MICROREACTORS IN ALASKA

Use Case Analysis

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Table of Contents

Table of Figures

Table of Tables

Executive Summary

Alaska's energy landscape is made up of a dynamic patchwork of systems, from extremely small islanded micro-grids and remote mining operations to one larger interconnected system. Energy producers within each of these settings experience high costs for fuel and operations compared to U.S. averages.

The over 100 energy systems 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, transportation, maintenance, and administrative costs. The cost per kWh for energy production in remote areas can range widely, from \$0.35 to \$0.60 per kWh, with an average of \$0.52 per kWh.[1] A handful of hydroelectric and solar systems have been constructed, and wind-diesel systems are growing in quantity annually. Heating needs are met with fuel oil primarily, with some communities supplementing with wood resources.

In urban Alaska, customers are served by an interconnected network of utilities and other energy producers, colloquially referred to as the Railbelt. Energy producers meet the demands of residential, commercial, and industrial users through a patchwork 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;[2] however, those costs remain significantly higher than the U.S. average of \$0.13 per kWh.[3]

Power system size varies widely, with electric utilities hosting generation systems which range from 0.5 MW electric (e) to 566 MW(e). Figure 1 maps the range of installed power capacity across the state.

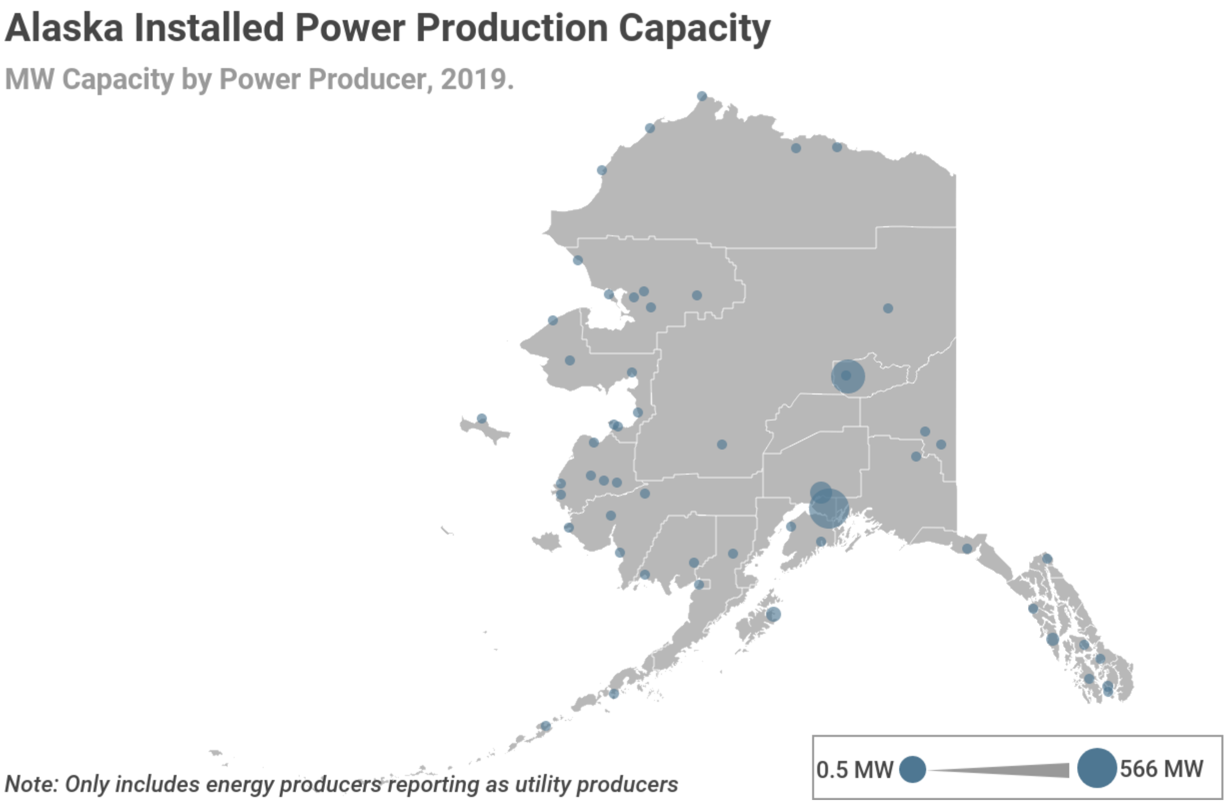

Figure 1: Alaska Energy System Size by Energy Producers.
Source: EIA, 2019.

Driven by the high costs and other factors impacting the energy systems across Alaska, the state's energy landscape has been the focus for alternative or early stage energy technologies. Alaska energy systems have served as a proving ground for emerging energy technologies, to varying degrees of success.[4]

One emerging energy technology has been identified as a potential solution for Alaska energy systems of all sizes. Microreactors are under development by a number of companies, with small, remote energy systems in mind.[5] The reactors, which are in the early stages of development, include a number of characteristics which make them potentially well-suited to Alaska energy systems. These include:

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

However, the critical variable which would accommodate remote Alaska energy systems is the capacity size, with microreactors estimated to range from 1MW to 20 MW electric(e).[6] 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 size and costs. To examine the variables which could impact microreactor deployment in Alaska, this analysis grouped energy producers into five categories and developed case studies based off those groupings. The cases examined include:

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

This analysis identifies and tests value propositions for each of the case studies using available data and information collected through interviews with energy operators and energy stakeholders across Alaska. The intent is to identify opportunities and barriers to implementing microreactors across five user groups present in Alaska. Some of these value propositions are discussed in Table 1 below.

The goal of this analysis was not to identify specific energy users or communities as potential microreactor users, but to put context behind some of the drivers of energy technology decisions and discuss how they might relate the reactors being developed. For that purpose, the case studies discussed here do not attempt to call out any one energy user or community and instead use hypothetical energy users to model energy needs and characteristics.

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: Alaska Energy Value Propositions and Barriers

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 1 Continued…

Green=not a major barrier to adoption
Yellow=mixed or uncertain
Red=likely to be a significant barrier to adoption

Small Rural Community

Alaska's energy landscape can be roughly divided into two parts: the road system and rural Alaska. Outside of the Railbelt, energy systems across the state are made up of very small micro-grids. Alaska is home to over 100 very small, islanded micro-grids. These micro-grids typically serve communities with fewer than 1,000 residents isolated from the road system with air and, sometimes, barge access.

This analysis is primarily concerned with the remote, rural parts of Alaska in the western, northern, and interior parts of the state. With some exceptions, communities in these regions rely on diesel power generation and lack economies of scale to produce affordable power. This analysis excludes the larger 'hub communities', which are scattered across remote, rural Alaska and are larger in population size (measured in the thousands) and exhibit different energy characteristics.

Population and Demographics

Communities across rural remote Alaska vary widely in size, from fewer than 10 residents to several thousand. Figure 2 maps community population across Alaska. 'Hub' communities, such as Kotzebue, Bethel, Dillingham, Nome, and Utqiaġvik serve as transportation and administrative centers for surrounding villages with populations numbering in the hundreds. Most of these villages are home to Alaska Native people practicing a subsistence lifestyle with a limited cash economy. These latter communities are the focus of this analysis, rather than the larger hubs which are addressed separately.

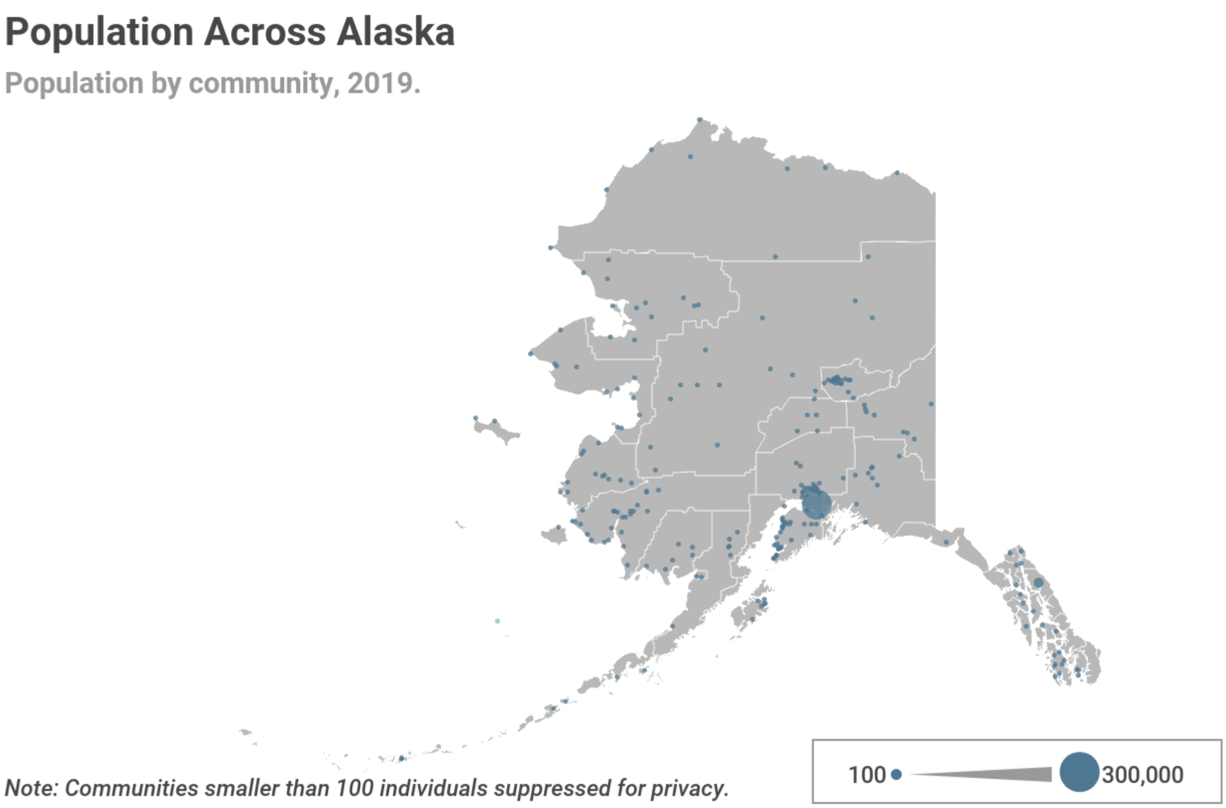

Figure 2: Population density across Alaska
Source: Alaska Department of Labor and Workforce Development (AKDOLWD), 2019.

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. A sample of five communities were taken at random to show population (Figure 3), education (Figure 4), and workforce characteristics (Figure 5) common across rural Alaska.

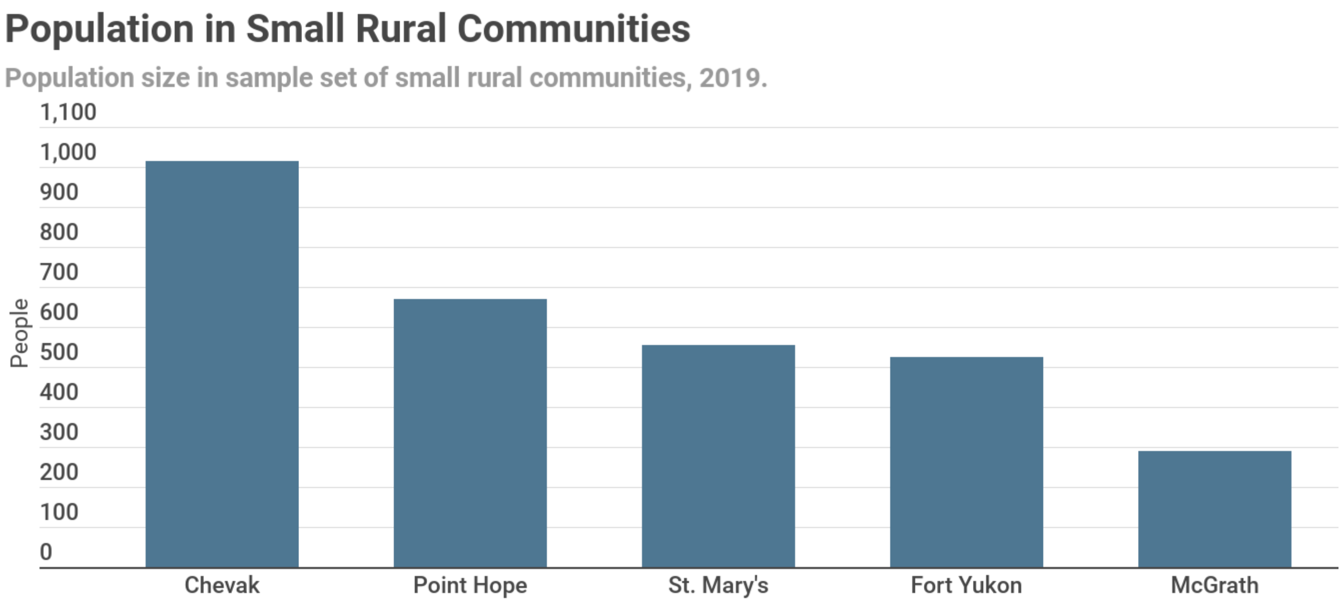

Figure 3: Population size in sample small rural communities
Source: AKDOLWD, 2019.

Rates of educational attainment in rural communities differ significantly from statewide averages. For example, the proportion of the population 25 and older in the sample communities examined here with a high school diploma are significantly higher than statewide. However, the proportion of the population with a bachelor degree is lower than statewide averages, ranging from 2 to 10 percent.[7]

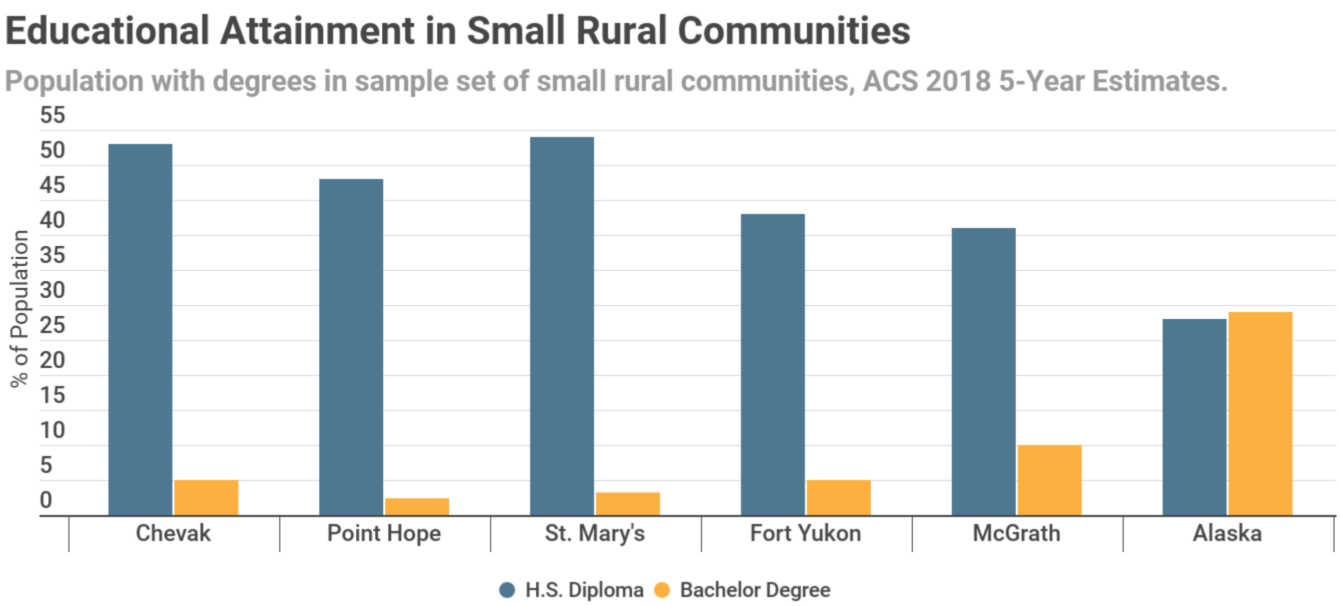

Figure 4: Education Attainment in Sample Small Rural Communities.
Source: American Community Survey (ACS), 2018 Five-Year Estimates.

Cash employment opportunities are limited. Local government, education and healthcare, and trade, transportation, and utilities are the three largest sectors. Subsistence activities play an important economic and cultural role.

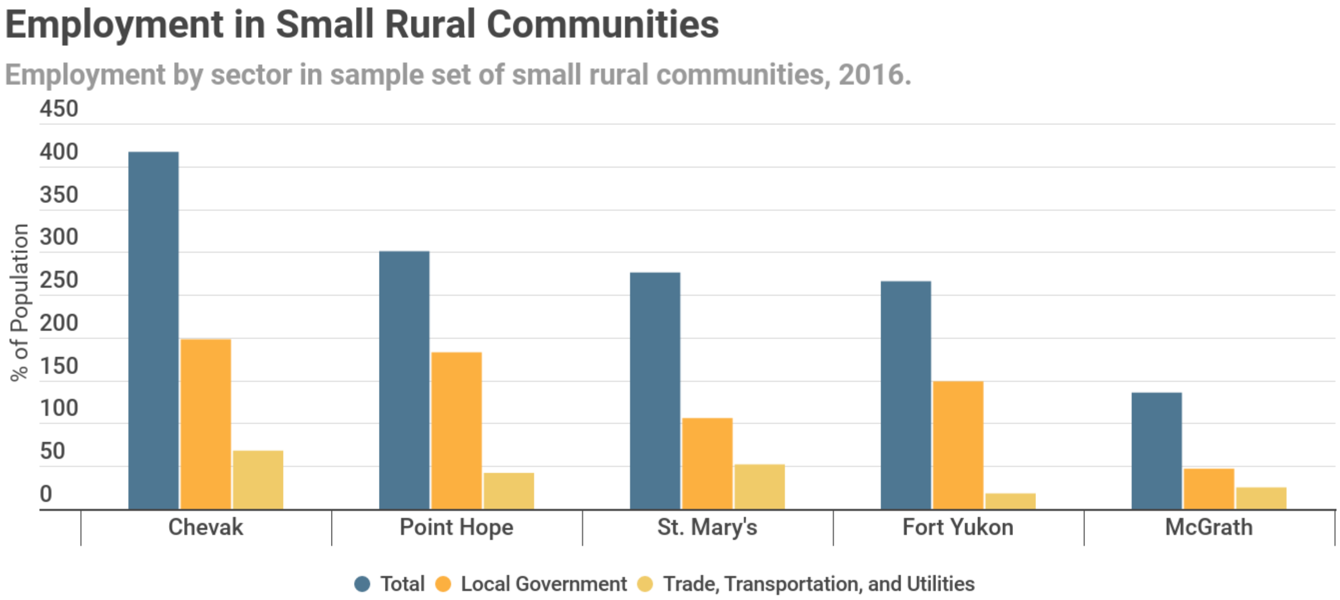

Figure 5: Employment in Sample Small Rural Communities.
Source: ACS 2018 Five-Year Estimates.

Poverty rates in rural Alaskan communities are higher than the statewide average of 10.8 percent. Figure 6 compares poverty rates in the sample set of rural communities. Average household income is significantly lower than the statewide median of $76,000.[8]

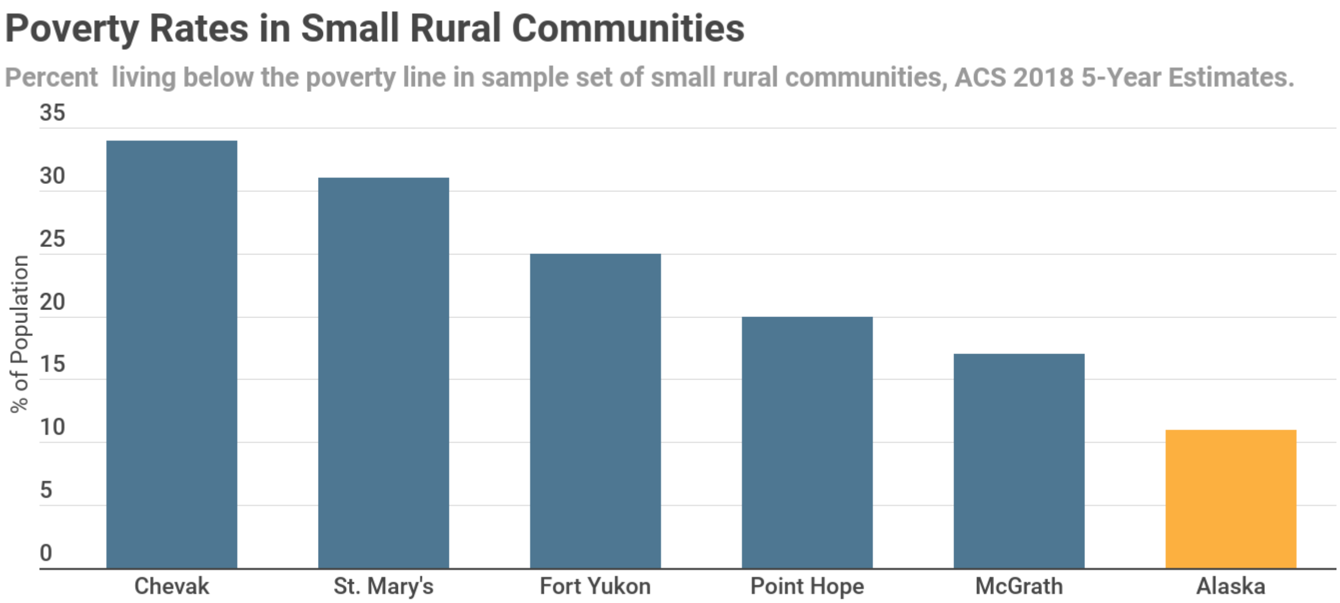

Figure 6: Poverty Rates in Sample Small Rural Communities.
Source: ACS 2018 Five-Year Estimates.

With lower household incomes and high energy costs, households dedicate a large portion of their income to energy costs. Figure 7 compares median household income across a sample set of rural communities.

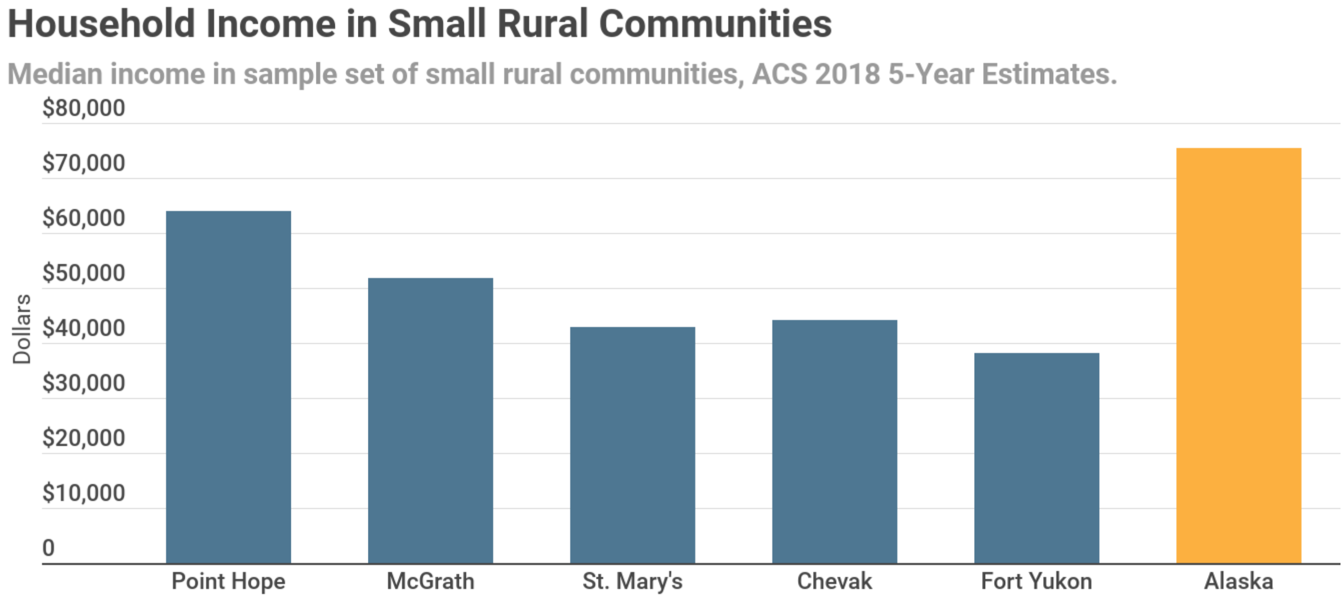

Figure 7: Average Household Income in Sample Small Rural Communities.
Source: ACS 2018 5-Year Estimates.

Energy Systems

Electric

As rural Alaska communities vary in size, so do the size of the 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.[9] Most communities have health clinics which require constant power.

Eligible communities across rural Alaska participate in the Power Cost Equalization (PCE) program, a State 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 Alaskan residents. However, commercial energy users do not qualify for the program and bear the full burden of energy costs in rural communities.[10]

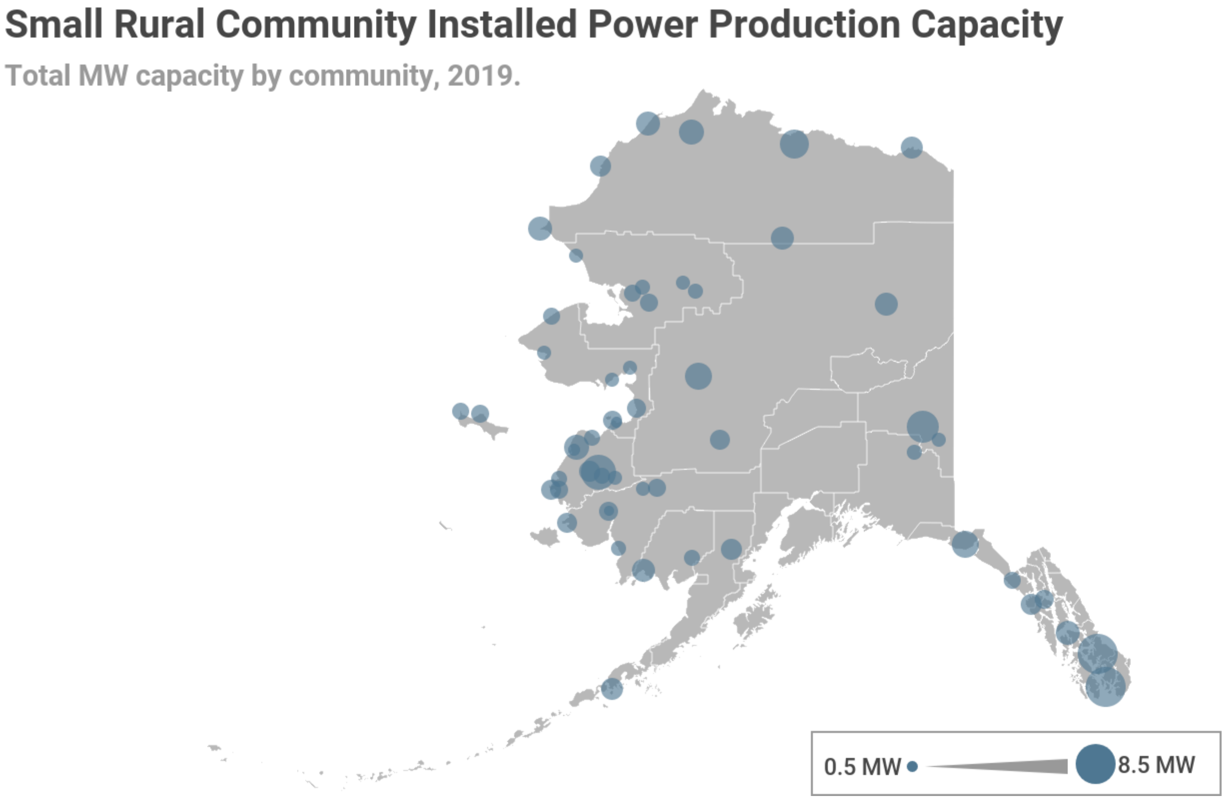

Figure 8: Small Remote Community Generation Capacity.
Source: U.S. Energy Information Agency (EIA), 2019.

