Distributed Renewables for Arctic Energy: A Case Study

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1 National Renewable Energy Laboratory
2 Renewable Energy Alaska Project

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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List of Acronyms

AEA	Alaska Energy Authority
ANCSA	Alaska Native Claims Settlement Act
AOC	Atlantic Orient Corporation
AVEC	Alaska Village Electric Cooperative
BESS	battery energy storage system
CWG	Chaninik Wind Group
EIA	Energy Information Administration
EWT	Emergya Wind Technologies
F	Fahrenheit
IPP	independent power producer
KEA	Kodiak Electric Authority
kW	kilowatt
kWh	kilowatt-hour
Li-ion	lithium-ion
MW	megawatt
N/A	not applicable
NWAB	Northwest Arctic Borough
PCE	power cost equalization
PV	photovoltaics
REF	Alaska's Renewable Energy Fund
SCADA	supervisory control and data acquisition
SEGA	Sustainable Energy for Galena Alaska

Executive Summary

Alaska is a vast state that stretches into the Arctic Circle. Roughly 140,000 people in the state depend on isolated electric grids, traditionally burning expensive fossil fuels. These fuel sources have negative impacts on air quality and climate. As the climate warms, fuel supply chains and traditional ways of life are threatened. Renewable energy systems offer a clean, resilient alternative with less volatile costs to remote Arctic communities, but developing them raises a variety of technical, social, economic, and political challenges. Examples include harsh operating conditions, lack of local technical and managerial capacity, complex funding mechanisms, and lengthy permitting processes.

With many isolated energy systems incorporating a variety of renewable technologies, Alaskan communities provide valuable lessons that can be applied across the Arctic. In this case study, we interviewed communities that are interested in adding renewables to their energy systems to understand their needs and challenges. We also interviewed communities that have successfully installed renewable energy to understand how they overcame such challenges and the lessons they learned. Notable results include the importance of local buy-in, education, and technical involvement; procuring external funding sources; intercommunity collaboration; installing bespoke systems; working with reliable equipment suppliers; and having a local "project champion”. The goal of this report is to orient and inspire Arctic communities that want to begin their renewable energy transition, by providing helpful examples and points of contact.

Table of Contents

List of Figures

List of Tables

1 Introduction

Alaska is a vast state that stretches into the Arctic Circle. Its biggest urban area is known as the "Railbelt," which stretches between the Kenai Peninsula through Anchorage to Fairbanks and is home to about 81% of the state's population (Fall 2019). Outside of the Railbelt, roughly 140,000 people (Fall 2019), making up about 13% of Alaska's electricity consumption (McMahon and Jordan 2021), depend on isolated energy systems that have traditionally operated on diesel generators and other fossil-fuel-based energy sources for electricity and most heating.

These same conditions, though with different underlying drivers, are present in many remote and island communities across the globe, especially in the circumpolar Arctic. Although diesel-powered generators have continued to provide reliable electricity, their continued use raises economic, reliability, and sustainability challenges, especially in the face of increasingly lower-cost energy generation options. Diesel fuel can be expensive to transport and store, and although relatively affordable at times, is susceptible to large global price shocks. For example, between the winter of 2021 and summer of 2022, average diesel prices in the state of Alaska rose by 26% (DCRA 2022).

Fuel transportation to remote Alaskan communities is also becoming more susceptible to climate-related disruptions. In these communities, fuel is typically delivered by barge, which for inland communities is only available during the summer when the rivers are free of ice. Changes in river paths, low water levels, increasing sediments, or unexpected storms can put shipments at risk, leaving a community without the energy stores needed to meet high heating loads during the long winter. Alternative methods of delivery, such as ice roads and winter-based overland routes, are becoming less secure as the climate warms. The emergency alternative—flying diesel in on small planes or even by helicopter—increases costs exponentially, with some communities paying over $16/gallon (Hughes 2022). Burning diesel also releases greenhouse gasses and other pollutants, accelerating climate change and reducing local air quality. The effects of climate change are being experienced acutely in Arctic regions like Alaska, as melting permafrost further reduces transportation options and puts building foundations at risk. A changing climate also has other ecological and cultural effects, putting subsistence hunting and fishing at risk.

