MICROREACTORS IN ALASKA

Customer Discovery and Perception

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Executive Summary

Alaska's energy landscape made up of a dynamic patchwork of systems, from extremely small, islanded community micro-grids to remote mining operations and one larger interconnected system. Energy producers within each of these settings experience high costs for fuel and operations compared to U.S. averages. Each of the individual micro-grids across the state are unique, but some can be grouped and described based on a basket of shared characteristics.

The over 100 power grids scattered across rural Alaska, in communities, at remote industry installations, and government sites are predominantly powered by diesel generation systems. The cost of producing power in remote areas is high, driven by fuel, infrastructure, maintenance, and administrative costs. The cost per kWh for energy production in remote areas can range widely, from $0.35 to $0.60 kWh, with an average of $0.52 per kWh.[1] A handful of hydroelectric and solar installations have been constructed and wind-diesel systems are spread across Western Alaska. Alaska Village Electric Cooperative (AVEC), an electric utility serving communities in rural Alaska, operates wind-diesel systems in 13 of its 58 communities.[2]

Heating needs are met with fuel oil primarily, some communities supplementing with wood resources. Fuel oil used for space heating ranges in cost from $3.89 to $5.60 per gallon on average. Transportation costs are also high, with cost per gallon of gasoline ranging from $4.39 to $5.91 per gallon across Alaska.[3]

In the most populated stretch of the state that runs from the Kenai Peninsula to the Interior region, customers are served by an interconnected network of utilities, in a loose region colloquially referred to as the Railbelt. Power producers meet the demands of residential, commercial, and industrial users through a familiar mix of energy sources: including natural gas, coal, diesel, hydroelectric, wind, solar, landfill gas, and naphtha. Power costs on the Railbelt are significantly lower than the average for rural Alaska at $0.24 per kWh;[4] however, those costs remain significantly higher than the U.S. average of $0.13 per kWh.[5]

Driven by high costs and other factors impacting energy systems across Alaska, the state's energy landscape has often been the focus for alternative or early-stage energy technologies. Alaska power grids have served as a proving ground for emerging energy technologies, with varying degrees of success.[6]

Heat represents another energy challenge across Alaska. However, attention in this area has focused on energy efficiency. Cost and geographical issues can create challenges for distributed heating system construction across the state.

One emerging energy technology has been identified as a potential solution for Alaska energy users of all sizes, including power, heat, and transportation markets. Microreactors are under development in the U.S. by companies like the Westinghouse Electric Corporation, Ultra Safe Nuclear Corporation, and OKLO Inc. with small, remote energy systems in mind.[7] The reactors, which are in the early stages of development, include characteristics which make them potentially well-suited to Alaska applications. These include:

- Minimal moving parts and maintenance requirements,
- Remote or semi-autonomous operation,
- Load following characteristics, heat and power production capabilities,
- Modular design,
- Infrequent refueling.

However, the critical variable which would best address remote and interconnected Alaska energy systems is the capacity size, where microreactors range from 1 MW to 20 MW electric (e). Nuclear reactors range upward from 50 MW(e) to 600 MW(e) are called small modular reactors (SMRs). Both SMRs and traditional nuclear reactors, which can range to over 1,000 MW(e), are typically too large for most applications in Alaska. [8] In addition, the Nuclear Energy Institute (NEI) estimates that the first 50 microreactors deployed could produce energy at costs range as high as $0.40 per kWh in remote communities to $0.10 per kWh in Alaska's Railbelt.

Technology fit is determined by more than system capacity and costs. To examine the variables which could impact microreactor deployment in Alaska, this analysis grouped energy users, producers, and operators into five categories and analyzed the value propositions of each segment based on a customer discovery framework. The five segments examined are:

- Small Rural Communities,
- Rural Hub Communities,
- Railbelt Energy Producers,
- Remote Mining Operations,
- Military Installations.

This analysis identifies and tests a number of value propositions for each of the energy market segments using available data and information collected through interviews with energy users, producers, and operators and energy stakeholders across Alaska. The intent is to identify opportunities and barriers to implementing microreactors across a number of user groups present in Alaska. Some of the value propositions are discussed in the Table 1 and 2 below.

The goal of this analysis is to identify the motivations of Alaska energy producers in pursuing alternative generation technologies, both nuclear and non-nuclear. Several cases for initial adoption of microreactors are discussed, as well as expanded opportunities for reactor deployment across Alaska's energy landscape. This analysis focuses predominantly on electric applications, with some discussion of the opportunities to electrify isolated heat and transportation markets with more readily available power.

Value Proposition	**Small Rural Community**	**Rural Hub Community**	**Railbelt Utility**	**Remote Mine**	**Defense Installation**
Cost predictability/ containment	🟩 A major issue for diesel-dependent communities.	🟩 A major issue for diesel-dependent communities.	🟨 Some cost sensitivity but existing access to lower-cost fuels like natural gas.	🟩 A major issue, especially for non-grid connected mines using diesel generation.	🟨 Some cost sensitivity but less of a concern than other segments.
Low maintenance/ Remote operability	🟩 Potentially a major benefit but still discomfort with unknowns, since diesel systems are well-understood.	🟩 Potentially a major benefit but still discomfort with unknowns, since diesel systems are well-understood.	🟨 Less of an existing challenge but opportunities to reduce maintenance needs would be welcome.	🟨 Reducing on-site staff requirements to maintain powerhouses could be an advantage.	🟨 Less of an existing challenge but opportunities to reduce maintenance needs would be welcome.
Supply chain independence	🟩 Opportunity to reduce dependence on diesel fuel deliveries would be an advantage.	🟩 Opportunity to reduce dependence on diesel fuel deliveries would be an advantage.	🟨 More of a "nice to have" than a necessity.	🟩 Opportunity to reduce dependence on diesel fuel deliveries would be an advantage.	🟩 A major advantage; installations seek to be independent of an interruptible fuel source.
Decarbonization and air quality	🟨 An issue in some communities more than others, depending on priorities and local conditions.	🟨 An issue in some communities more than others, depending on priorities and local conditions.	🟨 Potentially an important issue in areas with air quality concerns and climate action plans in place.	🟨 Potentially valuable if carbon taxes are implemented in the future. Could also signal good corporate citizenship.	🟩 Advantageous to help meet defense targets for reducing carbon emissions.

Table 1: Customer Segment Value Propositions

Green=value proposition is a likely fit for the customer segment
yellow=uncertain

Barriers to adoption	Rural Village	Rural Hub	Railbelt Utility	Remote Mine	Defense Installation
Regulatory uncertainty/ risk	Limited ability to absorb new regulatory burdens, depending on specifics.	Limited ability to absorb new regulatory burdens, depending on specifics.	Greater ability to manage regulatory compliance.	Generally high ability to manage compliance, but may not wish to add to existing regulatory burdens.	Greater ability to manage regulatory compliance.
Public perception risk	A major potential challenge until technology is more widely understood.	A major potential challenge until technology is more widely understood.	Presents some risk but not certain currently.	A possible threat to pre-development projects during planning and permitting phase.	Less sensitivity than other segments given higher trust in reactors for military use.
Cost uncertainty	Access to capital limited, posing problems for upfront costs even if operating costs are low.	Access to capital limited, posing problems for upfront costs even if operating costs are low.	Greater ability to access capital and predict operating costs.	Strong access to capital for upfront costs, able to predict operating costs.	Likely able to absorb upfront costs through installation budgets.
Operational unknowns	Generally averse to being an early adopter until technology is better understood.	Generally averse to being an early adopter until technology is better understood.	Preference for known technologies but some willingness to adopt micro-reactors depending on costs/benefits.	Willing to be an early adopter if risks, costs, and benefits are well analyzed.	Willing to accept the operational unknowns of being an early adopter.

Table 2: Customer Segment Value Propositions Continued.

Green=not a major barrier to adoption

Yellow=mixed or uncertain

Red=likely to be a significant barrier to adoption

Introduction

Traditional nuclear reactor technology calls to mind images of enormous energy complexes and multi-story coolant towers. The business model of traditional nuclear energy systems relies on the economies of scale associated with size and costs spread out across an enormous number of kWh and hence, customers. Traditional reactors under construction worldwide average over 1000 MW(e) capacity. In the U.S., Plant Vogtle units 3 and 4 are under construction in Waynesboro, Georgia each with a capacity of about 1,117 MW(e).[9]

However recent developments in nuclear technology are trending toward the greater cost efficiency and built-in safety of small, pre-fabricated microreactors. These reactors are being developed largely with remote, isolated energy users in mind. While still in the early stages of permitting and development, the reactors are reported to range in size from 1 MW(e)to 20 MW(e) and have improved capabilities, which include reduced footprint, combined heat and power (CHP) and load follow characteristics, and autonomous operating capabilities.

Based on size and energy costs alone, Alaska's remote, isolated energy grids may be an initial market for early stage microreactors. Most of the more than 100 isolated energy systems scattered across Alaska are dependent on diesel fuel power and many are actively seeking lower cost, clean energy alternatives. In the more populous highway-connected communities, some utilities have limited access to inexpensive natural gas and seek greater energy independence and reliability that a microreactor might offer. Figure 1 maps installed power capacity across Alaska.

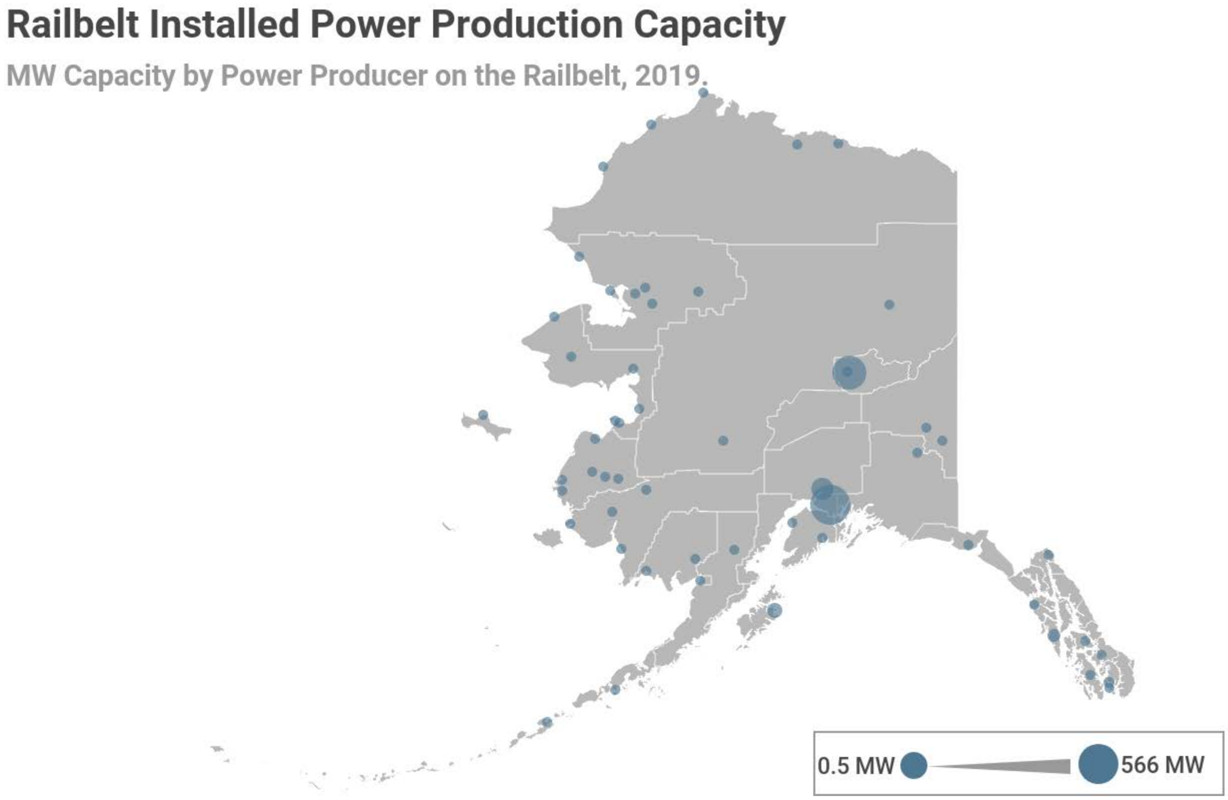


Figure 1: Alaska's Installed Power Production Capacity.
Source: EIA, 2019.

However, while size and cost are important drivers for technology adoption, the energy market in Alaska is comprised of a dynamic group of energy producers who experience unique needs impacting technology fit. The goal of this analysis is to identify the challenges and pain points experienced by segments of Alaska energy producers, and discuss perspectives on how those challenges may interact with microreactor technology. This analysis focuses predominantly on electric applications, with some discussion of the opportunities around heat and transportation energy uses.

Alaska's Energy Landscape

The energy market in Alaska is made up of many different, often isolated, components. Alaska's energy landscape can be roughly divided into two parts: the road system and rural Alaska. The majority of Alaskans live on the road system, most of which is serviced by a network of five interconnected, but separately owned and operated utilities stretching from Homer in the south to Fairbanks in the north, encompassing what is colloquially called the 'Railbelt.' Outside of the Railbelt, energy systems across the state are made up of very small micro-grids serving both communities and industry, such as seafood processors and resource development sites.

Outside of the Railbelt grid, distance and cost of infrastructure makes interconnecting communities in an energy network unfeasible. Eighty-six percent of Alaska's 240 communities are not connected to the road system. In those places, transportation needs are met by air and by water. This drives energy costs higher in remote areas. Fuel used to energize and heat communities and industry installations must be barged or flown in, and requires the use of expensive tank farms. Fuel delivery infrastructure varies across rural areas and can also impact the end cost of heat and power.[10]

Cost of constructing and maintaining such energy systems increase the already high costs of power in remote areas. A small number of remote communities have been interconnected when geography and scale acts as an enabler. However, given the cost, building economies of scale in remote energy systems remains difficult. Transmission lines can cost as much as $400,000 per mile to construct, according to the Alaska Center for Energy and Power (ACEP), and a single community could require hundreds of miles of transmission line to connect to the nearest grid.[11]

Energy producers across the state can be roughly divided into five categories based on their size, users, and other attributes. These include community producers—small rural communities, hub communities, and Railbelt utilities; and industry sites—defense installations, mine sites, and seafood processors. Depending on the producer type, load size varies widely. The system capacities of each type are shown in the Table 3 below.

Alaska's Energy Producers and System Size	
Producer Type	**System Size (MW)**
Small Rural Community	0.5 to 10
Hub Community	10 to 25
Railbelt Utility	170 to 566
Military Installation	7 to 40
Mining Site	10 to 40

Table 3: Alaska's Energy Producers and System Size.
Source: EIA, 2019.

Small Rural Communities

Small rural community producers are largely bound by the demand characteristics of the local economy. Figure 3 maps the installed capacity in Alaska small rural communities, which range from 0.5MW to 8.5 MW. Many small producers serve communities with limited traditional economic activity and energy use patterns that are bound by residential characteristics and subsistence activities. Major single energy users in most remote communities are schools, water treatment facilities, washeterias, and local government or tribal offices. Community heating needs across rural communities are met predominantly with fuel oil, with some biomass and waste heat recovery where available. Data on community heating and transportation loads is limited.

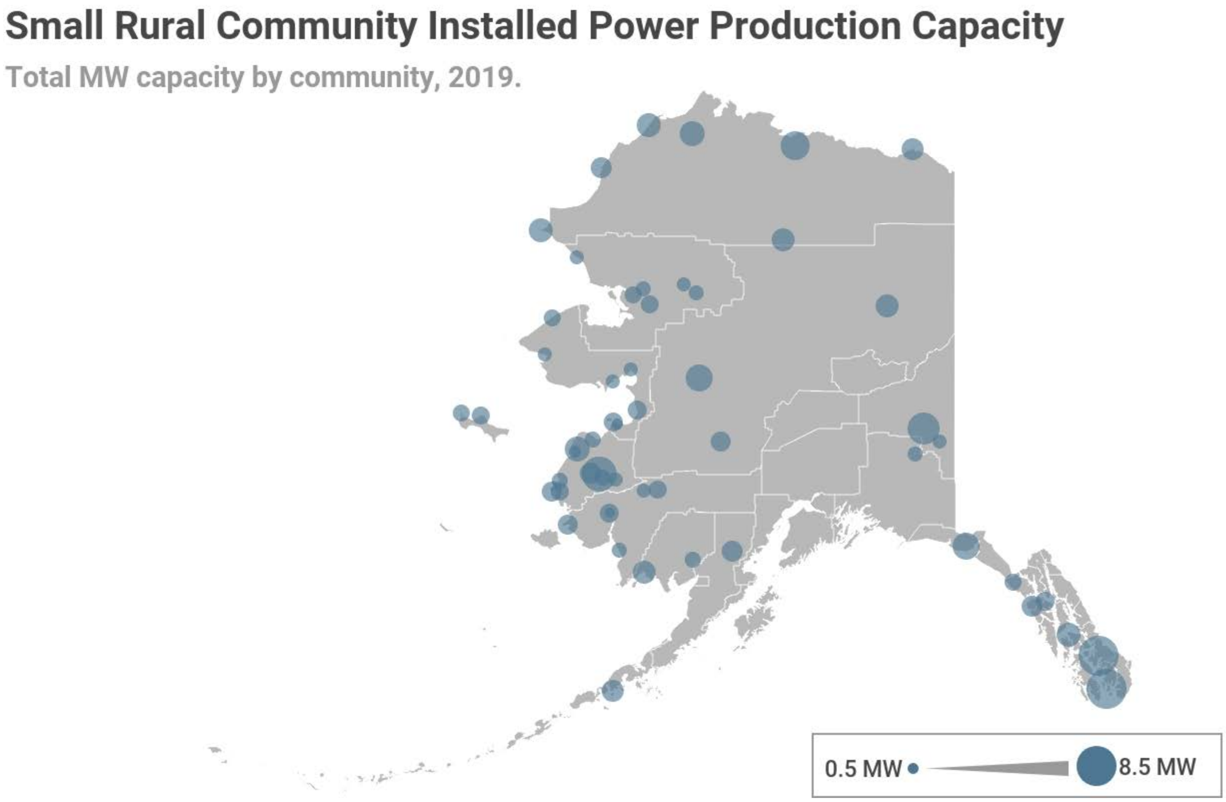


Figure 2: Small Rural Community Installed Power Capacity.
Source: EIA, 2019.