Alaska hosts 170 seafood processors, many of which are located across rural Alaska.[11] Processors represent large industrial loads for the communities they are located in. In some cases, processors maintain their own energy systems and in other they are tied into community systems. Processors usually operate seasonally and building a community energy system to accommodate a large seasonal processor would far outsize the capacity of the system for the community's load through much of the year.

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(e) is considered very large. Figure 8 maps the installed power capacity of rural communities. Figure 9 below compares the installed capacity in the sample set of communities discussed above.

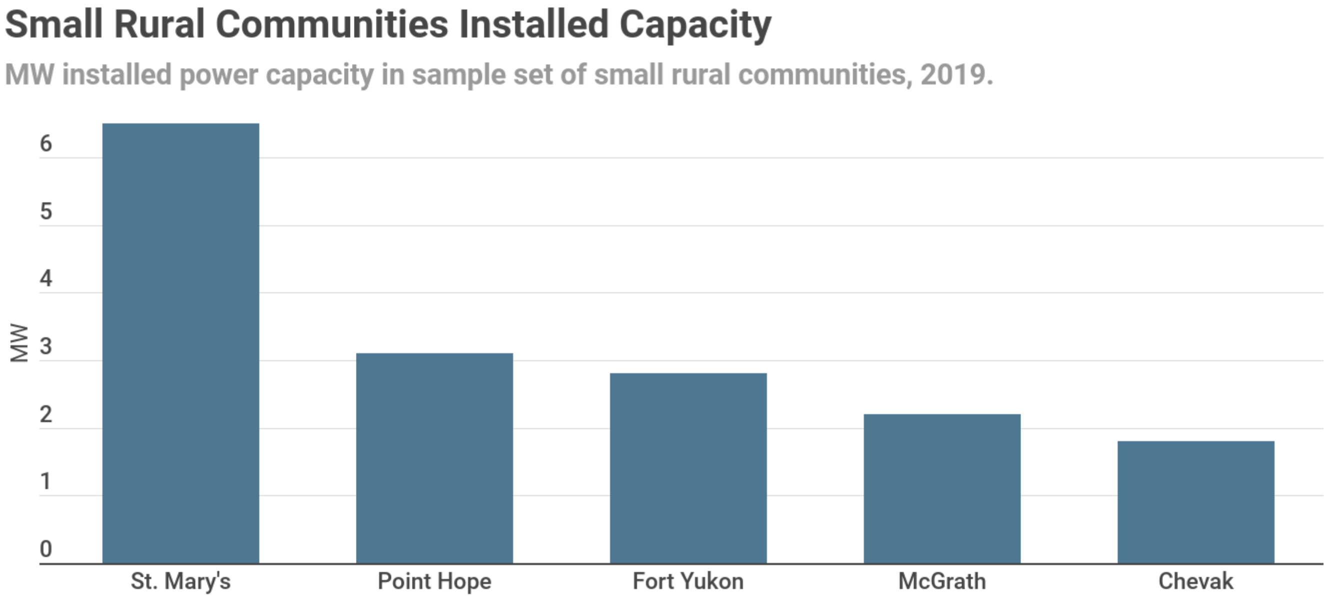

Figure 9: Sample Small Rural Community Installed Capacity.
Source: EIA, 2019.

The ownership models of rural hub utilities vary, and include city ownership, co-op models, tribal ownership, and private ownership. Alaska Village Electric Cooperative serves 58 individual communities across Alaska and is the largest energy coop to deploy the business model of serving multiple islanded communities to spread costs over a larger number of kWh. Table 2 discusses the ownership models of the community utilities from the sample set of communities.

Sample Small Rural Community Utility Ownership Structure	
Community	**Ownership Type**
Chevak	Cooperative
Fort Yukon	Tribal Corporation Owned
McGrath	Tribal Corporation Owned
Point Hope	Local Government
St. Mary’s	Cooperative

Table 2: Sample Small Rural Community Utility Ownership Structure.
Source: Regulatory Commission of Alaska, 2019.

Over 30 PCE eligible communities across rural Alaska operate systems monitoring a combination of diesel and other renewable assets, including: wind, solar, and hydro.[12] 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. Across Southeast Alaska, many of the communities are primarily powered by mature hydro assets with diesel backup. Western Alaska hub communities are mostly dependent on diesel fuel for power generation. Alaska Village Electric Cooperative operates wind-diesel hybrid systems in 13 of the 58 communities it serves.[13]

Two of the five sample communities discussed above operate systems which utilize a mixture of diesel and non-diesel resources. Both St. Mary’s and Chevak operate wind diesel hybrid systems. Figure 10 below shows the annual kWh composition of power generated from diesel and non-diesel sources.

Power Production by Source in Small Rural Communities

Annual kWh production by generation source in sample set of small rural communities, FY2019.

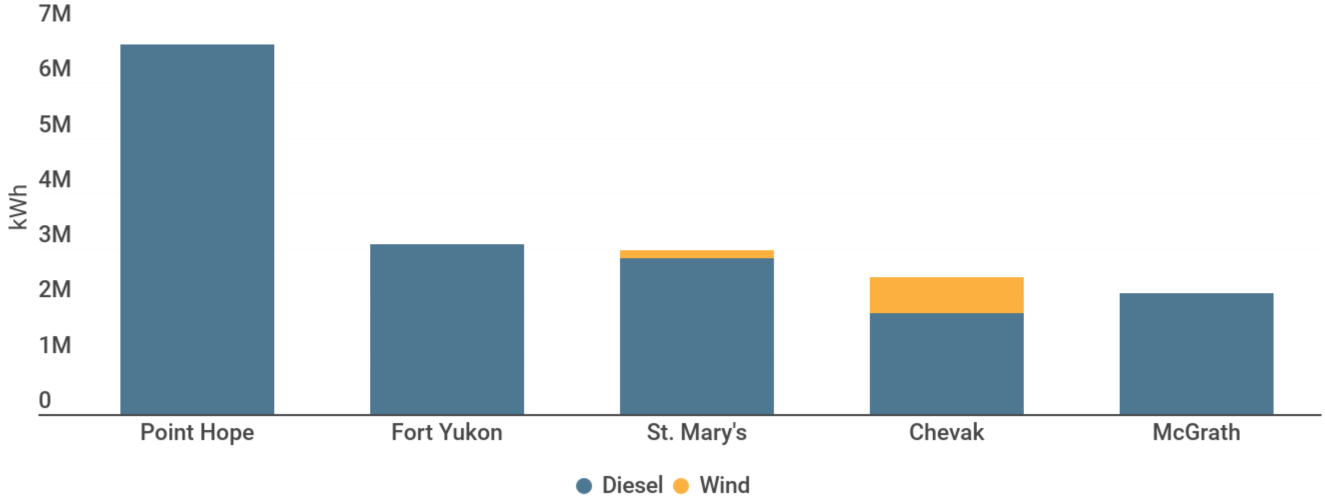

Figure 10: Sample Small Rural Community Power Production by Generation Source.
Source: Alaska Energy Authority (AEA), 2019.

The costs associated with maintaining and operating a diesel system in rural Alaska are notoriously high. Maintenance costs represent a high cost and a technical challenge in some communities.[14] Difficulty with routine maintenance activities is common, largely due to a lack of technical capacity in some communities and access to replacement parts.[15] Fuel costs also represent a large and variable cost for many communities. Fuel deliveries occur once or twice a year, in the summer, and are delivered by barge or plane. [16] Figure 11 compares the average residential rate paid by community customers and Figure 12 compares annual utility power production costs for the sample set of rural communities.

Average Rate in Small Rural Communities

Average rate for residential service in sample set of small rural communities, 2020.

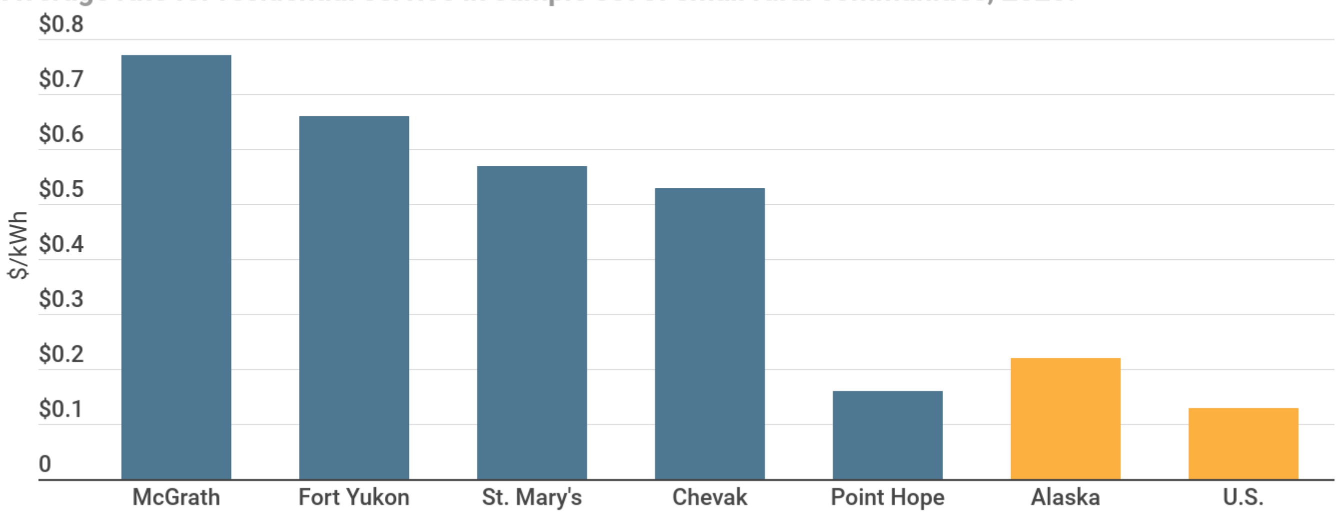

Figure 11: Average Rates for Residential Service in Sample Small Rural Communities.
Source: RCA, 2019.

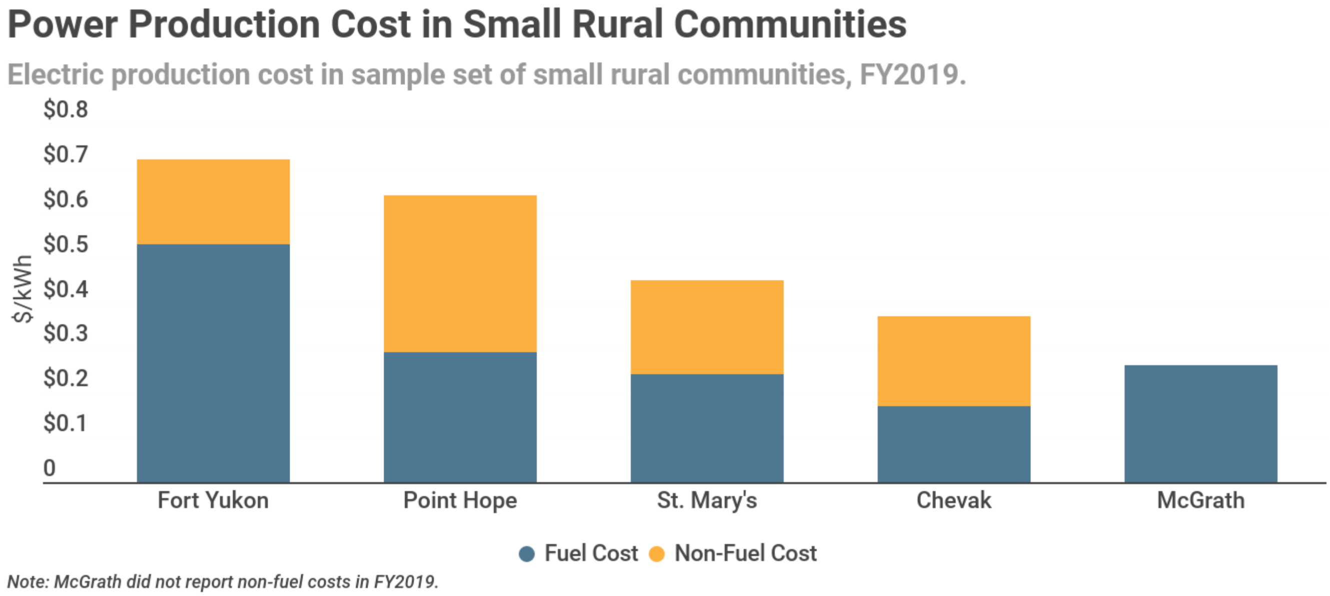

Figure 12: Power Production Costs for Sample Small Rural Communities.
Source: AEA, 2019.

Diesel generation systems’ high cost and variability 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 chain systems have been built throughout the state to serve the multitude of remote diesel systems in servicing, operation, and repair.[17] Similar systems are only now starting to emerge to support other energy systems, such as wind and solar technology.[18]

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.

Cost of power across rural Alaska communities is extremely variable, and the factors influencing that variability are inconsistent. For example, the chart above shows the breakdown of fuel and non-fuel costs for five remote communities. Figure 13 compares the annual electric production costs for Chevak and St. Mary’s, two power systems operated by the same utility in western Alaska. Despite those commonalities the communities have cost structures which differ by approximately $0.10 per kWh. This can be driven by several factors: including the cost of delivered fuel, amortization of generation assets, maintenance costs, costs associated with transmission, and more.[19]

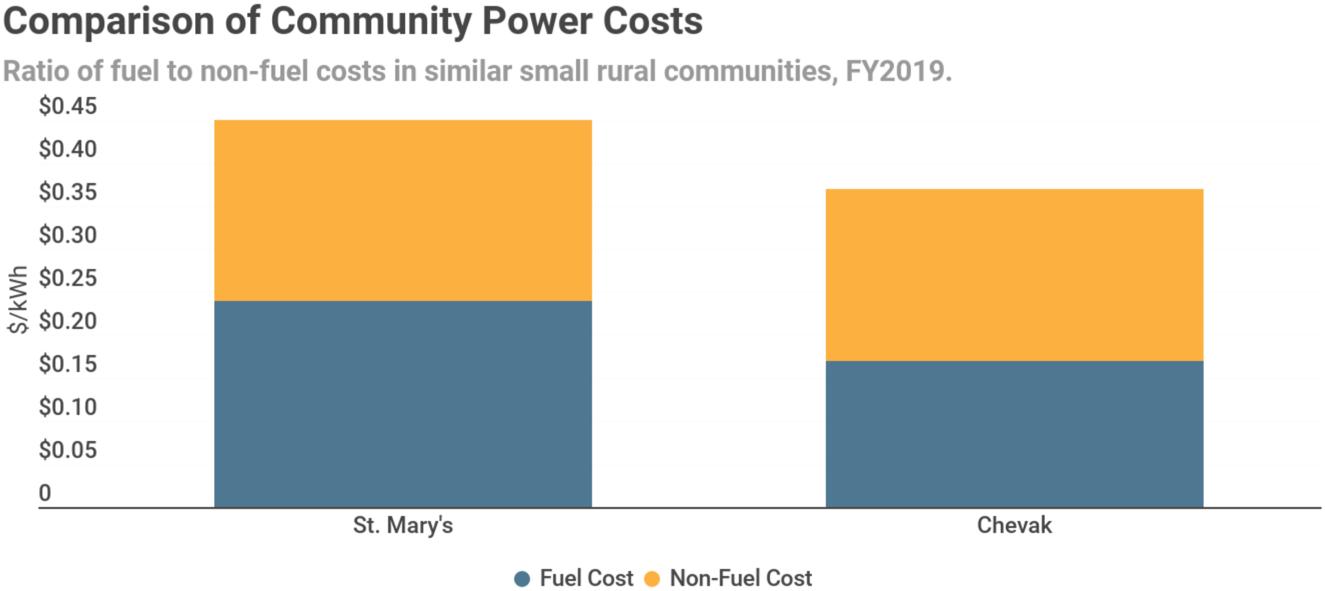

Figure 13: Comparison of Community Power Costs for Small Rural Communities.
Source: AEA, 2019.

However, in some cases access to transportation and logistical networks helps drive down operations and maintenance costs. For example, fuel delivered by barge is almost always cheaper than fuel delivered by aircraft.

Heat

Heat remains an area of the energy landscape in rural Alaska that has seen less attention than electric. 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 the city government and public-school systems, purchase heating fuel in bulk, lowering the cost of heat by a certain amount. Residents purchase heating fuel from public or private distributors. Figure 14 presents a sample of heating fuel costs from the communities referenced above.

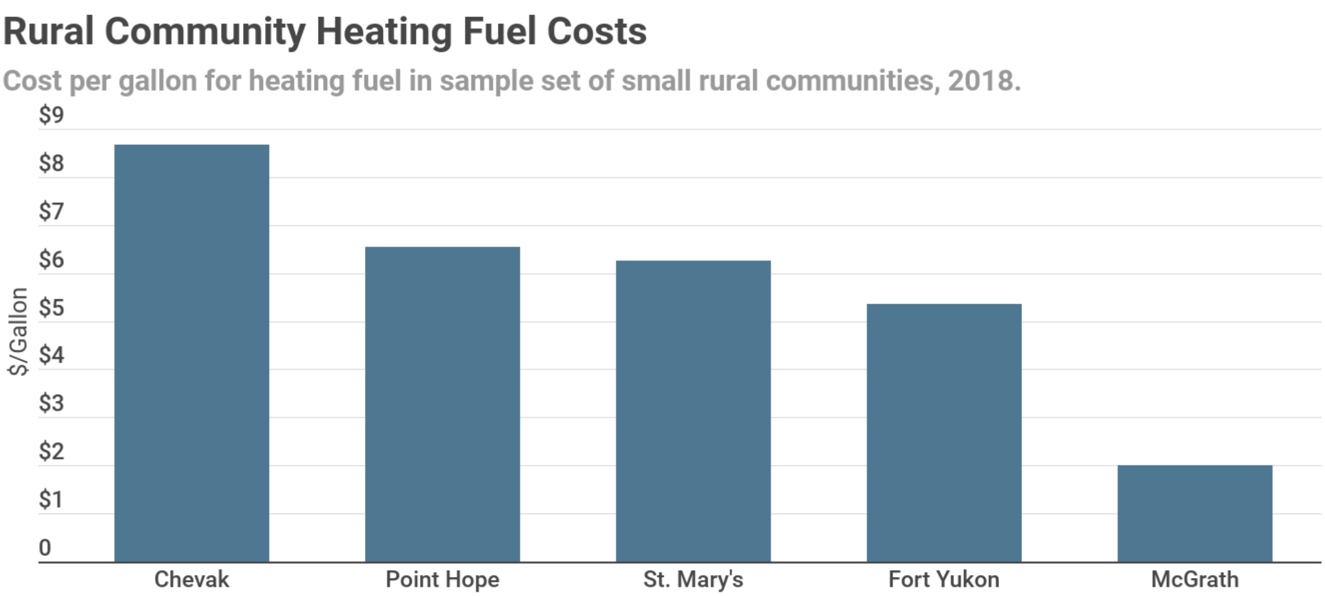

Figure 14: Heating Fuel Cost in Sample Small Rural Community.
Source: Division of Community and Regional Affairs (DCRA), 2018.

To provide an example of the costs associated with heating a single residential building, heating fuel in McGrath was recorded at $8.68 per gallon in 2018.[20] The average annual heating degree days in McGrath is 13,916 days. The most recent reported heating fuel consumption for McGrath showed the community consumed 108,000 gallons of fuel for residential heating purposes.[21] Using those numbers, it cost approximately $937,440 in 2018 to heat residential buildings in McGrath.

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 several 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.[22]
- **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.[23]
- **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.[24]

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 (AEA), 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.[25] However, momentum has stalled due to State of Alaska budget issues.[26]

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.

Microreactor Themes and Perspectives

Due to the variability and availability of renewable resources, full replacement of diesel fuel through renewable integration remains unlikely for the foreseeable future for many communities. In order to entirely replace diesel generation in small rural hub communities, alternatives to traditional renewable resources and advanced technologies will need to be deployed. However, those technologies will need to meet the existing system requirements present in communities across Alaska

The size range for the advanced microreactors being developed is wide. Systems could range from 1 MW(e) to 20 MW(e) with additional potential heat capacity.[27] While these represent extremely small systems for most electrical grids in the US, without finding opportunities for other dispatchable loads (heat and transportation), even a 1 MW(e) system could be outsized for many rural communities.

Many technical and regulatory specifications of microreactors remain unknown and will be determined as the technology moves through the permitting and testing phases. While the high cost of power in small rural communities makes them an attractive market for deploying emerging energy technology, some of the technical requirements microreactors may make remote operation complex. Microreactors will likely need to include but are not limited to the following characteristics:

- Load-following capabilities.
- Autonomous operations or minimal operating requirements with remote operations capabilities.
- Design specifications accounting for high levels of earthquake activity and permafrost characteristics.
- Minimal construction footprint and security requirements.

Utility operators and energy stakeholders interviewed for this report noted that when making technology decisions, comfort level has historically been an important factor. Microreactors are still in the technology testing stages; therefore, establishing a certain degree of comfort with the technology will be critical for motivating customers. Factors to consider could include:

- A robust understanding of lifetime costs and operational processes.
- Established plans for the life of the reactor: including installation, fueling, and disposal.
- Clear processes for fuel transportation and disposal.
- Emergency preparedness and disaster mitigation planning.
- Processes for technology support and system repair and maintenance.
- Understanding of federal and state regulatory requirements.

Use Case: A Hypothetical Rural Community

Consider a hypothetical rural community along the Yukon River in the interior of Alaska. The town has a population of 200 people, roughly half of which are of working age. The community is predominantly Alaska Native and subsistence activities play an important role in the lives of most residents. The community is able to get fuel delivered by barge twice a year depending on river conditions. Depending on the winter and springtime weather, the community has been known to experience seasonal flooding as the ice breaks up on the river and erosion along the banks of the river. The community has considered relocating, but no significant action has been taken.

The utility is owned by the local tribe and is considering its options for integrating renewables into its energy system; furthermore, the utility is planning for an overhaul of its aging powerhouse. The community has asked its regional energy planning organization for assistance in assessing its options and recently finished an energy resource study.

Economic and Housing Information

Local government is the largest sector of employment in the community, followed by trade, transportation, and utilities, and education and health services. The utility plays an important role in the community as an employer and enabler of other economic activities. There are limited businesses in the community and the bottom line of those businesses is closely tied to electricity availability and costs.

Traditional employment opportunities are limited in the community and the unemployment rate is high. However, subsistence practices play an important cultural and economic role in the community.

Median annual wage in 2019 was approximately $20,000. In addition, roughly 70 percent of the residents meet the criteria for being economically 'distressed'.[28] Twenty-two percent of households are considered 'cost-burdened' or 'very cost-burdened'.[29] Figure 15 compares the percentage of cost burdened household in the community to the statewide average.

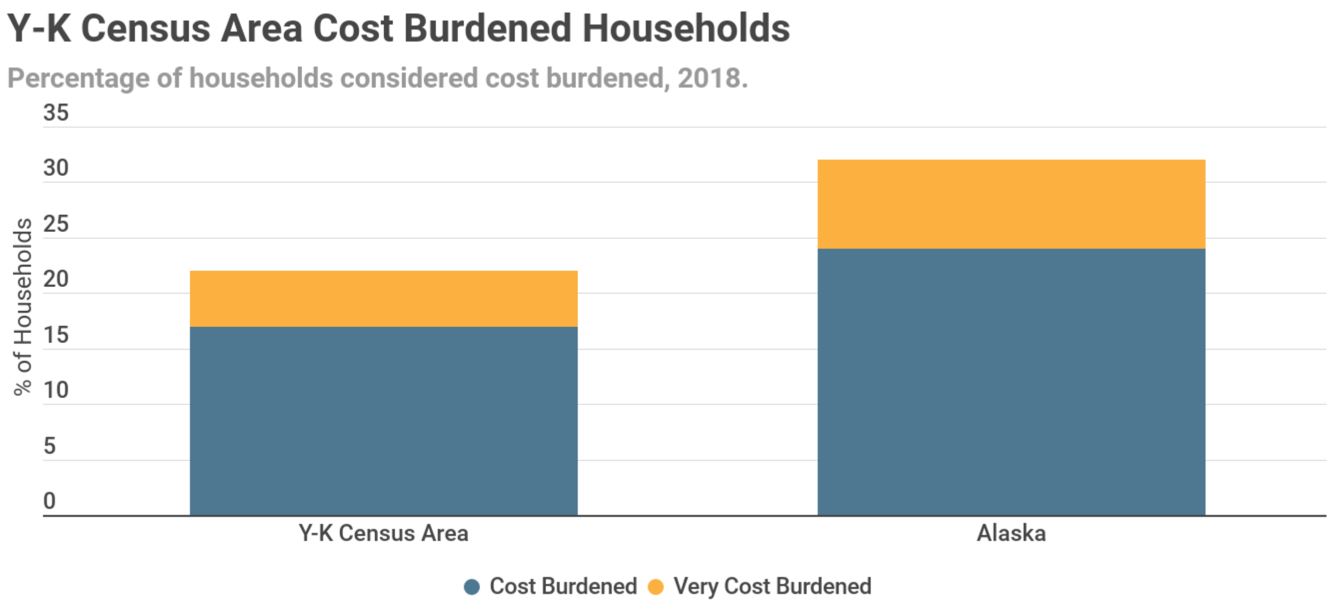

Figure 15: Cost Burdened Householding in the Yukon-Koyukuk (Y-K) Census Area.
Source: AHFC, 2018.