Remote Alaskan communities have and will continue to lead in community-based renewable energy development, serving as an example for similar communities throughout the world. Many communities have excellent wind, solar, hydropower or biomass resources waiting to be used. Sixty-nine Alaskan communities have so far integrated some form of renewable energy (McMahon et al. 2022), and between 2014 and 2018, 5,210 households in rural Alaska received building energy efficiency improvements to reduce overall energy demand (Alaska Housing Finance Corporation 2018). A variety of funding sources and programs are available to support communities in the complex transition to renewable energy.

The goal of this study is to orient communities considering the integration of renewable energy into their isolated grids, building on the experience gained across Alaska. In developing this work, we interviewed communities that do not yet use renewable energy to understand their needs and challenges. Informed by these interviews, we then interviewed "case study" communities that have successfully deployed renewable energy, compiling the development process and lessons learned. Holdmann et al. (2022) found that communities with successful renewable energy projects shared the following characteristics:

- They had no subsidies for fossil fuels beyond the power cost equalization (PCE) program, a subsidy that reduces electric costs for residents in a community to a certain level, agnostic of how it is generated.
- They had either high capacity to manage projects and infrastructure, or pooled resources with other communities, or both.

The authors found these characteristics to be consistent with the "case study" communities we interviewed but also identified several other characteristics that led to more successful outcomes. We hope that this study provides actionable information and inspiration for communities to build their own local capacity and work with like-minded partners to incorporate larger amounts of renewables into their energy systems.

2 Methods

We first interviewed six representative communities without renewable energy to identify the needs and challenges that they face in considering renewable energy development. Our goal was to ensure that the following round of interviews with communities that have renewable energy would be broadly helpful for this first group of communities. The communities vary in population, Alaskan Native Claims Settlement Act (ANCSA) region, income, technical proficiency, and local renewable resource potential. We wanted the communities to be diverse enough to represent the common needs and challenges throughout remote Alaskan communities and, to the extent possible, other Arctic communities with similar characteristics. These communities are listed in Table 1 and key findings are provided in the next section.

Table 1. Interviewed Communities Without Renewable Energy Systems. Generator Efficiency Is the Metric Used to Represent the Technical Capability for Energy Projects.

Community	Population[a]	Median Household Income[a]	ANCSA Region	Natural Resource Potential	Utility[b]	Utility Ownership	Diesel Generator Efficiency (%)
Utqiagvik	4,354	$87,870	Arctic Slope	Wind	North Slope Borough	Community	95
Noorvik	562	$65,000	NANA	Wind	Alaska Village Electric Cooperative	Cooperative	88
Angoon	497	$41,500	Sealaska	Hydropower	Inside Passage Electric Cooperative	Cooperative	92
Tuluksak	269	$28,571[c]	Calista	n/a	Tuluksak	Community	72
Tanacross	145	$53,750	Doyon	Solar Photovoltaics	Tanacross	Community	91
Nikolski	15	$35,000	Aleut	Wind	Umnak Power	Community	75

[a] Census Reporter (2020)

[b] PCE data; Jordan (2020)

[c] Data USA (undated)

Next, the project team interviewed five "case study" communities with renewable energy to understand their renewable development stories, and the recommendations they had for interested communities. Based on the feedback from the first series of interviews, we focused on their motivation for development, how they prepared for and executed the development process, what the results were, the challenges they faced, and the lessons they learned. We chose a group of five communities that varied in population, region, income, and local renewable resource used so that their stories would be broadly helpful. The chosen communities are listed in Table 2.

Their stories are presented in Section 4. The locations and relative sizes of all interviewed communities are shown in Figure 1.

Table 2. Interviewed Communities with Renewable Energy Systems. Generator Efficiency Is the Metric Used to Represent the Technical Capability for Energy Projects.

Community	Population[d]	Median Household Income[d]	ANCSA Region	Natural Resource Potential	Utility[e]	Utility Ownership	Diesel Generator Efficiency (%)
Galena	505	$76,111	Doyon	Biomass, Solar	City of Galena	Community	N/A
Shungnak & Kobuk	361	$50,850	NANA	Solar	Alaska Village Electric Cooperative	Cooperative	86
Kotzebue	3,283	$87,000	NANA	Wind, Solar	Kotzebue Electric Authority	Cooperative	92
Kodiak	5,983	$69,259	Koniag	Hydro-power, Wind	Kodiak Electric Authority	Cooperative	90
Kongiganak	478	$48,958	Calista	Wind	Puvurnaq Power Company	Community	77

[d] Census Reporter (2020)

[e] PCE data; Jordan (2020)