Hub Communities

Regional hub communities have larger loads as a result of greater populations and the presence of more commercial and institutional energy users. While there are a handful of larger rural communities in southeast Alaska, they are not considered in this analysis. Hub communities are home to hospitals, stores, state and federal government offices, tribal organizations, and schools, functioning as a hub of regional transportation and logistics activities. Energy needs scale according to the population and commercial activities present in the community. System size ranges from 11 MW in Dillingham to 20 MW in Utqiaġvik. Figure 4 maps the installed power capacity in Alaska hub communities. As with smaller villages, heating needs are met with fuel oil and wood, where available. Some hub communities use recovered heat for processes at the community’s water treatment facility. Data on community heating loads is limited

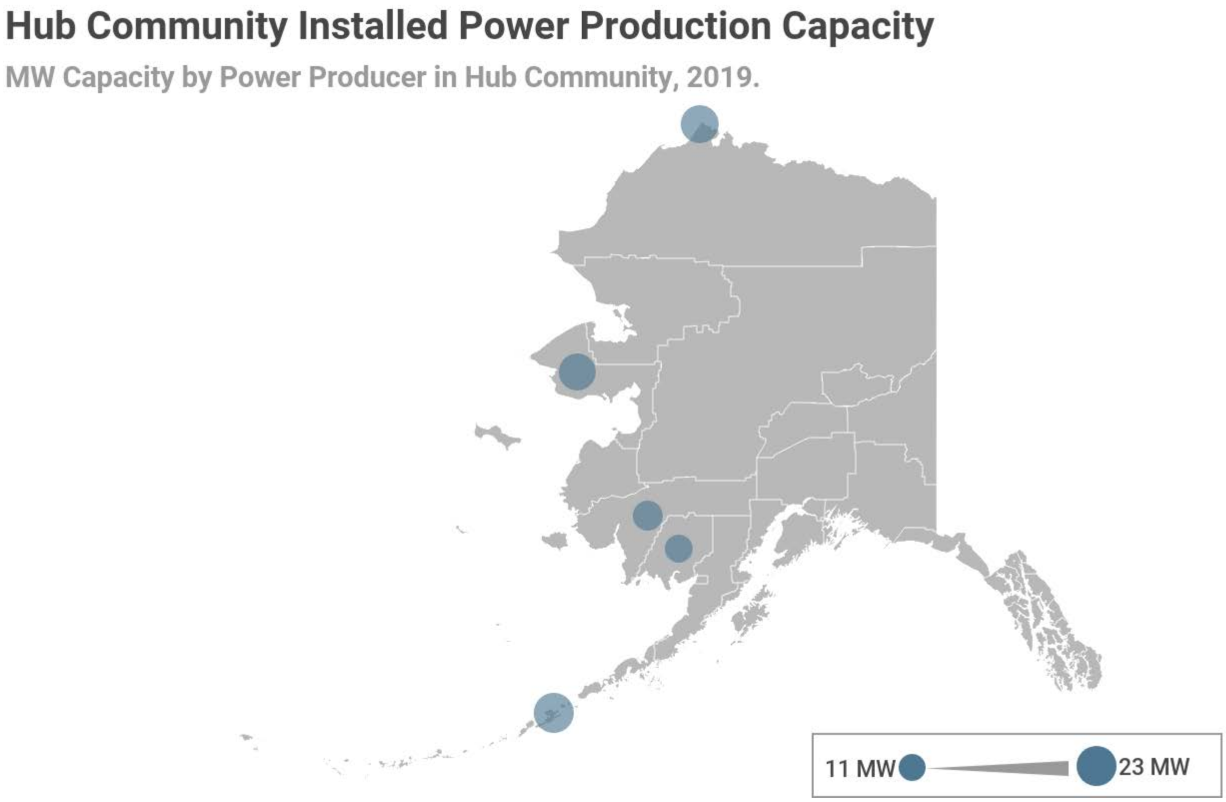


Figure 3: Hub Community Installed Power Capacity.
Source: EIA, 2019.

Railbelt Energy Producers

Five main utilities are the primary Railbelt energy producers, varying in size from 165 to 566 MW in installed capacity. Figure 5 maps the installed power capacity across the Railbelt. These utilities serve a dynamic array of user groups, including industry operations, mines, military installations, small and large businesses, hospitals, state and federal government facilities, and residential customers. Electricity is delivered through a dispersed network of transmission lines covering hundreds of miles. A handful of independent power producers (IPPs) sell power to adjacent utilities. With the creation of an electric reliability organization (ERO) energy planning on the Railbelt is expected to shift, with a focus on reliability, diversification of energy resources, and decarbonization.

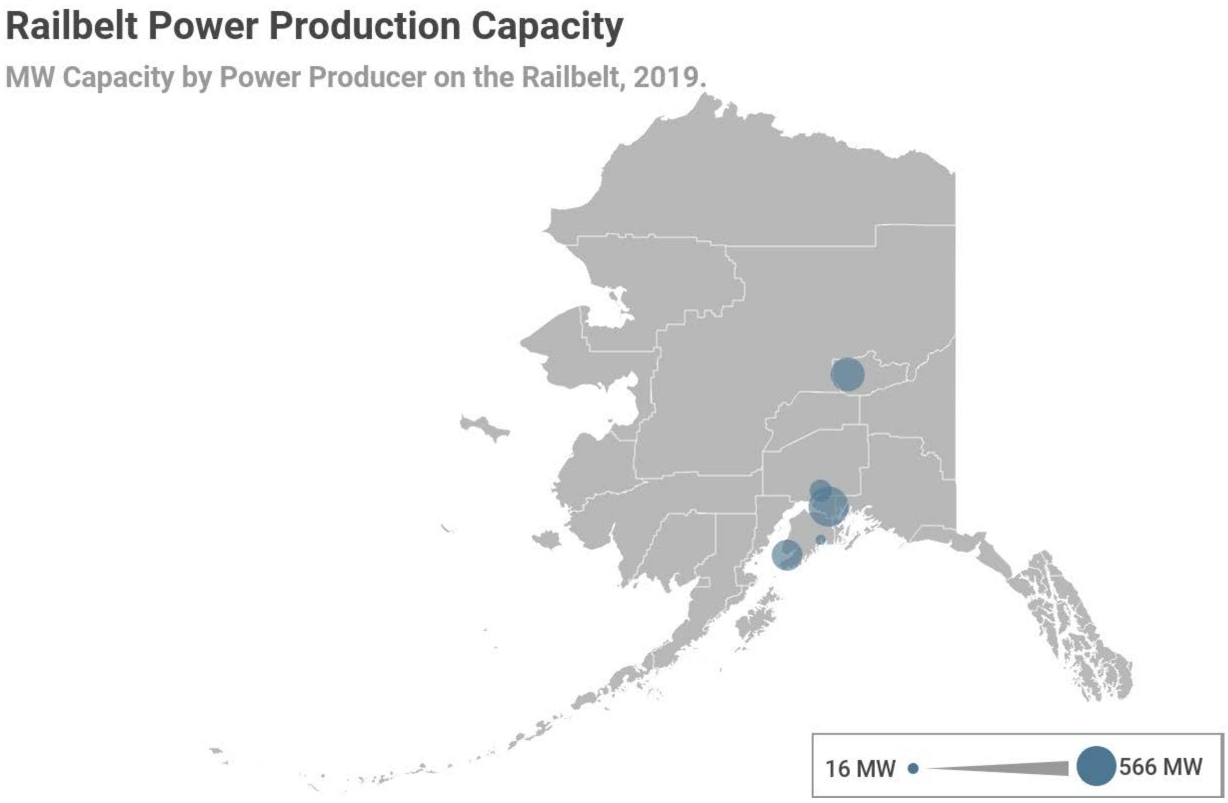


Figure 4: Urban Utility Power Capacity.
Source: EIA, 2019.

Industrial Energy Producers

Industrial energy users are centered around large energy intensive industries, such as seafood processing and resource extraction. Alaska is home to 170 seafood processors, many of which are located in remote communities across Alaska. Some seafood processors generate their own electricity, while others purchase power from community utilities. Oil and gas drilling operations in Cook Inlet and the North Slope provide their own power, typically through diesel generation. Alaska's major mining operations generate their own power and purchase some from local utilities, depending on the location. Mining operations host large electric, heat, and transportation energy loads. Figure 6 maps the installed power capacity at Alaska mining installations.

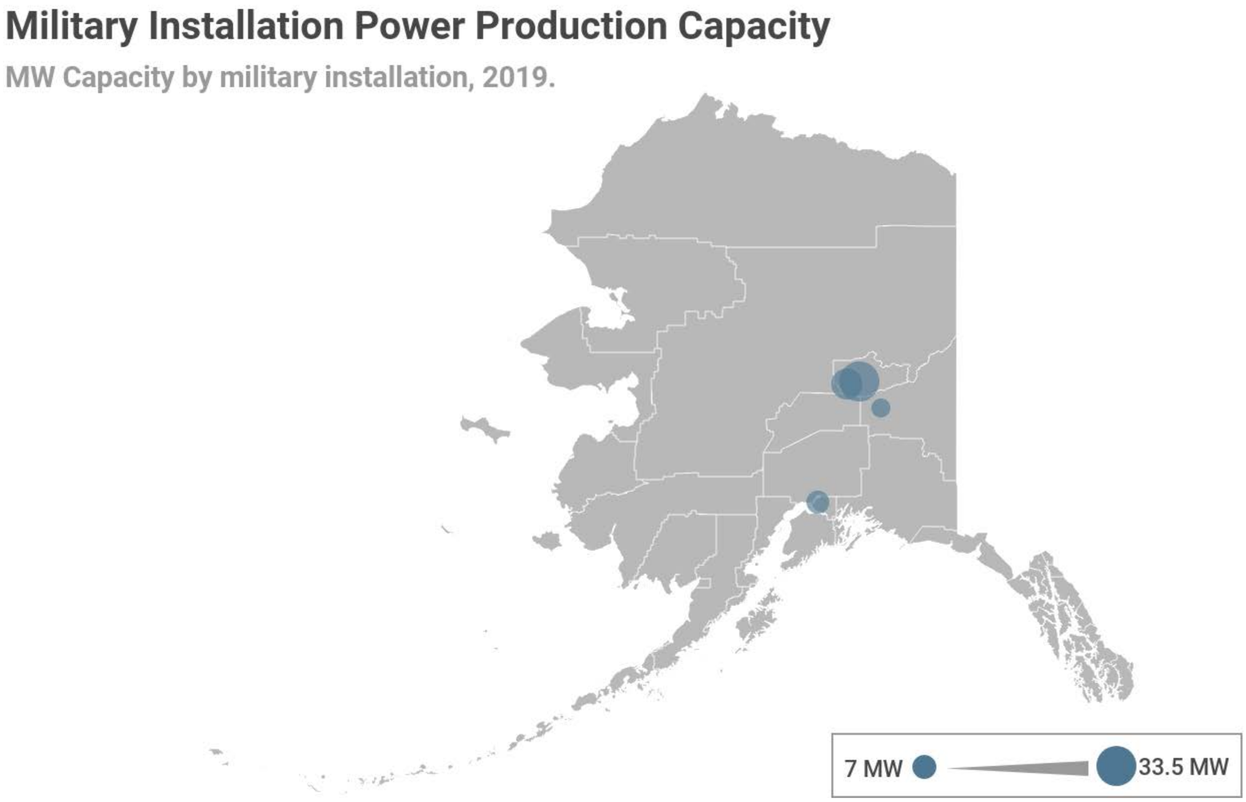


Figure 5: Power Capacity in Alaska's Metal Mines.
Source: EIA, 2019.

Military Installations

Military installations are another large single energy user in Alaska. Alaska is home to nine major military installations, with Air Force, Army, and Coast Guard presence, four of which are the focus of this analysis. This analysis focuses on the five primary military installations located in southcentral and interior Alaska. Installed capacity ranges from 11.5 MW at Joint Base Elmendorf Richardson in Anchorage to 33.5 at Eielson Air Force Base in Fairbanks. Figure 7 maps installed capacity at Alaska major military installations. All of the major bases purchase power from local utilities – Anchorage Municipal Light and Power (ML&P) and Golden Valley Electric Association (GVEA) – and use installed capacity for generating power during peak periods and as backup capacity. Military power needs somewhat resemble those of the adjacent urban communities, with a mix of residential and industrial-type demands. However, these installations often place a premium on the ability to operate self-sufficiently in times of emergency or outside disruption.

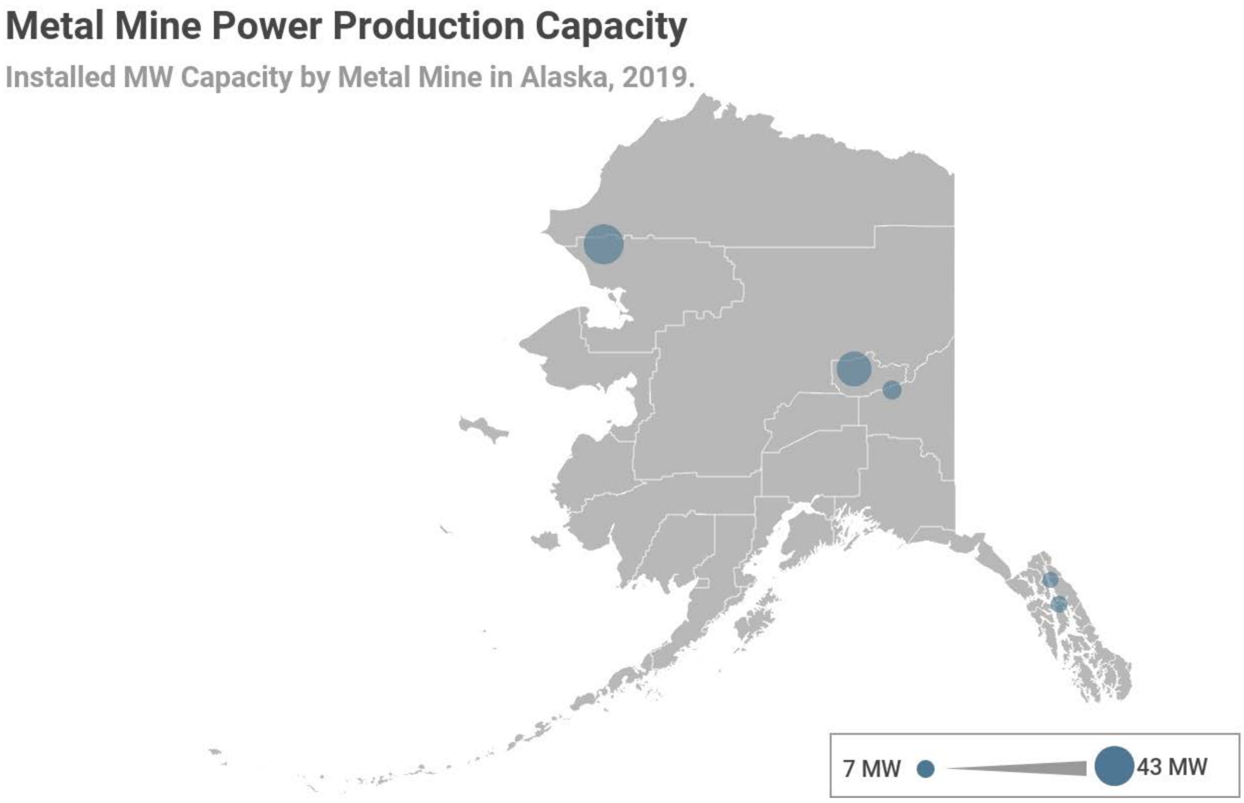


Figure 6: Defense Installation Installed Capacity.
Source: EIA, 2019.

Energy Themes and Trends

Eligible rural communities participate in the state's Power Cost Equalization (PCE) program, which uses state funds to subsidize the price of power for rural residential and eligible community facilities, moving it closer to the average price in Railbelt Alaska. The PCE program plays a role in lowering the costs of power for most residential users in rural Alaska. However, in many communities power prices still do not reach parity. Commercial energy users, which include small businesses, do not qualify for the PCE program and must pay the full market cost. As a result, energy costs can play a role in limiting business growth and development.

Across Alaska, sustainable alternative energy technologies have been sought as a solution for diversifying and reducing dependence on fossil fuels. Alaska is widely perceived as being wealthy in renewable resources, including hydro, wind, geothermal, solar, biomass, and more. However, in practice turning to those resources for power and heat production has proved challenging.

The state is home to numerous wind, hydro, biomass, and solar projects across urban and rural Alaska. The Alaska Energy Authority (AEA), specifically, has assisted in the construction of 80 projects through the State of Alaska Renewable Energy Fund since its creation.[12] However, cases of unfeasible projects due to cost and resource quality are equally numerous. In addition, stories of defunct renewable energy systems due to maintenance failures are common. ACEP at the University of Alaska Fairbanks has helped communities address the intermittency of wind power and complexity of integrating it into small diesel grids. However, maintaining these systems is difficult and not all communities have the trained individuals or local energy resources to adopt them.

Despite ongoing challenges, communities and energy producers continue to explore opportunities for diversification and decarbonization. The State of Alaska has a non-binding goal of generating 50 percent of the state's power through renewable or alternative sources by 2025. Boroughs and local governments across the state have their own energy goals.

