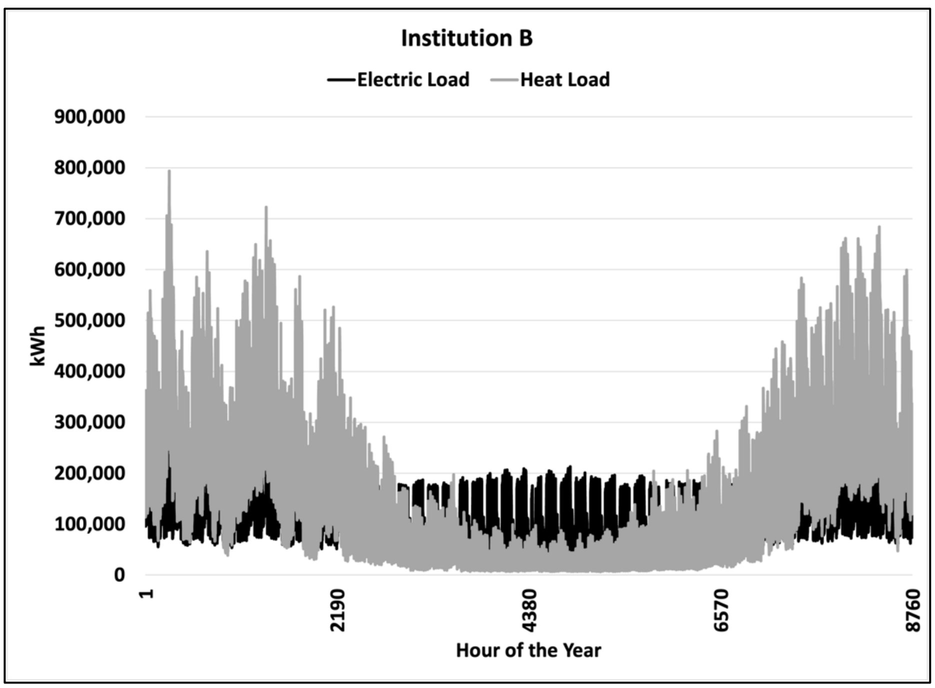

Figure 21. Electric and heat load for hypothetical Institution B on the Railbelt.

We test this proposition using the cost assumptions in Macdonald and Parsons (2021). We assume that each institution sits on the electric grid and can buy electricity from the grid or deliver electricity to the grid. We discuss the terms of those purchases and sales below.

Using these cost assumptions together with assumptions driving the price of electricity purchases and sales, we find that a microreactor is a cost competitive element of institution A's utility system, but not of institution B's utility system. Table 27 summarizes the capacity choices of the two systems and how they provision their electric and heat loads. Institution A has 74 MW of electric generation capacity, of which 10 MW is a microreactor and the balance are OCGT units, where all these generators are outfitted with waste heat recovery. Institution B, on the other hand, only owns 25 MW of electric generation capacity, split 2/3 and 1/3 between OCGTs without and with waste heat recovery (W HR) capability. Where Institution A sometimes purchases and sometime sells electricity, Institution B relies heavily on the grid for its electric load. The picture for heat is consequently different. Institution A obtains more than 40% of its heat needs from its electric generators, with most of the balance provided as direct heat from natural gas boilers. Institution B only obtains 16% of its heat needs from its electric generators. Instead, it relies primarily on natural gas boilers. These are a cost-efficient way to provision its highly variable heat load since the capital cost of the boilers is low and most of the operating cost is in the fuel.

Table 27. Modeled system cost minimizing capacity choices and dispatch outcomes for two different institutions on the Railbelt System.

	Institution A		Institution B	
	Capacity MW	Generation GWh	Capacity MW	Generation GWh
Electricity				
Owned				
OCGT			15	70.172
OCGT w/ WHR	64	296.597	10	174.077
NGCC				
MR w/ WHR	10	72.079		
Grid				
Purchases		4.633		866.223
Sales		8.015		13.519
Heating				
WHR OCGT		380.988		203.607
WHR MR		159.775		
Bypass MR		50.937		
Boilers	226	770.696	759	1,163.482
Electric	10	3.649		

This system cost calculation illustrates how the topology of the heat load across the Railbelt region will determine whether microreactors are a cost competitive option.

Self-Supply, Grid Connection and Gains from Trade

Table 28 provides some distributional statistics on the hourly marginal cost of electricity on our modeled Railbelt System grid with Institution A. The simple average hourly marginal cost is $0.08/kWh. The marginal cost varies greatly. It is highest when the load is high, so the load weighted average hourly marginal cost is higher at $0.10/kWh. The range is very, very wide. The marginal cost goes as low as $0.03/kWh and as high as $1.26/kWh at system peak hours.