Housing conditions are poorer than state averages. Rates of overcrowding remain higher than the statewide average at 15 percent. Figure 16 compares the regions overcrowding to the statewide average. Conditions in existing housing units are poor. Sixty percent of housing units are considered drafty or very drafty, with 18 percent of the community's homes achieving a one-star energy rating. Almost 40 percent of the homes in the community have incomplete plumbing.[30]

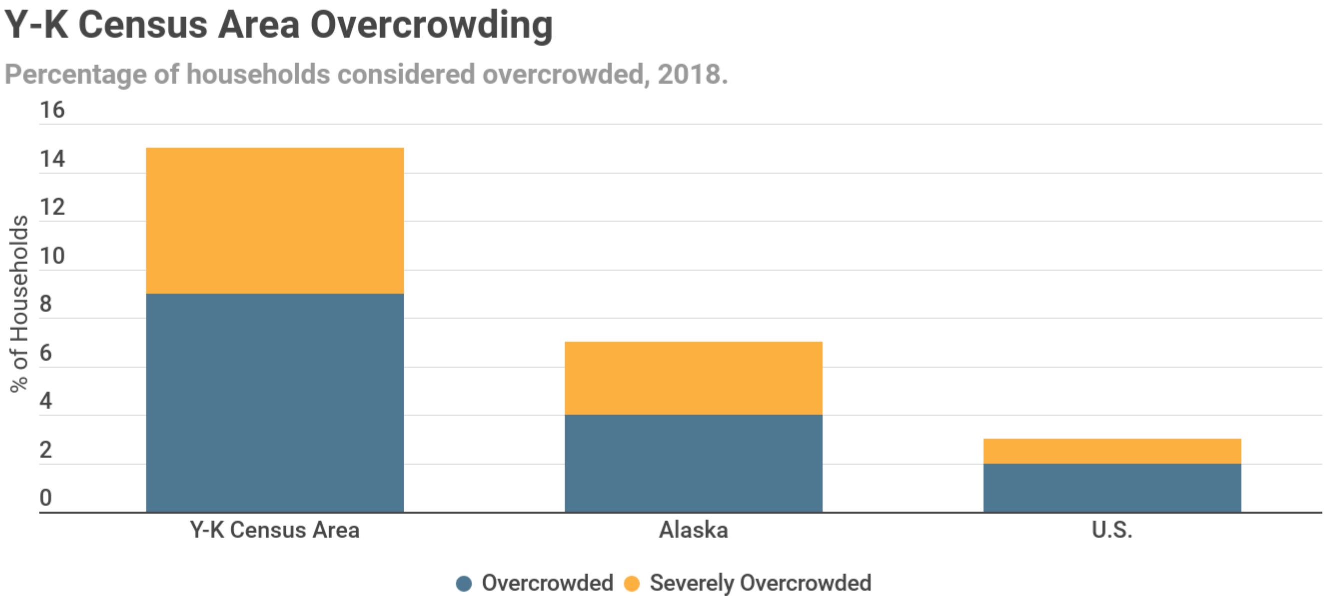

Figure 16: Overcrowding in the Y-K Census Area.
Source: AHFC, 2018

Energy efficiency efforts focused on community buildings and the school has reduced the community's energy load. Energy efficiency retrofits were funded through state and federal grant programs. Figure 17 compares energy efficiency in the region to Alaska as a whole.

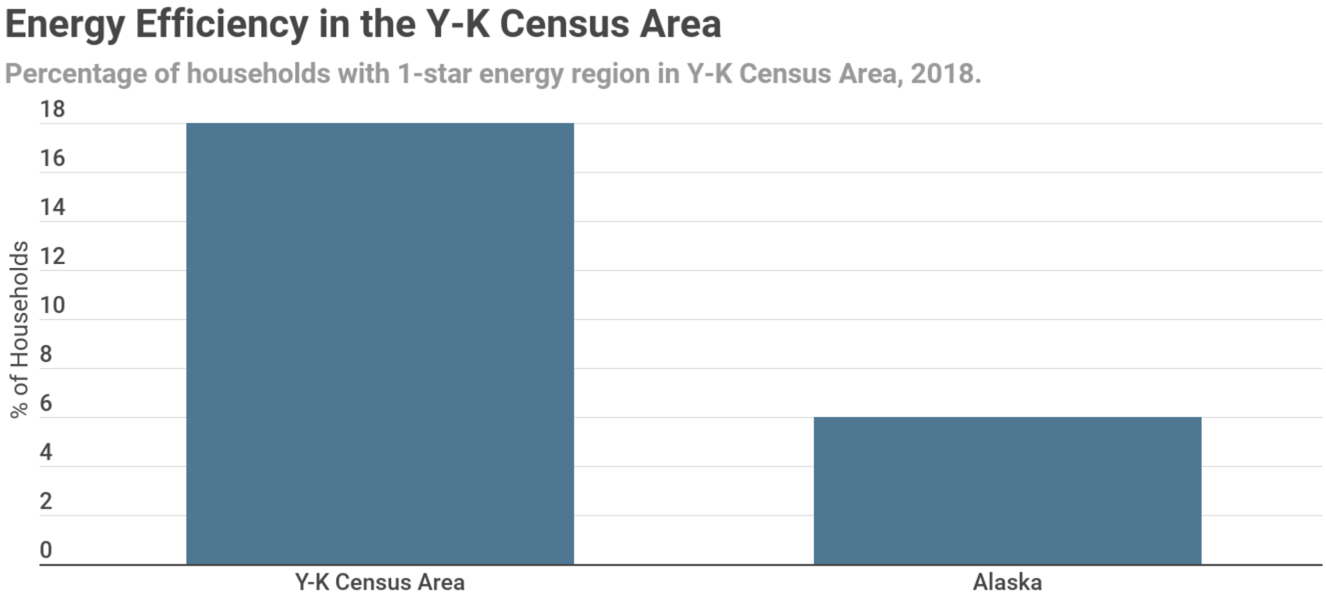

Figure 17: Homes with 1-Star Energy Rating in Y-K Census Area.
Source: AHFC, 2018

Region and Climate

The interior region of Alaska is one of the largest and most diverse regions of Alaska. It spans from the mid-Yukon to the Canadian border. In the Yukon-Tanana subregion, the climate is in the continental climate zone and is characterized by extreme temperatures. Temperatures are warm in the summer and extremely cold in the winters.

Energy System

Electric

The community utility operates an aging diesel system. The utility is planning for a powerhouse replacement in the next five years. The design for the new powerhouse is a modular unit built in Anchorage and shipped to the community. The current system does not operate any heat recovery; however, the new generators will include a heat recovery system which will be used to heat the community washeteria. The utility is working with the Department of Energy Bureau of Indian Affair for technical assistance in designing and executing the project.

The energy study commissioned by the community showed few locally available renewable energy resources. Solar energy systems with installed energy storage assets provide the best renewable energy option for the community; however, solar will only provide partial diesel displacement mostly in the summer months.

The system has a maximum capacity of 2.5 MW with five 0.5 MW generators which can be turned on or off to accommodate system needs at any given time. In 2019, the utility sold 2,000,000 kWh of power. As PCE program participants, power costs are subsidized for residential customers for the first 500 kWh and for approved community facilities. Figure 18 presents the composition of power sales by customer type for this sample community.

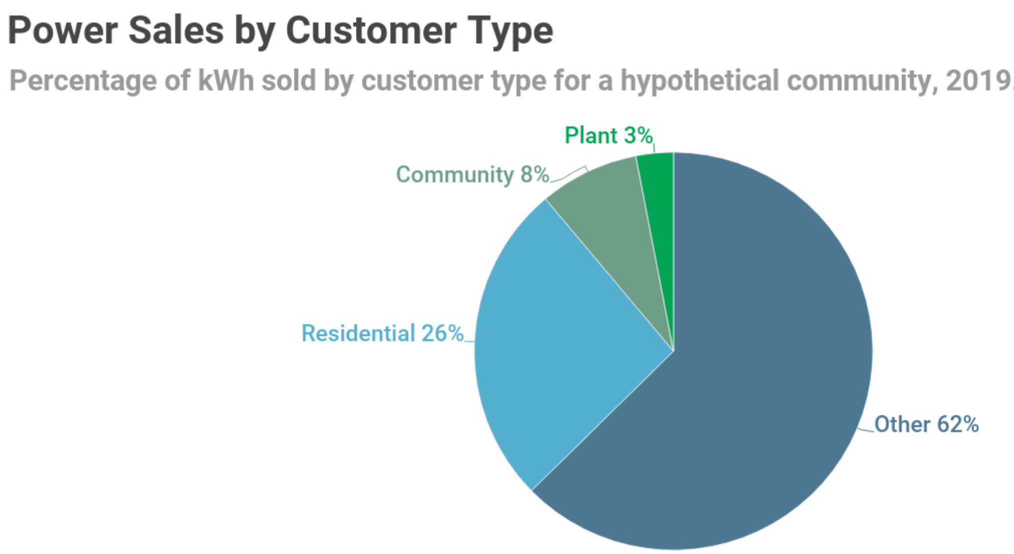

Figure 18: Hypothetical Community Energy Sales by Customer Type.
Source: AEA, 2019

The system is run by three plant operators, with two office staff supporting management activities and billing. A stated challenge the utility grapples with is access to capital when high cost items are needed. The utility generates enough revenue to cover operations and most maintenance costs but is unable to fund large infrastructure projects such as a new generator. The new powerhouse is expected to be funded through a patchwork of grants and loans.

Administrative operations are a challenge. As a small community the labor pool is limited and access to candidates with specific skill sets is limited without in-house training. Finance skill sets specific to utility operations can be a niche, and PCE reporting requirements add a layer for which there are few training programs.

The system primarily serves residential customers, community facilities, and small commercial customers. The community hosts a clinic which requires uninterrupted power. There are no 3-phase energy users and the daily energy demand to the system cycles according to daily and seasonal residential demand patterns.[31]

Power costs in the community are high, even with PCE subsidization. The Table 3 below shows energy cost characteristics for this hypothetical community. Note, Figure 19 shows that the average rate is higher than the cost per kWh experienced by the utility. Rate setting in rural Alaska is not always indicative of the present costs of utility operations. Rate calculations and design occur infrequently, if at all, compared to urban Alaska and the U.S. as a whole. However, the utilities rates remain the best way to gage the costs realized by customers.

Hypothetical Community Energy Cost Characteristics	
Total Power Costs ($/kWh)	$0.65
Non-Fuel Cost ($/kWh)	$0.35
Fuel Cost ($/kWh)	$0.30
Residential Average Rate - Pre-PCE ($/kWh)	$0.75
Residential Average Rate - Post-PCE ($/kWh)	$0.35

Table 3: Hypothetical Community Energy Cost Characteristics.
Source: AEA, 2019

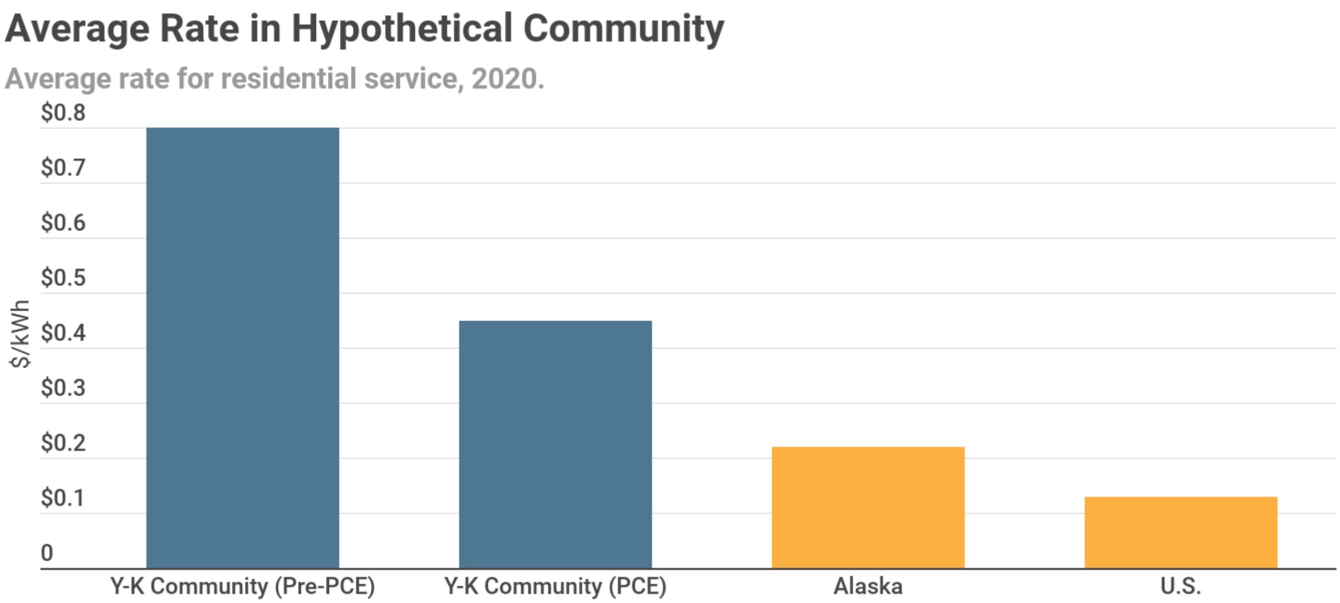

Figure 19: Average Power Rate Comparison for Hypothetical Small Rural Community.
Source: AEA and EIA, 2019.

Heat

Community heating needs are met through a combination of diesel heating fuel and wood harvested from the surrounding area. Figure 20 presents the makeup of heating fuel usage in the community. The retail rate for heating fuel ranges from $5.50 to $6.50, and the community only has one local fuel retailer. There is some concern over air quality issues from inefficient wood burning.

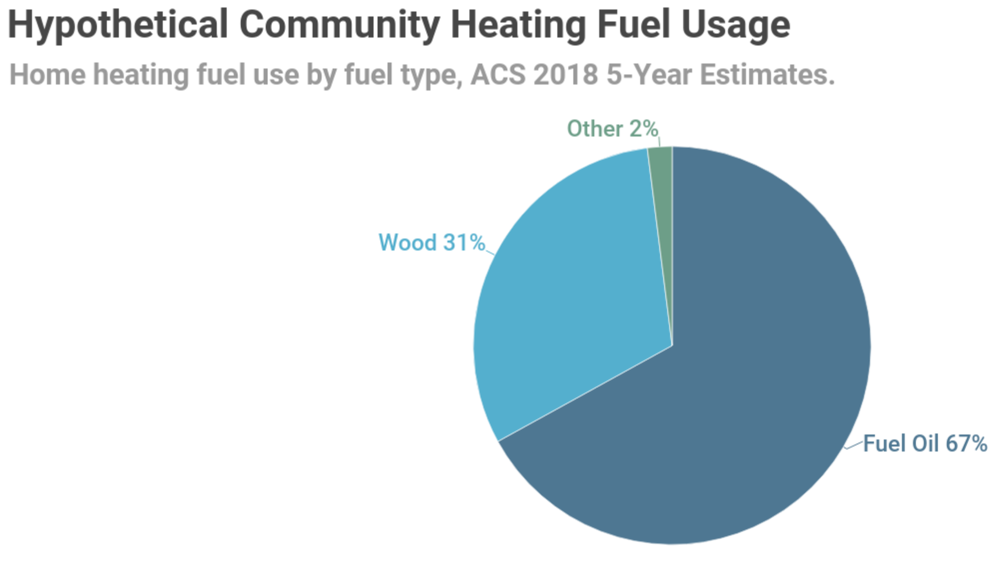

Figure 20: Hypothetical Community Home Heating Fuel Use by Fuel Type.
Source: ACS 2018 5-Year Estimates.

The school operates a biomass boiler which was installed a decade ago and heats the school buildings. Other community buildings, such as the city and tribal offices, washeteria, and others, make bulk fuel purchases at a lower per gallon rate.

Energy Technology Market Drivers

The community electric utility is owned by the local tribe and, therefore, is unregulated. The community participates in the PCE program and makes filings to the State of Alaska to justify allowable costs for the program. Key going concerns for the community and utility management include: cost, operational ease, reliability, and decarbonization, all of which drive operational and technological decisions.

Cost: Costs are one of the clearest drivers of decision-making processes as the community's primary goal is lowering or stabilizing the cost of power. Decisions about generation technology are made through considering the upfront capital costs and long-term operations and maintenance costs and fuel costs (if applicable). Access to capital is a challenge and the utility does not have cash reserves to put toward large infrastructure projects. Funding programs can play a role in some technology decisions and the community has utilized State of Alaska, Department of Energy, Bureau of Indian Affairs, and U.S. Department of Agriculture grant programs and funding mechanisms for past projects.

Technical Capacity: Technical capacity is limited within the community and surrounding areas. Currently, plant operators have the training to operate the installed diesel and conduct routine maintenance activities; however, the skills and confidence required to diagnose and resolve non-routine issues are limited. Therefore, operational ease of any energy system is critical to the success of any energy project. Training to operate new energy systems will likely need to occur no matter the technology integrated, which could place a cost burden on the utility.

Reliability: Reliability is a major going concern for the community. The utility has struggled with outages related to aging transmission infrastructure, an especially critical concern in the winter. The utility operates on a N+1 principle of redundancy, meaning if any one generator needs to be shut off, there is enough redundant capacity to meet peak energy demand. In Interior Alaska, where winter temperatures can frequently reach negative 50 degrees, reliability of the power system is also a critical health concern. Reliable power is tied to healthcare and food systems, as well as local water supply and more in the community.

Sustainability: The community has experienced the adverse effects of climate change through impacts to subsistence resources and erosion; therefore, decarbonization is a strong motivator toward reducing dependence on fossil fuels. However, another strong driver is reduction of the risk of environmental contamination from fuel spills. The community discussed here has limited fuel delivery infrastructure and aging fuel storage tanks. Fuel spills have created a number of contaminated sites in the community which have only been partially cleaned and reclaimed.

Familiarity: Comfort with a given energy technology has been a driver away from renewable energy adoption in the community. One of the benefits of diesel generation technology is that the system technology is well known and broadly utilized; therefore, maintenance and operations issues are well known. The community is wary of the time and financial resources necessary to operate emerging technologies.

Market Fit for Microreactors

Technical Capacity and System Fit

The hypothetical small rural community discussed here operates an extremely small energy system. Without industrial power users, the utility serves an energy load which is largely dependent on residential energy demand characteristics. The advanced nuclear technologies under development would need to accommodate the existing power demands in many small rural communities. This likely includes: load following characteristics, remote or autonomous operation, 'plug-and-play' capabilities suited to the existing distribution infrastructure, minimal operational and security requirements, and a low impact footprint which considers geological activity and permafrost characteristics.

In a small, consolidated community such as the hypothetical one discussed here, there are opportunities for electrification of consistent dispatchable loads. Heat and transportation are two areas that could be electrified. Microreactor developers have noted the recovered heat potential of the systems under development could be used to heat district heating loops. Further excess energy could be used as an electric heat source. Additionally, with an isolated road system, mobility systems could be transferred to electric vehicles and ATVs.

Ownership Models

There are several ownership models for integration which could provide varying levels of technical fit for nuclear reactors: utility operation and integration, contract operation, and power purchase agreement with commercial operators. Each of these models could be viable in a rural setting and each addresses challenges which rural utilities face. However, maintaining local hire and operation of the community's energy system is likely to be an ongoing point of interest, and microreactor operating models should be designed with that in mind. Table 4 compares some of the advantages and disadvantages of different ownership models.

Microreactor System Ownership Model		
Ownership Model	**Advantages**	**Disadvantages**
Utility operation and integration	• Community control • Retention of local hire	• Operational complexity • Need for retraining • High capital cost
Contract operation	• Less operational liability • Specialized support	• High capital costs • Potential loss of local hire
Power purchase agreement	• Specialized support • reduced operational liability • Potential costs spread over lifetime of reactor	• Loss of local hire • Limited community control

Table 4: Microreactor System Ownership Models.

One of the concerns of the hypothetical community discussed here is the operational liability associated with microreactors. The regulatory and operational requirements of microreactors is as yet unknown. Any number of requirements placed by the NRC and by the technology developers could present a hurdle for the community. Unknowns around operational and security requirements and physical requirements could present a hurdle for the community.

Financial Fit

In our hypothetical community in interior Alaska, the rate for electricity is $0.75 per kWh. Only a portion of the realized cost to customers includes variable cost which could be replaced through integrating a microreactor.[32] The cost of power for the utility is a function of generation, distribution and transmission, and administrative costs. Cost replacement could occur for fuel costs and operations and maintenance costs (generation costs). In the community discussed here, 57 percent of the utilities' annual costs are associated with diesel generation and could be replaced by costs related to an alternative energy source.

An additional consideration is that historically, integration of alternative energy technologies in rural Alaska has had little to no impact on the energy costs of residential customers. This is a product of the PCE subsidy calculation. In the community discussed here, energy rates after applying PCE subsidies for residential service is $0.35 per kWh. Potential savings from implementing microreactors would likely only be passed on to residents using in excess of 500 kWh a month and commercial energy users, such as local small businesses.

Given the unknowns and technical hurdles associated with integrating the technology, it is likely that the cost savings would need to be significant for the community. In addition, community education around the impact to energy rates would likely need to be robust.

There is little published cost information on the cost per kWh to provide a robust financial analysis, but initial 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.[33]

Rudimentary financial modeling using information published by NEI and Alaska energy data, shows that the financial fit of microreactors in remote markets will be sensitive to upfront capital costs and refueling frequency and costs.[34] Financial data on microreactors is still undeveloped, making a thorough analysis for the hypothetical community difficult; however, understanding the key variable helps to reveal potential barriers to technology adoption. Access to capital to fund large infrastructure projects is a stated challenge in the hypothetical community. The community has utilized grants to subsidize infrastructure projects. Future creativity in assembling capital resources may be needed for a microreactor project.

Perception Fit

General understanding of nuclear technology in the hypothetical community discussed here likely mirrors the U.S. on average. Public awareness of nuclear energy has been tied to examples of the worst possible scenarios (i.e. Fukushima and Chernobyl). The utility manager and community leaders have discussed microreactors as a potential energy option but too many unknowns exist for definitive opinions to have developed.

Risk of environmental contamination is a prevalent concern across rural Alaska. Instances of point source environmental contamination in the community discussed here have had an impact on subsistence resources and influenced the community's perception on environmental remediation. Plans for a nuclear reactor would need to consider the entirety of the reactor's lifespan and would need to be in place well in advance: including specifics on safety measures, fuel disposal, cleanup procedures, and more.

It is impossible to generalize all rural communities under a single umbrella of public perception. Different communities have varying experiences with environmental contamination, investment in their energy systems, and attitudes toward energy technology risk. Any one of these factors could influence perceptions toward integrating microreactor.

In a community like the one discussed here, public acceptance of a nuclear project could likely require a broad and thorough education program. Points of education could include understanding of the technology and its difference from traditional nuclear, understanding the environment and physical security risk and mitigation measures, clear planning and agreement around disposal of nuclear waste, processes for fuel delivery and transportation, planning and environmental cleanup measures in case of incidence and more.

Given the community's attitudes toward adopting experimental or early stage energy technologies, there is an apparent aversion toward being the first user of microreactors. Like many rural energy stakeholders, community officials and energy operators may prefer to see the technology tested and deployed in urban Alaska or elsewhere to observe the functionality and success of the technologies before implementing it in communities.

Small Rural Community Energy Value Propositions

Current Value • Heavy dependence on diesel fuels. • High cost of power. • Small consolidated system allowing for heat and power functions. • Strong support of movement away from fossil fuels and energy diversification.	**Barriers:** • Availability of workforce and specialized technical skill sets. • Extremely small system size could force a heavy reliance on single technology. • General attitudes toward nuclear among the public and fear of risks. • Concerns over external environmental issues (i.e. earthquakes, erosion, and permafrost melting). • Undetermined regulatory hurdles, and operational and security requirements.
Future Opportunities: • Electrification of consolidated transportation systems. • Distributed district heating. • Electrification of heating systems.	**Challenges:** • Access to capital. • Aversions to implementing untried technologies. • Characteristics of small system cycling. • Perception around risk of nuclear contamination and waste disposal.

Table 5: Small Rural Community Energy Value Propositions.

Rural Hub Community

Alaska's energy landscape can be roughly divided following two separate characteristics. The majority of Alaskans live on the Railbelt. Outside of the Railbelt, the energy systems across the state are made up of micro-grids which range in size from 0.5 MW(e) to 85 MW(e) in installed capacity. Alaska is home to over 100 very small micro-grids serving communities with fewer than 500 residents isolated from the road system with air and, sometimes, barge access.

The larger range of these very small systems include handful rural 'hub' communities, which have larger energy demands and more complex 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 interior, southeast, western, and northern Alaska and range in size from approximately 10 MW(e) to 25 MW(e) of installed capacity.[35] Figure 21 maps the installed power capacity across hub communities.

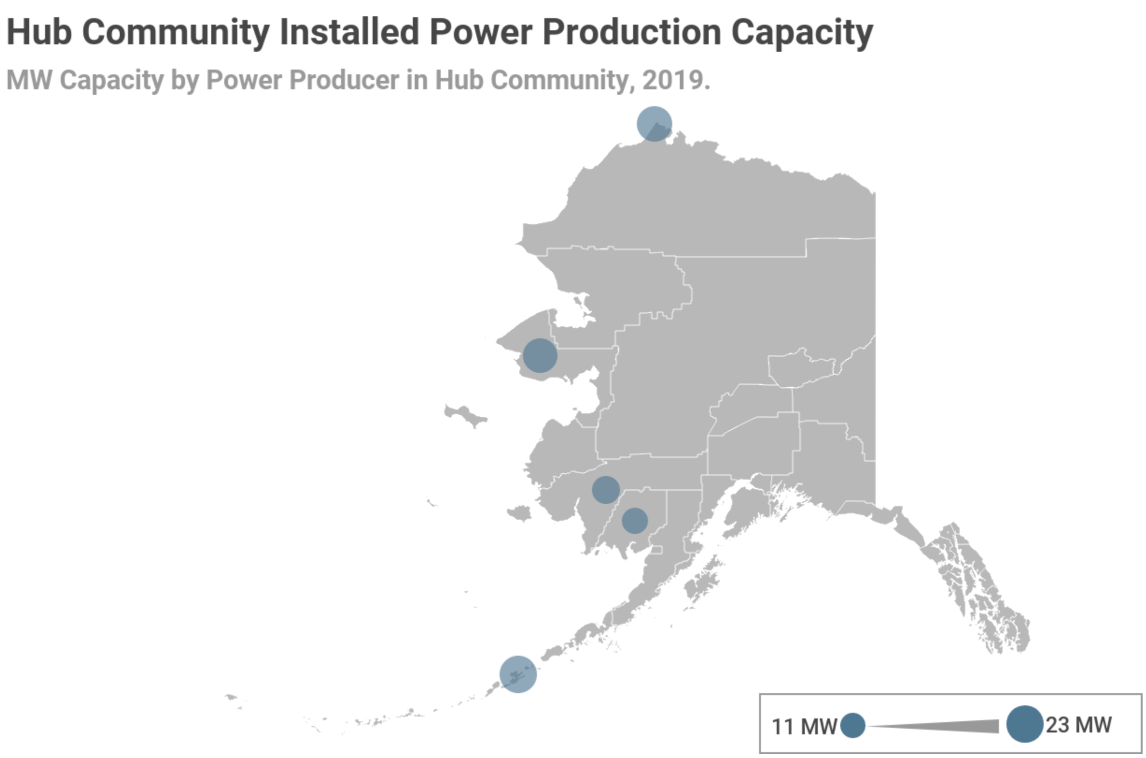

Figure 21: Hub Installed Power Capacity.
Source: Energy Information Agency (EIA), 2019.