Microreactor Technology Development

The subject of nuclear technology and nuclear energy is not new to Alaska. Through the mid-20th century, remote areas of Alaska were used as nuclear testing sites. Most notably, Amchitka Island in the Aleutian archipelago was used to conduct underground nuclear tests between 1965 and 1971. Radioactive materials are still buried beneath the ground on the island.[13]

In the 1950s and 1960s the federal government made plans to create a deep-water port in the Arctic by the simultaneous detonation of several nuclear bombs at Cape Thompson. The project was shuttered but remnants of the site remain.[14]

Although this history of nuclear testing in Alaska is unrelated to the use of nuclear as a fuel source for power, these episodes may continue to influence opinions of nuclear energy.

In the arena of power, Fort Greely in the Interior of Alaska was the site of the state's first and only nuclear reactor. The small reactor went critical in 1962 and was designed to be a test facility for nuclear energy technologies in extreme northern conditions. The unit was a 20.2 MW thermal reactor, which produced 72,000 pounds of saturated steam per hour. The reactor was decommissioned in 1972 as a result of high operating and refueling costs.[15]

Throughout the 20th century, to build the economies of scale necessary to make traditional nuclear energy economical, nuclear power production technology outgrew the small scale of Alaska power demands. However, with the development of SMRs, the topic has been re-emerging in Alaska. The most notable project exploring the use of nuclear reactors in remote Alaska was instigated by Galena, a small community in the Interior region of Alaska.[16]

Analysis conducted by UAF's ACEP examined the feasibility of SMRs in Alaska, indicating that the 10 to 125 MWe capacity of the reactors being developed were still beyond the needs of most Alaska energy systems. The 2011 analysis also reached the conclusion that if and when commercial SMRs are deployable, Alaska energy operators may struggle to meet the U.S. Nuclear Regulatory Commission's (NRC) evaluation of technical and financial capabilities. This included:

- Ability to finance project construction,
- Capabilities in attracting, retaining, and retraining a workforce with the required skillset,
- Capacity to construct and operate a plant which meets appropriate standards.[17]

Current developments in the realm of advanced nuclear technology include development of microreactors – very small, modular reactors which include characteristics that would accommodate small, remote energy systems. SMRs and microreactors can be readily confused with one another. Microreactors are a subset of SMRs, filling in at lower power capacities of 1-20 MW(e) according to the IAEA.[18]

Microreactors are being developed by a number of companies globally. They are still in the early stages of development, and the first reactor designs were submitted to the NRC in the spring of 2020. Table 4 describes some of the characteristic of the microreactors in the pre-permitting and permitting stages with the U.S. NRC. Note that microreactor technologies are also under development internationally in Japan, U.K, E.U., and other countries.

Microreactor Characteristics		
Reactor	**Capacity**	**Characteristics**
Westinghouse eVinci[19]	2 to 3.5 MWe	• Power and heat capabilities • 40 design life, 3+ year refueling interval • Factory assembly • Semi-autonomous operation • Load following capabilities • Autonomous operation
Ultra Safe Nuclear Corporation MMR[20]	5 to 10 MWe	• 20 year design life, single lifetime fueling • Power and heat capabilities • Minimal operations requirements
Aurora OKLO[21]	1.5 MWe	• Load following • Power and heat capabilities • Autonomous operation • 20 year design life, single lifetime fueling
NuScale[22]	60 MWe (SMR)	• Factory assembly in three segments • Truck, rail, or barge transportation • 24 month refueling cycle

Table 4: Microreactor Characteristics.
Source: Oklo, 2020; Westinghouse, 2020; IAEA, 2020; NuScale, 2020.

To the extent that microreactors are the smallest nuclear power units under development, the energy systems could accommodate power and heat production in some Alaska energy markets. Reactor developers advocate that by reducing the scale of nuclear reactors, safety can be increased and passive cooling systems more easily implemented. In addition, reactor simplicity and uniformity reduces operational requirements. The modular design enables manufacturing at scale, as opposed to each plant having its own design, as well as transportability to the point of use.[23]

The NRC is working with the National Laboratories and advanced reactor manufacturers to develop permitting criteria more specific to the technology's operating capabilities. Current NRC criteria are focused on traditional nuclear energy plants.[24]

However, unknowns around cost and the future NRC requirements for microreactors could create barriers for deployment in Alaska's energy markets. Concerns about local energy producers' capabilities in funding, operating and maintaining a reactor according to strict requirements, and training a qualified workforce remain valid.

NEI estimates that the first 50 microreactors deployed could produce energy at costs ranging from a high of $0.40 per kWh in remote communities to $0.10 per kWh in Alaska's Railbelt.[25] As microreactors move through the development stages, more concrete estimates on costs will likely become available. However, at the current stage unknowns around capital, operations, and refueling costs makes determining financial feasibility difficult.

Research Questions and Methodology

To study the potential market for microreactors in the Alaska energy landscape, a number of research questions were developed to examine market drivers.

1. What factors influence new technology decisions?
2. What market barriers are energy producers currently experiencing?
3. What economic opportunities could exist with low-cost, easily available power?
4. What motivators exist that are specific to microreactor technology?
5. What questions or concerns do energy producers and stakeholders have about the technology?

To conduct a robust analysis of the market fit, and to identify the characteristics of initial first users of advanced micro-reactors, a qualitative, open-ended interview process was used to collect information from more than 20 energy producers and stakeholders across Alaska. Interviews ranged from 30 minutes to an hour and covered a range of topics, including:

- Current energy production,
- Past experiences implementing new technologies,
- Energy planning processes and considerations,
- Perceptions and questions surrounding microreactors,
- Potential barriers and benefits to adopting microreactors.

Feedback from interviews were used to develop five hypothetical case studies that discuss the specific energy needs of potential customer segments (small rural community, rural hub community, Railbelt utility, remote mine, and defense installation). The case studies are presented in a separate document.

Interview results were combined with relevant publicly available data to examine the drivers present in Alaska's energy market which could influence adoption of microreactors across five customer segments.

- Small rural communities
- Rural hub communities
- Railbelt utilities
- Military installations
- Mining operations.

Value Propositions and the Customer Discovery Process

The qualitative data collection process for this report implemented a foundation of principles from entrepreneurial practice, value proposition identification, and customer discovery. The phases of the customer discovery process include:

1. Identification of a hypothesis: Determine the core business assumptions of the value a product or service brings to customers.
2. Hypothesis testing: Validation of core business assumptions through discussion with the target market, customers, and stakeholders; developing an understanding of the customer's problem.
3. Test product concept: Determine product relevance through sharing information with potential customers.
4. Evaluate feedback and identify next steps: Reflect on customer feedback and determine next steps for the business model or product.[26]

Customer discovery is the process through which a business or entrepreneur tests assumptions about their customer and the value their product brings to that customer, often through an interview with a potential customer. The interview questions should get to the root cause of a customer's preferences or habits, dissecting that customer's practices, values, and needs.

In the analysis discussed here, the ‘businesses’ are microreactor developers – companies in the process of developing and testing advanced nuclear technology and stakeholders working to move the industry forward. The ‘customers’ are energy operators and planners across Alaska – organizations operating and maintaining energy systems, and identifying and making decisions about future energy assets. The value propositions discussed and analyzed here include:

1. Alaska energy operators’ existing high costs enable adoption of early stage technologies, allowing them to enter the market at a cost higher than traditional energy markets will bear.
2. The operating characteristics of microreactors match the operational characteristics of Alaska energy operators, including:
    a. Limited workforce requirements matching the labor characteristics of potential sites;
    b. Siting, which considers geological activity and permafrost; and
    c. Reduced need for physical and environmental security measures as a result of technology safety.
3. The small size and modular construction will lower costs and transportability, as well as increase safety factors, which will suit remote or isolated energy systems.
4. Extended refueling intervals of microreactors supports desire for increased supply chain independence.
5. Decarbonization and air quality goals are unlikely to be fully met through renewable resource integration. The clean heat and power characteristics of micronuclear system will act as a motivator toward technology adoption.
6. Load following capabilities will add flexibility to energy systems, while accommodating baseloads. Partial or dedicated use in non-electrical applications can add value to the energy system.

While the customer discovery process used in this analysis is not identical to the process implemented directly by businesses, the framework is useful in testing the value proposition of micro-reactors in remote Alaska energy markets. Specifically, in validating assumptions about why advanced microreactors could be a solution to the energy challenges that Alaska faces, and barriers that energy operators have to adopting new technologies.

Energy Customer Segments

Five potential customer segments were identified as having several attributes that could play a role in microreactor adoption, including:

- Cost predictability/containment,
- Cost uncertainty,
- Low maintenance/remote operability,
- Supply chain independence,
- Decarbonization and air quality,
- Regulatory uncertainty/risk,
- Public perception risk,
- Operational unknowns.

While each energy operator is unique, with varying characteristics, settings, and energy needs, there are some shared characteristics within groups. Table 5 describes those characteristics.

Alaska Energy Consumer Segment Characteristics		
Customer Segment	**System Size Range**	**Characteristics**
Small Rural Communities	0.5 to 10 MW	• Isolated microgrid. • Primary power source is diesel. • Primarily single-phase, with few to no three-phase energy users. • Energy users are primarily residential consumers and community facilities. • Technical capacity: limited based on workforce characteristics of small population. • Heating: predominantly heating oil. • Per kWh Cost: $0.35-$0.60 kWh, average of $0.52 per kWh.
Rural Hub Communities	10 to 25 MW	• Isolated microgrids. • Primarily single-phase users, with some three-phase industrial users such as seafood processors. • Primary power source is diesel. • Defined as regional service and transportation hubs. • Technical capacity: mid-range, limited by workforce characteristics of small population. • Heating: predominantly heating oil for residential heating, recovered heat used in some communities to heat community facilities such as water plants. • Per kWh Cost: $0.17 to $0.48.
Railbelt Intertied System	170 to 566 MW	• System made up of separate, intertied utilities and independent power producers. • Primary energy sources include natural gas and coal; wind, solar, diesel, hydroelectric, and battery systems are also present. • Large distributed systems centered around urban populations located across the road system. • Technical capacity: high, however specialized skill sets can be difficult to access. • Heating: natural gas, propane, district heat, and wood systems are used across the road system depending on resource availability, cost, and system access. • Per kWh Cost: $0.20 to $0.28.
Remote Mines	10 to 40 MW Current (220 to 270 MW Proposed Projects)	• Isolated systems providing power and heat to remote mining operations. • Primary energy source is diesel. • Power used for mining operations and living facilities. • Constant daily and annual load characteristics. • Heavy regulatory burden and high interest group oversight. • High operating costs. • Opportunity for electrification of other energy intense operations, like transportation and heavy equipment.
Defense Installation	7 to 33.5 MW	• Installation intertied with utility grids, capable of providing backup power for essential services in case of emergency. • Energy systems provide heat and power, using diesel, coal, and landfill gas. • Installations purchase power from GVEA and ML&P.[27] • Concern with minimizing supply chain disruptions, like dependency on fuel shipments. • Fuel source and transportation security a critical component of energy systems. • Mission readiness driver for energy operations.

Table 5: Alaska Energy Customer Segment Characteristics

Customer Segments in Detail

Small Rural Communities

Communities across rural remote Alaska vary widely in size, from fewer than 10 residents to several thousand. The average population size across this customer segment is approximately 350 individuals.[28] Figure 8 displays the population in a sample group of small rural communities.

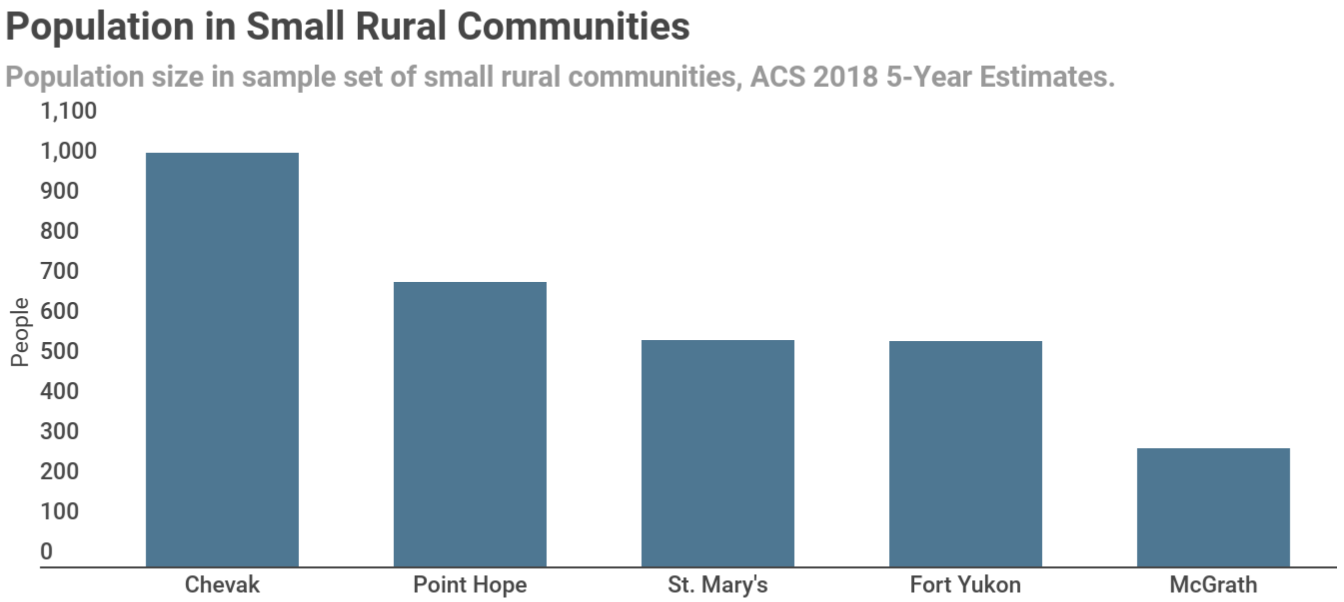


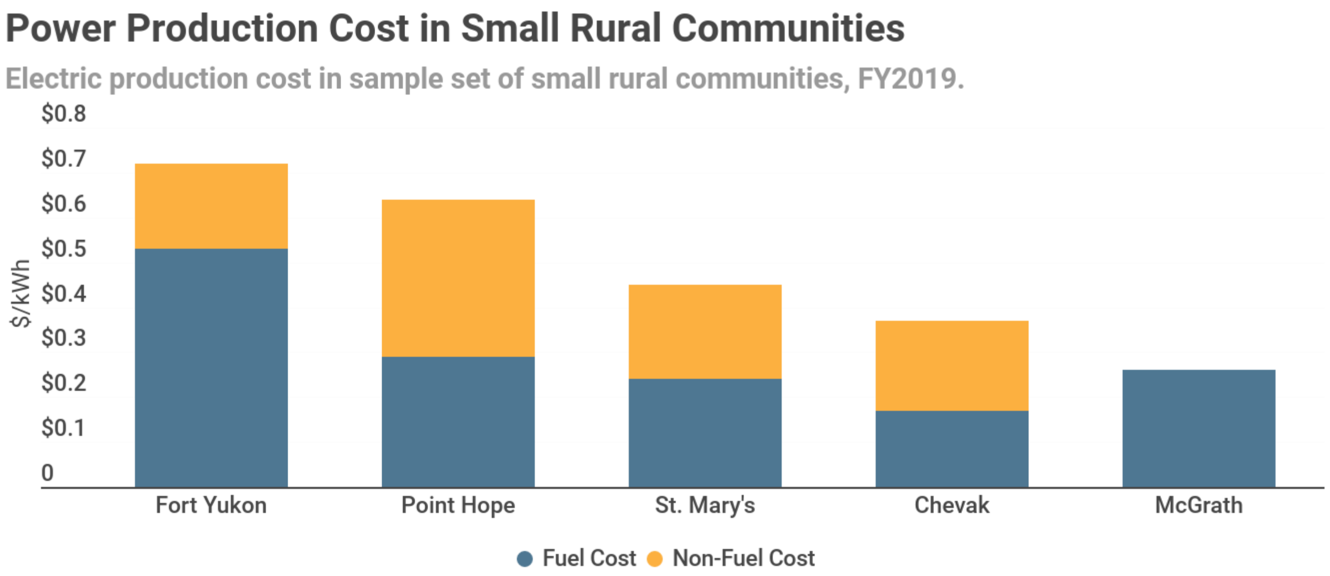
Figure 7: Sample Small Rural Community Population.
Source: AKDOLWD, 2019.

Because population size is small and labor pools are isolated, the workforce is less diverse than in larger communities on the road system and even rural hub communities. Most of these villages are home to majority Alaska Native residents from the state's 229 federally recognized tribes. Local government; education and healthcare; and trade, transportation, and utilities are the three largest employers in these small rural communities, yet traditional cash employment opportunities can be limited. Traditional ways of life that include hunting, gathering, fishing, and more – play important economic and cultural roles.

Energy Overview

As rural Alaska communities vary in size, so do the size of their energy systems. Electric loads are primarily made up of residential customers and community facilities. Schools, washeterias, and water treatment facilities often make up the largest single energy users.[29] Most communities have health clinics which require constant power.

Power production costs are high across rural Alaska. Figure 9 presents Eligible communities across rural Alaska participate in the PCE program, a state government subsidy which lowers the cost of power for residential customers up to the 500 kWh and for eligible community facilities. The program subsidizes qualifying fuel and non-fuel costs, lowering the realized cost of energy for rural Alaska residents. However, commercial energy users do not qualify for the program and bear the full burden of energy costs in rural communities.[30]



Note: McGrath did not report non-fuel costs in FY2019.

Figure 8: Small Rural Community Power Production Cost.
Source: AEA, 2019.