Table 28. Hourly marginal cost of electricity on the Railbelt together with the marginal cost of electricity for Institution A's purchases and sales to the Railbelt grid.

	Hourly Marginal Cost of Electricity ($/kWh)		
	Railbelt System	Institution A Purchases	Institution A Sales
Average			
time weighted	0.08		
load weighted	0.10	0.03	0.36
Min	0.03	0.03	0.06
Max	126.46	0.06	126.46

Table 28 also provides distributional statistics on the hourly marginal cost of electricity when Institution A is purchasing or selling electricity. The load weighted average of the marginal cost when Institution A is purchasing is approximately the minimum marginal cost of $0.03/kWh. However, the load weighted average cost when Institution A is selling reaches $0.36/kWh. Institution A sells at the highest marginal cost hour.

In contrast, the hourly marginal cost of heat is roughly constant at the price of natural gas for direct heating with boilers. Only in a small number of hours does it drop below that, lowering the load weighted average marginal cost by about 10% from the cost of fuel.

Looking back at Table 27 and how Institution A supplies its electricity and heating load, we can see a pattern. Note, in particular, the possibly surprising fact that Institution A supplies a small portion of its heating load with bypass heat from the microreactor. This occurs in the hours of the year when the electric load is very low. If we had evaluated Institution A in isolation, without regard to its connection to the grid, we would say that it had mistakenly oversized its reactor. Looking just at the heat load, these hours would have been more cheaply covered using direct heat from natural gas boilers. However, there are other hours of the year when having the extra electricity generating capacity is valuable. Institution A can provide valuable electricity generating capacity to the grid in those hours as reflected in Table 27.

Table 28 makes clear that the marginal value of a unit of electricity generating capacity varies dramatically across the hours of the year. The choice of capacities shown in Table 27 is optimal for Institution A and for the balance of the Railbelt system given that both parts of the system share the costs according to the pattern shown in Table 28. That is, Institution A must be able to buy and sell power to the grid at varying prices depending upon the liquidity of the market, e.g., a tight market is one with narrow bid-ask spreads.

This highlights the complexities in determining the terms of trade between Institution A and the balance of the Railbelt system. A number of studies have addressed the general problem of setting electricity rates between a co-generator or self-generator and a grid to which they are connected. It is commonly thought that deployment of cogeneration in the U.S. has low value in comparison to the techno-economic potential because of the difficulty in setting correct rates. A useful introduction to the problem is the U.S. Department of Energy (2007) study pursuant to the Energy Policy Act of 2005. Much has been written since then, although it is not clear how much progress has been made. Further study on the value of cogenerated heat is needed to advance the economics for deployment of microreactors.

REFERENCES

Chaney, R.E., Colt, S., Johnson, R.A., Wies, R.W. and White, G.J., 2008. *Galena Electric Power-a Situational Analysis*. National Energy Technology Laboratory.

Holdmann, G., Fay, G., Witmer, D., Williams, F., Schwoerer, T., Pride, D., & Stevens, R., 2011. *Small-Scale Modular Nuclear Power: An Option for Alaska?* Alaska Center for Energy and Power, University of Alaska Fairbanks.

Holdmann, G., Roe, G., Colt, S., Merkel, H., & Mayo, K., 2021. *Small-Scale Modular Nuclear Power: An Option for Alaska? Update.* Alaska Center for Energy and Power, University of Alaska Fairbanks.

Macdonald, R. and Parsons, J.E., 2021. The Value of Nuclear Microreactors in Providing Heat and Electricity to Alaskan Communities. *MIT Center for Energy and Environmental Policy Research Working Paper 21-018*, November.

Nichol, M. and Desai, H., 2019. Cost competitiveness of micro-reactors for remote markets. Nuclear Energy Institute (NEI): Washington, DC, USA.

Nome Joint Utility Systems (NJUS). 2022. *Nome Community Energy Today and Tomorrow*, Report.

Pike, Chris and Nathan Green. 2017. *Nome Wind-Diesel System Overview*. Draft Technical Report, Alaska Center for Energy and Power, University of Alaska Fairbanks.

University of Alaska Center for Economic Development, 2020. *Microreactors in Alaska, Use Case Analysis*, October.

U.S. Department of Energy, 2007. The Potential Benefits of Distributed Generation and Rate-Related Issues That May Impede Its Expansion, June.