Population and Demographics

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 5 below is a list of some of the rural communities that can be considered regional hubs for the purposes of this analysis.

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

Table 6: Hub Community Population Size.
Source: Alaska Department of Labor and Workforce Development (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. Table 7 shows a sample of the largest employment industries in three hub communities: Dillingham, Kotzebue, and Nome.

Hub Community Employment Characteristics	
Industry	**Number of Jobs**
Dillingham - Total	1,023
Educational and Health Services	401
Local Government	201
Trade, Transportation, and Utilities	193
Kotzebue - Total	1,357
Education and Health Services	370
Local Government	312
Trade, Transportation, and Utilities	230
Nome - Total	1,720
Education and Health Services	562
Trade, Transportation, and Utilities	276
Local Government	262

Table 7: Hub Community Employment Characteristics.
Source: AKDOLWD, 2016.

The ‘Trade, Transportation, and Utilities’ sector in each of the above referenced communities is among the top employers. A trend that is present across rural Alaska.

Unemployment rates are slightly higher in hub communities than the state average. Furthermore, poverty rates also tend to be higher than state averages. Figures 22 and 23 compare unemployment and poverty rates in several hub communities.

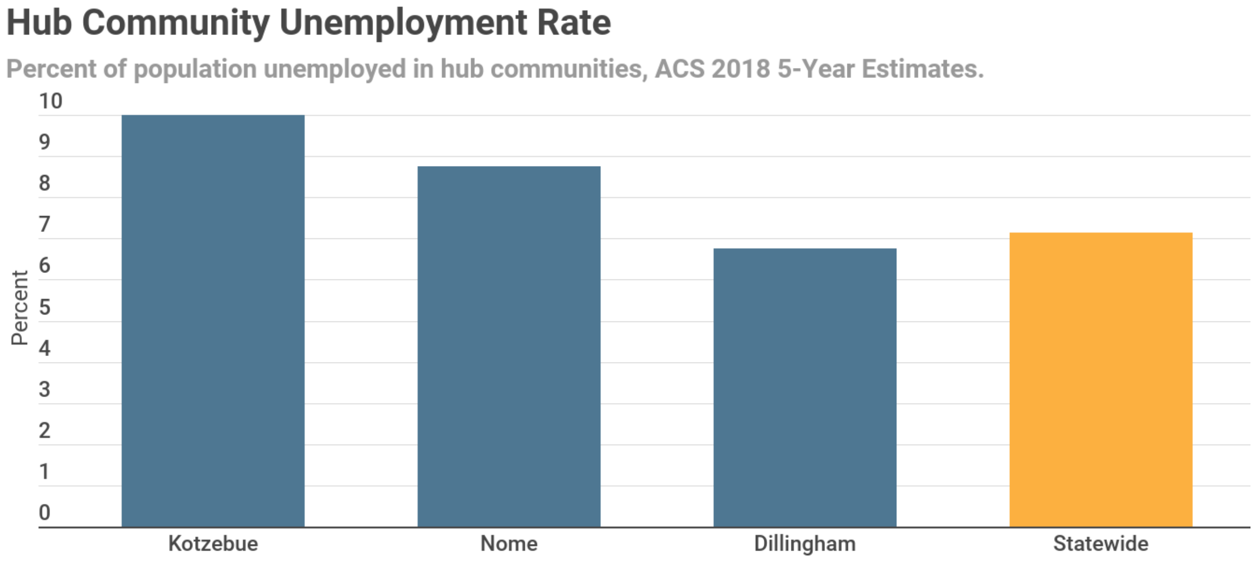

Figure 22: Hub Community Unemployment Rates.
Source: American Community Survey (ACS) 5-Year Estimates, 2018.

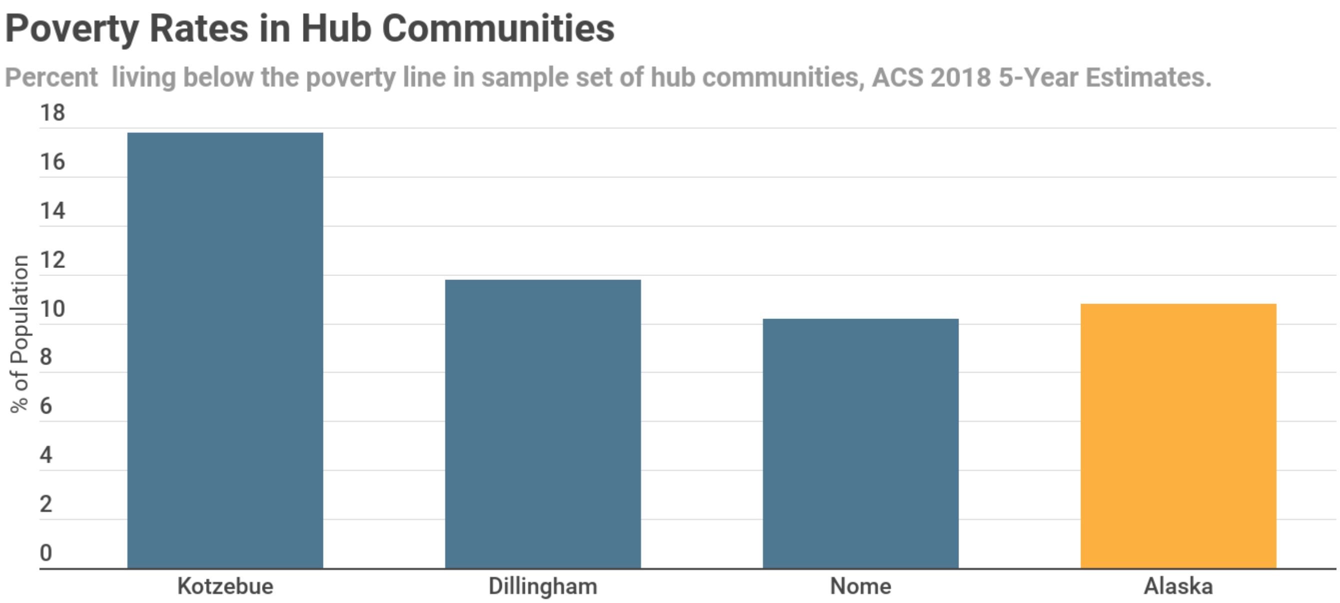

Figure 23: Hub Community Households Below Poverty Line.
Source: ACS 5-Year Estimates, 2018.

Current Energy Systems

Electric

Alaska's hub communities or Rural hub community power systems vary in size depending on the community size and industrial loads. In the previously referenced communities, roughly 35 to 40 percent of community electrical loads are made up of residential customers and community facilities. Table 8 discusses the power characteristics of several hub community utilities.

Hub Community Utility Power Characteristics			
Community	**Ownership Model**	**Power Cost per kWh**	**kWh Sales**
Dillingham	Cooperative	$0.36	18,144,633
Kotzebue	Cooperative	$0.39	19,495,001
Nome	Local Government	$0.31	29,802,574

Table 8: Hub Community Utility Power Characteristics.
Source: AEA, 2019.

Schools and health facilities represent larger community loads with individual energy priorities. Nome, Bethel, Utqiaġvik, Dillingham, and Kotzebue all host hospitals and play a critical role in their respective regional health systems.

Several hub communities host fish processors, which represent large industrial loads for many communities. Most processors operate seasonally, so their energy needs fluctuate annually. Figure 24 compares annual power sales by customer type for several hub communities.

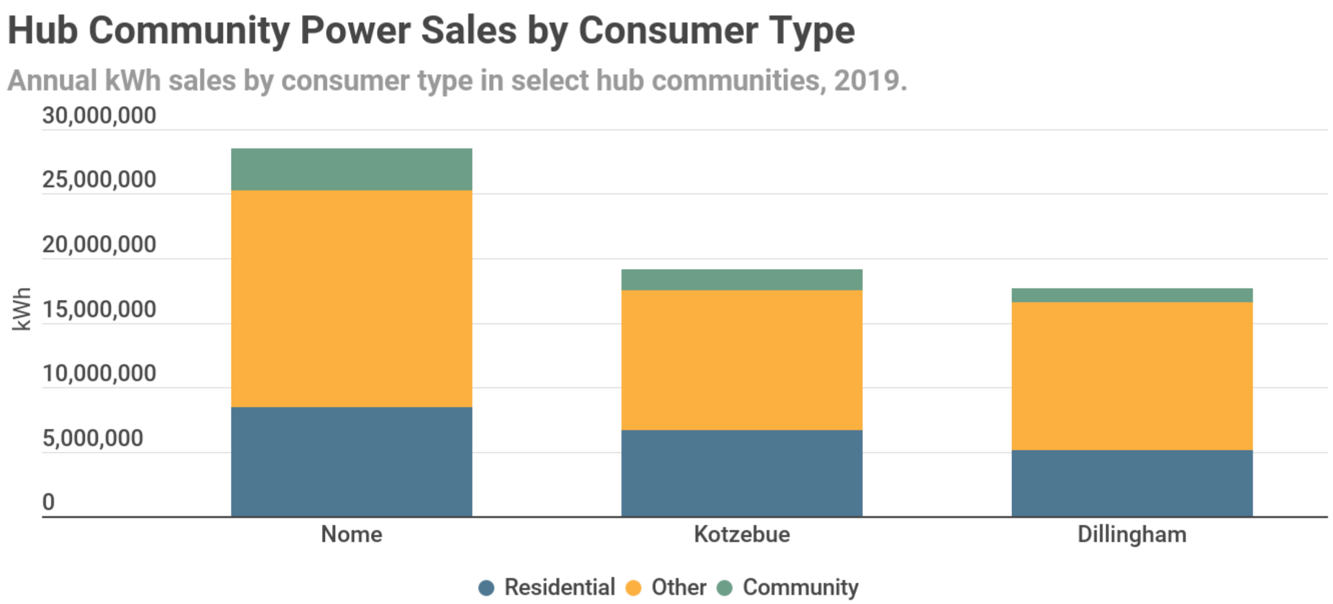

Figure 24: Hub Community kWh Sales by Consumer Type.
Source: AEA, 2019.
**Note: "Other" denotes all other kWh sales, which includes: commercial power users, non-PCE eligible community facilities, and power house usage.*

The ownership models of rural hub utilities vary, and include city ownership, co-op models, tribal ownership, and private ownership. Hub community utilities operate sophisticated systems and monitor a combination of generation assets and energy sources.

Western Alaska hub communities are mostly dependent on diesel fuels for power generation; however, several communities operate wind-diesel hybrid systems. Utqiaġvik, in northern Alaska, utilizes local natural gas resources for power production.

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. Delivered cost of fuel is variable across hub communities. Figure 25 shows the breakdown in per kWh power production costs by fuel and non-fuel costs. Figure 26 compares hub community utility average residential rates.

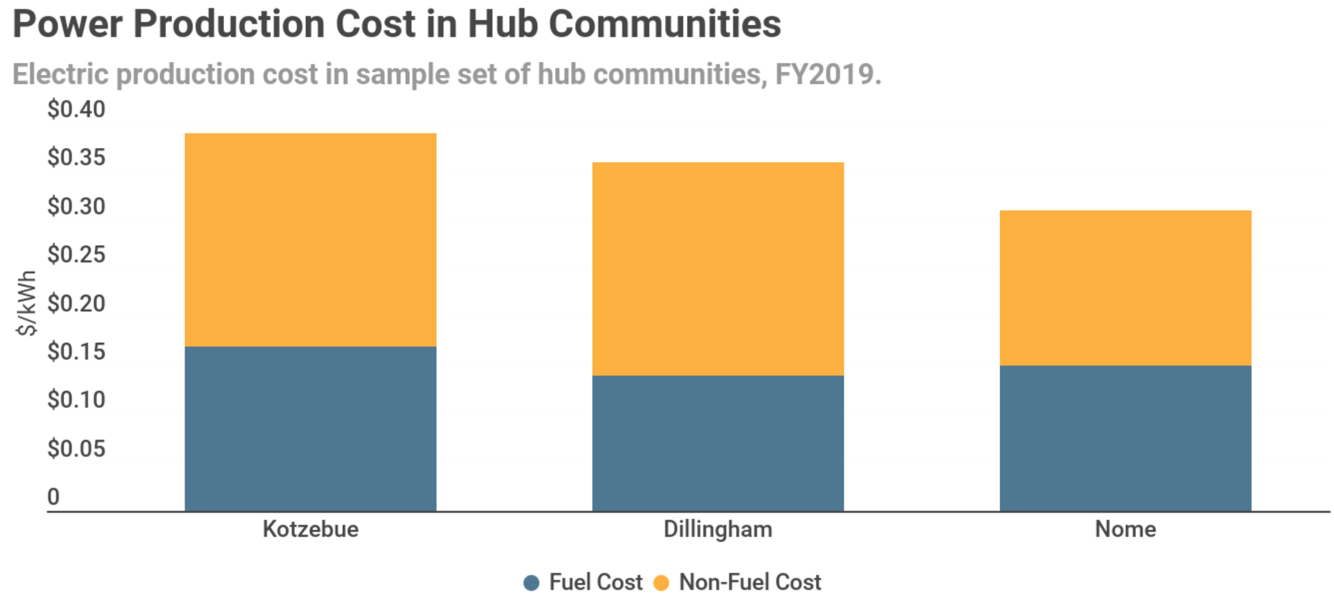

Figure 25: Utility Energy Cost per kWh.
Source: AEA, 2019.

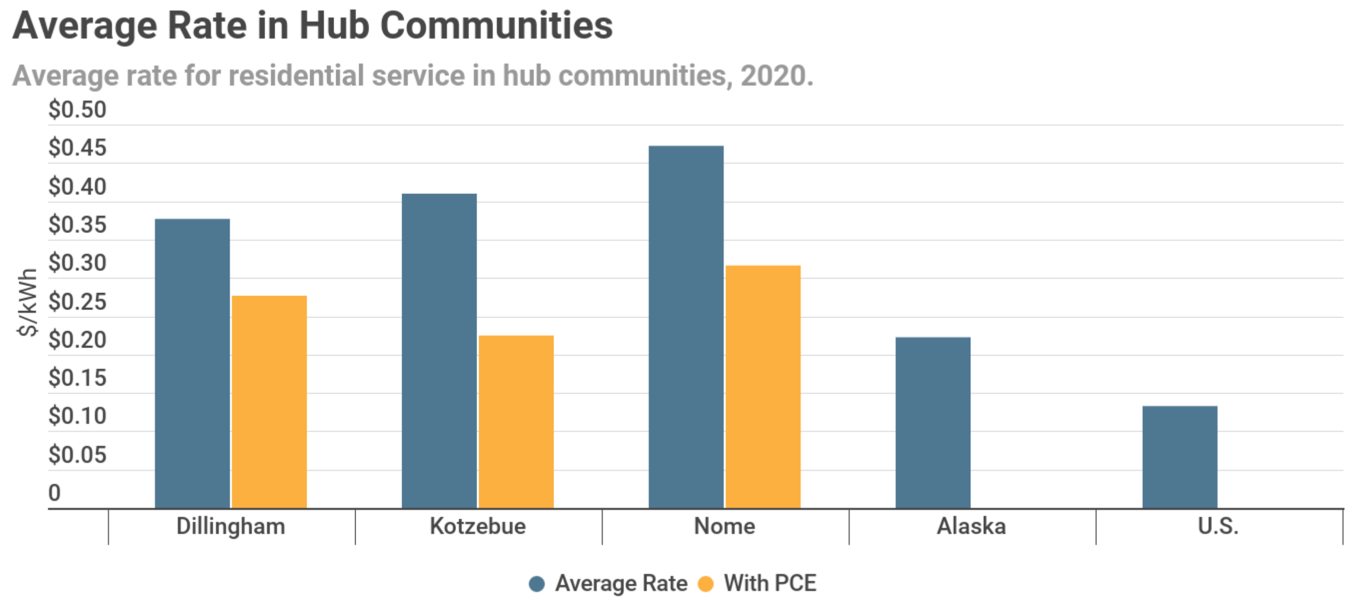

Figure 26: Hub Community Average Residential Rates for Service.
Source: Regulatory Commission of Alaska (RCA) and EIA, 2020.

Heat

Heating-related energy needs is an area of the energy landscape in Alaska that has received less attention than electricity. Across hub communities, heating fuel is used almost ubiquitously to heat homes, community facilities, and commercial facilities. Larger facilities, such as the city government and schools, purchase heating fuel in bulk, lowering the cost by a certain amount. Figure 27 compare heating fuel costs for several hub communities.

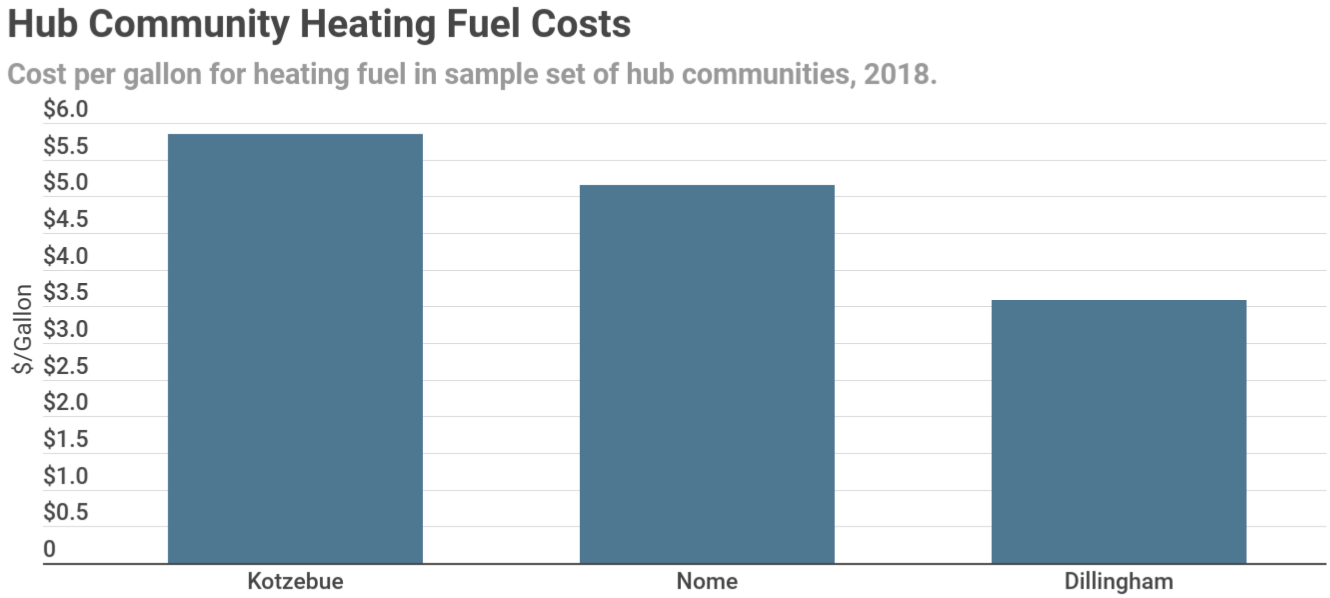

Figure 27: Hub Community Heating Fuel Costs.
Source: Alaska Division of Community and Regional Affairs (DCRA), 2018.

Residents purchase heating fuel from public or private distributors. Depending on available resources, residents in some communities use wood for residential home heating. Figure 28 shows estimated household heating fuel usage by fuel type for Nome and Dillingham.

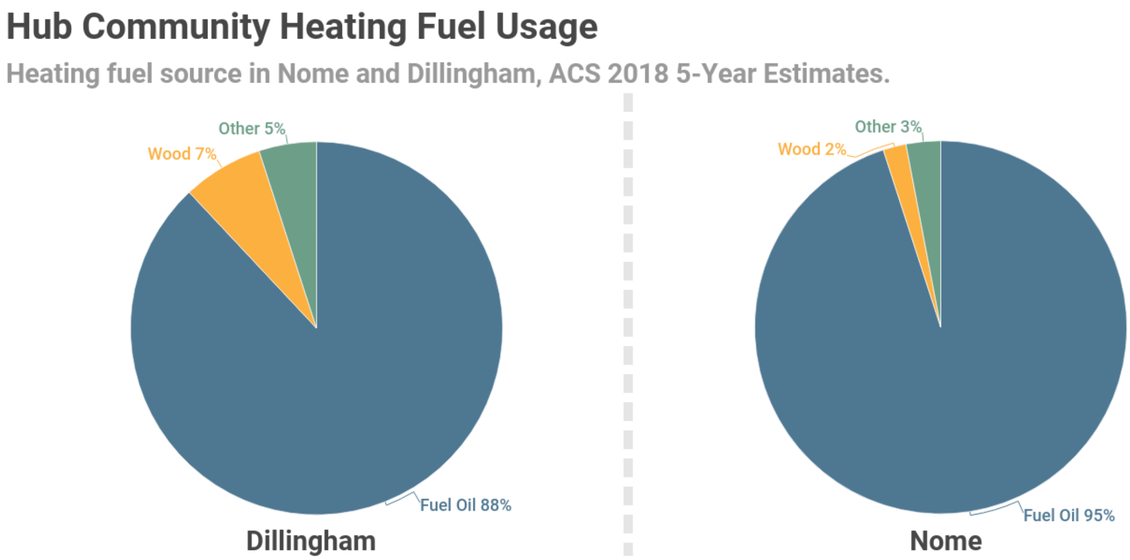

Figure 28: Hub Community Heating Fuel Source.
Source: ACS 5-Year Estimates, 2018.

Some communities have installed heat recovery systems to heat community buildings, power houses, and water treatment facilities. Energy efficiency and weatherization projects across the state have made steps toward heating fuel savings; however, work remains in this area, even in hub communities.[36]

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.

Microreactor Themes and Perspectives

Due to the variability and availability of renewable resources, full replacement of diesel fuel through renewable integration is unlikely.

With their high cost of power, technical capacity, and average system size and base load, the hub communities would seem to be a likely candidate for an initial customer of microreactors; however, a number of rural hub utilities and energy stakeholders expressed reservations about adopting early stage technologies on a system with less resiliency or backup capacity. Interviewees noted that in the case of integrating wind technologies, hub community energy producers tended to be more risk averse. Some hub communities have chosen to track progress of early adopters of wind-diesel technology to learn more about how technologies integrated with remote diesel systems before entering the market as a second or third stage technology adopter.

Interviewees noted that when making technology decisions, comfort level has historically been an important factor. Microreactors are still in the technology testing stages; therefore, establishing a certain degree of comfort with the technology will be critical for motivating customers. Factors to consider could include:

- A robust understanding of lifetime costs and operational processes.
- Established plans for the life of the reactor, including installation, fueling, and disposal.
- Clear processes for fuel transportation and disposal.
- Emergency preparedness and disaster mitigation planning.
- Processes for technology support and system repair and maintenance.
- Understanding of federal and state regulatory requirements.

Use Case: A Hypothetical Rural Hub Community

Consider a hypothetical rural hub community along the coast of western Alaska. The community is home to roughly 4,000 individuals, half of which are of working age. The residents of the community are predominantly Alaska Native and subsistence activities play an important role in the lives of many residents. The community plays a role as the supply, service, and transportation hub for its region, facilitating services to other, more remote communities. As a hub community, the local economy hosts retail stores, social service providers, air carriers, state and federal government offices, and local and regional tribal administrations, and a large bulk fuel storage farm. The community finished a new hospital in 2015 and now also plays an important role as a healthcare hub for the region.

Management of the local electric utility has been given guidance by the board of directors to investigate alternatives to offset diesel fuel consumption by 50 percent by 2030. Considering its options, the utility commissions an energy study, which considers the known energy alternatives and local renewable energy resources.

Economic and Housing Information

Roughly 100 residents hold commercial fishing permits. Other employment is predominantly in government, health and education, and trade, transportation, and utilities. Other jobs in the retail sector and other small businesses provide other year-round employment and income. Subsistence activities play an important role in the local economy.

The community is interested in expanding its tourism sector. In the region, several mines under development could provide jobs for locals.

Median household income is $81,000 annually, slightly higher than the statewide median of $76,000.[37] As a regional hub, employment opportunities are greater, and the workforce is more diverse than most of the small villages of rural Alaska.

In the region, access to affordable housing is an ongoing issue. Roughly 25 to 30 percent of housing units in the region are considered overcrowded or severely overcrowded, higher than the statewide and national averages.[38] While overcrowding is less of an issue in this hypothetical community, the cost of residential construction is still greater than the market value of housing units, causing rates of new housing construction to remain low.[39]

Region and Climate

Western Alaska is one of the most remote regions of the state. Bordering the Bering Sea, the region roughly stretches from the Aleutian Islands in the south to the Bering Strait in the north. The climate in the region ranges from transitional to sub-arctic, with tundra patchworked with boreal forest flowing across much of the landscape.

The hypothetical community discussed here is in the sub-arctic zone on the coast of the Bering Sea. The community is located in an area with permafrost. Historically, sea ice covers the coast in the winter, although ice thickness and coverage has been decreasing in recent years.[40] The community has been considering climate change impacts in long-term strategic planning.

Western Alaska is known for its wealth of renewable energy resources. Wind resources in the area local to this hypothetical community are plentiful. The community has also investigated a number of local wind and hydroelectric/hydrokinetic concepts.[41]

Energy System

Electric

The utility operates a wind-diesel hybrid system with six wind turbines of varying age and six diesel generators of varying capacity. The generation assets are operated with an integrated SCADA system which manages the diesel and wind assets and allows communication between the system and engineers in Anchorage and the rest of the U.S. who monitor system performance and provide remote maintenance.

Table 9 describes some of the community energy characteristics. The system has a maximum capacity of 18 MW which is overbuilt for the utility's peak demand. In 2019 the utility sold 35,000,000 kWh. Depending on wind speed, the turbines can offset up to 20 percent of the annual energy demand, the remaining demand is met through diesel generation. The utility has investigated other alternative energy sources but has not identified a cost-effective alternative to diesel systems. One MW of energy is captured in waste heat which is used to heat the community's water supply.