These small rural communities are defined separately from rural hub communities largely by their size. In many cases, an energy system with a capacity of 1 MW is considered very large. Communities range in size from 0.5 to 10 MW. Figure 10 presents the installed power capacity in a sample set of rural communities

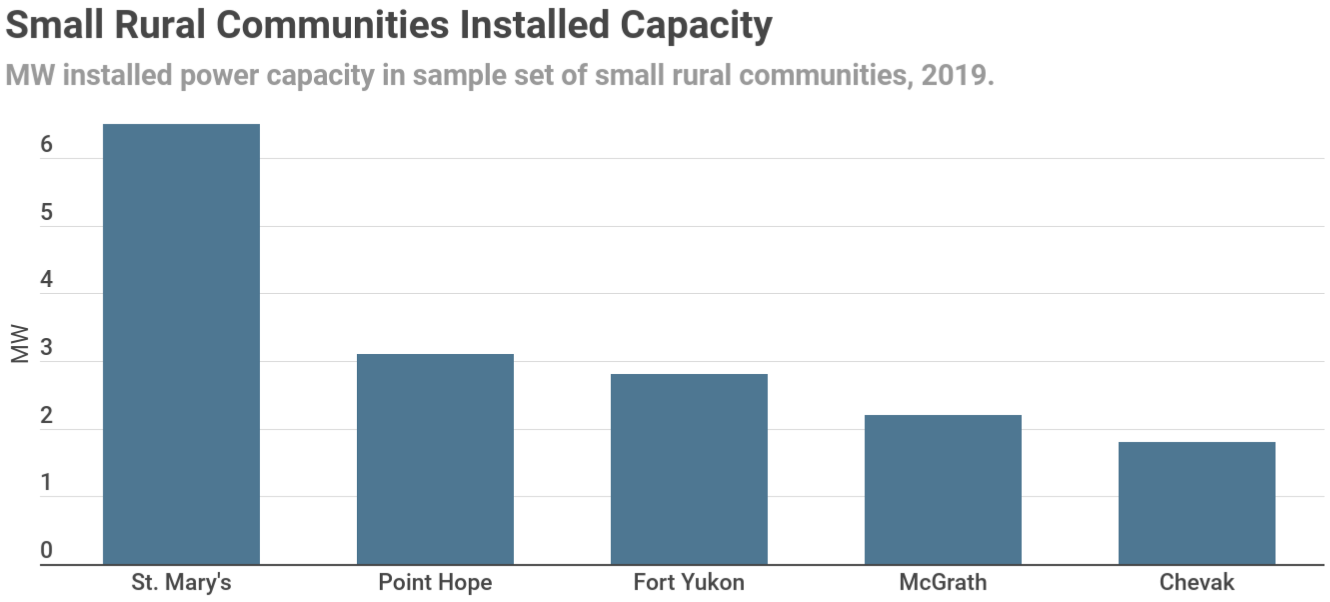


Figure 9: Small Rural Community Power Capacity.
Source: EIA, 2019.

Over 30 communities across rural Alaska operate systems integrating diesel and renewable sources like wind, solar, or hydro.[31] Systems which can coordinate with engineers and operators in Anchorage and the rest of the U.S. are increasingly prevalent. Other communities operate very simple, dated systems, where routine maintenance can be a challenge.

High cost and the variability of diesel generation is balanced by the relative dependability and operational ease of such familiar technology. A common refrain across Alaska is “diesel is easy,” meaning the comfort level with the technology and supply chain dynamics are solid and understood. In addition to government and tribal support services providing technical assistance to energy providers, supply chains have been built throughout the state to serve the multitude of remote diesel systems in servicing, operation, and repair.[32] Similar structures are only now starting to emerge to support other energy systems, such as wind and solar technology.[33]

While diesel is a known technology with widely understood maintenance needs, it should be emphasized that 'operational ease' is a relative term. Breakdowns and maintenance failures of diesel gensets are frequent problems leading to periodic, and sometimes extended, blackouts. The expertise to repair and maintain the engines exists within the state, but not in every small community. Rural villages experiencing breakdowns often require assistance from technicians who must fly to the community to fix a failing system.

Heating fuel is the most common heat source across rural Alaska. However, wood and in some circumstances, coal are also used for residential heating. Larger facilities, such as city government and schools purchase heating fuel in bulk, lowering the cost of heat by a certain amount. Residents purchase heating fuel from public or private distributors. Figure 11 displays a sample of heating fuel costs from the communities referenced above.

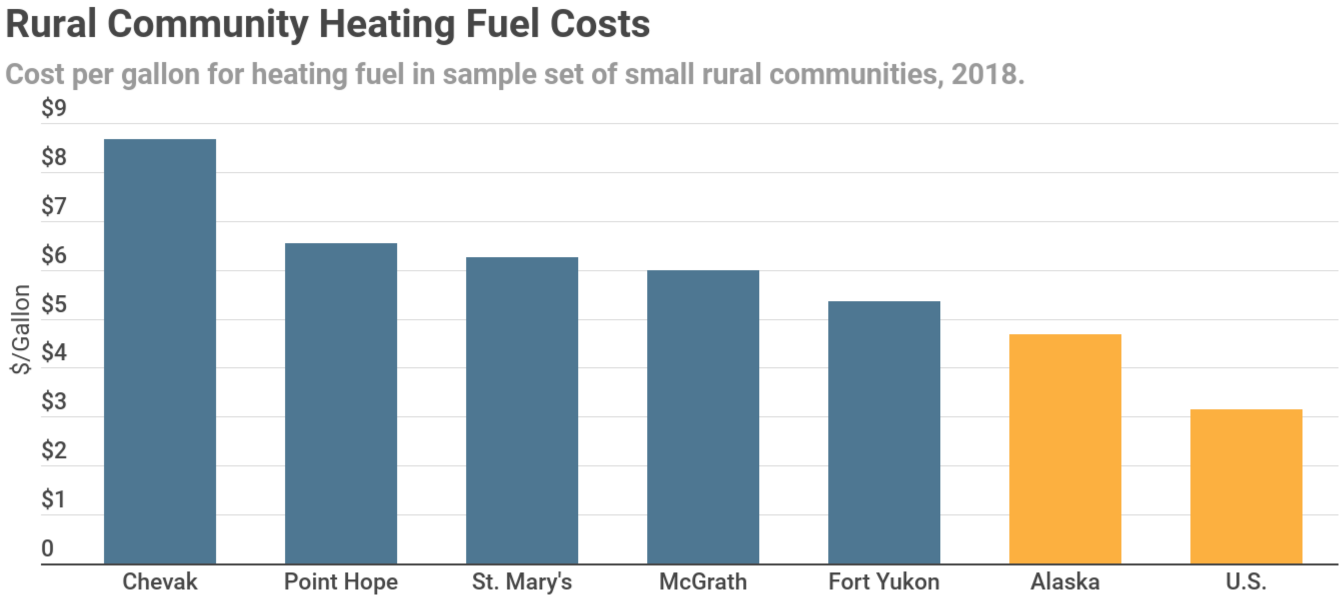


Figure 10: Small Rural Community Heating Fuel Cost.
Source: DCRA, 2018.

Efforts have been made to use recovered heat from diesel generators to heat community buildings, power houses, water treatment facilities, and washeterias. Energy efficiency and weatherization projects across the state have made steps toward heating fuel savings. However, work remains in this area.

District heat infrastructure is limited across rural Alaska. District heat and water systems face a number of challenges in rural communities. The first reason for this is the high cost of constructing rural infrastructure. The second is due to extra considerations to accommodate permafrost, which inhibits construction of underground utility corridors.

Investigating Alternatives

Leaders from many rural communities have expressed a vested interest in expanding their renewable and alternative energy generation portfolio. Interest in this comes from various angles.

- **Sustainability:** Climate change is a reality in Alaska, with particular impacts in rural areas. As such, many utilities have set goals to reduce emissions.[34]
- **Dependence on fossil fuels:** Diversification of generation assets increases community resilience by reducing dependence on a single energy source. Even with renewable energy asset integration in some communities, most rural communities are entirely dependent on a single resource -- imported diesel fuel.

- **Maintenance and operation:** Both routine and non-routine maintenance can present a technical challenge for small rural energy producers. Maintenance failures for diesel and non-diesel technology may require technicians to fly in from outside the community, causing repair delays and high costs.
- **Supply chain independence:** Imported diesel presents a logistical and financial hurdle for many utilities. The energy supply chain is dependent on a small number of diesel suppliers who deliver fuel in the non-winter months. Deliveries are subject to the variability in weather and ice conditions.[35]
- **High cost:** Power costs and heat costs are high in rural Alaska. In remote communities, costs per kWh are approximately double costs in urban Alaska. Fuel costs and operations and maintenance costs are two variables which influence the end costs realized by energy consumers. Remoteness, fuel delivery infrastructure, bulk purchasing capability, workforce costs, and more, drive these high costs for community utilities. In the heating realm limited competition in fuel retails create an extra layer influencing heating fuel costs
- **Cost variability:** In addition to the high cost per gallon of diesel fuel used to power the energy system in rural Alaska, diesel costs are also highly variable. That variability presents a hurdle for utility planning.[36]

Many rural utilities are investigating and installing alternative energy sources and detailed energy plans and resource studies exist at both the regional and local levels. One key player, the Alaska Energy Authority, has appropriated more than $257 million toward investigating and installing renewable energy capacity across rural Alaska through the Renewable Energy Fund (REF). More than 55 projects have been completed with REF funding.[37] However, momentum has stalled due to State of Alaska budget issues.[38]

Progress toward integrating renewable capacity has largely been limited by resource availability, variability, cost, and access to storage technologies. All of these are issues that all utilities struggle with, but are more pronounced at the small scale of rural Alaska utilities.

Rural Hub Communities

There is no cohesive definition for a hub community. One of the most common definitions includes population; however, others include criteria for communities to serve as a regional services hub. Table 6 presents a list of some of the rural communities that can be considered regional hubs for the purposes of this analysis.

Hub Community Population Size	
Community	**Population**
Unalaska	4,592
Bethel	6,259
Dillingham	2,327
Nome	3,690
Utqiaġvik	4,536
Kotzebue	3,112

Table 6: Hub Community Population Size.
Source: AKDOLWD, 2019.

Because population size is small and labor pools are isolated, the workforce is less diverse than in larger communities on the road system. However, hub communities do have access to a larger labor pool than the small villages of rural Alaska. The 'Trade, Transportation, and Utilities' sector in each of the above hub communities is among the top employers, as it is across rural Alaska.

Energy Overview

Hub communities have larger energy demands and more complex power systems. They serve as transportation and administrative centers for surrounding villages, and have populations numbering in the thousands rather than hundreds. These hub communities are scattered across the Interior, Southeast, Western, and Northern Alaska regions and range in size from approximately 10 MW to 25 MW of installed capacity.[39] Figure 12 shows the power capacity installed in a sample of hub communities.

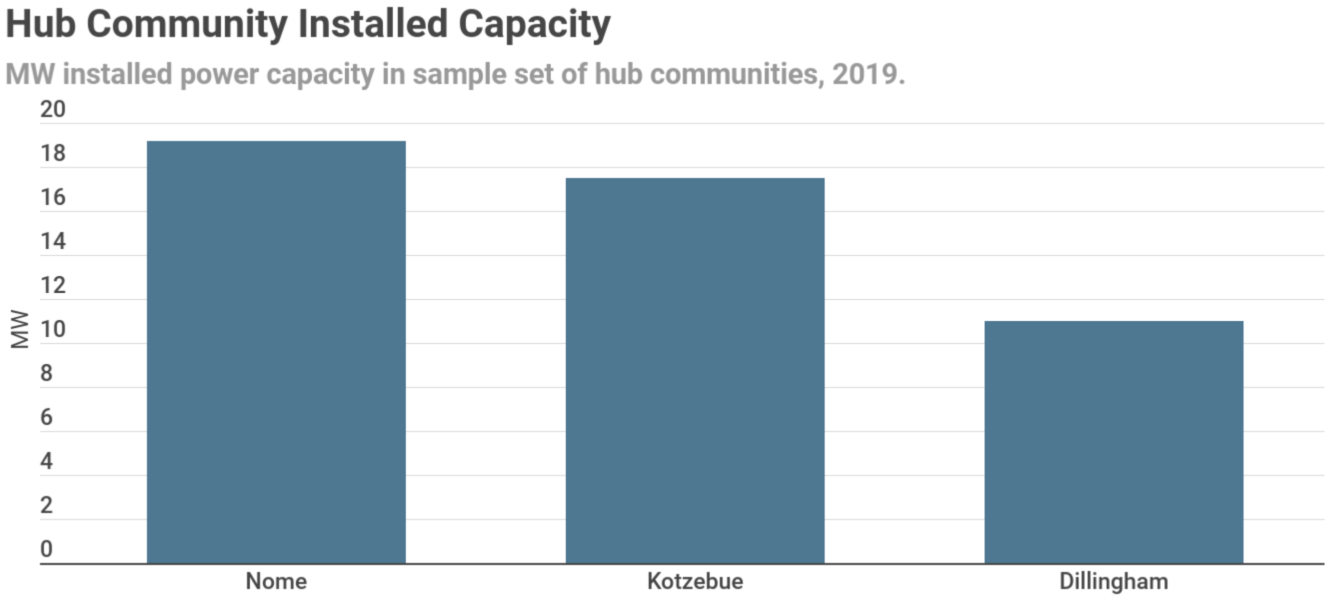


Figure 11: Hub Community Installed Capacity.
Source: EIA, 2019.

The communities rely on a number of resources: including, wind, natural gas, diesel, and batteries. Outside of Utqiaġvik, which utilizes local natural gas resources, all of the communities are dependent of diesel generation to meet demand. Table 7 displays the energy sources installed in Alaska hub communities. Given that even communities with large renewable resources are required to maintain diesel back-up systems for consistent output, most hub communities are subject to the variability and high costs of diesel fuel.

Hub Community Power Production Energy Sources

City	**Generation Fuel Source**
Unalaska	Diesel
Bethel	Diesel, Wind
Dillingham	Diesel
Nome	Diesel, Wind
Utqiaġvik	Natural Gas
Kotzebue	Diesel, Wind, Battery

Table 7: Hub Community Fuel Sources.
Source: EIA, 2019; AVEC, 2020.

Energy users in hub communities can vary, including seafood processors, hospitals, state and federal government buildings, schools, and university satellite campuses. A sample of three communities were selected to examine relevant heat and power information, Dillingham, Kotzebue, and Nome. Figure 13 presents annual kWh sales by customer type in those communities.

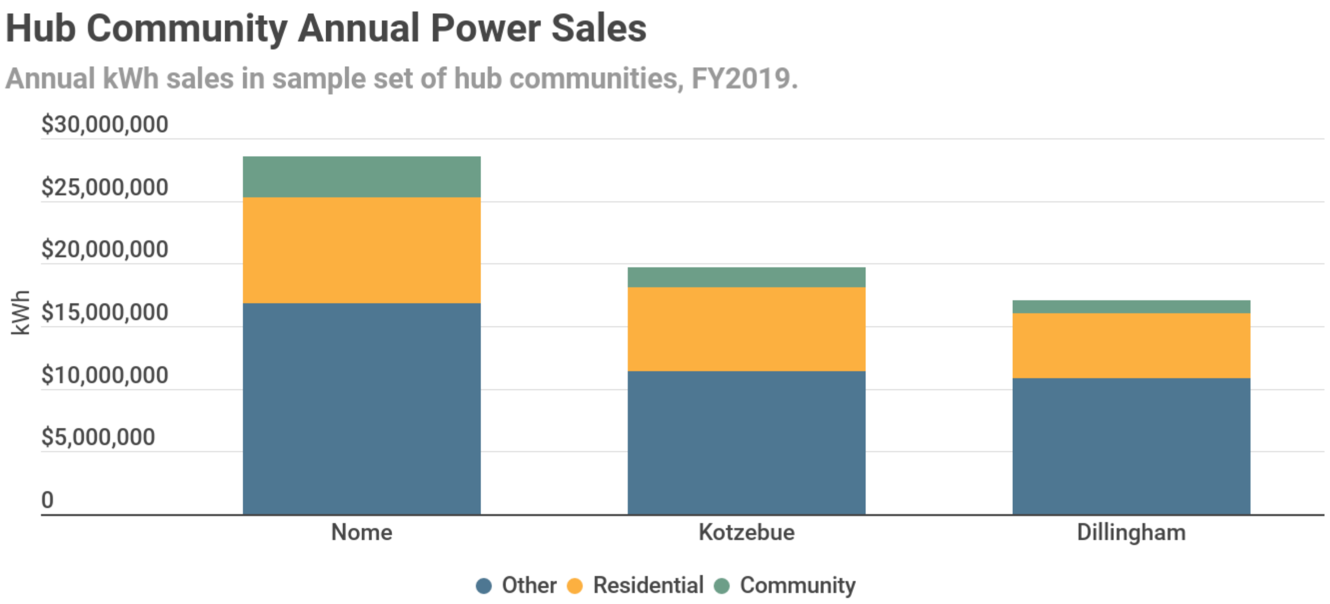


Figure 12: Hub Community Annual kWh Sales.
Source: AEA, 2019.

Delivered cost of fuel is variable across hub communities and is one of the key drivers of the high cost of power in rural areas. High costs associated with transmission and distribution infrastructure, maintenance, and administration drive the cost of utility operations even higher. A sample of hub utility cost of power is shown in Figure 14 below.

