MICROREACTORS IN ALASKA

Use Case Analysis: Remote Mines

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Remote Mining Installations Customer Analysis

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 1 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 1: 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.[i]

Table 2 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 1 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 2: 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.

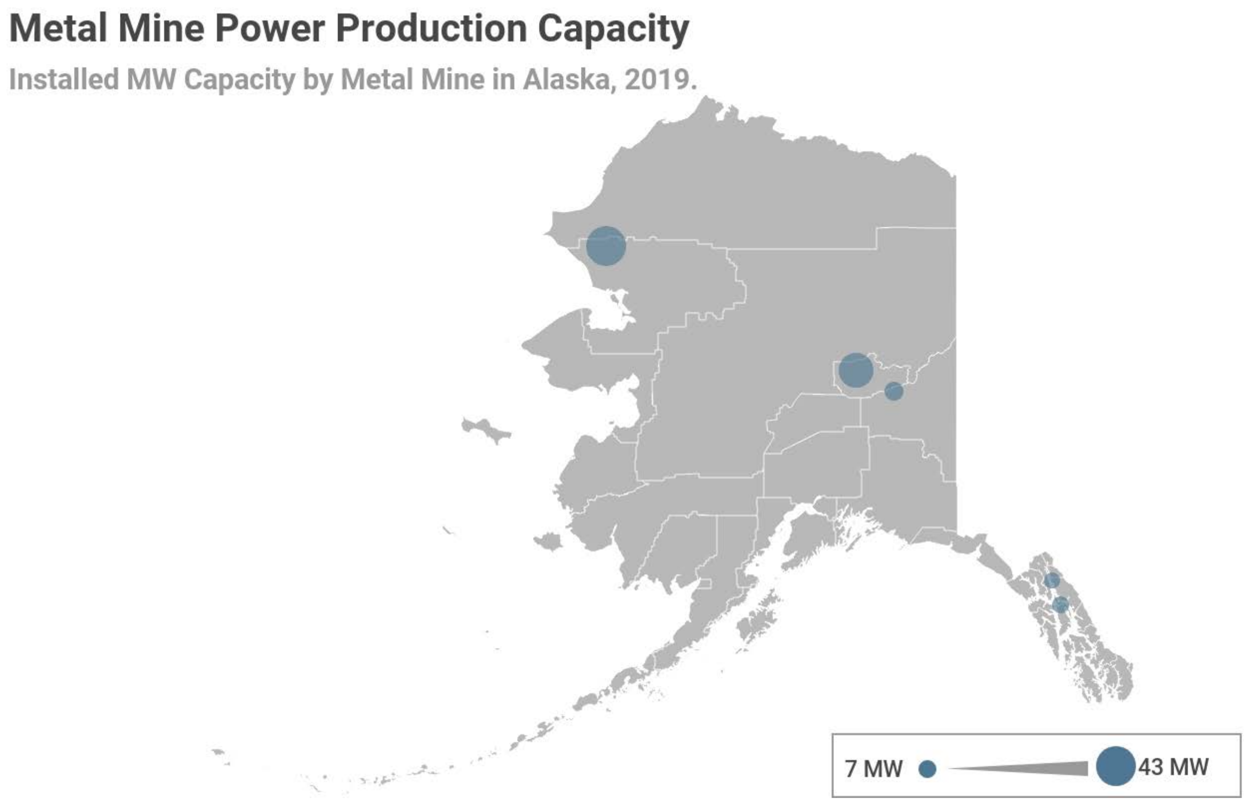

Figure 1: Hub Installed Power Capacity.
*Source: Energy Information Agency (EIA), 2019. *Note: This map does not show Usibelli.*

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.[ii]

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.[iii] The Red Dog Mine, owned by another ANC, NANA, commits to a goal of 100 percent shareholder hire for NANA shareholders.[iv]

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 3 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 3: 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.[v] Table 4 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.[vi] 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 4: Producing Mine Fuel Consumption for Energy Production.
Source: Council of Alaskan Producers, 2010.

As shown in Figure 2, 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.[vii] In addition to self-generating, Green Creek purchases power from Alaska Electric Light and Power in Juneau, which is not shown in the figure below.