Hypothetical Hub Energy System Statistics	
System Capacity (MW)	18
Diesel Capacity (MW)	15
Wind Capacity (MW)	3
Annual Sales (kWh)	35,000,000
Percent Residential Sales	30%
Percent Community Facilities Sales	10%
Percent Commercial and Other Sales	60%

Table 9: Hypothetical Hub Community Energy Characteristics.
Source: AEA, 2019.

The system is run by nine plant operators, with three fiscal and administrative professionals supporting management activities. A stated challenge the utility grapples with is access to capital. The utility generates enough revenue to cover operations and maintenance costs, but is unable to fund large infrastructure projects. The most recent wind turbine was funded through a patchwork of grants and a small loan.

Administrative operations are a challenge. As a hub community there is access to a larger labor pool than much of rural Alaska; however, skill sets in finance are more difficult to access. In addition, individuals in management positions are nearing retirement age and it is unclear if there are individuals who will be able to fill those roles.

The system primarily serves residential customers (30 percent), community facilities (10 percent), and commercial customers (60 percent).[42] The community hosts a hospital and federal and state offices, all of which have large, well-defined loads. There are few 3-phase energy users and the daily energy demand to the system cycles daily and seasonally.[43]

Hypothetical Hub Community Energy Cost Statistics	
Total Power Cost ($/kWh)	$0.30
Non-fuel Cost ($/kWh)	$0.16
Fuel Cost ($/kWh)	$0.14
Rate for Service - Pre-PCE ($/kWh)	$0.20
Rate for Service - With PCE ($/kWh)	$0.11

Table 10: Hypothetical Hub Community Energy Cost Statistics.
Source: AEA and RCA, 2019.

Note, the rate for service is lower than the cost per kWh experienced by the utility. Rate setting in rural Alaska is not always indicative of the present costs of utility operations. Rate calculations and design occur infrequently, if at all, compared to urban Alaska and the U.S. as a whole. However, the utilities rates remain the best way to gage the costs realized by customers.

Power costs in the community are high compared to urban Alaska; however, they are lower than surrounding villages. The community participates in the PCE. In 2019, the rate for service for residents was $0.11/kWh. Commercial customers and businesses are not eligible to participate in the PCE program and pay a higher rate per kWh, roughly $0.20/kWh.[44] Table 10 describes the community's power costs.

Heat

For space heating, the community relies almost entirely on heating fuel which is sold by various entities in the community. Residential heating fuel costs between $4.50 and $5.50 per gallon and homes are heated with Toyo stoves. Larger users are able to purchase fuel in bulk and sometimes pay a lower price per gallon. There is no district heat system in the community, and permafrost makes the logistics and cost of constructing a district heat system difficult.

Energy Technology Market Drivers

The utility in this community operates under a cooperative model and is not regulated. However, the community does participate in the PCE program and makes filings to the State of Alaska to justify allowable costs for the program. The utility is also accountable to the board of directors and cooperative members.

Key energy concerns for the community include: cost, reliability, and decarbonization, all of which drive operational and technological decisions. In a region where costs of power are high and fuel costs are variable, costs are one of the clearest drivers of decision-making processes. Decisions about generation technology are made through considering the upfront capital costs and long-term operations and maintenance costs and fuel costs (if applicable) of the alternative technology compared to the current system.

Reliability: Reliability is a growing concern for this hypothetical community as it seeks to lower or stabilize costs through diversifying its energy resources. Reliability is critical; power must be there when people go to turn the lights on, especially in the middle of winter. As a result, the community operates with redundant capacity to ensure that if any single generation unit is shut down, enough capacity remains to meet peak demand.

Decarbonization: Decarbonization is a layered driver in this hub community. While there are motivations from the utility leadership to reduce reliance on fossil fuels as a result of environmental concerns and emissions reduction, an even stronger driver is reduction of risk of environmental contamination from fuel spills. Decarbonization is also synonymous with diversification to the extent that it includes integration of multiple resources. Decarbonization also reduces variability in costs.

Familiarity: Comfort with energy technologies is a forceful driver for technology adoption. The community has observed the experiences of other energy systems adoption of emerging energy technology and tried to learn through collaboration. Despite a moderate tolerance for risk, the utility remains wary of adopting unfamiliar technology. This is caused by several factors, including: relative isolation, access to resources, high capital costs, and workforce constraints.

Cost: While not as high as much of remote Alaska, power costs in this hypothetical community are high. High costs associated with diesel fuel and operations and maintenance have been a key driver in investigating technology alternatives which would lower energy costs.

Market Fit for Microreactors

Technical Capacity and System Fit

Hub communities operate advanced systems with sound technical capacity. A hub community without a seafood processor or large industrial users accommodate loads which cycle according to residential and seasonal demand characteristics, but without large spikes in demand. Hub communities with large industrial users, mostly seafood processors, experience greater seasonal loads. With, or without, a large industrial power user, nuclear systems would have to be designed to accommodate system cycling and function with integrated wind and solar resources. Alternatively, a nuclear system would have to be sized to accommodate the utility's base load with diesel integration to meet demand spikes.

There are several ownership models for integration which could provide varying levels of technical fit: utility operation and integration, leased operation, and power purchase agreement with commercial operators. Each of these models could be viable in a rural setting and each addresses challenges which rural utilities face.

One of the concerns expressed by rural hub communities in interviews was over operational liability. The regulatory and operational nuance of microreactors is as yet unknown. Any number of requirements placed by the U.S. Nuclear Regulatory Commission (NRC) could present a hurdle for utility operators. A solution to this could be removing operational obligation from the utility, allowing another entity to either operate nuclear assets owned by the utility or sell nuclear power from a local entity which owns and operates nuclear assets. However, the challenge with either of those models is removing operational control of a community's energy source from the utility.

Many questions over operational characteristics remain unanswered in this hypothetical community. Energy operators and stakeholders have expressed concern over operational characteristics matching existing energy system needs, including workforce requirements, security requirements (both physical and environmental), and operating parameters. Given the existing physical, system, and energy characteristics of hub communities, as these questions are answered by the nuclear industry and regulatory agencies, technical compatibility will become more solid.

Microreactor developers are working toward testing operational characteristics which would suit remote operation conditions. These characteristics include: infrequent refueling, remote or autonomous operation, reduced security requirements, reduced maintenance requirements, and load-following capabilities.

Knowledge gaps around microreactor operations will need to be filled with concrete evidence on operational characteristics as they are established. Comfort levels with the operation of the technology will have to be built before the hypothetical community discussed here begins firm discussions about technology adoption.

Financial Fit

In our hypothetical community in western Alaska, the per kWh rate is $0.20/kWh for non-PCE customers and $0.11/kWh for PCE recipients. Energy rates are a composition of costs associated with depreciation and interest, administration, transmission, generation, and fuel. Only a portion of that includes variable cost which could be replaced through integrating a microreactor, specifically, generation and fuel costs.[45]

In the hypothetical community discussed here, generation and fuel costs make up approximately 60 percent of the cost of power. Given currently available cost data on nuclear systems, it is unclear how costs associated with microreactors would compare to existing diesel systems. 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.[46] As microreactors move through the development stages, more concrete estimates on costs will likely become available.

One clear indication provided by energy planners and utility operators is that the financial fit could not be equal to or greater than current costs. Given the risk and technical hurdles associated with integrating the technology, many rural utilities would have to experience significant financial benefit.

With the function of the PCE program, these benefits may not be realized by residential customers; however, if the per kWh cost is low enough, some financial benefits could be experienced by commercial users and small businesses. In the hypothetical hub community discussed here, the majority of kWh produced are sold to non-PCE customers; therefore, any savings associated with integrating microreactors would have a real impact on the local economy.

Perception Fit

While energy leaders in the hypothetical community discussed here expressed that microreactors could offer a viable energy alternative to the community's diesel infrastructure, energy leaders agree public perception could be a hurdle. Specific information on attitudes surrounding nuclear energy in the community remain unknown, but energy leaders assume they are likely to match national attitudes.

Historical and current accounts of environmental contamination have impacted the community discussed here and the health of residents. Point source contamination from projects which were never remediated according to plan exist throughout the community. In addition, high levels of polychlorinated biphenyls (PCBs) and other chemical contamination have been found.[47]

In the hypothetical hub community discussed in this analysis, awareness of the impacts of environmental contamination and global warming are high and could act as a pull toward or push away from local nuclear energy depending on community perception levels. Local, widespread support of a microreactor could require broad and thorough education program facilitated by a trusted source. Points of education could include:

- Understanding of the technology and its difference from traditional nuclear.
- Understanding the environment and physical security risk and mitigation measures.
- Clear planning and agreement around disposal of nuclear waste and decommissioning of the plant.
- Understanding of system operation and maintenance requirements, safety measures, and differences from traditional nuclear technology.

There is a clear aversion toward being the first user of any new energy technology, including microreactor While interest from community energy stakeholders is high, as a potential 'first customer', the hub community discussed in this analysis is more likely to prefer to see the technology tested and deployed in urban Alaska or elsewhere to observe the functionality and success of the technology before making decisions on implementing it in a local setting.

In addition, attitudes toward the disposal of nuclear waste and environmental remediation following the life of a microreactor are likely to be strong. Clear, firm plans on waste disposal and site decommissioning will need to be expressed early in the planning process to reinforce comfort levels in the community discussed here.

Rural Hub Community Energy Value Propositions

Current Value:	**Barriers:**
• Heavy dependence on diesel fuels. • High cost of power. • Small consolidated system allowing for heat and power production. • Strong support of movement away from fossil fuels and energy diversification. • Medium-sized base load which could allow for integration of a single small system initially.	• Availability of workforce and technical skill sets. • Small energy system could force a heavy reliance on single technology. • General attitudes toward nuclear among the public and fear over risks. • Concerns over external environmental issues (i.e. earthquakes, erosion, and permafrost melting). • Undetermined regulatory hurdles and workforce and security requirements.
Future Opportunities: • Electrification of consolidated transportation systems. • Distributed district heating. • Electrification of heating systems.	**Challenges:** • Access to capital. • Aversions to implementing untried technologies. • Characteristics of small system cycling. • Perception around risk of nuclear contamination.

Table 11: Hub Community Energy Value Propositions.

Railbelt Energy Producer

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

Population and Demographics

The Railbelt region had an estimated population of 550,000 individuals in 2019,[48] 63 percent of which is of working age—between the age of 20 to 64.[49] Figure 29 maps population size by community across Alaska. More than half of the state's 280,000 jobs are located on the Railbelt.[50] In the utility sector, 1,348[51] are employed across the Railbelt at electric, gas, water, and other utilities.[52] As a region, the Railbelt has access to a deeper labor pool than isolated rural communities, both within and outside of the utility sector.

Trained personnel are an important component of the success of any energy system. NRC's current regulations include requirements for system operators. These requirements are designed for traditional nuclear reactor systems, and it is still unclear what requirements will be placed on advanced reactors; therefore, a flexible workforce will be an important component of commercial deployment of the technology at the local level.

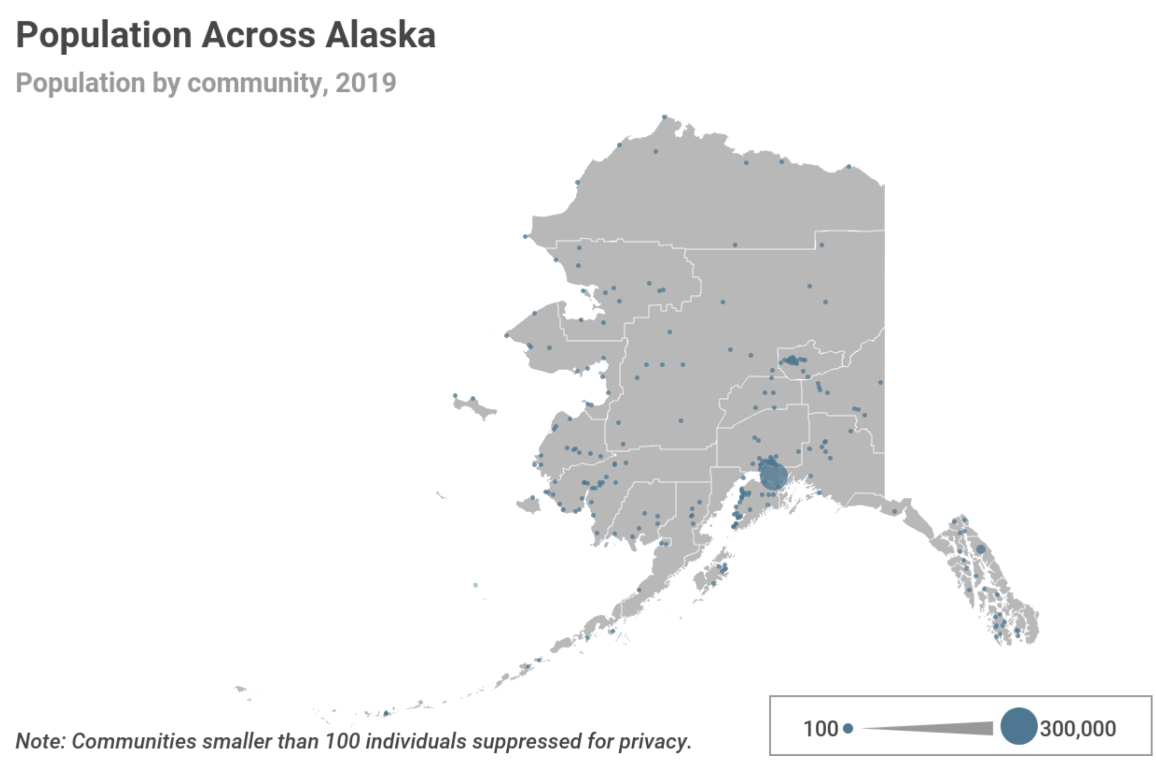

Figure 29: Alaska Population by Community.
Source: Alaska Department of Labor and Workforce Development (AKDOLWD), 2019.

Current Energy System

The five electric utilities that serve the Railbelt region operate an integrated system which enables all of the utilities to buy and sell power from each other. Several independent power producers (IPPs) produces and sell power to local utilities. The Alaska State Legislature passed a bill in April 2020 to enable the creation of an electric reliability organization (ERO) tasked with the planning of all new generation and transmission projects.[53] The ERO's other potential duties include development of reliability standards for interconnected utility systems, developing integrated resource plans, and overseeing planning and integration of new transmission, generation, and interconnection infrastructure. In addition, through the ERO, the Regulatory Commission of Alaska (RCA) will also be enabled to play a role in approving future generation projects.[54]

The Railbelt utilities are powered through a mix of natural gas, coal, diesel, and renewable resources.[55] Figure 30 maps the installed power capacity across the Railbelt. Each of the utilities purchases power from an established hydro-electric asset, Bradley Lake. An extension of Bradley Lake, the Battle Creek Diversion Project, is currently under construction.[56] An addition 20 MW(e) of wind capacity and 27.5 MW(e) of coal generation capacity is used to sell power to adjacently-located utilities.[57]

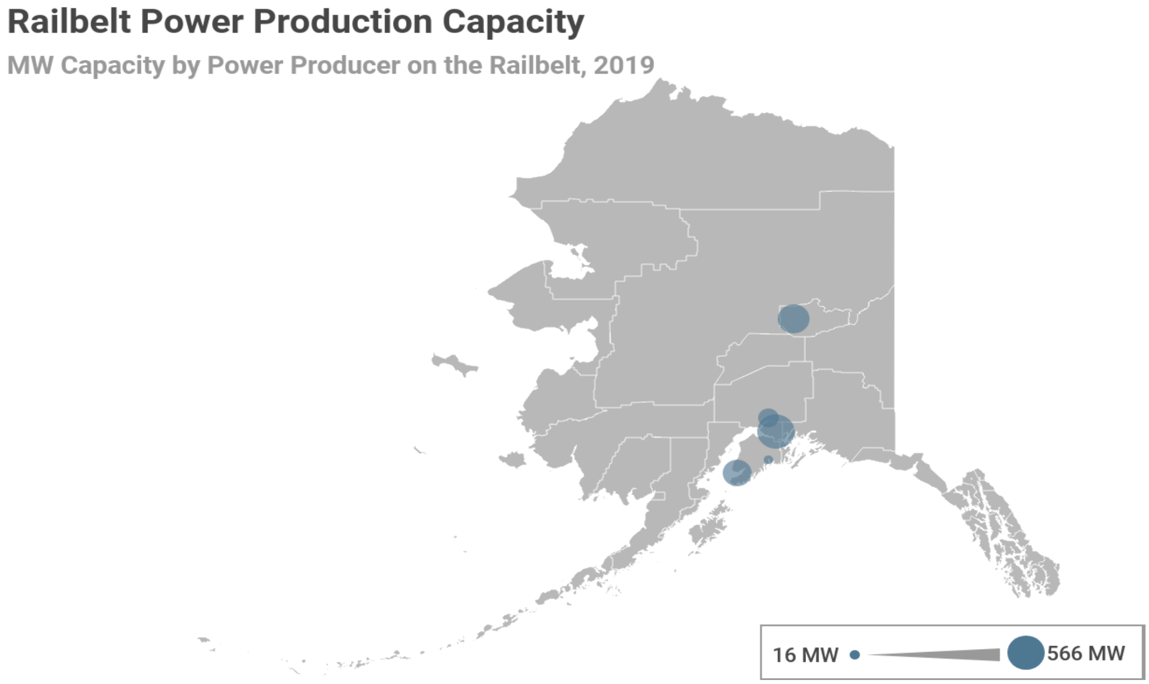

Figure 30: Railbelt Utility Generation Capacity.
Source: EIA, 2019.

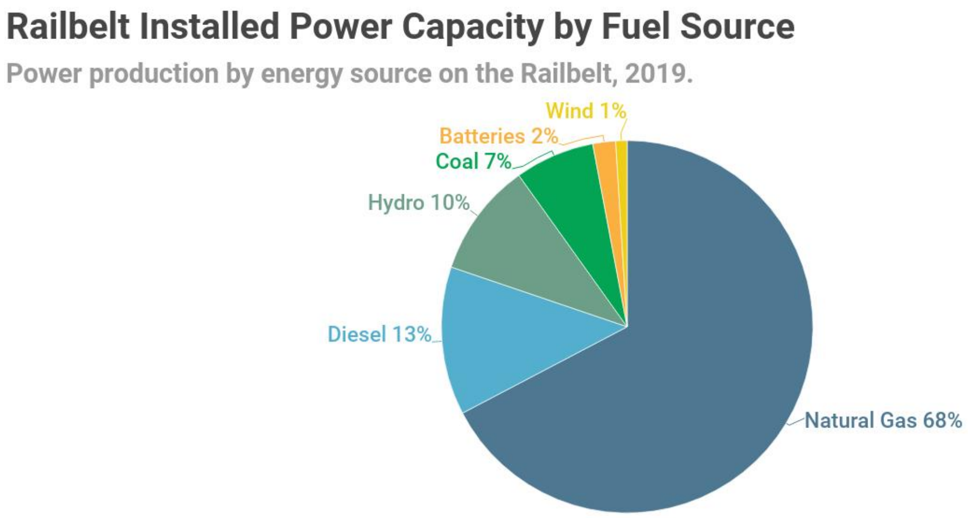

Figure 31: Railbelt Utility Installed Capacity by Energy Source.
Source: EIA, 2019.

Four of the utilities are able to purchase Cook Inlet natural gas. A locally available and relatively cheap resource, natural gas enables most of the Railbelt to keep the realized cost of power to customers down.

Approximately 45 percent of Alaska's electricity is produced through natural gas, and nearly 70 percent of Railbelt power comes from this source.[58] Figure 31 shows the portion power production by energy source. Each of the utilities operate newly built generation assets.[59] Tables 12 through 16 discuss the currently operable generation asset owned by each Railbelt utility.

ML&P Generation Capacity by Unit		
Energy Source	**Capacity (MWe)**	**Year Built**
Natural Gas	48.9	2007
Natural Gas	27	1972
Natural Gas	60.4	2017
Natural Gas	30.9	2017
Natural Gas	102.6	1979
Natural Gas	60.4	2017
Natural Gas	92.6	1984
Diesel	2	2012
Hydroelectric	22.2	1955
Hydroelectric	22.2	1955

Table 12: ML&P Generation Capacity by Unit.
Source: EIA, 2019.

HEA Generation Capacity by Unit		
Energy Source	**Capacity (MWe)**	**Year Built**
Diesel	1.2	2004
Diesel	1.0	2017
Natural Gas	20.7	1971
Natural Gas	28.8	1978
Natural Gas	27.2	1981
Natural Gas	40.8	1986
Natural Gas	40	2013
Natural Gas	50	2014
Hydroelectric	63	1991
Hydroelectric	63	1991

Table 13: HEA Generation Capacity by Unit.
Source: EIA, 2019.

GVEA Generation Capacity by Unit		
Energy Source	**Capacity (MWe)**	**Year Built**
Diesel	18.4	1972
Diesel	23.1	1976
Wind	24.6	2013
Batteries	40	2003
Diesel	1.2	2004
Diesel	1	2017
Natural Gas	20.7	1971
Natural Gas	28.8	1978

Table 14: GVEA Generation Capacity by Unit.
Source: EIA 2019.

Chugach Generation Capacity by Unit		
Energy Source	**Capacity (MWe)**	**Year Built**
Natural Gas	15	1964
Natural Gas	15	1965
Natural Gas	48.8	2013
Natural Gas	48.8	2013
Natural Gas	48.8	2013
Natural Gas	57.5	2013
Natural Gas	16	1968
Natural Gas	16	1968
Natural Gas	59.1	1972
Natural Gas	68.3	1975
Natural Gas	76.5	1976
Natural Gas	76.5	1978
Hydroelectric	9.7	1961
Hydroelectric	9.7	1961

Table 15: Chugach Generation Capacity by Unit. Source: EIA, 2019.

Matanuska Electric Association Generation Capacity by Unit		
Energy Source	**Capacity (MWe)**	**Year Built**
Natural Gas	17.1	2015
Natural Gas	17.1	2015
Natural Gas	17.1	2015
Natural Gas	17.1	2015
Natural Gas	17.1	2015
Natural Gas	17.1	2015
Natural Gas	17.1	2015
Natural Gas	17.1	2015
Natural Gas	17.1	2015
Natural Gas	17.1	2015

Table 16: MEA Generation Capacity by Unit. Source: EIA, 2019.

A merger is currently underway between two of the Railbelt utilities and was conditionally approved by the RCA in May 2020. Chugach Electric Association (Chugach) is in the process of acquiring Municipal Light and Power (ML&P).[60] When finalized, Chugach will possess 1,035 MW(e) of capacity or 51 percent of the total utility-owned capacity of the Railbelt.

One utility on the Railbelt system, Golden Valley Electric Association (GVEA) in the Interior, does not have direct access to natural gas and maintains a mix of generation assets which utilize diesel, coal, naphtha, wind, and solar. Coal used for generation is purchased from the nearby Usibelli Coal Mine.[61] The absence of natural gas makes power in GVEA's service area more expensive than other parts of the Railbelt.

While the current resources maintain a low cost of power throughout much of urban Alaska, there are resiliency gaps in a system which relies heavily on two fuel sources. Disruptions in the fuel supply chain would significantly impact the energy systems across the Railbelt. At various times in recent decades, policymakers have raised concerns about dwindling supplies of natural gas in Cook Inlet, a basin that has produced the fuel since the 1950s. This natural gas supplies not only power production but also residential and commercial space heating needs.

The utilities vary in size according to the population in their respective service areas and the outlay of industrial energy users. Chugach, ML&P, and GVEA serve a number of large industrial power users, including mines, hospitals, and military installations, and, therefore, a larger percentage of those utilities' kWh sales are attributed to commercial power usage.[62] Figure 32 breaks down Railbelt utility power sales by customer type.

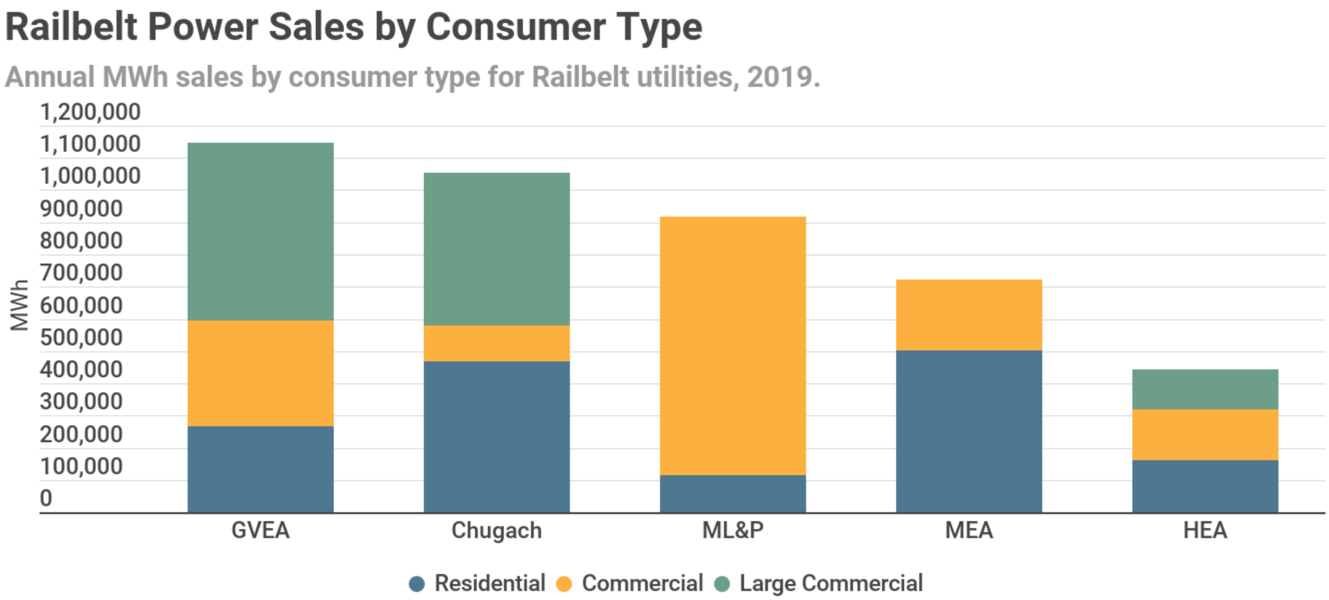

Figure 32: Railbelt Power Sales by Customer Type.
Source: RCA, 2019

Average rates for electric service also vary. Rates for all of the utilities are higher than the U.S. average. Figure 33 compares average residential rates for Railbelt utilities.