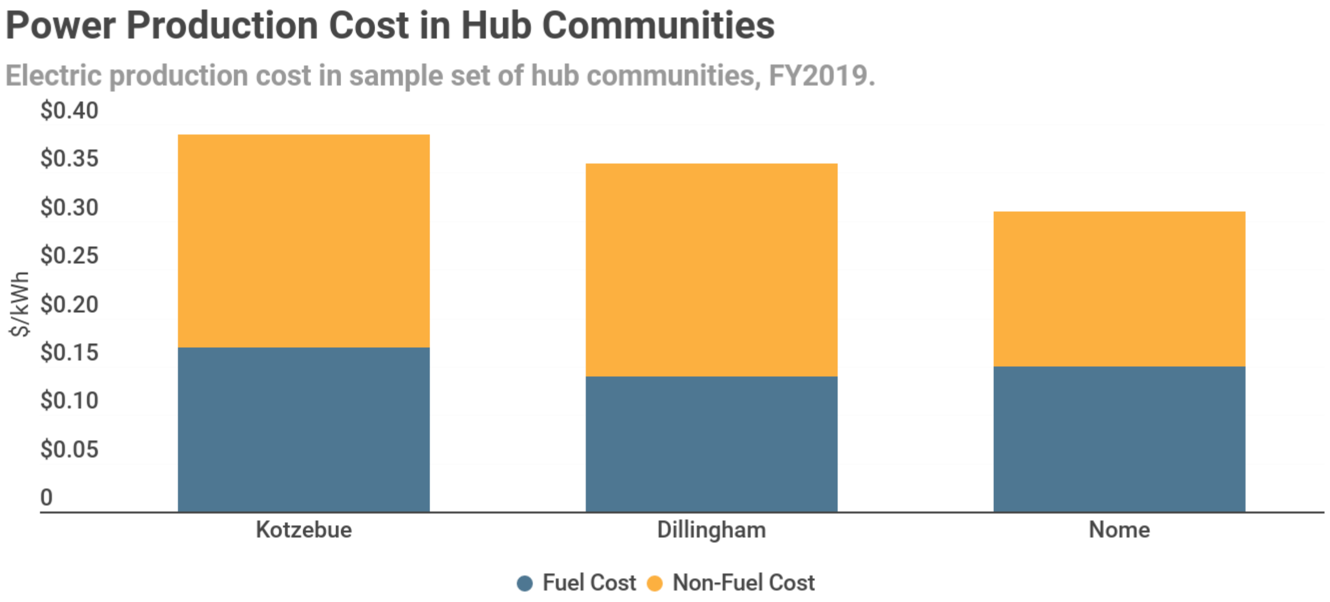


Figure 13: Hub Utility Power Production Costs.
Source: AEA, 2019.

Heating costs are equally high. Costs for heating fuel in the same hub communities ranged from $3.59 to $5.85 per gallon in 2018. Fuel oil costs are shown below in Figure 16. Space heating needs are predominantly met with fuel oil, or with wood where resources are available. For example, in Nome it is estimated 95 percent of the residential space heating needs are met with fuel oil, a further 2 percent by wood and 3 percent with other resources. Household fuel usage in Nome and Dillingham are shown below in Figure 15.

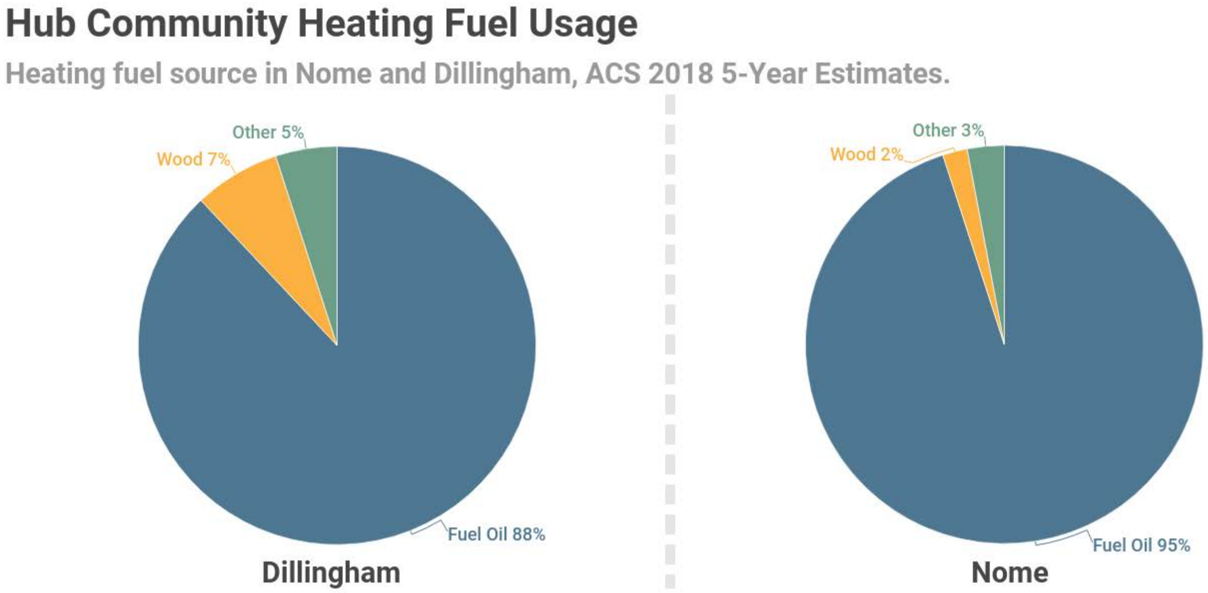


Figure 14: Dillingham and Nome Space Heating Fuel Usage.
Source: ACS, 2018 5-Year Estimate.

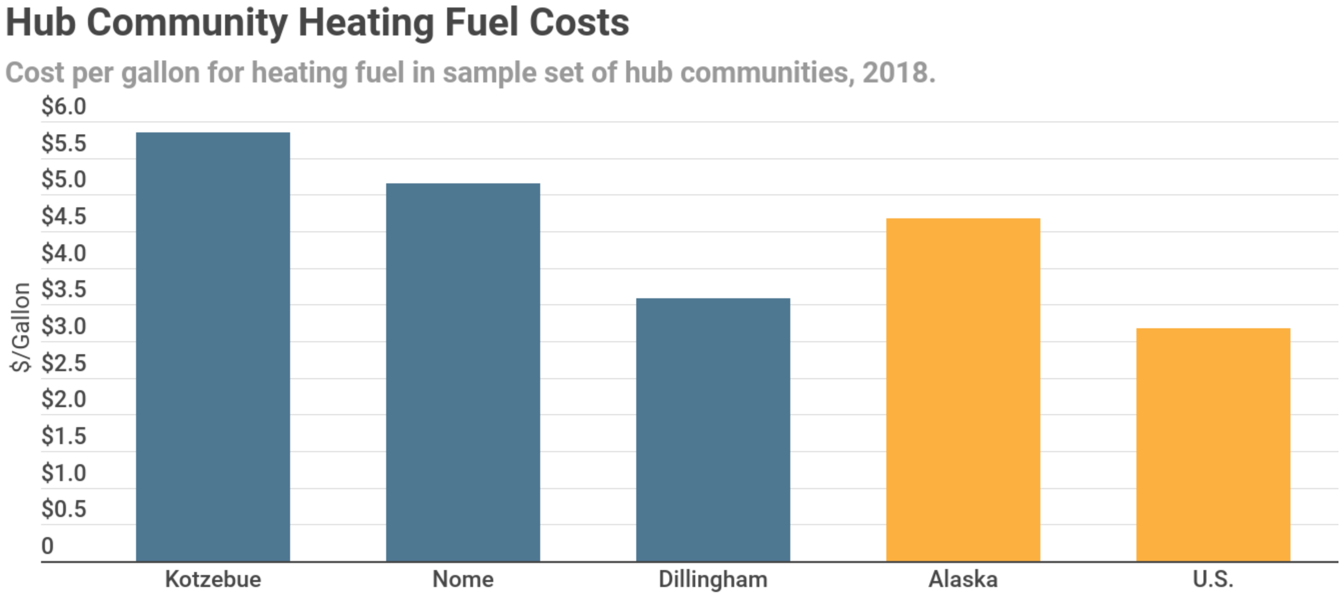


Figure 15: Hub Community Space Heating Cost.
Source: DCRA, 2018.

Investigating Alternatives

Many rural hub communities have expressed a vested interest in expanding their renewable and alternative energy generation sources. Interest in this comes from various angles.

- **Decarbonization:** Climate change is a reality in Alaska, with particular impacts in rural areas. As such many utilities have set goals to reducing emissions.
- **Dependence on fossil fuels:** Diversification of generation assets increases community resilience by reducing dependence on a single, imported, energy source. Even with renewable energy asset integration in some hub communities many energy systems are entirely dependent on a single resource—imported diesel fuel.
- **Supply chain independence:** Imported diesel presents a logistical and financial hurdle for many utilities. The energy supply chain is dependent on a small number of diesel suppliers who deliver

fuel in the non-winter months. Deliveries are subject to the variability enforced by weather conditions and ice conditions.

- **High Cost:** Power and heat costs are high in rural Alaska. In hub communities, energy costs per kWh are approximately double costs in urban Alaska. Fuel costs and operations and maintenance costs are two variables which influence the end costs realized by energy consumers. Remoteness, fuel delivery infrastructure, bulk purchasing capability, workforce costs, and more drive high costs for hub community utilities. In the heating realm, limited competition in fuel retailers create an extra layer influencing heating fuel costs.
- **Cost variability:** In addition to the high cost per gallon of diesel fuel used to power the energy system in rural Alaska, diesel costs are also highly variable. That variability presents a hurdle for utility planning.

Rural hub utilities have investigated alternative energy sources to varying degrees of success. Kotzebue and Nome both have integrated wind sources. Nome is investigating local geothermal resources and Dillingham is investigating local hydro-electric resources. One of the challenges many communities face is the location and availability of renewable resources. Many utilities still struggle to replace base load generation year around.

Railbelt Energy Producers

The majority of Alaskans live on the road system that connects Southcentral Alaska and parts of the state's Interior. This is a region serviced by a network of five interconnected, but separate utilities stretching from Homer in the south to Fairbanks in the north.

The Railbelt region had an estimated population of 550,000 individuals in 2019,[40] 63 percent of which is of working age—between the age of 20 to 64.[41] More than half of the state's 280,000 jobs are located on the Railbelt.[42] In the utility sector, 1,348[43] are employed across the Railbelt at electric, gas, water, and other utilities.[44] As a region, the Railbelt has access to a deeper labor pool than isolated rural communities, both within and outside of the utility sector.

Energy

The Railbelt utilities experience high costs and, therefore, higher energy rates compared to electric utilities across the contiguous U.S. However, compared to energy systems in rural areas, Alaska Railbelt rates are significantly lower. Energy rates for residential ratepayers ranged from $0.20 to $0.28 per kWh in June 2020. Figure 17 compares utility electric rates for Railbelt utilities.

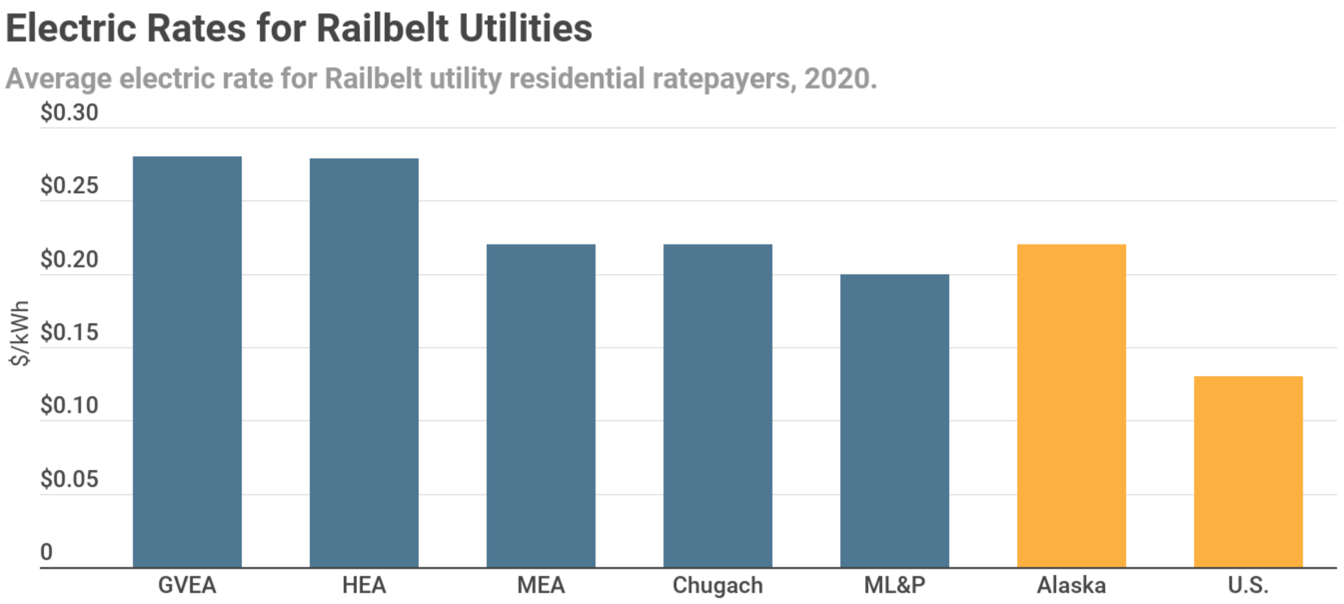


Figure 16: Railbelt Average Rate for Residential Service.
Source: RCA, 2020.

A number of variables contribute to lower costs, including: access to resources for operations and maintenance; access to lower cost fuel sources; utilization of mature, subsidized hydro resources; and ability to buy and sell power across utilities according to price and availability. Given the larger size, utility costs are divided across a greater number of kWh sales, further driving down costs.

Investigating Alternatives

Each of the Railbelt utilities have clearly identified priorities regarding energy alternatives. Guidance has been given to the utilities from multiple angles to investigate options for decarbonization and resiliency. Most are actively investigating alternative energy systems, including: expansion of the Bradley Lake hydro resource, installation of a Battery Energy Storage System (BESS), landfill gas projects, solar projects, and wind projects. These efforts are guided by a number of core issues, including cost, decarbonization, reliability, and security.

Reliability and Security: The newly-established Railbelt ERO will likely play a role in determinations on future energy asset integration. As of yet, particulars on how those roles will function within the energy landscape remain unclear. Ensuring reliability includes determining cyber and physical security protocols and guaranteeing the reliability of energy sources.

Decarbonization: The quality of available renewable energy resources remains a challenge for many of the Railbelt utilities integrating large scale solar and wind assets. However, small scale residential and commercial renewable energy adoption has been growing. Net metering capacity grew by 75 percent in 2019, reaching an installed capacity of 5,636 kW.[45] Energy storage solutions are being implemented across the Railbelt, but it is unlikely that renewable energy assets will be able to fully replace baseload needs. Therefore, the question of diversification of energy resources is a recurring theme.

Cost: As regulated utilities, Railbelt utilities act under requirements to minimize costs to consumers.[46] Advanced nuclear technologies would be compared against the costs associated with other alternative energy sources and the current sources. Advanced nuclear reactors are still in the early stages of development and concrete cost information is unavailable. However, with the relatively low cost of power compared to much of Alaska, to be competitive with existing sources of power generation the early costs of micro-reactors would have to comparable.

As regulated utilities, all of the Railbelt utilities are subject to significant cost oversight. Interviewees in this customer segment noted that cost is a defining variable when energy technologies are evaluated. Homer Electric Association (HEA) noted that a number of renewable energy projects have been evaluated, but not implemented due to the delivered cost of power. GVEA, at the other end of the system, noted that while costs are not the most important variable, energy projects are highly dependent on cost factors.

Defense

Alaska's military installations have been celebrated for their strategic importance for the U.S. Alaska occupies geopolitically important position on the Pacific Rim and within the Arctic. The state is home to the Long-Range Discrimination Radar (LRDR), a missile defense installation, and fifth-generation fighter aircraft – the F-22s and F-35s. Maintaining mission readiness in harsh and relatively isolated conditions is of critical importance. Energy is at the center of that objective as an enabler of military operations across vast distances and in cold climates.

Defense installations in Alaska are large energy users with complex energy needs, from residential heat and power to transportation and base operations. Alaska is home to nine major military installations, a mix of Army, Air Force, and U.S. Coast Guard bases. A host of other minor military sites are scattered across the state, including remote air stations and radar sites. There is limited U.S. Navy presence in the state. Alaska defense installations and associated military branches is shown below in Table 8.

Alaska Major Military Installations	
Military Installation	**Branch**
Joint Base Elmendorf Richardson (JBER)	Air Force/Army
Fort Wainwright	Army
Fort Greely	Army
Eielson Air Force Base	Air Force
Clear Air Force Station	Air Force
Coast Guard Air Station Kodiak	Coast Guard
Coast Guard Sector Juneau	Coast Guard
Coast Guard Base Ketchikan	Coast Guard
Coast Guard Air Station Sitka	Coast Guard

Table 8: Alaska Major Military Installations.
Source: DHS and DOD, 2020.

Energy

Energy security is a critical to the Department of Defense (DOD) and Department of Homeland Security (DHS) missions, especially resilience and independence.[47] In the case of military installations resiliency can be defined as security and operational continuity despite outside forces. This is the case across all of the DOD and DHS installations, but is especially critical in Alaska where there is a greater need for self-sufficiency. Despite producing large amounts of oil and gas, Alaska is at the end of the energy supply chain, exposing vulnerabilities to disruptions in those supply lines.

Power generation, heat, and transportation capabilities at Alaska's military installations are dependent on a handful of local fuel resources—coal and natural gas in Interior and Southcentral Alaska—and imported diesel fuel and heating oil. Military installations across the state pull together a number of resources to meet power and heat need. Bases purchase power from local utilities, contract with Doyon Utilities in Fairbanks to provide heat and power services, and maintain and operate their own heat and power systems as circumstances and operational needs demand. Table 9 describes the energy sources utilized by the four major defense installations.

Military Installation Energy Sources	
Military Installation	**Power Source**
Joint Base Elmendorf Richardson (JBER)	Purchased Power/Landfill Gas
Fort Wainwright	Purchased Power/Coal
Fort Greely	Purchased Power/Diesel
Eielson Air Force Base	Purchased Power/Coal

Table 9: Alaska Military Installation Energy Sources.
Source: Doyon Utilities, 2020; U.S. Army Corps of Engineers, 2005.

Table 10 describes the installed capacity and historical system peaks of four Alaska defense installation. Fort Wainwright's generation assets are powered by local coal resources, only when the power demand from the base exceeds the 2.5 MVA transformer rating at the GVEA substation. Power demand below that is provided by GVEA.[48] Fort Greely is similarly situated, predominantly powered by GVEA. However, when demand exceeds the substation transformer rating, additional power is provided by diesel generators on-base.[49]

JBER energy demand is primarily met by power from a landfill methane gas power plant. The plant is capable of meeting 26 percent of JBER's electrical load.[50] The remaining 74 percent of the base's energy demand is met by ML&P, which is soon to be merged with Chugach Electric Association (Chugach).