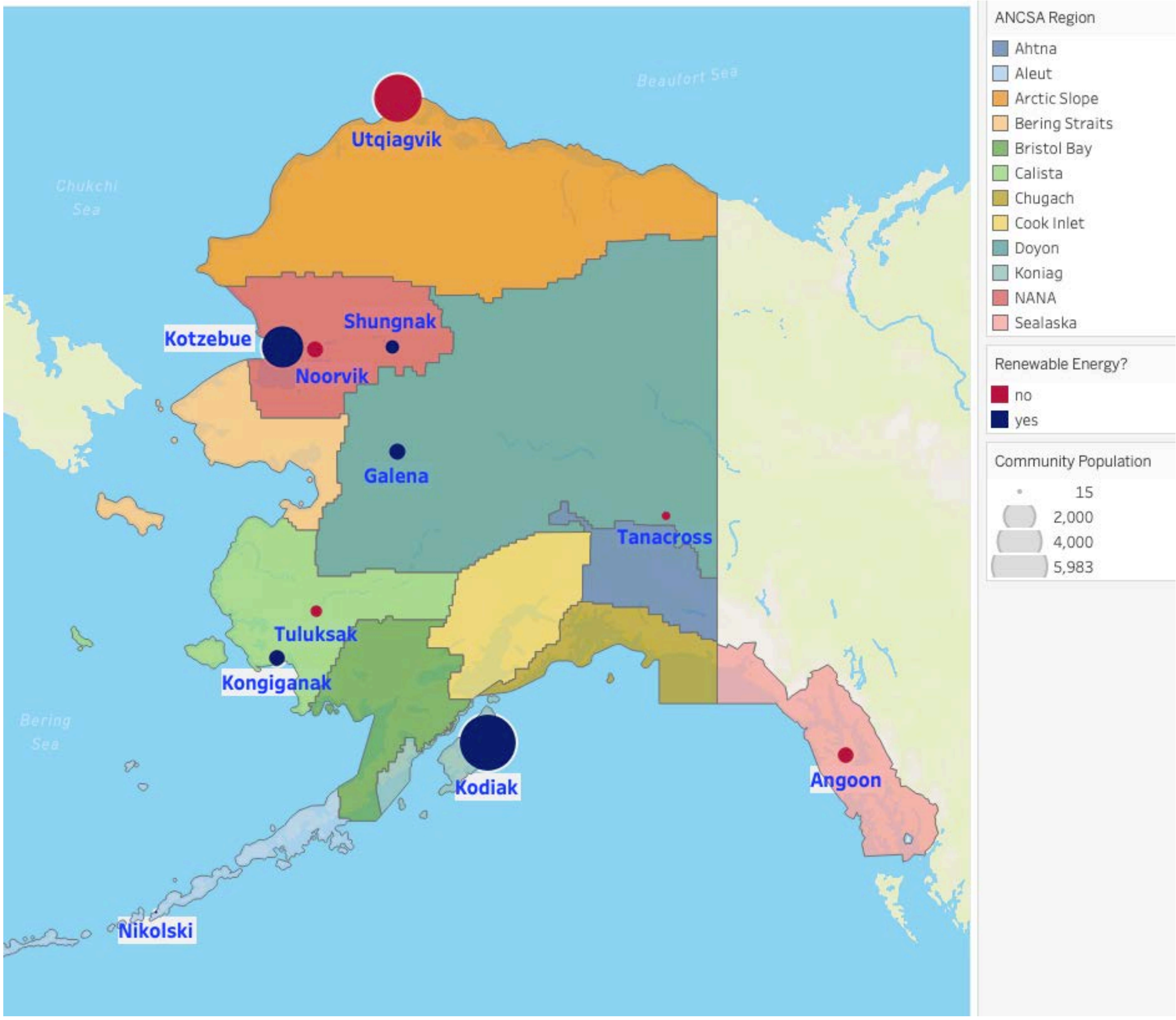

Figure 1. Interviewed communities by ANCSA region and population

3 Needs and Challenges

Communities without renewable energy projects identified a variety of needs and challenges associated with developing such projects. We break these into several categories: technical, human capital, economic, and social & political. Cited examples show how communities with renewables have addressed these needs and challenges.