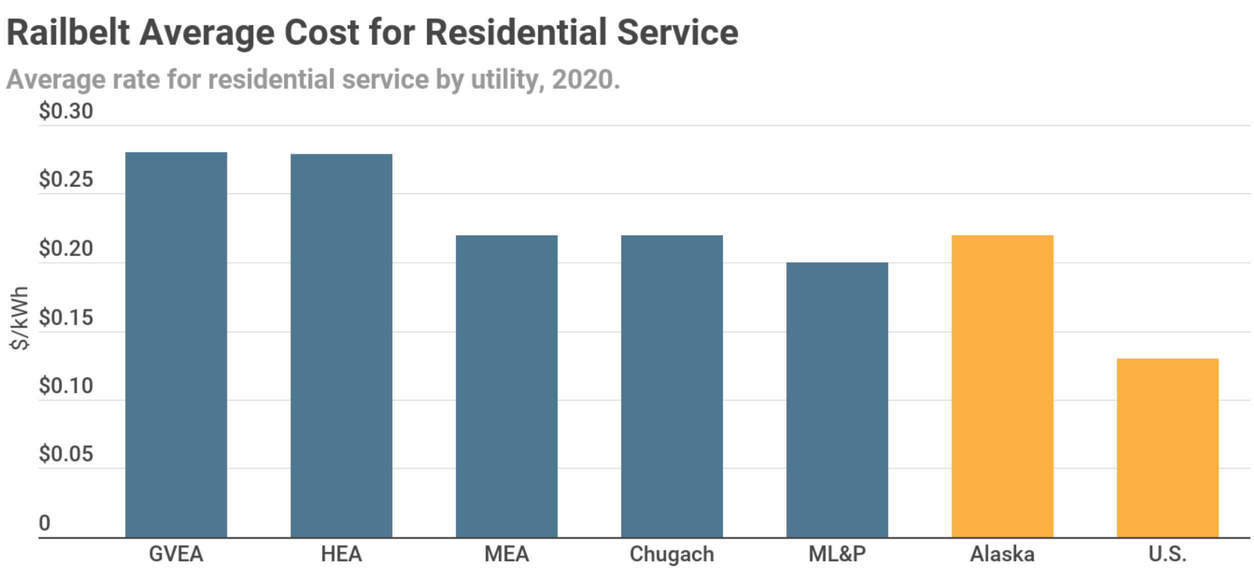

Figure 33: Railbelt Average Rates for Residential Service.
Source: RCA, 2019.

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. It is clear that 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, but the ERO will play an important role on the Railbelt. 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.[63] Energy storage solutions are being implemented across the Railbelt, but it is unlikely that renewable energy assets will be able to fully replace base load needs. Therefore, the question of diversification of energy resources is a recurring theme.

Cost: As regulated utilities, the Railbelt utilities act under requirements to minimize costs to consumers.[64] 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 microreactors would have to comparable.

Microreactor Themes and Perspectives

Given that full replacement of fossil fuels through renewable integration remains unlikely, nuclear technology may provide one of the few non-carbon alternatives for energy on the Railbelt to fully offset hydrocarbon usage. Furthermore, studies show that Cook Inlet natural gas production has been declining since the mid-2000s and projections show continued declines in production, which may lead to further incentive to seek alternatives to natural gas resources.[65] Figure 34 shows Cook Inlet natural gas production from 1981 to 2020.

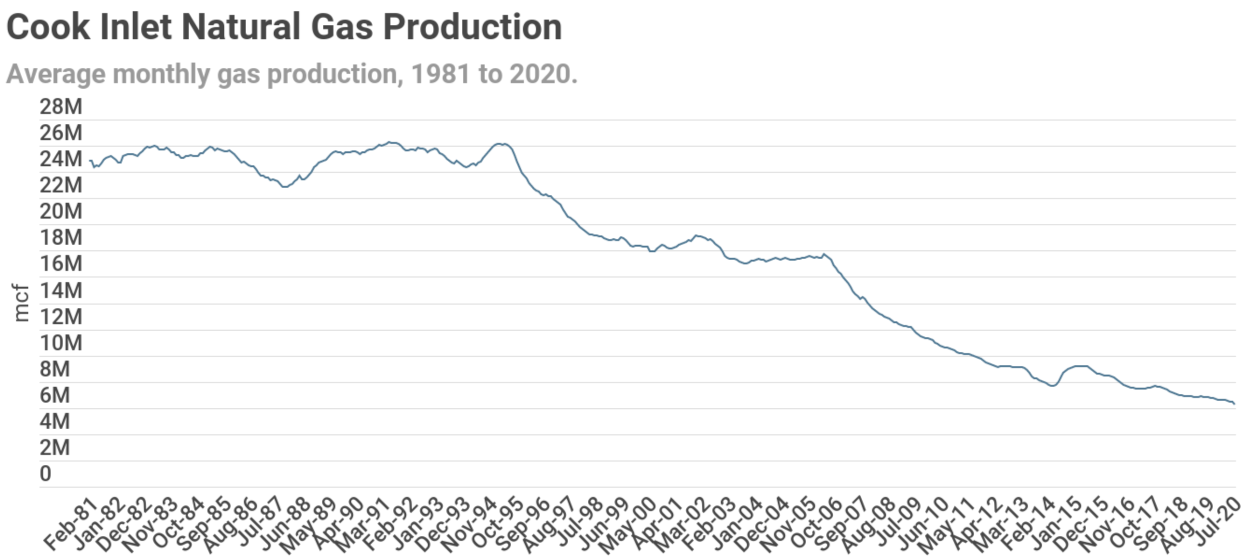

Figure 34: Cook Inlet Natural Gas Production.
Source: Alaska Oil and Gas Commission, 1981-2020.

With its relatively heavy dependence on fossil fuels and consistent base load, it would seem that installation of a microreactor on the Railbelt would offer some of the necessary characteristics of a first user of the technology. To start, the technical capacity of the utility workforce across the Railbelt could enable running and troubleshooting as it moves from initial deployment to wider market adoption. However, cost and public perception are not yet certain.

From the perspective of determining initial users of microreactors, both ends of the Railbelt, in the north and south, have stronger motivation to take actions toward diversification and system resiliency. Both have a higher risk of becoming islanded in the case of a weather event or natural disaster, having to operate solely on their own resources and driving costs higher.

Interviews were conducted with Railbelt utility operators and the results indicated that to fit in the urban Alaskan landscape, microreactors will need to have technical characteristics which include:

- Design specifications accounting for high levels of earthquake activity.
- Comparable or lower cost per kWh produced than the operating norm.
- Siting and security requirements matching the physical land availability and local population density.

Energy stakeholders noted that public perception around microreactor technology is unknown, and a robust education and outreach program could be necessary to ensure public buy-in. However, proven and tested specifics on microreactor operation characteristics, which could ensure both energy stakeholder and public comfort with the technology, remain unknown. These variables could include:

- A robust understanding of lifetime costs and operational processes.
- Established plans for the life of the reactor: including installation, fueling, and disposal.
- Clear processes for fuel transportation and disposal.
- Emergency preparedness and disaster mitigation planning.
- Processes for technology support and system repair and maintenance.
- Understanding of federal and state regulatory requirements.

Use Case: Railbelt Integration

Business models for microreactor integration in urban Alaska could vary. In addition to utility integration, there have been some discussion of integration and operation by an IPP. The model examined here is a microreactor integration by an established utility.

Given the age of existing generation assets, current fuel sources, and power costs, GVEA was used as a hypothetical example, with the Fairbanks North Star Borough (FNSB) serving as the primary setting to analyze workforce, demographic, and other contextual characteristics. System characteristics and microreactor themes which could impact a potential urban technology integration were examined to develop a more robust understanding of the factors which could impact integrating microreactor in an urban Alaskan setting.

Region and Climate

GVEA sits at the northern end of the Railbelt system. GVEA's service area is located in interior Alaska. The transmission system extends from 48 miles north of Fairbanks, south to Cantwell, and east to Delta Junction and Fort Greely. The utility manages over 3,000 miles of transmission line and serves 100,000 customers.

The Interior region is characterized by a continental climate zone, with extreme temperature variation. Winters are extremely cold and summers are hotter than the state average. The average daily low in January is -15 degrees Fahrenheit, but -40 degrees is common.[66] The Fairbanks area has historically struggled with air quality issues in the winter related to wood stove home heating use, burning of fuel oil, and industrial energy users contributing to high levels of particulate pollution exceeding EPA maximums.[67]

One result of the extremely cold seasonal climate is high demand for thermal energy and limited access to economical fuel sources like the natural gas enjoyed in most of Southcentral Alaska.

Demographic and Economic Characteristics

Located in the FNSB, GVEA has access to the second largest workforce in Alaska. In FNSB specifically, not including the surrounding areas, average monthly employment was 38,000 jobs in 2019. The utilities sector (which includes the electric utility) employs 396 individuals. [68]

The median household income is $77,000, slightly higher than the statewide median household income of $76,000. Figure 35 compares FNSB educational attainment to statewide averages. Twenty-two percent of the population is 25 and older has a high school diploma. A further 20 percent of the population 25 and older has a bachelor degree.[69]

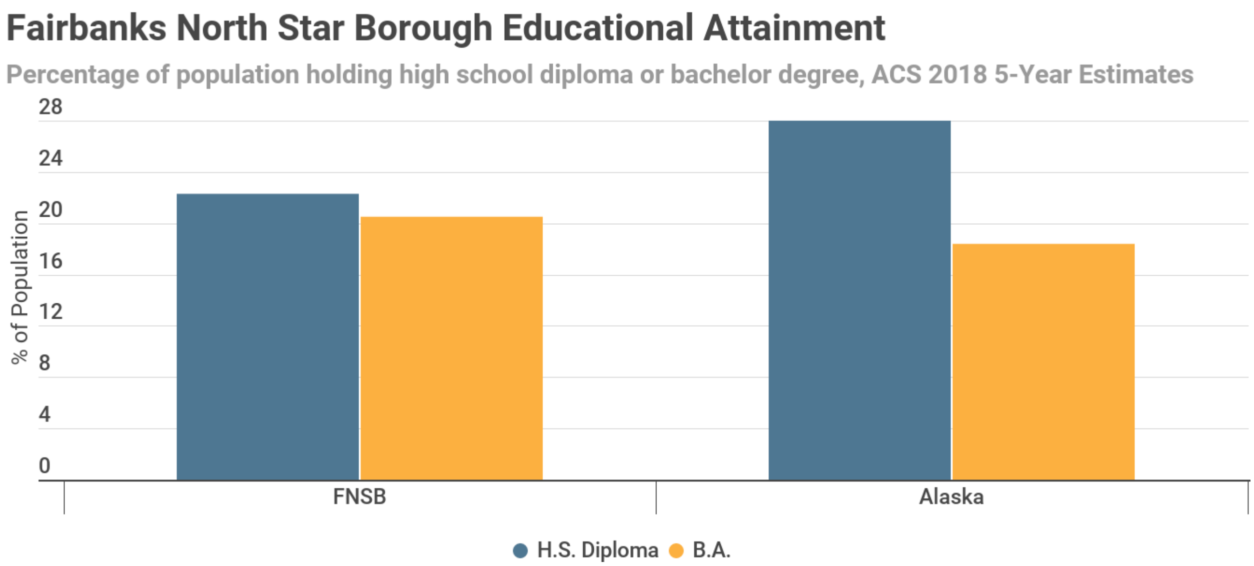

Figure 35: FNSB Educational Attainment.
Source: ACS, 2018 5-Year Estimates.

FNSB hosts one of the three University of Alaska campuses. The university hosted 2,400 students and 544 faculty in fall 2019. The university offers 139 degree programs and 37 certificates in 112 disciplines. Mechanical engineering ranks among the top six degree programs for incoming first-year students.[70]

Eight percent of the population is estimated to live below the poverty line, which is lower than the statewide average of 10.4 percent.[71] Figure 36 compares FNSB cost burdened rates to statewide averages. Housing costs are high and energy costs represent a large portion of household expenditures.

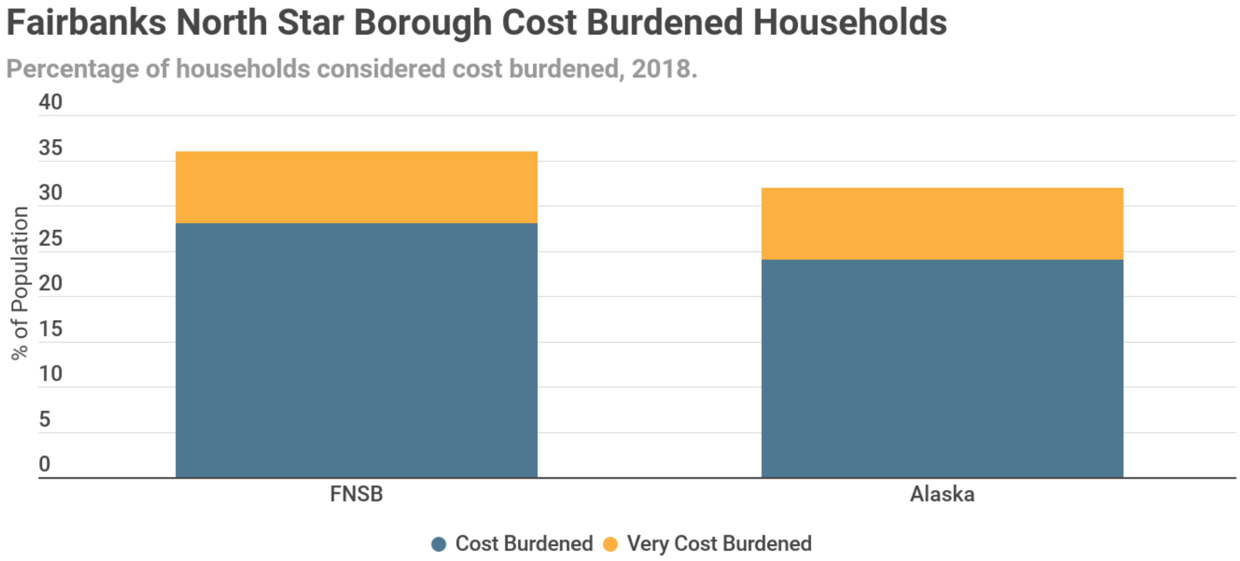

Figure 36: Cost Burdened Households in FNSB.
Source: Alaska Housing Finance Corporation (AHFC), 2018.

Energy Systems

Electric

The local utility operates a variety of assets which vary in age and fuel source. Current utility operated generating assets include 296 MW of installed capacity with an additional 70 MW of additional capacity available from the Railbelt. GVEA's generating assets include:[72]

- 41 MW diesel power plant, est. 1972,
- 27 MW diesel power plant, est. 1976,
- 60 MW Naphtha power plant, est. 2006,
- 120 MW diesel power plant, est. 1976,
- 25 MW wind farm, est. 2012,
- 28 MW coal power plant, est. 1967,
- 50 MW coal power plant, est. 2016,
- 567 kW Solar PV system, est. 2018.

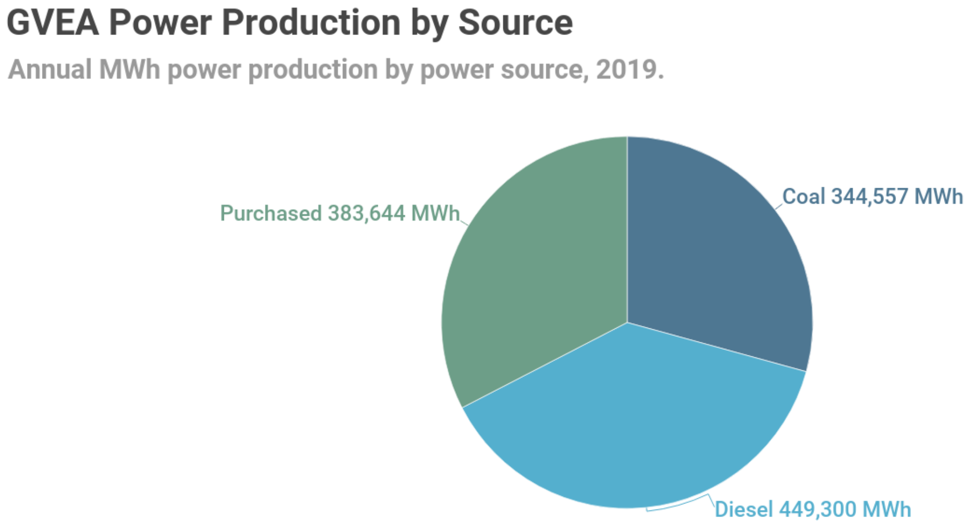

Figure 37: GVEA Annual Power Production by Generation Source.
Source: RCA, 2019.

Figure 37 presents the breakdown of MWh by source. The utility also purchases 27 MW of power from IPPs and owns a 17 percent share in the Bradley Lake Hydroelectric Project, which provides an additional 20 MW of hydro power. GVEA also operates a BESS which can provide 27 MW of power for 15 minutes.

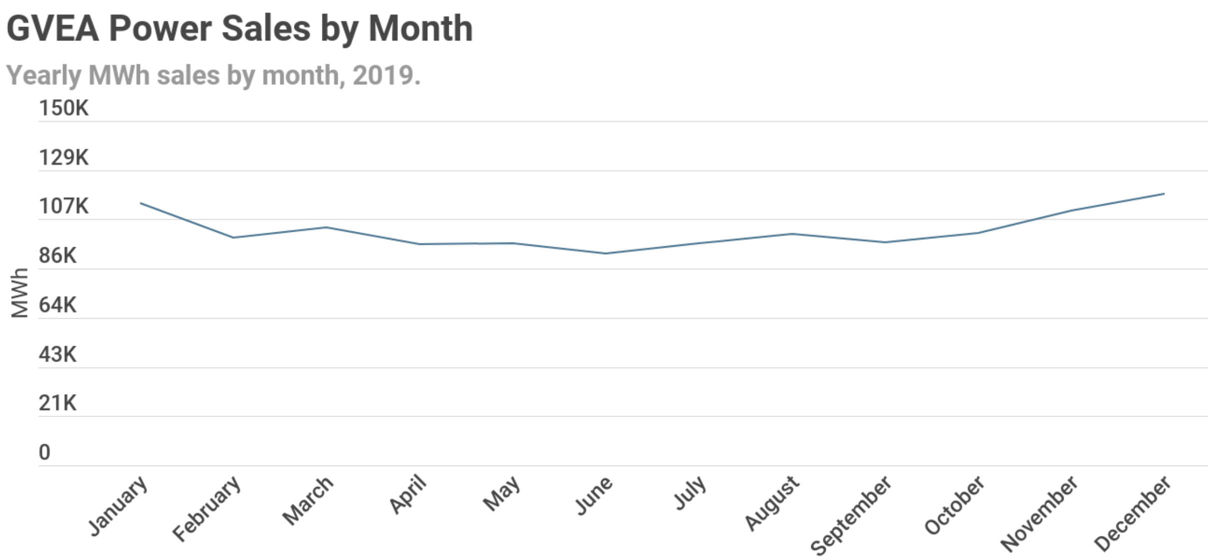

Figure 38: GVEA Annual Energy Sales by Month.
Source: RCA, 2019.

Figure 38 shows GVEA sold 1.2 MWh in 2019, providing service to 44,800 meters.[73] Over the last five years GVEA's sales have declined.[74] Figure 39 shows GVEA power sales from 2014 to 2019.

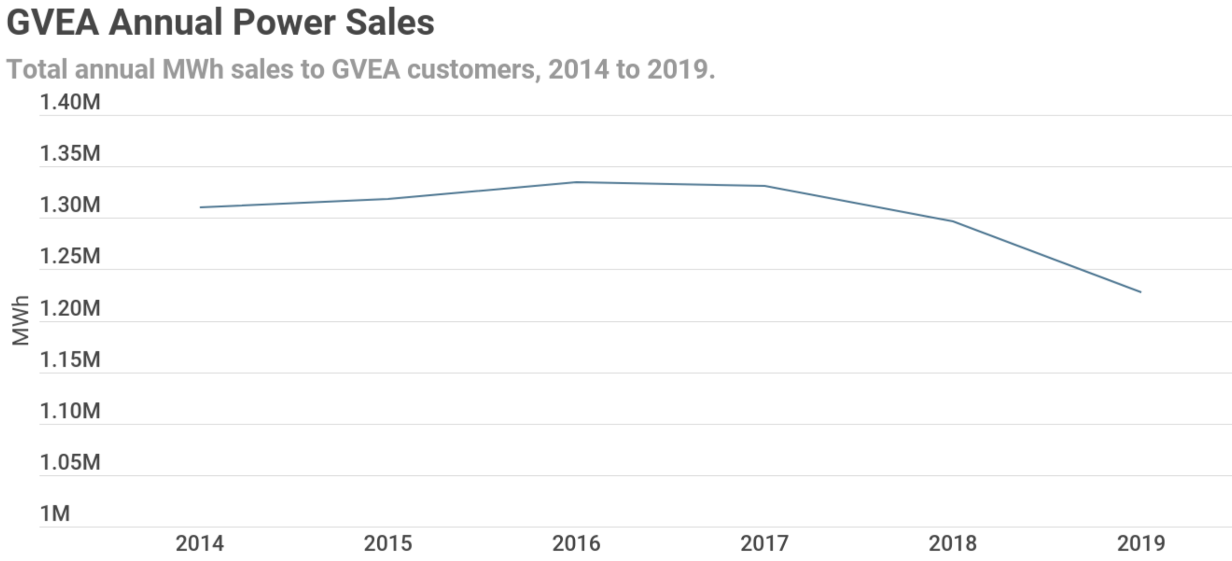

Figure 39: GVEA Power Sales by Year
Source: RCA, 2014-2019.

The system is interconnected with the University of Alaska Fairbanks (UAF) campus, Eielson Airforce Base, Fort Wainwright, Fort Greely, Pogo Mine, Fort Knox Mine, the Trans-Alaska Pipeline, and two refineries. UAF, Eielson Airforce Base, and Fort Wainwright all have generating capabilities of their own, but still draw power from GVEA's system when needed. Each of these large users have energy needs and demand characteristics which are unique and separate from the demand characteristics of residential and business customers.

Heat

Heating sources throughout FNSB are varied. A district heat loop is operated by Aurora Energy, powered by waste heat from power sold to GVEA. Outside of that, residences and businesses are heated with a mix of wood, fuel oil, electricity, and in a limited number of cases, natural gas.[75] Figure 40 shows FNSB home heating fuel usage by fuel type. In the winter, FNSB struggles with air quality issues, mostly caused by inefficient wood heating, fuel oil, and industrial sources.[76] A natural gas storage facility became operational in Fairbanks in 2019, supplied by liquified natural gas (LNG) trucked from Cook Inlet. However, a limited number of homes and businesses are currently connected to the gas distribution grid. Infrastructure to support greater utilization of natural gas should gradually be built in the coming years.[77]

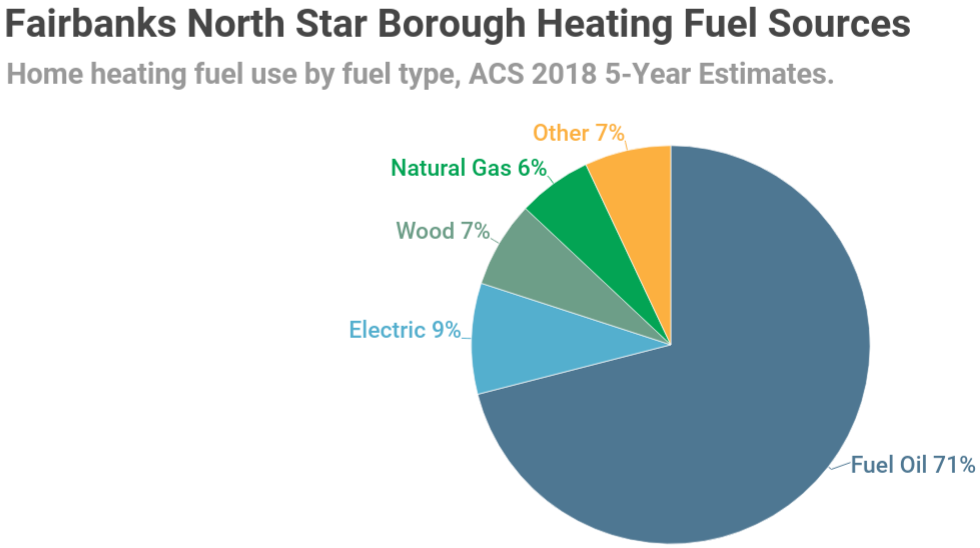

Figure 40: FNSB Household Heating by Fuel Type.
Source: ACS, 2018 5-Year Estimates.

Heating fuel and propane were reported to cost $3.20 and $3.99 per gallon, respectively.[78] With the extreme winters in the Interior, heating degree days are high at 13,815.[79] A 2019 analysis showed that homes in the FNSB which heated with fuel oil spent an average of $2,274 annually to heat their homes.[80]

Energy Technology Market Drivers

As a regulated energy cooperative, GVEA is accountable to its elected board of directors and federal and state regulatory agencies, and, therefore, is expected to adhere to set standards and statutes set by those bodies.

Key concerns for the Railbelt utilities include: cost, reliability, and decarbonization, all of which drive operational and technological decisions. As a regulated utility, costs are one of the clearest drivers of decision-making processes. Utilities are statutorily permitted to set rates at a level which recovers allowable costs with a determined rate of return. Decisions about generation technology are made through considering the upfront capital costs and long-term operations and maintenance costs and fuel costs (if applicable).

Reliability is a major going concern for regulated utilities. Provision of reliable, consistent power is a priority. Reliability is two-fold: generation and transmission. Utilities must ensure that there is no lapse in supply to meet to demand. New technologies must be integrated into the existing system and be designed to fit the existing infrastructure and demand characteristics.

Railbelt utilities have identified decarbonization and diversification of generation assets as a goal over the near term. All of the Railbelt utilities have invested in exploring and implementing renewable energy systems: Chugach purchases power from Fire Island Wind, LLC, a.17.6 MW wind farm, GVEA has invested in a small 563 kW solar PV system and operates a wind farm, and HEA continues to investigate utility scale solar and landfill gas energy projects. The challenge associated with renewable energy sources is variability. There are fewer options for offsetting the baseload provided through fossil fuels.

Market Fit for Microreactors

Technical capacity and system fit

Any one of the Railbelt utilities have characteristics which would be necessary in a first adopter of microreactor. The technical capacity of the utilities on the microgrid allow for testing and diagnosing early stage advanced technology. In addition, each of the individual utilities are of large enough scale to integrate an asset of 1 to 20 MWe size without overhauling the entire system. Furthermore, drivers toward system diversification and de-carbonization show a vested interest in adopting advanced generation technologies. However, other factors such as cost and public perception could play a stronger role in technology decision making.

Specifically, GVEA contains the above-mentioned attributes in addition to experiencing higher costs. GVEA is reliant on aging coal- and diesel-powered systems and can only purchase natural gas-generated power through other utilities in limited supplies as they must serve their own rate-payers. GVEA's coal generation assets are co-located with the only coal mine in Alaska, making GVEA dependent on a single fuel source for almost a third of the power supply. Coal is subject to increasing regulations and an uncertain market. Given comparative or cheaper costs, microreactors could play a role in replacing aging assets and diversifying the utility's energy mix.