Eielson operates a coal-fired, CHP system which provides the majority of the power to the Air Force base. During peaking periods, additional power demands are met by GVEA. The coal used to power Eielson and Wainwright's CHP systems is sourced from Usibelli coal mine.[51]

Military Installation Installed Capacity		
Installation	**Installed Capacity (MW)**	**Historical Peak Capacity (MW)**
Eielson AFB	33.5	17.1
Ft. Wainwright	20	18.4
Ft. Greely	7.4	2.4
JBER	11.5	Not Available

Table 10: Military Installation Installed Capacity.
Source: Doyon Utilities, 2020; U.S. Army Corps of Engineers, 2005.

Heating needs at JBER, Fort Wainwright, Eielson, and Fort Greely are served by distributed heating sources. Table 11 describes the fuel source utilized for those installation heating needs. The distribution systems, and where applicable, generation facilities are operated by Doyon Utilities and powered by coal or diesel CHP systems or natural gas furnaces.[52]

Military Installation Heat Systems	
Installation	**Heat Source**
Eielson	Coal-Fired CHP Plant
Ft. Wainwright	Coal-Fired CHP Plant
Ft. Greely	Diesel-Fired CHP Plant
JBER	Natural Gas

Table 11: Military Installation Heat Systems.
Source: Doyon Utilities, 2020; U.S. Army Corp of Engineers, 2005.

Investigating Alternatives

Energy security and independence is an important driver of installation energy planning and decision making. Energy is especially important for ensuring installation mission readiness.[53] Security is referred to as one of the critical drivers of energy decision making for the military. However, this is a layered variable that includes power and fuel availability, infrastructure capabilities, independent operations, and physical and cyber security. Installation energy values can be broken into the following categories:

- **Fuel Security:** Fuel source security and fuel transportation security both contribute to analysis of potential fuel sources.[54] Fuel must be available from any given source when needed and must be capable of being transported securely. In addition, power received from the utilities and produced at the installations is dependent on a handful of fuel sources and the supply chains that deliver them, predominantly natural gas, coal, diesel, and landfill gas. Supply chain interruption of any one of those sources would have impacts on installations power and heat production capabilities.
- **Power Availability:** While each of the military installations discussed here have backup generation capabilities, each are dependent to some extent on power provided by local utilities. The possibility of power curtailment from utility sources presents a risk. Installed generation infrastructure, in some cases, is aging and is not always reliable.
- **Infrastructure Capabilities:** The capabilities of power and heat generation assets and delivery systems to reliably deliver energy to the end user represents a critical infrastructure concern for military installations. Aging infrastructure can present a risk to energy delivery capabilities. However, new energy infrastructure must also be capable of integrating into the current systems. In addition, aging coal systems are expected to experience increased pressure to reduce coal consumption.
- **Independent Operations:** While each of the military installations are interconnected to the urban Alaska energy system, the ability to operate independent of those systems has been a goal and planning objective. This is a critical component of ensuring installation mission readiness under extra ordinary conditions.[55]
- **Physical and Cyber Security:** Related to the goal of mission readiness, characteristics of an energy system's physical security are important. This can relate to location characteristics, resilience from natural disasters, threats from climate change, and ability for the installation or a qualified contractor to operate the system independently. In addition, cyber security is a growing concern in the energy field and within Defense installations.
- **Cost:** While cost is not the leading variable in considering energy technology at installations, life-cycle costs of a given technology do play a role.

Remote Mines

Mining operations represent some of the largest single industrial power users in Alaska. Currently operational mines are located across the Interior, Southeast, and Northwest Alaska regions, while a number of proposed mines at various stages of exploration and permitting could be located across the state.

Table 12 shown below discusses the currently operating and proposed mines in Alaska. Of the six major producing mines, two can be considered truly remote—lacking connection to any power grid or road system and dependent on production of their own power supply: Red Dog and Kensington. The remaining four – Fort Knox, Greens Creek, Pogo, and Usibelli – are connected to adjacently located power grids and purchase all or a portion of their energy from utilities. Two mining projects in the advanced permitting stage, Pebble and Donlin Gold, would also be considered remote if they are constructed.

Alaska Large Mining Operation Characteristics		
Mine	**Stage**	**Location**
Usibelli	Producing	Non-Remote
Ft. Knox	Producing	Non-Remote
Greens Creek	Producing	Non-Remote
Pogo	Producing	Non-Remote
Red Dog	Producing	Remote
Kensington	Producing	Remote
Donlin Gold	Advanced Permitting	Remote
Pebble	Advanced Permitting	Remote

Table 12: Alaska Large Mining Operation Characteristics.
Source: Alaska Mining Association, 2020.

Energy

Mining operations are energy intensive, with large power, heating, and transportation loads needed to accommodate mining and processing operations. Table 13 discusses the current installed capacity of mining operations across Alaska. Even if connected to an external power grid, mines must have redundant power capacity and be capable of self-generating to ensure a constant supply of power.

Mining Industry Installed Power Capacity	
Mine	**MW Capacity**
Producing	
Red Dog	40
Greens Creek	11.25
Kensington	10
Ft. Knox	35
Pogo	10
Advanced Permitting	
Donlin Gold	228.6
Pebble	270

Table 13: Mining Industry Installed Power Capacity.
Source: Council of Alaskan Producers, 2010.

Of the mines that self-generate power, the generation infrastructure is owned and operated by the mine. Current generation systems at producing mines are powered by diesel fuel. Proposed mines Donlin Gold and Pebble are both expected to self-generate electricity using natural gas delivered by pipeline. There is limited publicly available data on the operational costs associated with power production in the mining industry, like distribution, maintenance, transmission, and overhead costs.

Mine heating needs are largely focused on space heating for buildings. Heating demand at currently producing mines is met with recovered heat from power generation, diesel, and propane. There is data on diesel and propane consumption for mine operations, which includes heating and transportation. However, detailed information on heating needs is limited. Figure 18 presents the estimated diesel fuel quantities used for non-power mine operations.

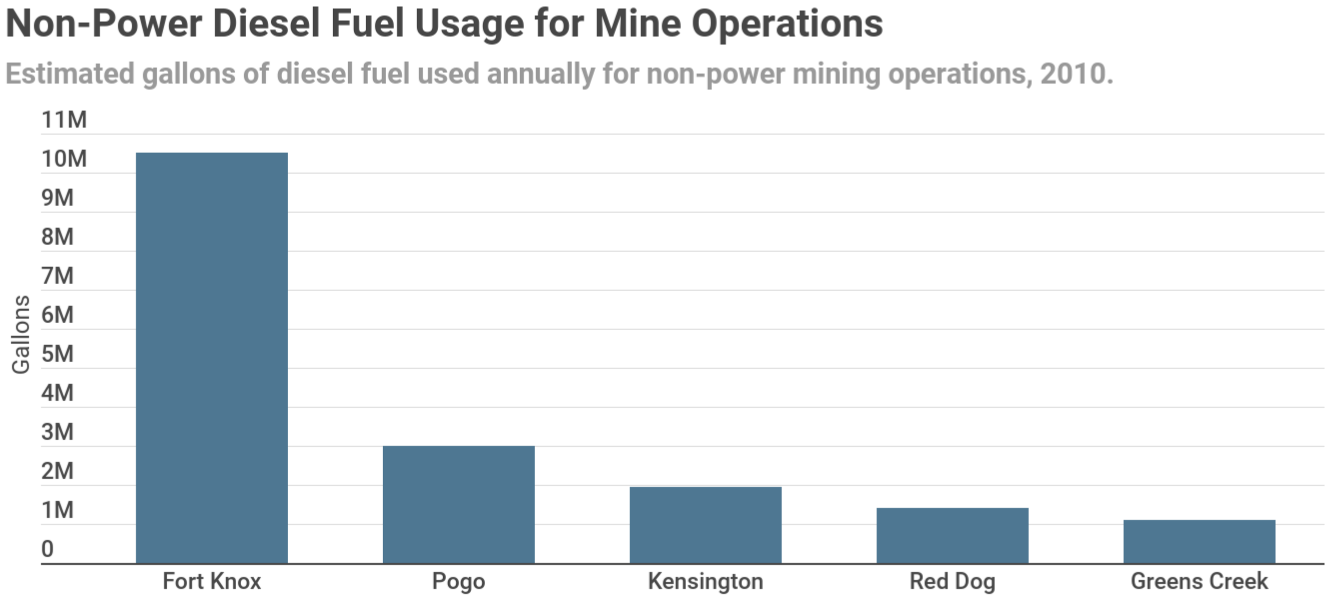


Figure 17: Gallons of Diesel Fuel Used for Remote Mine Operations
Source: CAP, 2010.

Red Dog mine operates a heat recovery system, lowering the diesel fuel requirements. Pogo mine utilizes an additional 1,000,000 gallons of propane for heating in the winter.[56]

Investigating Alternatives

Energy costs are a critical driver of remote mine profitability. The cost of fuel and electric power directly impacts mine operation costs and the lifespan of a mine.[57] As a result of fuel and production costs, Greens Creek mine in southeast Alaska interconnected with the Juneau city utility, Alaska Electric Light and Power, agreeing to purchase the utility's surplus hydroelectric power. The interconnection was completed in 2006 and works to lower the mine production costs.[58]

During the planning stages of a mine, energy sources are a key operational and financial consideration. As an example, energy planning for the proposed Donlin Gold mine determined natural gas to be the most cost-effective energy source. The mine has sought permits for constructing a buried natural gas pipeline corridor to service the energy needs of the proposed mine. Other energy sources considered in Donlin's feasibility analysis included coal, hydroelectric, power-line intertie, biofuel, and nuclear, but none met the expected needs of the project cost effectively.[59]

Drivers of mine energy technology decisions are discussed below.

- **Cost:** Lowering operating costs of a mine are one of the primary considerations in regard to mine energy usage. As mine operation costs decrease, mine profitability increases, sometimes enabling extensions to the life of the mine. Projected fuel prices play a role in this and price variability of fuel can be a barrier. Predictability of the lifetime cost of an energy system is important. Unforeseen costs can limit mine profits.
- **Regulatory Requirements:** Mines are subject to regulatory oversight by state and federal agencies, predominately in areas of environmental management. Energy infrastructure is expected to complement or improve the basic environmental impact expectations.
- **System Fit:** Mining energy systems experience specific demands related to the mines industrial processes. Mines in Alaska use energy for mineral extraction, materials handling and processing, port facilities, water treatment, transportation, and more. The balance of where energy demand is focused varies depending on the mine size and extraction processes.[60] Energy systems are required to accommodate the breadth of activities conducted at a mine site.

- **Flexibility:** Mine lifespans are variable and change based on fluctuations in cost and commodity prices, which are dependent on changes to global markets and technological advancement. Energy systems are built with that in mind and energy infrastructure which is expected to remain flexible depending on changes to mine operations. Ability for energy systems to scale up or down to accommodate shifts in production is important.
- **Public Oversight:** Mines in Alaska are subject to high levels of oversight by local and environmental interest groups. Currently producing mines and mines in the permitting stages weigh opportunities to improve local infrastructure and provide social benefit.[61] Energy infrastructure is one example of this. Energy technology can be used as a tool for distributing local or environmental benefit, but can also be an area of scrutiny by interest groups.

Market Themes for Microreactor Deployment

Interviews with energy producer and stakeholders revealed a number of drivers for adopting new energy technologies. Costs and routine operational challenges were two common drivers across most customer segments. Those drivers motivating energy producers, users, and operators toward microreactor adoption are balanced by perceptions and unknowns around early-stage microreactors acting as motivators away from adoption.

Power Cost Value Propositions

The average cost of power in Alaska is high. According to data available from the U.S. Energy Information Administration the average cost of electricity in the state is $0.24/kWh.[62] However, Alaska's energy landscape is made up of a patchwork of independent energy systems and each experiences distinct variables driving costs. Across the state, the middle 50 percent of communities' cost of producing electricity ranges from $0.36 per kWh to $0.60 per kWh.

One of hypotheses examined in this analysis is that the high cost of power in remote communities will act as a driver toward early stage energy technologies, such as microreactors. In the early stage of microreactor deployment, the cost per kWh for the technology will remain high until for at least the first 50 microreactors constructed. NEI estimates that the first 50 microreactors deployed could produce energy at costs ranging from a high of $0.40 per kWh in remote communities to $0.10 per kWh in Alaska's Railbelt.[63]

Interviews with energy operators and planners across the state indicated that high costs and cost variability associated with diesel fuels are strong drivers toward investigating alternative energy sources. Savings associated with easier operations and maintenance were also noted by interviewees. While interviewees in each of the customer segments vocalized thoughts on high cost of power, each interacts with the variable in a different way. Table 14 discusses some of the cost driven value propositions specific to each customer segment.

Cost Driven Value Propositions by Customer Segment	
Customer Segment	**Cost-Driven Value Propositions**
Small Rural Community	• Highest cost of power • Cost variability • Savings passed on to non-PCE eligible customers • Operations and maintenance cost savings.
Hub Community	• High cost of power • Cost variability • Savings passed on to non-PCE eligible customers • Operations and maintenance cost savings.
Railbelt Utilities	• Moderate costs, with higher costs on each end of the system. • Fuel availability and spot market pricing
Mine Operators	• High costs and cost variability impacting per ton profits. • Fossil fuel dependent heat and power systems
Military Installation	• Moderately high cost. • Financial resiliency and some independence from high costs as an adoption driver.

Table 14: Cost Driven Value Propositions by Customer Segment.

Small Rural Community Cost Themes

Variability in total cost of power is high across small rural communities in Alaska. Average cost of power in 2019 is this consumer segment was $0.52 per kWh.[64] On average, approximately 51 percent of those costs are fuel costs. The remaining 49 percent includes costs associated generation operations and maintenance, transmission, customer service and administration, and depreciation and interest.[65] However, only a fraction of these cost would be partially or fully offset by alternative energy sources. The remainder are sunk costs, which would not be impacted by implementing a new energy technology and would continue to be passed on to rate payers.[66]

Access to Capital: Margins are narrow for most energy operators in small rural communities. Interviewees noted accumulating cash reserves as a challenge. Citing difficulties accessing capital to fund maintenance and repair items. A common solution to this in the past has been to patch together a number of funding sources, including small loans, and state and federal grants. For example, a recent energy powerhouse and distribution system upgrade in Akhiok was led by Kodiak Area Native Association (KANA), piecing together project feasibility and funding, with KANA taking the lead on distribution system upgrades and the Alaska Energy Authority taking lead on powerhouse construction. Depending on the financial capacity threshold established by the NRC for micro-reactor operators, small community utility access to capital could create a barrier in the permitting stages.

Cost-Benefit Balance: Financial fit will play an important role in determining technology adoption of a nuclear reactor. However, interviewees indicated that the financial balance between the microreactor technologies and the alternative "could not simply be a wash." There would likely need to be some financial benefit to energy producers to incentivize microreactor adoption. Interviewees noted that given other unknowns surrounding the technology, such as regulatory requirements, community perception, and the likelihood of unforeseen maintenance and operations challenges, the financial benefit for the operator would need to be distinctly positive.

Lifetime Costs: Other interviewees noted costs of energy technologies are examined using a holistic lens of the lifetime costs of the reactor, including: cost of capital, construction costs, operations and maintenance, shutdown and remediation costs, and more. Interviewees noted that the opportunity associated with microreactors in the potential to offset fuel costs, but also in offsetting costs through changes to operations and maintenance requirements.

Interviewees expressed questions about operational characteristics, requirements for energy operators, refueling requirements, and how those unknowns could impact costs. Some noted that traditional nuclear reactors require on-site security and specially qualified operators on-site 24/7. Energy producers and stakeholders expressed concern that similar requirements for a micro-reactor located in a rural community would be cost prohibitive and operationally difficult.

PCE Impacts: Communities across rural Alaska participate in the PCE program. Energy operators and stakeholders noted that because of the PCE program, any savings from implementing a new energy technology, would likely not result in any real savings to residential customers and qualifying facilities. Interviewees commented that savings could potentially be realized by the State of Alaska, through lower PCE payments, and by commercial businesses who do not receive the subsidy.

Rural Hub Community Cost Themes

Hub communities in rural Alaska experience power costs which are high, but to a lesser degree than many small rural communities. Access to repair and maintenance parts, better infrastructure for fuel delivery, and ability to purchase larger fuel quantities all impact operation costs. Larger kWh sales enable operators to spread costs over a larger number of kWh, developing small, but significant, economies of scale. Rural hub communities power production costs range from $0.17 to $0.48 per kWh.

On average, 49 percent of total power costs are associated with fuel and purchased power. The remaining 51 percent are derived from generation operations, transmission, customer service and administration, and depreciation and interest. A 2016 report published by the Institute for Social and Economic Research notes that only a portion of costs for rural utilities, including hub utilities, can be offset when renewable resources are integrated.[67]

Fuel Costs: Interviewees in this customer segment noted that fuel costs, specifically, are one of the more difficult challenges for energy operators. Fuel purchases are made annually or biannually and require significant cash reserves or bulk fuel loans. In addition, one hub community energy producer cited cost variability as a specific challenge. Spikes in fuel prices can make financial planning difficult and can result in variability in rates passed on to energy users. Microreactors could offset part or all of a community’s diesel fuel costs. However, one utility operator noted:

> “Taken all into account, it would have to be economically appropriate, it could not be just a wash. The economic benefit would have to be clear.”

Access to Capital: Access to capital was a stated challenge from the interviews. Energy operators generate enough revenues to cover operations and maintenance costs, but find it difficult to build capital reserves to fund infrastructure projects. For example, recent purchase and installation of wind turbines in Nome were funded through a patchwork of grants with a small loan component. Depending on the financial capacity threshold established by the NRC for micro-reactor operators, hub utility access to capital could create a barrier in the permitting stages.