3.1 Technical Needs

Integrating components and controls is key to renewable energy project success. To avoid technical problems, engineers and project developers must carefully consider how proposed renewable generation will integrate with the existing power system, including generation, controls, thermal heating systems, and the distribution network. System-specific engineering will be needed, so customized solutions are more effective than potentially less-expensive, off-the-shelf approaches that may not include the flexibility needed to integrate with local configurations. Remote communities Buckland and Deering worked with their solar-battery system supplier Box Power to create inexpensive solutions tailored to their environment. Notably, they buried an entire Conex unit underground and filled it with gravel to keep the attached solar panels from blowing over in high winds. Gravel was an abundant local resource, and conventional concrete foundations would have been expensive due to the high cost of shipping in Portland cement. In Shungnak, Alaska Native Renewable Industries used a helical pile foundation instead of a cement foundation for their solar arrays.

Excellent logistics and project planning are critical. Shipping equipment is difficult and expensive for many remote communities. Large equipment may only be accessible by barge for limited amounts of time each year, and other transport options are much more limited and expensive. Therefore, understanding potential needs for spare parts and preparing a robust parts inventory can mitigate significant system downtime and repair costs. Shungnak learned from previous failed renewable energy projects in their region, emphasizing project planning and spare part availability. This approach allowed their renewable project to be completed rapidly, within a year.

Stories about reliable, economical systems are required to build public trust in renewable energy. Although renewable energy integration is becoming more common and its value better understood, examples of success need to be well-documented to overcome previous negative experiences and to articulate the benefits for different communities. In Kodiak, the renewable energy sources have been reliable and saved the community money. There is now a strong sense of community pride for renewable projects.

The use of battery energy storage systems (BESSs) can increase grid stability and even allow diesel-off operation. Reliable and demonstrated battery systems provide a valuable complement to wind and solar energy deployments. Multiple systems have been deployed where short-term, battery-based electrical storage is used across a variety of system architectures. In Kotzebue, battery storage provides spinning reserves to displace diesel generation during high renewable periods and has reduced blackouts. In Kodiak and Kongiganak, storage is used to regulate grid voltage and frequency. Shungnak has run its system in “diesel-off” mode during high renewable periods.

Good resource assessment campaigns set projects up for success. It is important to accurately characterize renewable energy resources and community loads prior to performing feasibility and design studies. Kotzebue and Kodiak both performed rigorous wind resource assessment campaigns before installing successful wind energy projects. These provided realistic projections of renewable energy potential, important for managing expectations.

Equipment installed in isolated communities must be designed for those environments and undergo supported demonstration prior to wide deployment. It is not unusual for equipment installed in isolated areas, especially in the Arctic, to be forced to operate outside of their design specifications due to unusual environmental conditions. In many cases this is unavoidable, but all equipment should be assessed for its ability to operate in the expected environment, performance de-ratings should be assessed and applied, and mitigation measures, such as assessing longer break-in periods or higher initial maintenance costs, should be implemented. In Kotzebue, a Zinc-Bromide flow battery that the utility initially deployed was not suited for the local conditions and failed. The utility replaced it with a well-tested lithium-ion (Li-ion) battery. In Kongiganak, winterized Windmatic wind turbines were used, and required further modifications to work in the local cold, gusty, and weak-grid conditions.

3.2 Human Capital Needs

Community buy-in and ownership is essential. Projects must be community-driven and supported, with community members understanding and participating in the value proposition of moving to a stronger reliance on renewable energy. It is critical to include and receive buy-in from key stakeholders like utility managers, operators, project champions, and local government officials. Beyond project development, community engagement must be ongoing, and continue after the project is deployed to maintain community support and ownership. Long-term engagement is an essential element of sustainability. For example, a strong community focus enabled a successful project in Kongiganak: the community trained and retained a local workforce, built community trust through presentations in village meetings, and received community leader and tribal council support. In Galena, hiring and training an all-local workforce provided enhanced job satisfaction, increased local capacity, and strengthened the community overall.

Proposed systems should be commensurate with the training, education, and availability of the local workforce. The use of community-appropriate technology reduces system failures and the community's dependence on long-term, expensive, external assistance. Local capacity should determine how simple or complex the system should be, and what assets it can include. Robust operations and maintenance plans must be considered from the start. Communities have found that small, easy-to-maintain pilot systems with solar photovoltaics (PV), batteries, and/or wind can be a good stepping stone to larger, more complex systems with higher contributions of renewable energy. Community-based technical capacity may be increased over time through community education and expanded experience from operating power systems. Many communities have been successful in engaging local youth, with energy providers gaining traction by speaking through credible, community-based educators. In Kotzebue, installing small wind turbines provided the technical capacity for subsequent installations of much larger wind turbines, batteries, and solar PV systems. In Galena, a focus on community education and training allowed the community to perform increasing portions of system maintenance locally and has enabled it to set its sights on future solar projects.