Local workforce is another component of system fit. Local labor should have the capacity to operate or be trained to operate a microreactor in adherence to the regulatory requirements. Operational requirements remain an unknown and will likely be established by the NRC. However, with access to a diverse workforce, an urban utility like GVEA would likely be able to meet those requirements with more ease than rural utilities.

Ownership Models

There are a number of ownership models for integration which could provide varying levels of technical fit for nuclear reactors: utility operation and integration and power purchase agreement with commercial operators are two of the more likely scenarios. Table 17 compares the advantages and disadvantages of microreactor ownership models

Ownership Model	Advantages	Disadvantages
Utility operation and integration	• System control • Potential retention of local hire	• Need for retraining and access to qualified workforce. • Additional regulatory liability • High upfront costs.
Power purchase agreement	• Reduced operational liability • Potential costs spread over lifetime of reactor	• Limited community and utility control. • Limited community control • Potentially fewer savings to the rate payer.

Table 17: Microreactor System Ownership Models.

Financial Fit

The cost of power across the Railbelt is low compared to much of Alaska. The average residential rate ranged from \$0.21/kWh to \$0.28/kWh across the five Railbelt utilities in 2019. The average price per kWh for GVEA residential customers was the highest on the Railbelt at \$0.28 per kWh in 2019. Only a portion of that includes variable cost which could be replaced. For example, Figure 41 shows that costs associated with power generation and maintenance made up 68 percent of GVEA's costs in 2019. The remaining 32 percent of GVEA's annual costs are made up of costs associated with transmission, distribution, depreciation and taxes, and administration.[81]

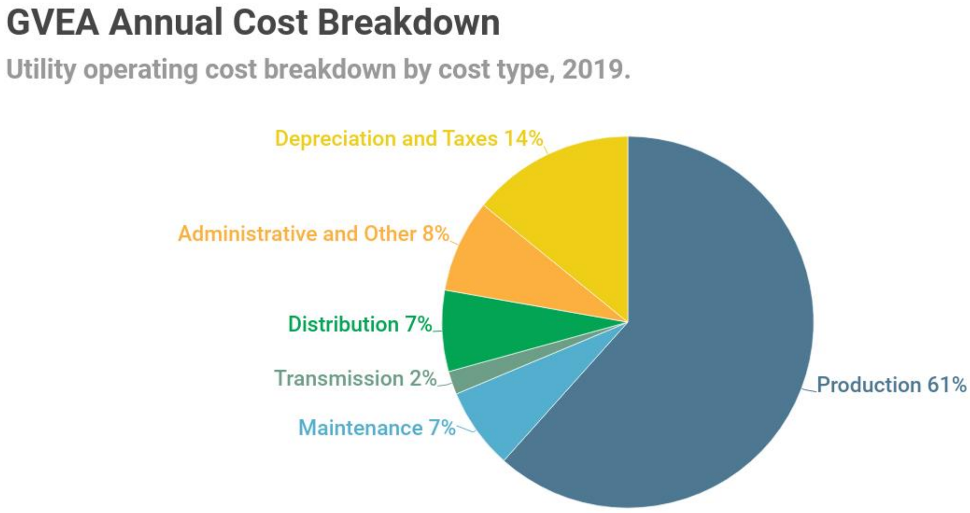

Figure 41: GVEA Annual Costs.
Source: RCA, 2019.

While the comparison of rates and annual costs does not directly translate to cost per kWh for microreactors, a discussion of GVEA's average rates and annual costs does serve as a benchmark. Many costs, including those associated with the operations and maintenance of generation assets, would not be offset with microreactor generation.

There is little published cost information on the cost per kWh to provide a robust analysis for the financial fit, but initial analysis performed by 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.

Rudimentary financial modeling using information published by NEI and Alaska energy data, shows that the financial fit of microreactors in remote markets will be sensitive to upfront capital costs and refueling frequency and costs.[82] Financial data on microreactors is still undeveloped, making a thorough analysis for the hypothetical community difficult; however, understanding the key variables helps to reveal potential barriers to technology adoption.

Access to capital to fund large infrastructure projects or even to fund refueling is not a challenge experienced by GVEA to the same degree as smaller rural utilities. However, with lower costs than many rural Alaskan communities, an urban utility like GVEA will be more sensitive to the margins, making other variables such as operations and maintenance costs, and cost of financing more critical.

Perception Fit

Feedback from interviews with energy stakeholders and utility operators across the Railbelt showed that while there was mutual agreement from energy specialists that while microreactor could offer a viable energy alternative, public perception could be a hurdle. Themes in public perception toward nuclear energy are likely to be similar in Alaska as across the U.S. Public awareness over the examples of the worst possible scenarios (i.e. Fukushima and Chernobyl) is likely high, even though microreactors are lower risk than conventional reactors.

There are two questions critical to perception and microreactors. First, does perception of microreactors vary from traditional nuclear energy? Second, does perception around nuclear in Alaska differ from the nation as a whole? Information on public perception specific to Alaska is limited to qualitative observations from interviews, making the second question difficult to answer without a robust investigation. However, some studies on nuclear public perception are beginning to include perspectives around small modular and microreactors, lending some perspective to the first question.

National survey results from the University of Oklahoma Center for Energy, Security and Society (UO) show that 42 percent of individuals find small modular reactors safer than traditional nuclear reactors once the technology is briefly explained to them. Perceptions around siting is another critical study area, with many individuals adopting a “not in my backyard” attitude. Results showed that 47 percent of survey respondents supported small nuclear reactors for civilian usage and 51 percent supported siting on military bases.[83]

UO notes that one of the challenges around public perception of emerging energy technologies is education on the technology and differences from traditional energy. Survey reliability is dependent on the ability of respondents to give informed responses.[84] Similar themes were expressed by energy stakeholders in Alaska, noting that the large number of unknowns influence perception at the technical level and among the general public. In interviews, energy stakeholders noted more comfort with the technology but expressed concerns around perception from the broader public.

Energy stakeholders throughout the interview process noted that public acceptance of a nuclear project could require a broad and thorough education program. Areas of education suggested included understanding of the technology and its difference from traditional nuclear, understanding the environment and physical security risk and mitigation measures, cost differences, carbon offset, and more.

Railbelt Energy Producer Value Propositions

Current Value: • Heavy dependence on fossil fuels. • Availability of workforce and technical skill sets. • Existing energy capacity allowing for testing of new tech without complete reliance. • Strong support of movement away from fossil fuels and energy diversification. • Consistent base load with key industrial sources.	**Barriers:** • High cost per kWh. • General attitudes toward nuclear among the public (co-op model) and not in my backyard mentality. • Concerns over external environmental issues (i.e. earthquakes). • Undetermined regulatory hurdles and security requirements.
Future Opportunities: • Electrification of transportation systems. • Distributed district heating. • Electrification of heating systems.	**Challenges:** • Regulatory obligations to keep costs low. • Overbuilt new capacity across the Railbelt system. • Declining demand.

Table 18: Railbelt Energy Producer Value Propositions

Remote Mining Installations

Mining operations represent some of the largest single industrial power users in Alaska. Currently, operational mines are located across Interior, Southeast, and Northwest Alaska, while a number of proposed mines at various stages of exploration and permitting could be located across the state. Mining operations are energy intensive, with large power, heating, and transportation loads needed to accommodate mining and processing. Even when connected to an external power grid (not a given), mines must have redundant power capacity and be capable of self-generating to ensure a constant supply of power. Table 19 compares the installed power capacity of Alaska's metal mines.

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

Table 19: Alaska Mining power Capacity.
Source: Council of Alaskan Producers, 2010; Donlin Gold, 2016; The Pebble Partnership, 2018.

Alaska's major mines produce gold, silver, lead, zinc, and coal. Proposed mines could produce rare earth elements, graphite, gold, silver, copper, zinc, barite, and molybdenum. Alaska also hosts over 200 small placer mines which produced 41,000 lbs of gold in 2019.[85]

Table 20 shows of the six major currently 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 producing mines, 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. Figure 42 maps the installed capacity of operable mines across Alaska.

Producing and Advanced Permitting Mines in Alaska		
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 20: Producing and Advanced Permitting Mines in Alaska.
Source: Alaska Mining Association, 2020.

These remote mines are the focus of this analysis; however, the energy loads of Fort Knox, Greens Creek, and Pogo are also used to assess the energy demands of the mining industry. Usibelli coal mine is excluded as a result of the mine's power and heat demand being served by the mine's production of a usable fuel source. It is assumed that, while a microreactor could be located at an interconnected mine for redundancy, the value propositions would likely differ.

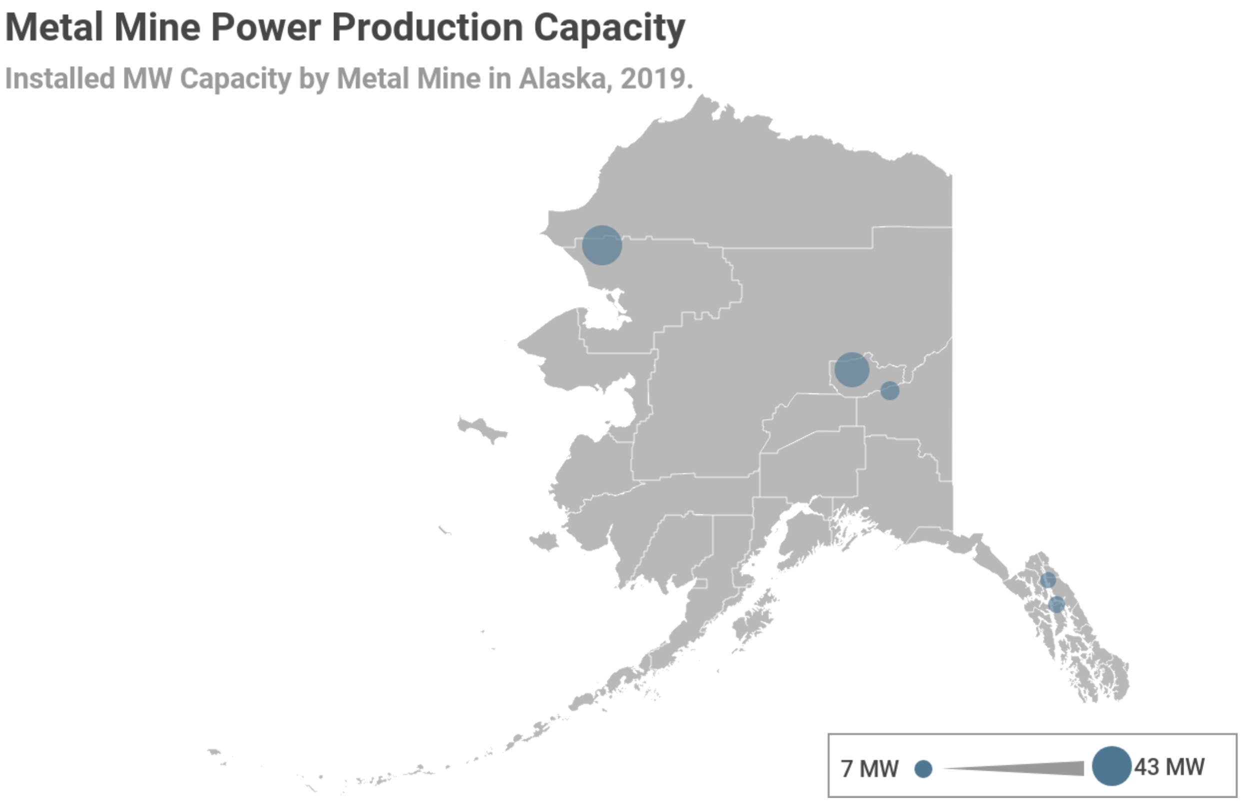

Figure 42: Hub Installed Power Capacity.
*Source: Energy Information Agency (EIA), 2019. *Note: This map does not show Usibelli.*

Population and Demographics

As a remote industry installation, and not a community setting, mine population and workforce characteristics are largely homogenous—the demand is driven by operational need and the 'population' served are the workers who commute to the site for their shifts. Current operational mines represent large employers in Alaska. The mining industry in total contributes 4,600 jobs to the Alaska economy, with an average annual wage of $112,800.[86]

As a result of the remoteness of the mining industry and the mining operations schedule, mining employees are sourced from across the state and from the contiguous U.S. An expressed effort is made by some mines to hire employees from within given regions of the state. For example, Donlin Gold has committed to a 90 percent local hire threshold for operations and has developed training programs, scholarship programs, and internships to promote mining jobs for regional residents and shareholders of the regional Alaska Native Corporation (ANC), Calista Corporation.[87] The Red Dog Mine, owned by another ANC, NANA, commits to a goal of 100 percent shareholder hire for NANA shareholders.[88]

Current Energy Systems

Electricity

Alaska's remote mines energy systems vary in size depending on mine production and all are entirely or partially powered by diesel fuel. Table 21 compares the installed power capacity at metal mines in Alaska. Red

Dog mine in the Northwest Arctic Borough has the largest power system of the currently producing remote mines, with 43 MW of electric generation capacity. Proposed mines in the advanced permitting stages are expected to require larger energy capacity. Pebble has proposed installing 270 MW of generation capacity fueled with Cook Inlet Natural Gas to meet the mine's expected energy needs.

Mining Self-Generation Installed Capacity	
Mine	**MW Capacity**
Producing	
Red Dog	40
Greens Creek	11.25
Kensington	10
Fort Knox	N/A
Pogo	N/A
Advanced Permitting	
Donlin Gold	228.6
Pebble	270

Table 21: Mining Self-Generation Installed Capacity.
Source: Teck, 2017; Hecla Mining Company, 2019; Coeur Mining, 2018; Donlin Gold, 2016; The Pebble Partnership, 2018.

Publicly available energy cost information is limited. Estimates from 2010 note that Red Dog used 15,500,000 gallons of fuel annually for power production.[89] Table 22 compares diesel fuel consumed for power production. Cost per gallon of fuel delivered to remote areas varies depending on the market price, bulk purchase discounts, and delivery conditions.[90] The cost of power on a per-kWh basis is not currently available, but the ability to buy fuel in bulk means power costs are lower than for rural villages, and likely similar to larger rural hub communities due to similarities in scale of power production. On this basis, a reasonable estimate of power costs for a diesel-dependent remote mine might be between $0.20 and $0.35 per kWh.

Producing Mine Fuel Consumption for Energy Production	
Producing Mines	**Estimated Fuel Consumption for Power Production (Gallons)**
Red Dog	15,500,000
Greens Creek	1,400,000
Kensington	900,000
Fort Knox	N/A
Pogo	N/A

Table 22: Producing Mine Fuel Consumption for Energy Production.
Source: Council of Alaskan Producers, 2010.

As shown in Figure 43, using available data and estimates of power productions from annual diesel fuel usage, it is estimated that producing Alaskan mines use between 2,800,000 and 146,680,000 kWh of self-generated, diesel fueled power.[91] In addition to self-generating, Green Creek purchases power from Alaska Electric Light and Power (AEL&P) in Juneau, which is not shown in the figure below.

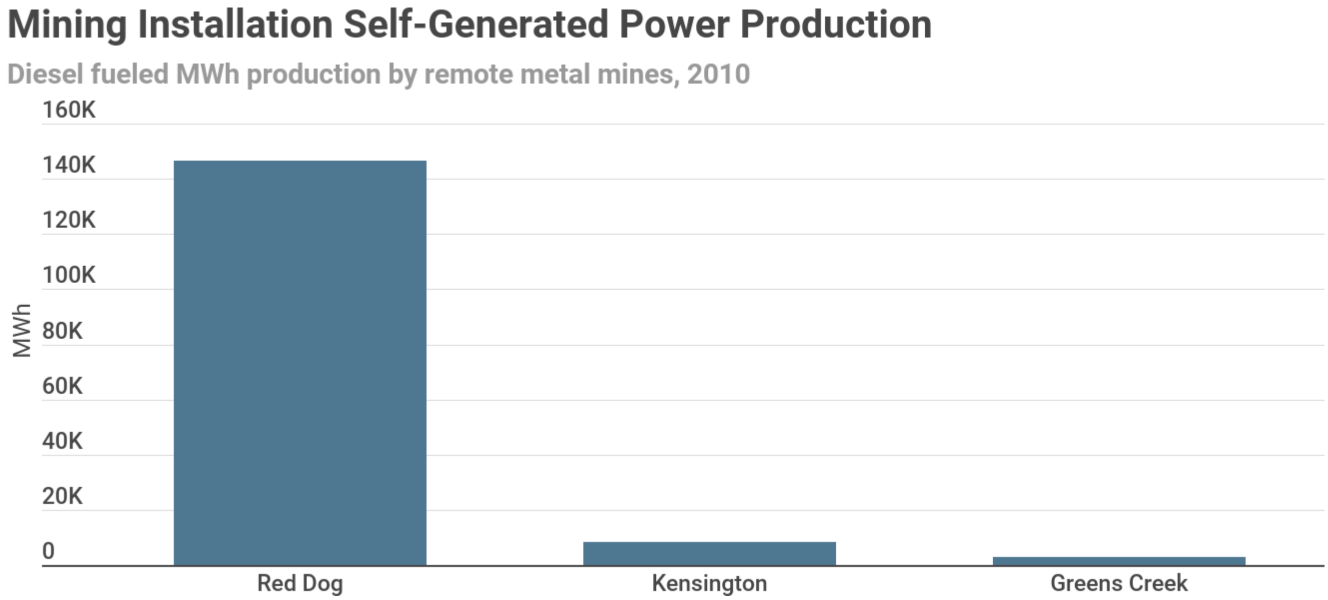

Figure 43: Remote Mines Self-Generated Diesel kWh Produced.
Source: Council of Alaskan Producers and CED Calculations, 2010.

The current mines that self-generate power own and operate the generation infrastructure which is powered by diesel fuel. Proposed mines, Donlin Gold and Pebble, are expected to self-generate electricity using natural gas delivered by pipeline. There is limited publicly available data on the operational costs associated with mining industry power production, like distribution, maintenance, transmission, and overhead costs.

Heat

Mine heating needs are largely focused on space heating for buildings. Heating demand at currently producing mines are 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 44 compares diesel fuel consumption for non-power mine operations

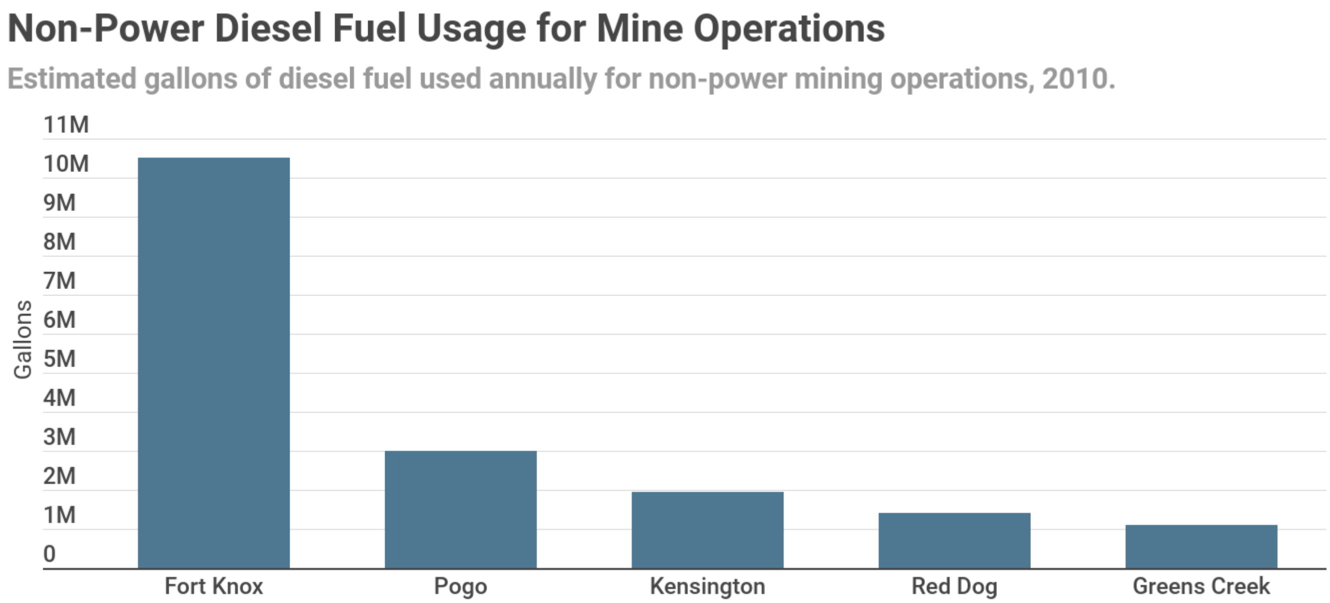

Figure 44: Gallons of Diesel Fuel Used for Remote Mine Operations
Source: CAP, 2010.

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.[92]

Mining in Alaska is conducted largely in isolated, harsh conditions, driving heat and transportation costs up. Similar to mining power costs, the actual dollar amount associated with heating and transportation usage is unavailable; however, if nearby communities are used as a benchmark, cost per gallon for fuel could range between $3.42 per gallon (Fairbanks) to $3.75 per gallon (Kotzebue) or higher. Bulk purchasing likely somewhat reduces costs for mines.

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.[93] Mining operations require flexibility and one way for this to be expressed it through energy production. An example of this is Greens Creek mine in southeast Alaska. The mine formerly self-produced power; however, the lower cost and availability of adjacently located hydroelectric power led to the mine interconnecting 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.[94]

During the planning stages of a mine, energy sources are a key operational and financial consideration. As an example, energy planning for the 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 were determined to not meet the expected needs of the project cost effectively.[95]

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 Burden:** Mines are subject to regulatory oversight by state and federal agencies, predominately in areas of environmental management. Energy infrastructure is expected to compliment 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.[96] 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 heavy 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.[97] Energy infrastructure is one example of this. Energy technology can be used as a tool for distributing local or environmental benefits, but can also be an area of scrutiny by interest groups.

Microreactor Themes and Perspectives

With their high cost of power, access to workers, scale of production, constant power load, and addition energy needs, mining sites could be a candidate for an initial customer of micronuclear technology. Likely for these reasons, representatives of mining companies have shown early interest in microreactors through stakeholder sessions held in Alaska in 2019 and 2020.

However, mining industry representatives and experts have noted that the early stage of microreactor and undetermined variables, predominantly in the permitting processes, make incorporating early stage energy assets into the planning process for mine development difficult.[98] While accustomed to working within regulatory frameworks, unknowns in the NRC permitting process create another layer of complexity for mine operators which they may be resistant to navigating.

Interviewees noted that the current level of regulatory oversight and public scrutiny could create a barrier for implementing nuclear technology. These factors all impact costs associated with developing and operating a mine. Microreactors are still in the technology testing stages; therefore, clarifying unknown variables will be critical for motivating customers. Factors to consider could include:

- A robust understanding of lifetime costs and operational processes.
- Established plans for the life of the reactor: including installation, fueling, and disposal, and associated costs.
- Clear regulatory process for permitting and operating system at state and federal levels.
- Costs associated with fuel transportation and disposal.
- Emergency preparedness and disaster mitigation planning.

An additional concern for mining companies, as with other power users, is public perception. As the high-profile examples of Pebble and Donlin show, mine development can stir public controversy over environmental concerns like potential damage to watersheds. If microreactors are perceived negatively by nearby communities, mine developers will be hesitant to adopt the technology. Conversely, if they are perceived in a more positive light (since they do not require spill-prone diesel or contribute to reduced air quality), mine developers may be encouraged to use the technology.

Use Case: A Hypothetical Proposed Mine

Consider a proposed mine in western Alaska. The region is largely unpopulated compared to urban Alaska, but is home to over 30 communities in 100 mile radius. The residents of the communities are predominantly Alaska Native and subsistence activities play an important role in the lives of many residents. The region is remote and communities lack connection by road to each other and to the rest of the state.

Energy costs in the region are high, related to remoteness and logistics. Communities are mostly dependent on diesel fuel for power and heat. The region is known for its wealth of wind resources and a growing number of communities operate wind-diesel hybrid systems.

The proposed mine is developing a feasibility study, considering its energy options for power, heat, and transportation. Mine operators are assessing a number of options, including: diesel, hydroelectric, natural gas, other renewable resources, and nuclear.

Mine Operations

The proposed mine is in the advanced exploration stages and is located on a landholding of approximately 150,000 hectares owned by the regional ANC. The deposit includes copper, zinc, gold, and silver mineral resources. The mine has an expected life of 15 years. Table 23 shows estimated annual value of mine production.

Estimated Annual Mineral Production and Value		
Metal	**Annual Estimated Production ('000 lbs)**	**Estimated Value**
Copper	160,000	$480,000,000
Lead	35,000	$35,000,000
Zinc	200,900	$220,990,000
Silver	4,000	$72,000,000
Gold	35,000	$45,500,000,000

Table 23: Estimated Annual Mineral Production and Value.

The proposed mine is an open pit mine located 30 miles inland. A port facility will need to be built with a road connecting the mine. Operating costs are estimated based off the ton milled, $50 per ton milled. Table 24 maps out estimated operating and capital cost.

Proposed Mine Operating and Capital Costs	
On-Site Operating Costs*	**$/ton milled**
Mining	$21.00
Processing	$21.00
General and Administrative	$5.00
Surface Service	$3.00
Total	$50.00
Capital Cost	**Total**
Initial Capital	$910,000,000
Sustaining Capital	$115,000,000
Mine Closure and Reclamation	$200,000,000
Total	$1,225,000,000

Table 24: Proposed Mine Operating and Capital Costs.
**Note: Costs do not include energy costs.*

The mine is expected to operate daily year-round without interruption. Early estimates determined that 1,500 individuals will be employed at the site during the operations stage. The mining site plan includes extensive housing facilities to house mine employees, office buildings, a milling and processing facility, port, airstrip, and water treatment plant.

Region and Climate

Western Alaska is one of the most remote regions of the state. Bordering the Bering Sea, the region roughly stretches from the Aleutian Islands in the south to the Bering Strait in the north. The climate in the region ranges from transitional to sub-arctic, with tundra patchworked with boreal forest covering much of the landscape.

The proposed mine discussed here is in the sub-arctic zone off the coast of the Bering Sea. The mine is located in an area with permafrost. Historically sea ice covers the coast in the winter, although ice thickness and coverage has been decreasing in recent years.[99] Residents of region have been experiencing the immediate impacts of climate change through sea ice change, coastal erosion, and permafrost melting.

Energy System

Electricity

The operational norm for mines in remote areas is diesel-powered electrical systems. The mine operators of this hypothetical proposed mine estimate a 150 MW(e) system will be needed to meet peak production.

Mine plans include a port facility, large bulk fuel tank farm, milling and processing facilities, a water treatment plant, and housing and office space. Table 25 shows that to meet energy needs, it is estimated that energy costs will total $350,000,000 annually, assuming diesel consumption for power production of 58,574,000 gallons annually at a cost of $3.00 per gallon.