PCE Perspective: Rural hub communities, like small rural communities, participate in the PCE program. With larger populations, hub communities host a larger number of residential customers receiving benefits from the PCE program; however, as regional businesses and logistics centers, hub communities host more businesses than small rural communities. For example, Nome has 324 active business licenses. One hub community energy producer noted that integrating energy technology which lowers operational costs could provide some benefit to small and medium size businesses and larger industrial energy users, where applicable.

Operating Costs: Interviewees in this customer segment also noted that while financial fit is an important variable in determining project feasibility, capital and refueling costs are not the only variables of importance. Operations and maintenance costs was one areas were interviews expressed questions about microreactors, specifically regarding the operations and security requirements. Balancing costs with other variables, such as system fit and workforce requirements was an important consideration indicated by energy operators and stakeholders.

Many of these variables remain unknown for microreactors and interviewees expressed questions about costs associated with upfront capital, operations and maintenance, security, and refueling.

Railbelt Utility Cost Themes

As regulated utilities, all of the Railbelt utilities are subject to significant cost oversight. Interviewees in this customer segment noted that cost is a defining variable when energy technologies are evaluated. Homer Electric Association (HEA) has evaluated a number of alternative energy projects, but not implemented due to the delivered cost of power. One Railbelt utility operator noted that while costs are not the most important variable, energy projects are highly dependent on cost factors, stating:

> “Costs are a big driver of technology assessment. The utility has to account to the Regulatory Commission of Alaska to recoup any costs and a required to justify costs associated with technology decisions.”

Given the small size of microreactors, it is unlikely that a single unit would play a role in significantly offsetting natural gas powered electric production. However, long term planning energy planning on the Railbelt may investigate microreactors as a solution to diversify and de-centralize power production. The $0.40 per kWh cost for microreactors on the Railbelt explored by NEI is specific to those small units investigated in this report.

Fuel Costs: Both HEA and GVEA noted that the significant impact to cost would likely only be felt if a generation technology can significantly or fully replace generation units. Both power producers noted that with the capacity size of installed generation units on the Railbelt, offsetting the generation of any one existing unit would require the combined capacity of multiple micro-reactor units or an SMR.

Cost Unknowns: Microreactor in a Railbelt setting would be compared to existing costs per kWh. Interviewees noted that with the estimated high cost of power for microreactors, early stage investment may not make sense in a Railbelt setting in the near term. One interviewer noted a basket of unknown variables which could impact costs, stating “Construction cost in Alaska are high, so size variation could impact costs. Security could also be a big cost to include.” However, as an energy system reliant on a small number of fuel sources, cost on the Railbelt could be more variable in the future, driving utilities to seek out cost stable energy resources.

Cost Variability: While the cost of Cook Inlet natural gas is low and stable via long-term gas supply contracts with four of the five Railbelt utilities, fuel supply has been decreasing. Cook Inlet natural gas production has decreased since 1995, impacting the gas contracts provided to utilities.[68] When gas requirements to meet power demands occur in excess of contracted and stored gas, utilities must make purchases on the natural gas spot market at significantly higher prices. Long term trends in Cook Inlet natural gas production could continue to impact utility cost variability.

Mining Operations Cost Themes

Energy costs represent a significant percentage of mine operating costs. Higher costs eat into mine profits. Lower energy costs enable mines to operate longer, and with a lower breakeven ore price. There is limited information on the costs experienced by mining operations; however, it can be assumed that remote mines experience high energy costs comparable to hub communities across rural Alaska, which use similar capacity diesel generators.

As energy operators of consolidated energy systems, mining operations evaluate power and heat options thoroughly through the permitting process. For example, as part of the mine operations planning process for Donlin Gold mine, a proposed mine in Southwest Alaska, lifetime costs associated with a number of energy options were evaluated, including diesel, natural gas, coal, bio-fuel, power line intertie, hydroelectric, and nuclear were all considered.

High Costs: Cost of energy represents a significant component of mine operations costs for the mining industry, especially for remote mines in Alaska. An estimated 21 percent of the U.S. mining industries expenditures on supplies are related to energy.[69] Energy technology which lowers the cost of energy acts expands mine profitability. Energy costs act as one of the lead enablers of mine feasibility. If capable of lower lifetime energy costs, microreactors could fit in the energy landscape of the mining industry in Alaska.

Cost Unknowns: Unknowns around the lifecycle costs of microreactors presents a challenge for mine operations. More robust understanding of capital, refueling, permitting, and operations costs will be required to determine feasibility for microreactors.

Financial Security: Despite being more vulnerable to unforeseen costs, mining companies enjoy greater access to capital and, in some cases, more financial security than remote electric utilities. Therefore, financial capabilities are likely to be less of a barrier to the NRC permitting process.

Defense Cost Themes

Defense installations are a large industrial and residential energy user in Alaska’s energy landscape. DOD experiences high costs associated with heat and power at each of the military installations across the state, as a result of the remote characteristics of Alaska’s energy systems as well as the climate. However, military installations must maintain military readiness. This requirement means that fuel source and supply chain security play an important role in determining energy production technology, sometimes regardless of cost.

High Cost: As a function of fuel availability and aging energy systems, defense installations experience high energy costs for heat and power. However, interviewees noted that while cost does play a role in considering energy technology, it is not the sole driving factor. This could act as a benefit for microreactor technology, which would likely have higher costs of than larger generation sources available through a transmission network. In response to cost, one military energy operator noted:

> “Current costs are very low which is why [operators] have stuck with coal. We are not going to spend billion [on a microreactor] just because, but nuclear as a reliable backup is very appealing and important. We would pay a premium for reliability.”

Financial Vulnerability: Military installations are, generally, less financially vulnerable than most energy producers. Unexpected or unforeseen costs associated with deploying an early stage microreactor would be less burdensome and, therefore, less likely to impact operations.

Operations Value Propositions

Throughout the customer discovery process, interviewees cited a number of operational challenges for power production within their customer segment. Common themes included access to specialized workforce, natural disaster related challenges, demand spikes, and access to repair and replacement parts. Interviewees cited opportunities for microreactors to address those challenges. Each customer segment manages a unique basket of challenges, discussed below in Table 15.

Operation Value Propositions by Customer Segment	
Customer Segment	**Operations Value Propositions**
Small Rural Community	• Ease of operations and maintenance • Limited access to qualified workforce • Small systems with limited customer base driving demand characteristics, requiring small, but flexible energy systems.
Hub Community	• Moderate access to skilled labor pool. • Moderate operations and maintenance challenges driving search for easier solutions. • Significant baseload which can not be supplemented with variable sources.
Urban Power Producer	• Large labor pool and access to qualified workforce. • Large distribution system with concentrated pockets of generation assets.
Mine Operators	• Heavy regulatory burden and public oversight. • Flexible mine operations driving need for flexible energy systems. • Large heat, power, and transportation requirements.
Military Installation	• Large heat and power requirements. • Mission readiness drivers toward energy independence. • Aging generation infrastructure limiting on site power and heat capabilities.

Table 15: Operation Value Propositions by Customer Segment

Small Rural Community Operations Themes

Energy system operators in small rural communities cited a range of challenges. Individual operators noted that powerhouses are operated by a small team, three or four utility technicians, who perform routine maintenance and small repairs, like oil and filter changes. Interviewees noted two challenges: hiring finance staff to accommodate billing and regulatory needs, and accessing specialists to diagnose and repair non-routine issues. Repair technicians are flown in to diagnose and repair non-routine issues, creating a delay in repairs and increasing costs. If parts are needed delays and costs are exacerbated.

Operations and Maintenance: Interviewees noted that system diagnostics require a certain level of confidence and comfort with the technology. Part of the success of diesel systems throughout rural Alaska is the network of support for training and ease of operations associated with diesel technology. However, operations and maintenance failures remain prevalent across the state. One utility operator in Interior Alaska commented "diesel is easy, when it's the middle of winter and the system goes down you want a system that can be repaired and up and operational as soon as possible." Another energy planner state, "rural Alaska needs energy systems that are proven and reliable."

Related to operations and maintenance challenges, interviewees noted that the operational parameters and demand characteristics of communities frequently causes less efficient operation. Generators are commonly run outside of peak parameter to accommodate decreases in demand. One utility operator stated that the lifespan of their diesel generators is dramatically lower than nameplate, at five to eight years. If deployed in rural Alaska, microreactors will need to have load following characteristics capable of accommodating the demand characteristics of small remote communities which fluctuate daily and seasonally.

Operational Characteristics: Interviewees asked questions about operational ease of microreactors, including questions regarding the operations and maintenance requirements, workforce training requirements, physical security requirements, refueling process and frequency, and supply chain concerns. One utility operator stated:

> “There are still a lot of unknowns. There are questions about the logistics of the technology. What are the requirements for transportation and installation? What are the security requirements? How will waste fuel be removed and disposed of? Most of these are identifiable and easy to answer, but everything needs to be laid out, confirmed, and be clear and open.”

The microreactors under development are expected to require minimal staffing and be capable of remote or semi-autonomous operation, properties with could be beneficial in a small remote community setting. However, interviewees expressed concerns about occurrences outside of the operational norms, citing lack of immediate access for experts in case of emergency.

Workforce Requirements: Energy operators and stakeholders expressed questions of the skill sets required to operate micro-reactors match existing workforce characteristics in small rural communities. Unknowns remain about the operational characteristics of micro-reactors and corresponding requirements for operators. One energy planner noted, “nuclear engineers are not prevalent in rural Alaska and a significant number of individuals with advanced degrees are unlikely to move to rural communities to operate energy systems.”

Microreactor developers have discussed semi-autonomous or remote operations, high reliability, minimal security requirements, and minimal moving parts. However, these capabilities could differ from the requirements placed on systems by the NRC. All of these characteristics would likely need to be addressed to accommodate the needs of a small rural community in Alaska.

Rural Hub Community Operations Themes

Hub communities operate more complex energy systems, with a more diverse group of energy users. Three of the six hub communities mentioned in this analysis operate wind-diesel hybrid systems. In addition, Nushagak Electric Cooperative in Dillingham is pursuing a hydroelectric project. Operations and maintenance represent less of a challenge for a hub community energy operator; however, interviewees did cite issues relevant to community remoteness, including delays in parts for routine and unexpected maintenance and logistics, and cost of service specialists.

Baseload Replacement: For hub communities, interviewees noted that the challenge in integrating alternative energy sources into hub community power systems is finding a reliable substitute for the community’s baseload. Wind, solar, and hydro can all be intermittent depending on seasonal conditions. One hub utility operator noted that an appropriately sized microreactor could be one of the few power sources that could replace diesel generation.

> “Integrating anything not load responsive causes challenges on a small grid but there are benefits of integrating a resource that is non-variable, like nuclear. A micronuclear system could allow a utility to pursue dispatchable loads for transportation and heat. So the question for

> these new systems is whether they require constant output or if it can cycle up or down to meet demand."

Operational Characteristics: Interviewees noted questions about operational ease of microreactors, including questions regarding the operations and maintenance requirements, workforce training requirements, physical security requirements, refueling process and frequency, and supply chain concerns. All of these variables would impact the dynamics of currently installed energy systems and the feasibility of integrating microreactors.

Workforce Characteristics: Interviewees noted that while hub community energy operators do struggle with workforce, these challenges do not seem to impact plant operations. One hub utility operator stated:

> "as a hub community [the utility] has better access to a qualified labor pool and ha low turnover among plant operators. But administrative operations are frequently a challenge. It is difficult to find finance people and utility management is nearing retirement age. It is not clear if there are individuals who can or will move into those role."

Administrative and finance related workforce requirements could present at challenge to meeting regulatory and permitting requirements for microreactors."

However, it should also be noted that hub utilities source workforce from established training programs across the state and diesel system operations could vary significantly from the operational requirements of microreactors. Training a qualified workforce for microreactors would represent a shift in training programing necessary to operate energy systems.

Railbelt Utility Operations Themes

Of any of the energy systems in Alaska, the grid operated by the five Railbelt utilities is one of the most dynamic. The intertied network is energized by a mix of assets operated by the utilities themselves or by a small number of independent power producers. While the grid does experience some of the challenges present in rural Alaska, the scale of the power system means the challenges can be less pronounced. Railbelt power producers struggle with workforce, maintenance issues associated with a vast distribution system, and environmental challenges impacting utility operations.

Workforce: The utility sector on the Railbelt is a large employer. While access to a qualified workforce does not have the impact on daily utility operations, it does represent a long-term challenge of the energy sector in this part of Alaska. One energy stakeholder noted the "greying of the energy workforce presents and immediate and long term concern." It appears unlikely that this could impact integration of a microreactors, but it could present a long-term shift in training needs for energy producers.

Distribution System: Railbelt utilities act as generation and distribution utilities. Generation assets are predominantly clustered around a number of locations, while distribution systems are fanned across hundreds of miles. Recent natural disasters revealed weaknesses across the entire Railbelt, isolating generation assets and increasing electric costs. In the long term, this could represent an opportunity for a distributed network of smaller generation assets, which likely will increasingly include renewable energy resources.

Defense Operations Themes

For Alaska's defense installations, energy remains a critical operational challenge as it relates daily installation operations and mission readiness. Challenges around this include aging of current energy infrastructure, independent operations capabilities, and fuel supply chain security.

Aging Infrastructure: Alaska military installation energy infrastructure—both generation and distribution systems—were largely installed in the 1960s or earlier. While updates and repairs have been conducted over the decades, the basic infrastructure continues to age. A 2005 analysis of energy infrastructure in the Fairbanks military complex noted the aging infrastructure presents a risk for the installations' operational capabilities.[70] Microreactors could match the current CHP infrastructure for distribution purposes. One military energy operator state, "nuclear as a reliable backup is very appealing and important, [they] would pay a premiem for reliability."

Independent Operation: All of the large military installations purchase power from Railbelt utilities—GVEA and ML&P. However, independent power production capabilities are critical to maintaining mission readiness.[71] This could act as a driver toward adoption of new generating capabilities, which could include microreactors.

Fuel Security: Fuel security plays an important role in assessing military energy infrastructure. Alaska military installations are currently reliant on a handful of fuel resources: Cook Inlet natural gas, locally-sourced coal, local landfill gas, and imported diesel fuel. The potential value of a microreactor to military energy operators is in the security from supply chain interruptions. The long refueling intervals could buffer the military in case of emergency.

In addition, military energy operators are expecting future pressure to reduce coal consumption. One energy operator noted, "[We} foresee pressures from federal government in the future regarding coal power generation. New regulations and standards could make it very difficult to purchase and burn coal."

Remote Mine Operations Themes

Remote mines are large industrial power and heat users. One industry organization discussing mining industry energy needs stated, "mining operations are like small towns and everything is dependent on energy needs. Energy systems need to be easy to use and maintain." A handful of existing mines have established energy systems—both heat and power. However, the challenges of proposed mines reveal more about the energy planning process for mining operations. Interviewees noted that mine operations intersect with the energy operations in three key areas: regulatory burden, public scrutiny, and required flexibility.

Regulatory Burden: Mining operations are subject to heavy regulatory oversight, largely focused in areas of environmental management. An industry expert interviewed noted:

> "The mining industry watched the Galena project closely for the permitting process and regulatory uncertainty. The project dragged on and on with no progress. No mine going into permitting wants a big question mark."

To that extent mining corporations are well versed in navigating regulatory hurdles, and have the capacity to ensure compliance. However, interviewees noted that with the already heavy regulatory burden placed on mines, operations may be reluctant to navigate a new, unknown regulatory landscape. The unknowns around the regulatory requirements the NRC may place on micro-reactors adds another layer to the challenge.

Public Scrutiny: The mining industry is subject to a high level of public scrutiny from nearby communities and public and environmental interest groups. Interviewees noted that given the public perception challenges experienced by the nuclear industry, mine operators may not be open to added levels of scrutiny. An industry expert stated:

> "Mining is in the cross-hairs of a large amount of national anti-mining action. Adding nuclear energy to their portfolios might pain such a huge target on them that they would never escape."

Flexibility Requirements: Mining sites are dynamic. As sites are developed, new deposits explored, and commodity prices fluctuate, mine life can increase or decrease and mine operations can scale up or down. Energy systems are required to be equally flexible. The modular, rapid installation characteristics could accommodate those needs; however, further analysis examining the technical characteristics of both mining energy needs and microreactors would be needed to confirm the technical fit.

Perceptions on Early Adoption

Given the operational challenges experienced by energy operators across the state, some interviewees expressed a reluctance toward early adoption of microreactors. Energy operators and stakeholders gave perspectives from past experiences and potential applications for nuclear.

Small Remote Communities

Given the operations and maintenance challenges experienced by energy producers in remote areas, the majority of interviewees noted that rural remote Alaska is not the setting for early adoption of microreactors. One energy planner expressed reservation, stating “rural Alaska should not be the first for anything.”

One utility manager noted that partnerships with urban utilities have aided remote utilities in successful demonstration of emerging energy technologies. In the past AVEC has partnered with Chugach Electric Association to test and demonstrate diesel turbine technology.

A demonstration project in partnership with rural utilities would enable testing of microreactors in an accessible location. Technology demonstration would enable rural operators to experience technology operation, learn from the operational hurdles experience by larger energy systems, and establish comfort with the technology.

Hub Communities

While some hub community energy operators have participated in integrating early stage technologies, like Kotzebue Electric Association’s early adoption of wind-diesel hybrid systems, others expressed an aversion to the risk associated implementing early stage energy technologies. Nome Joint Utility System noted that to avoid unforeseen operational issues and reduce costs the utility chooses to ride the second or third wave of technology adoption to learn from the experiences of other energy operators.

Another utility operator noted that adopt of nuclear energy would require likely require a significant outreach effort. Stating:

> “[The utility] would be interested but it might be a big push for the community. New technology is socially accepted usually, especially if it could be operating within available skill sets, but nuclear is a different technology from the renewable resource the public is familiar with.”