Having a regional or statewide pool of support resources increases the likelihood of success. Having a network of knowledgeable people actively engaged in operating projects, such as an energy cooperative, that can provide targeted education or technical knowledge, increases the likelihood of project success, and can allow communities to install systems that they may not be able to support on their own. Allowing a process for communities to access this network will streamline the renewable energy development process including planning, financing, installation, and operations. Such a network is especially helpful for small communities with limited human capital. A face-to-face knowledge sharing network would increase the number and success rate of community projects. Kongiganak is part of the Chaninik Wind Group (CWG), which helps secure wind energy project funding, shares training expenses, builds local capacity, and reduces energy costs. The CWG has built projects in each of its member communities, leveraging the capacity built from each successful project.

Competent, practical project managers are required. The technical, financial, managerial, and community engagement components of a renewable energy project must be overseen by experienced personnel to help ensure success. Managers must be able to validate project proposals from engineers and external entities, compare those proposals to community needs, and decline when necessary. Some communities also face rapid turnover of bookkeeping and managerial staff, reducing their financial and managerial capacity for projects. Such seemingly minor problems can have long-term impacts. In Kodiak, early renewable projects failed due to insufficient engineering and project management. Since then, a renewed focus on these components has enabled successful projects.

3.3 Economic Challenges

Communities that need renewable energy the most may have the hardest time developing projects. Communities with high energy burdens are generally supportive of renewable energy projects that can reduce energy expenditures, but these same households and communities are often the least likely to be able to afford large investments in new renewable energy systems.

Energy subsidies and policies favoring existing technology hinder energy transitions. Subsidies that incentivize one generation source over others have clear impacts on a community's energy mix, adding a political lens to decisions that may differ from community values. This situation is not inherently bad but should be clearly recognized by policymakers. Subsidies that reduce the cost of fossil energy for consumers affect renewable energy projects by reducing the incentive for change or making it harder for consumers to understand the value of that change. This understanding is particularly hard to achieve if only some portions of the community receive those subsidies.

Individual use of renewable energy, such as net metering, can have significant impacts on small, isolated energy systems. In small, isolated communities, generating one's own electricity can greatly impact the sustainability of the larger power network by potentially stripping away the highest-value utility customers. As a result, power providers may oppose customers installing renewable energy systems or supporting renewables through favorable connection agreements, such as net metering. Self-generation by larger, and in some cases institutional clients, can reduce utility revenue while still requiring the utility to be prepared to provide energy services when renewables are not available. This revenue reduction can drive electricity rates higher for other customers, often the ones who are already have high energy burdens. Collaborating on solutions that benefit both the utility and customer will improve community energy access and well-being.

Developing the funding for specific projects is complicated and requires a great deal of skill. Due to the wide variety of funding opportunities, such as including simple loans, guaranteed loans, and grants, funding entities (e.g., federal, state, philanthropic), recipient organizations (e.g., governments, utilities, tribal organizations), and focus areas (e.g., studies, design, hardware, infrastructure, operations), it can be difficult to obtain the funding needed to complete a new energy project. To pay for Kongiganak's renewable energy project, the community's skilled grant writer had to secure funding from several different sources.

3.4 Social and Political Needs and Challenges

Community engagement best practices should be employed. Several defined best practices for productive community engagement have been developed (for example, Ross and Day 2022) and should be applied by communities or outside parties while developing new renewable energy projects. Key concepts include hiring coordinators that are humble, authentic, honest, and understand local concerns and beliefs; and establishing democratized processes that respect and support community agency as well as meet the community where it is. Clear demonstration of how renewables can improve community life, and an enduring presence that shows appreciation for community life, are essential. Many communities could provide examples of both good and bad engagement efforts from a wide variety of state and national organizations.

Clear articulation of benefits and difficulties of renewable energy projects are needed. To enable community-based decision-making, credible and transparent information on costs, impacts, and benefits is needed. In Kongiganak, village meetings that articulated this information were essential to building trust and relationships in the community. Without transparency and community leaders' trust, projects can be used as scapegoats for other technical issues in the community.