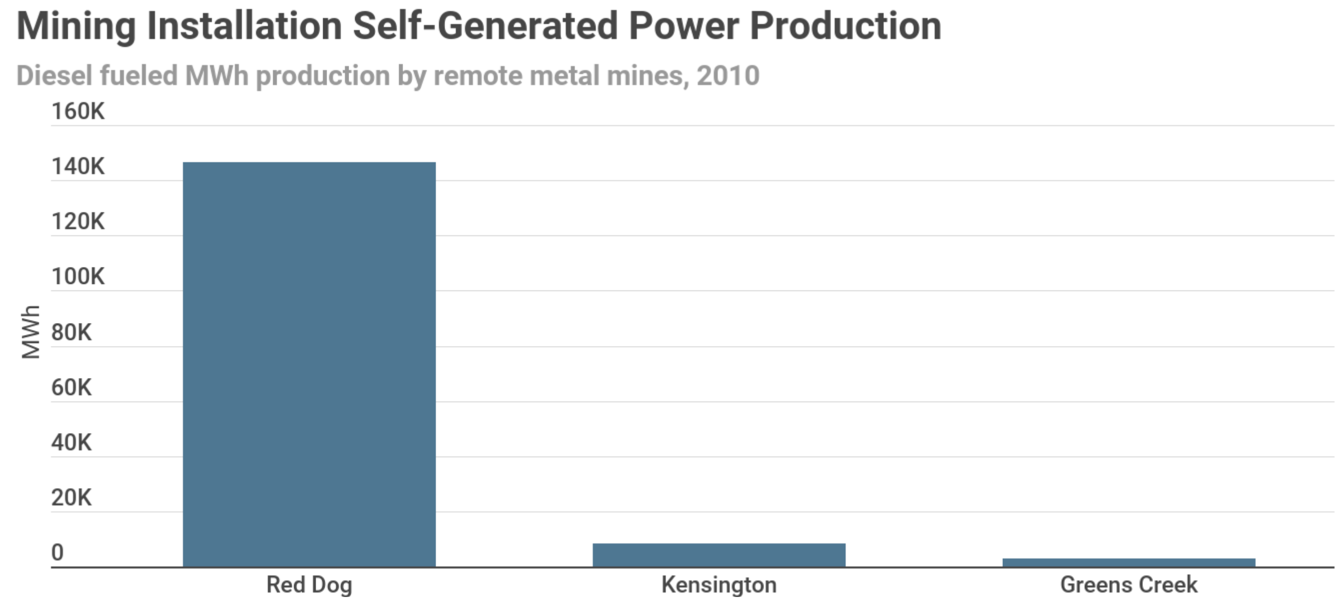

Figure 2: Remote Mines Self-Generated Diesel kWh Produced.
Source: Council of Alaskan Producers and CED Calculations, 2010.

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 3 compares diesel fuel consumption for non-power mine operations

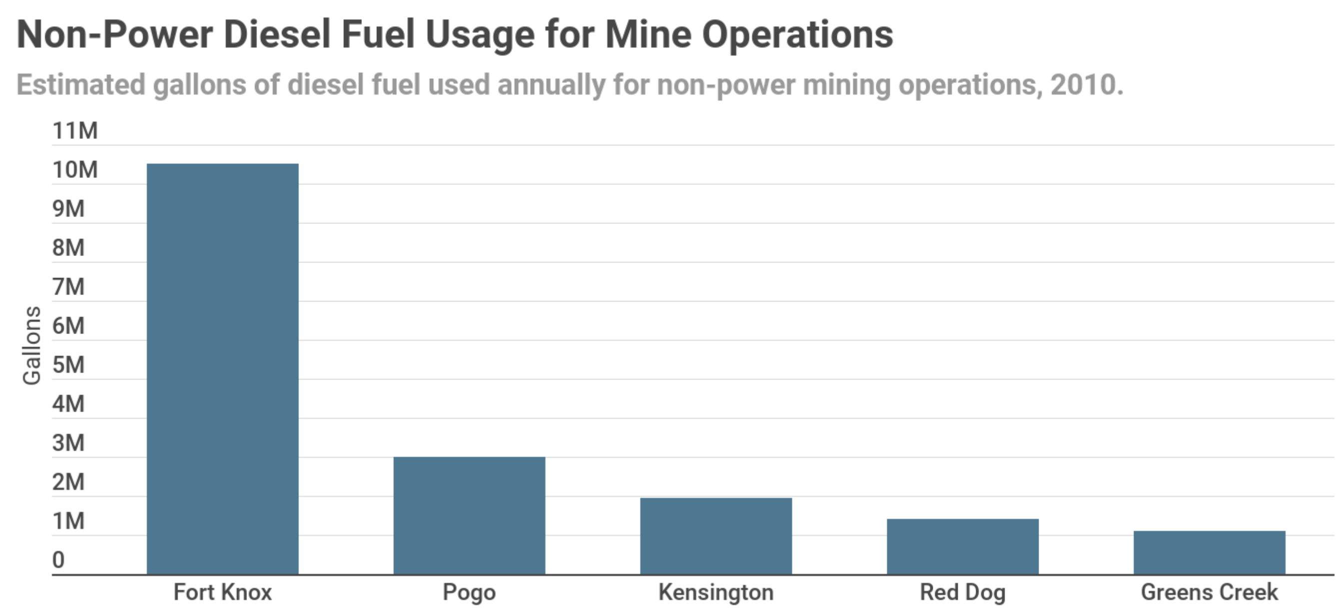

Figure 3: Gallons of Diesel Fuel Used for Remote Mine Operations
Source: CAP, 2010.

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.[viii]

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.[ix] 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.[x]

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.[xi]

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.[xii] 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.[xiii] 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.[xiv] While accustomed to working within regulatory frameworks, unknowns in the U.S. Nuclear Regulatory Commission 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 5 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 5: Estimated Annual Mineral Production and Value.
Source: UACED Estimates.

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 6 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 6: Proposed Mine Operating and Capital Costs.
*Source: UACED Estimates. *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.[xv] 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 electric 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 7 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 7: Proposed Mine Power Characteristics.
Source: UACED Estimates.

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.[xvi] Table 8 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 8: Cost Estimates for Diesel Fuel Power Production at Hypothetical Proposed Mine.
Source: UACED Estimates.

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.[xvii] 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 9: Mine Industry Energy Value Propositions.

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