Railbelt Utilities

Interviewees in this customer segment noted that, while Railbelt energy operators are not necessarily opposed to adopting early-stage energy technologies, cost has been a limiting factor. With the moderate cost of power production on the Railbelt, energy producers have lower cost threshold. However, with lower cost, more efficient storage technology entering the market, alternative energy technologies are becoming more feasible. With the high initial cost of production for microreactors, interviewees noted that early adoption on the Railbelt is unlikely. One Railbelt utility operator noted:

> “[In regard to nuclear] no technology is readily available that in not cost prohibitive. The licensing process seems fraught with disaster. Uncertainty plays a huge role in decision making and that seems to be a big variable still with microreactors.”

Perceptions of Microreactors in Alaska

Historically, nuclear power has often been a polarizing subject in the eyes of the general public. For supporters, nuclear means abundant energy without burning fossil fuels or diminishing air quality. Detractors point to rare, but potentially catastrophic accidents, and the problem of handling and storing radioactive waste. The design of micro-reactors and small modular reactors (SMR) theoretically eliminates or reduces many of the safety concerns associated with nuclear power. Their smaller cores are simpler to cool and do not require an outside source of power to function.[72] Despite this, the willingness of the public to accept this new form of nuclear near their homes will likely be tied to conceptions about the energy source more generally.

Alaska-specific opinion polling is not currently available to shed light on potential public reaction to micro-reactors. This represents an important gap in our understanding of the state’s suitability to the new technology. However, through analysis of U.S.-level public opinion data and qualitative interviews, we can begin to understand the potential pitfalls to, and enablers of, adoption of the technology with regard to the Alaska public. The major findings of this analysis are:

- U.S. public opinion on nuclear power is evenly divided. In 2019, Gallup reported that 49 percent of Americans favored nuclear and 49 percent opposed.[73]
- Asked to rate various energy sources in terms of desirable attributes, Jenkins-Smith et al (2015) found that respondents rated nuclear power less “safe” than all other sources: coal, oil, natural gas, hydro, wind, and solar. However, they also described it as more “clean” and “preferred” than coal or oil, but less so than natural gas, hydro, wind, or solar. (See table below)
- When presented with brief background information about SMRs and a description of pros and cons, Jenkins-Smith et al (2018) found that safety perceptions among survey respondents increased. This research also revealed stronger support for use of SMRs on military bases than in civilian settings. SMRs and micro-reactors are distinct technologies but share important characteristics.
- A majority of utility operators and energy stakeholders that were interviewed for this study did not raise concerns about public perception, but several did. Rural utility operators expressed the greatest concerns about safety perceptions, largely tied to unknowns about the technology.
- Mining subject matter experts agreed to the potential applicability of micro-reactors for remote mines, but also expressed worry about generating negative publicity for planned development projects.
- Military energy planners did not express any particular concern about public perception regarding their interest in micro-reactors.

U.S. Public Opinion

Global analytics firm Gallup has been asking Americans about the favorability of nuclear power at periodic intervals since 1994. Since then, favorability has ranged from a high of 62 percent saying they “strongly” or “somewhat” favor use of the energy source in 2010, to a low of 44 percent in 2016. Opposition has fluctuated between 33 percent in 2010 to 54 percent in 2016. The most recent survey in 2019 found public opinion evenly split between those who strongly/somewhat favor (49 percent) and strongly/somewhat oppose (49 percent) nuclear power.[74]

Gallup's results do not differentiate between traditional and next-generation nuclear power technologies, such as microreactors, but do illustrate the polarization of opinion on the subject. To place nuclear power in context compared to other energy sources in the eyes of the public, Jenkins-Smith et al (2015) at the University of Oklahoma Center for Energy, Security and Society conducted a survey to produce the results seen in the table below. Respondents rated nuclear as the least safe of all the energy sources mentioned. Table 16 notes that nuclear energy is also considered it cleaner and more "preferred" than coal or oil, but less so than renewables or natural gas.[75]

Public Impressions for Different Sources of Energy: Percent Agreeing with Each Attribute

	Coal	Oil	Nuclear	Natural Gas	Hydro	Wind	Solar
Clean	6.9	7.5	31.5	42.1	77.4	88.7	85.4
Renewable	11.7	10.2	25.5	21.3	65.3	77.2	73.3
Safe	23.1	24.4	13.8	35.4	64.2	72.9	77.9
Plentiful	31.3	21.9	31.9	41.2	44.3	49.7	52.7
Preferred	9.6	8.8	16.7	31.3	56.9	60.2	64.8

Table 16: Public impressions for different sources of energy: percent agreeing with each attribute.
Source: Based on a survey of 2,465 individuals by Jenkins-Smith et al, 2015

Given the important safety distinctions between conventional nuclear and emerging micro-reactors, public opinion could theoretically become more favorable as the public learns more about the new technology. Public opinion information specific to microreactors is limited. However, work focused on SMRs can be used as a surrogate. Jenkins-Smith et al (2018) tested this thesis through a survey of over 2,000 respondents. Surveyors read a paragraph description of SMRs to the respondents, along with brief 'pro' and 'con' talking points about the technology. Following this, about 42 percent of respondents thought SMRs would be safer than traditional nuclear power, and 19 percent thought they would be less safe. The remaining 40 percent believed SMRs would have about the same level of safety.[76] Figure 19 shows the spread of safety perceptions of SMR compared to traditional reactors.

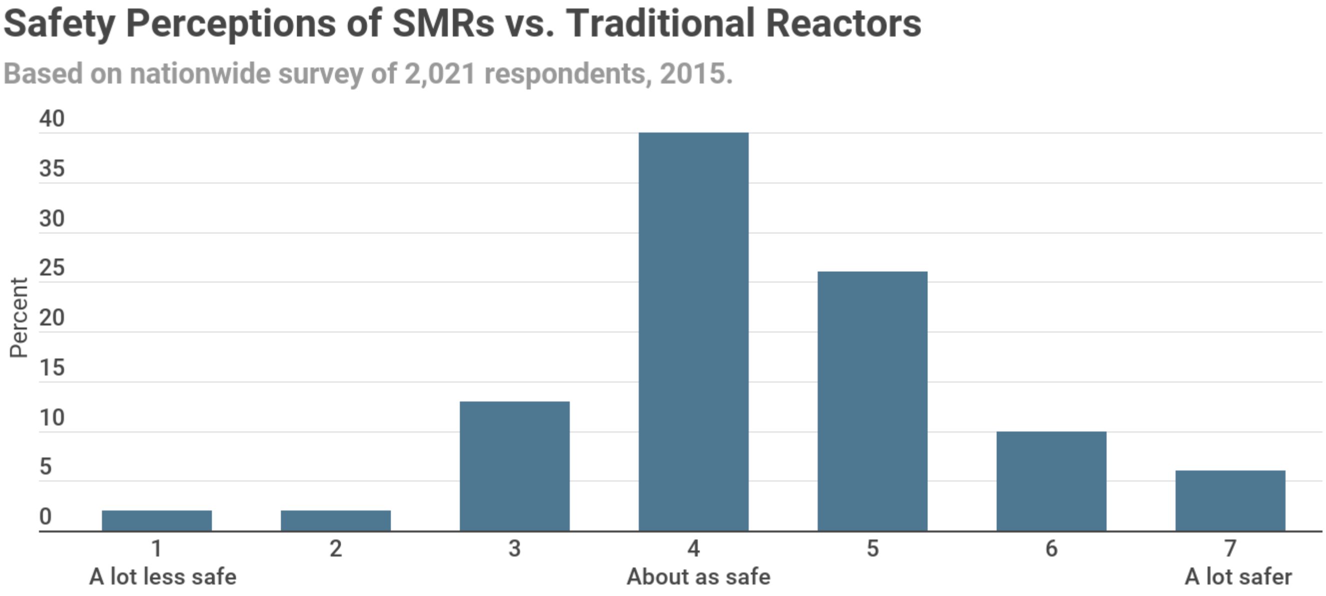


Figure 18: Safety Perceptions of SMRs vs. Traditional Reactors.
Source: Jenkins-Smith et al, 2015.

The work by Gallup and Jenkins-Smith and his colleagues at the Center for Energy, Security, and Society shows some level of discomfort with traditional nuclear power in the eyes of the general public. However, when told about some of the safety features and other benefits of SMRs, a technology similar to micro-reactors, perceptions of safety improve noticeably even if some doubt remains.

Rural Alaska Communities

Turning to the Alaska context, it is unclear to what degree public perception in the state might differ from the U.S. at large. In the early 2000s, the Yukon River village of Galena seriously considered adopting a Toshiba 4SSMR, to be installed by the company free of charge as a demonstration project. The concept had the backing of community leaders, but did face opposition from some residents and stakeholders who had doubts about an “unproven” technology.[77] Contributing to discomfort about nuclear energy is the aforementioned history of nuclear weapon testing during the Cold War. Although not directly related to nuclear power production, efforts like Project Chariot left a legacy of mistrust in parts of rural Alaska. The project proposed to create a deep water port in the Arctic by the simultaneous detonation of several nuclear bombs at Cape Thompson. Although it was never executed, some secretive preliminary work took place near Point Hope in the early 1960s, troubling local residents.[78]

Among the groups interviewed for the present study, representatives from rural electrical utilities were the most likely to voice concerns about public perceptions of safety regarding micro-reactors. In most cases, the interviewee had some familiarity with the technology and its advantages and disadvantages. Generally, these individuals had an interest in following the development of micro-reactors, but shared doubts as to whether the communities they served would accept them. As one described the challenge:

> “Most people only know the horror stories. But really the industry has come so far with recovering spent fuel. Advanced reactor tech[nology] has improved safety and reliability. They’re clean and reliable.”

Another pinpointed the problem as primarily an issue of public perception:

> “…the challenge is always perception. There are deep seated opinions on energy in Alaska and in regards to nuclear, there are strong associations with catastrophe. In rural Alaska, there are huge fears about contamination of subsistence resources.”

Contamination fears, likely connected to the issue of disposal of radioactive waste, also surfaced in a public meeting held in Anchorage in March 2019. An individual from the Norton Sound region (Nome area) pointed out the problem of waste materials, like scrap metals, often piling up in rural areas because of the high expense of shipping them elsewhere. In some cases, hazardous materials have remained in communities for years—rural Alaskans would need to trust that spent fuel would be promptly and safely removed, the person argued.

A repeated theme heard from different power user types was not wanting to be an early adopter. As a rural utility operator said, “Considering all of those things [unknowns], rural Alaska would like to not be the first of anything.” This highlights an important consideration for any potential user of micro-reactors, as a technology not yet fully prototyped: the level of conservatism and risk-aversion. However, this has as much to do with unknown regulatory requirements, costs, and operational details as with safety and the perception thereof.

Still, others noted positive factors connected to public perception. One noted U.S. Senator Lisa Murkowski’s public comments about the new generation of nuclear being a potential solution for the state’s high energy costs. Several described the need for public education about micro-reactors to alleviate some of the worries about safety, like the passive cooling systems, and describe the benefits in terms of reliability and air quality. One remote rural utility operator said the “biggest hurdle is good education on the subject to the people in the communities.” He and others felt acceptance would increase with greater knowledge of the technology. As one road-connected utility operator said:

> “[The] biggest thing [in] tackling public perception is a general lack of understanding of what the technology is. A successful project will need broad education of the difference between large scale and advanced technologies and understanding of risk. There will always be naysayers.”

Despite the uneasiness of utility operators, most indicated a feeling of uncertainty about public perception but not a belief that outright hostility to the technology existed. Acceptance of any form of nuclear power would require strong communication and trust-building with a variety of stakeholders. As one rural energy specialist said:

> “People are interested in learning more and are open to listening, but there's a long way to go before anyone feels comfortable. If something with nuclear power is really going to happen, conversations need to happen with a lot of people. There’s a big education piece there.”

The Mining Industry

Both the mining industry and the military often require high electrical loads in remote locations in Alaska and elsewhere where the need for fuel supply chains can be a liability. Micro-reactors are thus worth exploring for both groups. The issue of public perception impacts each differently, however.

Representatives from several mining companies in Alaska have expressed interest in micro-reactors by attending stakeholder meetings and information sessions. Interviews with mining experts indicated that the best fit for micro-reactors and the mining industry would be projects currently under development rather than operating mines. The cost of new infrastructure and the life of the mines would make adoption at an existing mine prohibitive; however, microreactors are expected to be portable a could be moved to new mines when current mines are exhausted. If true, this would eliminate the six operating mines in the state: Red Dog, Usibelli, Fort Knox, Pogo, Greens Creek, and Kensington. The two largest proposed mines are Donlin and Pebble.

Since both mines face public opposition, the question of public perception is particularly important. One industry representative noted that the mining companies watched the Galena project closely for lessons they could learn: “Galena dragged on and there was opposition. No project going into permitting wants a big question mark.” Another industry expert noted”

> “My first reaction is that mining is in the cross-hairs of a large amount of national anti- mining non-profit grants, and that adding nuclear reactors to their portfolios might paint such a huge target on them that they’d never escape.”

The overriding concern for both individuals was that large proposed resource development projects already often face hurdles in gaining public acceptance. Adding another potentially controversial element like nuclear power to the picture would be too risky, even if micro-reactors provided a technological advantage.

Military Installations

Alaska is home to nine sizable military installations, including three Air Force, three Army, and three Coast Guard installations. Several smaller posts also exist in the state. Micro-reactors are particularly attractive to the military because they have the potential to minimize supply chain concerns, among other issues. In the course of this research, one interested military installation presented itself as a potential candidate for a micro-reactor: Eielson Air Force Base near Fairbanks.

While the installation representatives did have some concerns about public perception, they felt these concerns were mild and manageable. Being located on a military base appears to reduce some public concern about the technology being used in a secure fashion. As Jenkins-Smith and colleagues (2018) found, a majority of survey respondents (51 percent) supported the construction of SMRs for military installations, with only 18 percent opposing (the remainder were neutral).[79]

Nuclear power on an Alaska military base would not be unprecedented. From 1962 to 1972, Fort Greely hosted a traditional nuclear power plant about six miles from the town of Delta Junction.[80] The past history of safe operations by the military could ease some concerns about nuclear power among nearby communities.

Perception Conclusions

The analysis presented here provides some insights into the issues of public perception surrounding a new form of nuclear power in Alaska. Energy experts and organizational managers interviewed for this project generally expressed comfort with the technology themselves from a safety standpoint. They were less sure about the impressions in the minds of the general public, particularly in rural Alaska.

The need for micro-reactors to establish a safe track record with early adopters and prototypes is apparent before some of these concerns can be eased. From the limited evidence available so far, rural utility operators are unlikely to embrace the early adopter role to prove the technology. Mining companies show interest in the technology, but fear a backlash during politically-sensitive pre-development timelines.

The military appears to be a stronger candidate for early adoption. With access to technical expertise and strong base security systems, the risks a small utility might face do not seem to apply. The fact that public survey data shows a higher comfort level with nuclear power on military bases could also help to enable adoption.

Importantly, the analysis presented here is not the last word in public perception concerns in Alaska regarding micro-reactors. The state’s residents have not been surveyed and this remains an important gap in knowledge of the subject. A scientifically-rigorous survey for the state should be a component for future work on the potential adoption of micro-reactors in the state.

Conclusions

Alaska’s energy landscape is dynamic and diverse. The high cost of power and operational challenges experienced by many energy operators across the state create opportunities for innovation and growth. However, while Alaska is home to many energy opportunities, it also has been home to project failures – from bankruptcy to maintenance breakdowns. Stories of those failures has led to some risk aversion.

Interviewees throughout all of the customer segments, outside of military installations, noted that successful energy projects in Alaska require a strong local advocate. Those projects are able to engage relevant partners, seek out technical assistance where necessary, access funding sources, train operators, and ultimately move a project from concept to operation.

As microreactors move from development, to testing, and eventually to commercial deployment, the complete perspective on the challenges Alaska energy operators face will need to be considered. While cost and system fit are a primary consideration in siting a micro-reactor, other factors for most customer segments to consider include:

- Operational requirements and local capabilities,
- Lifecycle processes, including refueling, routine maintenance, and remediation and the ease of conducting them in remote areas,
- Adaptability or flexibility for changing energy systems,
- Community acceptance and perceptions over local control of energy systems,
- Resilience from supply chain disruption and other forces which could impact energy services,
- Local investment in energy system and community advocates,
- Availability of support networks to provide technical assistance throughout the life of the reactor.

NRC regulatory requirements specific to microreactors as of yet remain undetermined. However, based on current permitting requirements for siting and operating reactors, each of these operating factors will be integral to a successful application.

Interviewees in all of the customer segments, excluding military installations, noted the many unknowns around the operational characteristics and requirements of the micro-reactors being developed. Those unknowns make it difficult to establish strong indicators of preferences. However, the interview process revealed a clear set of questions asked by energy producers and stakeholders:

- What are the environmental and physical security requirements?
- What are the siting requirements and how do they accommodate the geographical characteristics of Alaska, including permafrost and geological activity?
- What are the operations and maintenance requirements and what skill sets are required for plant operators?
- What are the re-fueling and fuel removal processes?
- What does the worst-case scenario look like and what are the disaster mitigation processes?

These questions reveal an opportunity for the nuclear industry and microreactor developers to engage with energy producers and stakeholders in Alaska. Interviewees indicated interest in the technology and market potential, but noted that comfort level and understanding of the technology will have to be developed. A number of energy stakeholders noted that a two-pronged education program, targeted at energy operators and the general public may be necessary.

Of all of the customer segments, defense installations identified the fewest challenges and indicated the most immediate interest in the technology. One defense sector energy operator indicated that the installation has the capacity and need to make integrating early stage microreactors in the near term feasible.

Energy operators and stakeholders in Alaska all expressed interest in nuclear energy applications. A number of energy producers expressed that, if the technology meets the scale of Alaska’s energy markets, nuclear energy may be one of the only ways to fully displace diesel systems. However, it is clear that work remains in moving the technology toward market readiness to determine actual feasibility in a remote Alaska setting.

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