Proposed Mine Power Characteristics	
Peak Capacity (MW)	150
Diesel Fuel for Power Production (Gallons/Year)	58,574,000
Power Production per Ton (kWh)	261
Total Annual kWh Production (kWh)	554,317,000

Table 25: Proposed Mine Power Characteristics.

Heat

Depending on the energy technology implemented, the proposed mine expects to utilize waste heat for space heating purposes. Space heating needs include: housing units, office space, materials handling and processing facility, and water treatment facility. Size and space requirements are yet to be determined.

Transportation

The proposed mine will have large transportation requirements for the mine site and for material transportation to the processing facility and port. It is expected that those needs will be met with traditional diesel and gasoline machinery. However, electric vehicles are being considered depending on the energy source established for power production and relevant costs.

Energy Technology Market Drivers

Key energy concerns for the mine planners include: cost, regulatory burden, and flexibility, all of which drive technological decisions. In a region where costs of energy are high and fuel costs are variable, costs are one of the clearest drivers of decision-making processes. Operational costs directly impact the profitability of the mine, and energy costs encompass a large portion of total operations. Decisions about generation technology are made through considering the upfront capital costs and long-term operations and maintenance costs and fuel costs (if applicable) of generation technologies.

Regulatory Burden: Regulatory oversight on mining project creates the need for intensive project planning and communication. Mining projects require an average of 10 to 15 years to move through the planning and permitting process, and the hypothetical proposed mine discussed here expects to adhere to that schedule. As a result, unknowns in planning process can cause barriers and delays in mine construction and add costs.

Flexibility: As mines move through their lifetime, production can scale up and down according to mineral pricing and demand. The status of mineral deposits can also be variable, with mineral loads being smaller or larger than initially projected. These factors impact the scale of mine operations and translate to necessitating flexibility in energy systems. The hypothetical mine discussed here is analyzing additional mineral deposits and is planning for an energy system which could scale up or down in capacity depending on energy needs.

Cost: Energy costs are a significant constraint for all mines. Energy costs for power, heat, and transportation are determined by resource availability and proximity. While Western Alaska is known for its abundance of renewable resources, like wind, those energy resources do not accommodate the energy needs of mining sites which require consistent output with little or no intermittency. Therefore, historically fossil fuels or hydroelectric have been used to meet power needs.

Market Fit for Microreactors

Technical Capacity and System Fit

Remote mines operate large diesel power systems, some with heat recovery infrastructure. Generation infrastructure is commonly pre-fabricated and installed at mining operation. For example, Red Dog mine's current power generation facility was prefabricated in urban Alaska, shipped to the Northwest Arctic Borough, and installed at the mine. The hypothetical proposed mine here is discussing using modular power systems like those used at Red Dog.

Microreactor developers have noted that the systems being developed will be pre-fabricated and pre-fueled and deposited in a given site. This model could accommodate the construction model of a remote mine like the proposed mine discussed here and would ensure ease of removal during the mine's decommissioning and reclamation process.

Flexibility in scaling an energy system up or down to meet the capacity needs of mining operations is a critical need of the proposed mine discussed here. Diesel energy technology provides this, with the ability to utilize a number of modular generators which can be turned on or off to meet system demands. Generators can also be added to the system to accommodate increased capacity needs. Microreactors are expected to range in size from 1 to 20 MWe and will be capable of being pancaked, intertying a number of reactor units to meet capacity requirements. Microreactors are also reported to have load following capabilities, which would accommodate smaller fluctuations to mine power demand.

Microreactor developers assert that the technology will be capable of heat and power production. Technology which would be capable of meeting the combined power and heat needs of the proposed mine would add value a microreactor. The challenge for the mine would be in building out the district heat infrastructure required.

As of yet, many of the operational characteristics of microreactors remain untested. In addition, the NRC has yet to determine rules around workforce requirements. While the proposed mine discussed here does not expect challenges accessing a qualified workforce, including energy operators, strict operational requirements could impact the cost of operating a nuclear system. In addition, other operational characteristics could impact mine operations and, therefore, costs. These include:

- Refueling process and frequency,
- Operation characteristics, including remote or autonomous operation,
- Security requirements,
- Maintenance requirements.

Microreactor developers are working toward testing operational characteristics which would suit remote operation conditions. To accommodate the planning processes of remote mines and the regulatory schedule, many of these characteristics will need to be confirmed for mine planners to concretely consider technology adoption.

Financial Fit

The proposed mine is studying a handful electric technologies for cost. Costs associated with building infrastructure for transporting natural gas to the mine site makes the fuel source cost prohibitive. The per kWh cost of diesel fuel generation are estimated at between $0.20 and $0.35 per kWh, but are expected to fluctuate depending on the price of fuel.[100] Table 26 below is an analysis of hypothetical fuel costs related to power production. These projections only represent costs associated with fuel, and do not include other costs associated with operations and maintenance.

Cost Estimates for Diesel Fuel Power Production at Hypothetical Proposed Mine			
Cost per Gallon Diesel	**Total Annual Fuel Cost**	**Cost per Ton Production**	**Cost per kWh**
$3 per gallon	$175,722,000	$82.89	$0.32
$5 per gallon	$292,870,000	$138.15	$0.53
$7 per gallon	$410,018,000	$193.40	$0.74

Table 26: Cost Estimates for Diesel Fuel Power Production at Hypothetical Proposed Mine.

Diesel-fueled power costs can serve as a benchmark for other utility costs. 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. As microreactors move through the development stages, more concrete estimates on costs will likely become available.

One clear indication provided by mining industry stakeholders was that cost is the biggest driver of technology decisions as it directly impacts mine profitability. Unknowns around each of the operational characteristics noted above could impact the cost of installing and operating a nuclear system. It is clear that accurate cost data and financial projections will play a critical role in determining if a proposed mine like the one discussed here will adopt microreactor technology.

Perception Fit

Energy analysis for operating and proposed mines indicates that mine operators are relatively energy agnostic, and more motivated by cost rather than the source of energy. However, public oversight could play a key role in energy planning decisions.

Mines in remote Alaska are subject to a heavy level of oversight by local, state, and federal government agencies, and local and environmental interest groups. Intense scrutiny over environmental issues related to mining activities could translate to scrutiny of energy sources.

Specific information on public perception around energy in the mining industry is limited, and the role that nuclear energy plays is yet to be determined. However, public perception could be impacted from two directions, environmental risk and greenhouse gas emission reductions.

The first direction is that reductions in carbon emissions could favor nuclear energy sources. Mining operations are large emitters of greenhouse gases. In Alaska, the industrial sector (which includes the oil and gas sector) make up 54 percent of the greenhouse gasses emitted annually.[101] To the extent that microreactor energy sources reduce emissions of greenhouse gasses, a microreactor installation at a mine could be perceived positively.

The second direction is the public perception of the environmental risk of nuclear energy. Mine operators work within a framework of environmental risk management constantly. Added perception of risk from nuclear energy sources may appear burdensome, depending on the specifics of the regulatory framework developed by the NRC. Diesel fuel, which is prone to spills (necessitating fines) and air quality concerns, also has its share of environmental and regulatory considerations.

For the hypothetical proposed mine discussed here, external support of a microreactor could require broad and thorough education program facilitated by a trusted source. Points of education could include:

- Understanding of the technology and its difference from traditional nuclear.
- Understanding the environment and physical security risk and mitigation measures.
- Clear planning and agreement around disposal of nuclear waste and decommissioning of the plant.

In addition, attitudes toward the disposal of nuclear waste and environmental remediation following the life of a microreactor are likely to be strong. Clear, firm plans on waste disposal and site decommissioning will need to be expressed early in the planning and outreach process to reinforce comfort levels in the community discussed here.

Remote Mine Energy Value Propositions

Current Value • High cost of power. • Flexibility to scale up or down in capacity. • Consolidated heat and power production. • Medium to large sized year-round load which could operate year-round, constantly.	**Barriers:** • General attitudes toward nuclear among the public and fear over risk. • Regulatory burden and unknowns for operational and security requirements.
Future Opportunities: • Electrification of mine transportation systems and machinery. • Hedge against future carbon taxes or emission caps.	**Challenges:** • Strict oversight from local and environmental interest groups. • Unforeseen costs which could impact mine profitability.

Table 27: Proposed Mine Energy Value Propositions.

Alaskan Defense Installations

Alaska's military installations have been celebrated for their strategic importance for the U.S. military. Alaska occupies a geopolitically important position on the Pacific Rim and within the Arctic; the state is home to a 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 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 shown in Table 28: a mix of Army, Air Force, and 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 naval presence in the state.

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

Table 28: Major Alaskan Military Bases
Source: U.S. Department of Homeland Security, 2020; U.S. Department of Defense, 2020.

Energy security is critical to the Department of Defense (DOD) and Department of Homeland Security (DHS) missions.[102] Resiliency and independence are two areas of focus for the military with regard to energy. This is the case across all of the DOD and DHS installations, but it is especially critical in Alaska with a greater need for self-sufficiency. In many ways, including with energy, Alaska is at the end of the supply chains. This adds additional nuance to priorities around defense resiliency and independence in Alaska as these supply chains are subject to disruption.

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 to provide heat and power services, and maintain and operate their own heat and power systems as circumstances and operational needs demand. Table 29 discusses the power sources utilized at each installation.

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

Table 29: Military Installation Power Sources.
Source: U.S. Army Corps of Engineers, 2005.

The focus of this analysis is the four larger military installations located in urban Alaska: Joint Base Elmendorf Richardson (JBER), Eielson AFB, Ft. Wainwright, and Ft. Greely. These installations were chosen for analysis as a result of data availability. Each of the installations purchase power from Fairbanks and Anchorage utilities and have some independent generation capacity. Figure 45 below presents the capacity of independent generation assets specific to Railbelt military installations, not including the capacity used from utilities in Anchorage and Fairbanks.[103]

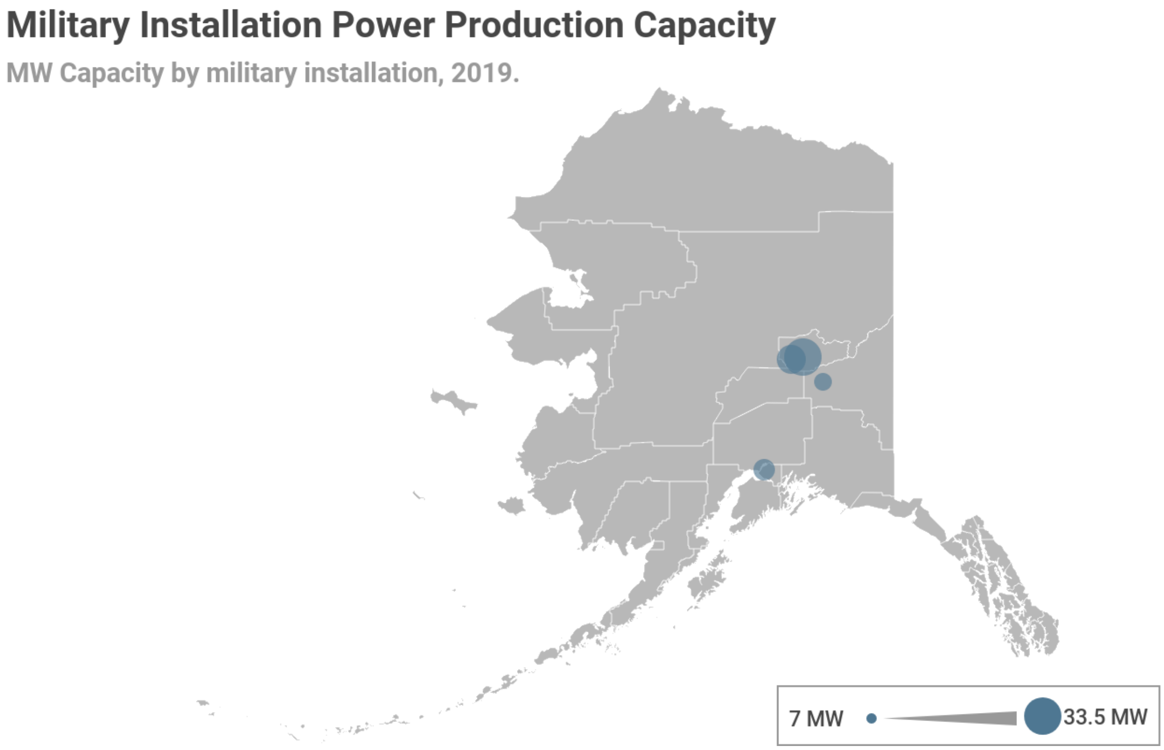

Figure 45: Alaska Defense Generation Capacity.
Source: EIA, 2019.

Population and Demographics

Military installations host a large workforce segment in Alaska. As shown in Figure 46, in 2019 the state was home to over 21,000 active-duty military personnel.[104] This number has mostly stayed steady over the last 10 years, with a slight increase beginning in 2016 related to the addition of the F35 squadrons to Fairbanks.[105] These personnel are primarily located in Anchorage and Fairbanks. Military personnel spouses and families provide additional contributions to the workforce in Alaska.[106] Defense and Coast Guard contracting activity and civilian employment also make important economic contributions to the state.

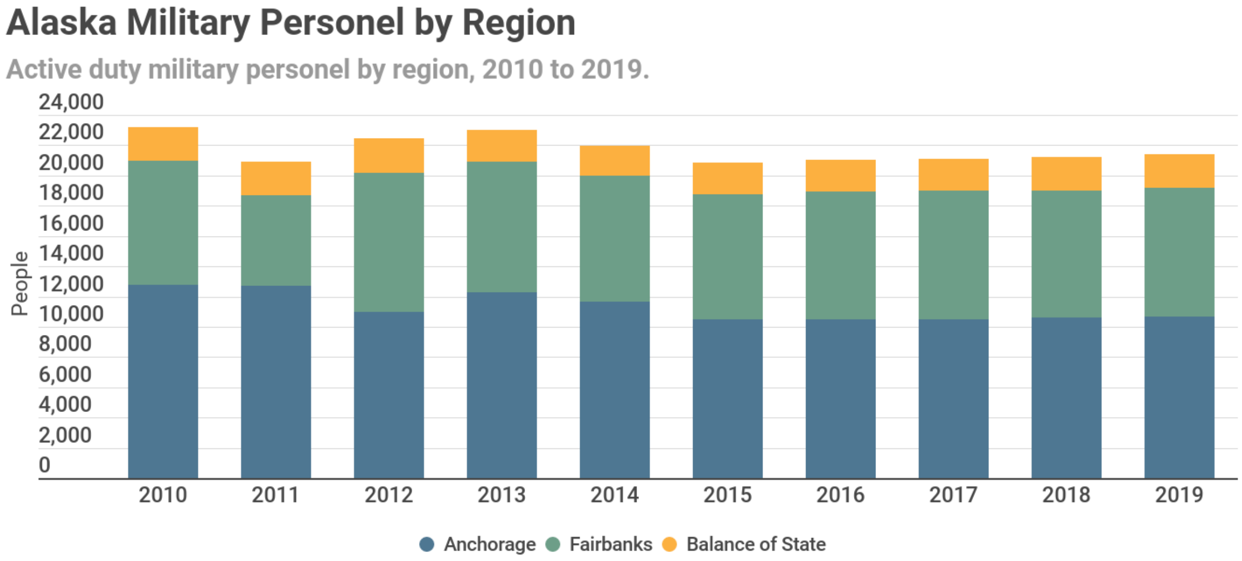

Figure 46: Alaska Military Personnel, 2010 to 2019.
Source: Alaska Department of Labor and Workforce Development, 2010-2019.

Current Energy Systems

Electricity

Alaska's military installation energy demands vary in size depending on base size, operational activities, and climate. Table 30 compares installed power capacity of the four major military installations.

Military Installation Power Capacity Requirements		
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 30: Alaska Military Installation Power Capacity Requirements.
Source: EIA, 2019; US Army Corps of Engineers, 2005.

Generation facilities at Ft. Wainwright, Ft. Greely, and JBER are operated by Doyon Utilities, an Alaska Native Corporation subsidiary. Ft. 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.[107] Ft. 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.[108]

A portion of JBER energy demand is met by power from a landfill methane gas power plant. The plant is capable of meeting 26 percent of JBER's electrical load.[109] The remaining 74 percent of the base's energy demand is met by ML&P, which is soon to be merged with Chugach.

Eielson operates a coal-fired combined heat and power (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.[110]

Electric cost information is limited for all military installations. Energy production data is also limited; however, Table 31 below details kWh purchased from GVEA by the Fairbanks area military installations.

Military Power Purchases	
Installation	**Annual kWh Purchased**
Eielson AFB	9,624,000
Ft. Wainwright	8,412,300
Ft. Greely	16,857,600

Table 31: Military kWh Purchases from GVEA.
Source: U.S. Army Corp of Engineers, 2005.

Eielson AFB purchases a relatively constant amount of power from GVEA, with Ft. Wainwright and Ft. Greely experiencing larger variations in demand. Demand cycles slightly seasonally, but extreme peaks are met by local installation sources.

Heat

Heating needs at all of JBER, Ft. Wainwright, Eielson, and Ft. Greely are all served by distributed heating sources. 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.[111] Table 32 below compares the heating systems installed at each installation.

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

Table 32: Military Installation Heat Systems.
Source: Doyon Utilities, 2020; U.S. Army Corp of Engineers, 2005.

Data on heating costs and capacity needs is limited. However, all of the installations are located in a sub-arctic climate. The Interior region especially, home to all of the above installations except JBER, experiences extreme variations in temperature from the summer to winter. It is not uncommon for temperatures to reach negative 50 degrees Fahrenheit in the winter.[112] The Interior also lacks ready access to the economical natural gas available in Southcentral. This places a premium on heat recovery systems working in concert with installation power plants.

Investigating Alternatives

While cost is the most obvious driver for adoption of new power technologies for most energy operators in Alaska, that is apparently less true for the military installations. Energy security and independence appears to be a more critical driver of installation energy planning and decision making. Energy is especially important for ensuring installation mission readiness.[113] Energy is connected with nearly every aspect of military operations and ensuring delivery of heat, power, and transportation capabilities enables installations to conduct both daily activities and critical operations.

Security is referred to as one of the critical drivers of energy decision making for the military. However, this is a layered variable which 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.[114] 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 which 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.
- **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.[115]
- **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 disaster, 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. Energy producers are paying attention to resistance to cyber-attacks.
- **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.

Microreactor Themes and Perspectives

The topic of nuclear energy is not new to the military, or even to the military in Alaska. DOD has been investigating using small nuclear reactors to independently power military installations for decades. In Alaska, Ft. Greely operated a small nuclear-powered energy system, which was shut down in the 1972.[116] The Navy has been testing and operating nuclear marine propulsion systems for 75 years, in nuclear-powered submarines, aircraft carriers, and other vessels.[117]

More recently, Congress passed legislation in 2019 for advanced nuclear reactor demonstrations. One specific goal is to see a microreactor demonstration at a military site in the next decade.[118]

With an established comfort level with nuclear technology and access to a robust, qualified workforce, system compatibility remains one barrier to adoption. Microreactor developers are moving into the permitting and development, and specifics on technical components are being confirmed. Developers note that the microreactors being deployed are expected to be between 1 and 10 MWe and have characteristics which include:

- Modular and rapid deployment capabilities,
- Load following,
- Ability to pancake reactor units to scale up or down in size,
- CHP characteristics,

- Remote or autonomous operation,
- Small footprint and minimal emergency planning zone,
- High reliability and minimal moving parts,
- 40-year design life with 3+ year refueling intervals.

Use Case: A Hypothetical Military Installation

Consider a military installation in the greater Fairbanks area in interior Alaska. The region is considered part of urban Alaska, and is home to nearly 100,000 individuals. The local economy is heavily tied to the military presence in the region, including approximately 8,500 military personnel.

The installation's power system is interconnected with the regional power grid and purchases most of its power from the local utility. Installation power demands in excess of the capacity the local utility can provide is generated by the installation's coal-fired CHP plant.

Installation heating needs are met by the CHP plant. Heat is delivered through a steam distribution system. Coal used to meet the installations heat and power needs is sources from Usibelli coal mine, located south of Fairbanks on the rail system.

The system infrastructure was installed in the 1960's. While updates and repairs have been made through the years, the basic infrastructure for generation, transmission, and distribution of heat and power is dated.

Energy costs in the region are high, related to the remoteness, availability of resources, and level of energy output needed to heat and power facilities.

The military installation is continuously reviewing its options for heating and powering its system. Costs play a role in this; however, the leading driver of this is mission readiness in independent operating capabilities.

Region and Climate

Interior Alaska is characterized by extremes, with hotter than average temperatures in the summer and extreme low temperatures in the winter. The Fairbanks area struggles with air quality issues, driven by extreme inversion events and high concentrations of PM-2.5 in the winter months, caused by residential wood burning, coal burning, and industrial activities.[119]

Energy System

Electricity

Installation power demand is met through a mix of power purchased from the local utility and power provided by the base's CHP plant. Demand on the installation has grown over the last 15 years. In addition, new facilities and a new hospital have added to the energy load of the installation. The projected peak in 2020 is approximately 30 MWe.

The CHP plant operated at the installation has a 20 MW capacity. In addition, the installation purchases approximately 6,000,000 kWh annually from the local utility at a cost of $1.12 million. Table 33 details power statistics for the installation.

Installation Capacity and Power Statistics	
Installed Capacity (MW)	20
Annual Power Purchases (kWh)	6,000,000
Purchased Power ($/kWh)	$0.19
Purchased Power total Annual Cost	$1,122,700

Table 33: Hypothetical Installation Power Characteristics.

Renewable energy options have been reviewed in the past. The local utility incorporates wind resources from purchased and installed sources and operates a small solar farm. An analysis of renewable energy options on the base showed that minimal operating levels for the installations' existing boilers could limit the ability to utilize renewable resources.

Immediate access to natural gas resources does not currently exist, although long-range plans for natural gas supply from either Cook Inlet or the North Slope have been contemplated. Local coal resources are valued as an immediately accessible resource which is easy to transport and store.

Heat

The installation operates a 20 MW coal-fired CHP plant which generates heat for a steam distribution system. The distribution system includes 24 linear miles of steam distribution lines.[120] Energy technology alternatives will need to consider the CHP needs of the installation.

Energy Technology Market Drivers

Key energy concerns for installation energy planners focus mostly on security and mission readiness: fuel security and availability, physical and cyber security, and infrastructure fit and operational capabilities, all of which drive technological decisions. While costs do play a role in decision making, it is not the sole driver of technology implementation.

Fuel security and availability: Power systems are clearly dependent on the fuel source and supply chain which supply them. The installation discussed here is largely dependent on the coal purchased from Usibelli coal mine and diesel backup sources. Dependence on a single fuel source presents a security challenge for the installation's energy systems. However, given the size of the installation's energy system, diversification of fuel sources is a challenge.

Physical and Cyber Security: Management of the physical security of the installation's energy infrastructure remains a going concern; however, cybersecurity represents a growing concern. Resilience to cyber-attacks is critical to keeping the installation operational and mission ready.

Infrastructure and operational fit: The installation currently operates an energy system which uses incumbent distribution and transmission infrastructure for power but is primarily used for heat. Technology solutions are expected to be compatible with the current infrastructure without significant overhaul. Operationally, the installation has the goal of being able to accommodate its own local power and heat demand without relying on outside power purchases.

Cost: As an installation which functions in a remote region with climatic extremes, energy costs are high. While costs are not the only driver of energy technology decision, life-time costs are considered as part of the decision-making process.

Market Fit for Microreactors

Technical Capacity and System Fit

As a system currently reliant on CHP applications, the installation is seeking technology applications which could provide heat and power capabilities. The microreactors currently being developed are expected to have heat and power production capabilities. In theory, a single microreactor at the installation discussed here could be intertied with the existing heat and power distribution and supplement coal-fired heat and power. However, any specifics on thermal output from microreactors are unavailable. Additionally, modular reactors could be intertied in a chain to supplement or replace coal technology and/or power purchased from the local utility.

DOD has a history of nuclear energy capabilities and applying the technical capacity to operate a microreactor is not expected to be a challenge. The installation also assumes it has access to the expertise required to implement an early stage technology, which could require a period to work through operational kinks in system design and integration.

One characteristic of microreactors which could be attractive to the installation discussed here is the refueling frequency. Reactor developers are expecting systems to require a three-year or greater refueling frequency.[121] An energy system which is capable of operating for three or more years independent of a fuel supply chain could provide benefits to the mission readiness of the installation.

Financial Fit

There is limited information of the installation's current energy costs. Estimates of the cost of purchased power from the local utility approximate that the installation pays is $0.19 per kWh. The installation experiences additional costs for heat and power provided by the CHP plant.

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.[122] As microreactors move through the development stages, more concrete estimates on costs will likely become available. Presently, it is not certain if a microreactor would save money compared to the current arrangements. However, the installation would be willing to accept the technology even if it provided no cost savings, or cost slightly more. The potential to operate self-sufficiently may justify adopting microreactors even in the absence of cost savings.

Perception Fit

Public perception has proven to be a challenge for nuclear energy implementation in the U.S. Themes in public perception are largely influenced by examples of disasters (i.e. Chernobyl and Fukushima). Opposition to implementation of nuclear technology largely stems from fear over technology safety.[123] While perception of nuclear on the military installation is not expected to be a hurdle, perception in the larger Fairbanks area could differ.

There is little information on public perception of nuclear energy specific to Alaska. However, work conducted by the University of Oklahoma (UO) indicates two areas that could be relevant to a nuclear project at the military installation discussed here.

First, safety of nuclear technology is one of the key areas of public perception study. Survey results show that 42 percent of individuals find small modular reactors safer than traditional nuclear reactors. Perceptions around siting is another critical study area, with many individuals adopting a "not in my backyard" attitude.

Surveys conducted by UO showed that 47 percent of survey respondents supported small nuclear reactors for civilian usage and 51 percent supported siting on military bases.[124]

UO notes that one of the challenges around public perception of emerging energy technologies is education on the technology and differences from traditional energy. Survey reliability is dependent on the ability of respondents to give informed responses.[125] Similar themes were expressed by energy stakeholders in Alaska, noting that the large number of unknowns influence perception at the technical level and among the general public.

Defense Installation Energy Value Propositions

Current Value	**Barriers:**
• Current dependence on purchased power. • Heat and power production capabilities. • Reduced supply chain dependence and infrequent refueling. • Medium to large sized year-round load.	• General attitudes toward nuclear among the public and fear over risk from larger regional community. • Uncertainty about timelines and readiness of the technology.
Future Opportunities:	**Challenges:**
• Electrification of installation transportation systems. • Potential to start with small nuclear system and scale up to meet installation system demand.	• Limitations of existing infrastructure. • Unforeseen variables which could impact lifetime costs.

Table 34: Defense Installation Energy Value Propositions.

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