Coordination across multiple engaged organizations can be difficult but is critical to success. There are typically many different authoritative entities that are involved in the project development process, including tribes; city, state, and federal government; native corporations; and energy cooperatives or utilities. Competition, mistrust, and not sharing responsibilities between the different organizations can hinder projects. Kongiganak found that cooperation between community leaders, the tribal council, Puvurnaq Power Company, Native Calista Corporation, and CWG enabled a successful project.

Overcoming the desire to "stick to what we know" is a key challenge. Risk-averse politics and utility managers, misconceptions about renewable energy, disenchantment from past failed projects, lack of information on successful project development, and culturally embedded reluctance to transition toward renewable energy generation all hinder the acceptance of renewable energy, even in areas where it could provide strong community benefits. The hesitancy or inability to implement federal or state policy can lead to project stagnation that could be addressed through more active political or organizational participation. Kodiak Electric

Association's healthy understanding of risk, including the risk of *not* doing renewable energy projects, combined with careful engineering and progressive development, overcame risk aversion. Kotzebue found that securing grant funding made stakeholders more open to renewable energy.

Energy inequality and energy poverty can be hard to navigate with communitywide solutions. Addressing communitywide energy challenges when there are diverse household-level needs and energy inequality can be challenging. Care, combined with community engagement best practices, is necessary to navigate the inequality of household needs and the perception of community fairness, especially when applying for and using grants. In Kongiganak, about half of the households have been equipped with electric thermal stoves, which are powered by local wind turbines at a much lower cost of energy than the heating oil that warms most homes. Some of the households that have not yet received these stoves are envious of those who have.

Persistence and respect are required to rebuild trust in renewable energy project development. In some locations, trauma from past federal, state, and nongovernmental organizations' actions have broken trust in the state and federal government and their representatives. Rebuilding trust will involve acknowledging past wrongs, respecting community values, spending time investing in communities, and including community members in decision making.

Complex federal review processes increase timelines and impact the likelihood of success. When projects are on federal land, slow, expensive, inflexible federal permitting can increase development timelines and costs, and make projects infeasible. Increased timelines and costs can lead to underfunded projects, leading to the implementation of shortcuts, using cheaper, less-suitable technologies, or neglecting needed engineering work to make the projects "fit within the budget". This can be problematic with fixed state or federal grant funding that typically has limited flexibility to address rising project costs.

4 Case Study Results

System-specific information of the five "case study" communities that have added renewable energy into their existing power systems are provided in Table 3. The renewable energy development process and results are described for each community as follows.

Table 3. Renewable Energy System Details in Case Study Communities

Community	Peak, Average Load (kilowatts [kW])[g]	Installed Renewable Capacity[h]	Storage Capacity and Function (e.g., Spinning Reserve, Frequency Regulation)	Annual Fuel Savings (gallons)
Galena	750, not applicable (N/A)	4.5-million British-thermal-unit biomass boiler	none	190,000
Kotzebue	3,500, 2,600	576-kW PV, 2,250-kW wind	1.2-megawatt (MW)/950-kilowatt-hour (kWh) battery - spinning reserve 450-kW electric boiler - absorbs excess renewable power	250,000–400,000
Shungnak and Kobuk	N/A	223.5-kW PV, with Two 100-kW inverters	250-kW/352-kWh battery	N/A
Kodiak	27,250, 20,000	33.6-MW hydropower, 9-MW wind	3-MW battery - voltage and frequency regulation 2-MW flywheel - voltage and frequency regulation, powers electric shipping crane	2.8 million[i]
Kongiganak	N/A	475-kW wind	300-kW/ 1,550-kWh total electric thermal stoves - absorbs excess wind power, electric boiler - regulates grid frequency 375-kW, 31-kWh Lithium-ion battery - voltage and frequency regulation	24,000

[g] PCE data (Jordan 2020)

[h] Infrastructure data (McMahon et al. 2022)

[i] Nowers (2022)

4.1 Galena

4.1.1 Background

The Galena Interior Learning Academy boarding school services 200 students and is a significant economic driver in the city. In 2008, ownership was transferred to the city from the United States Air Force, which left enough diesel to provide the district heating system for 10 years. Oil was expensive, leading to an interest in developing a biomass-fueled (wood) heating system to replace the oil by the time it ran out. A local engineer brought the city, school district, and Louden tribe together to develop a project plan.

4.1.2 Preparation

Community engagement was central to Galena's preparation, with the city manager, school superintendent, and tribal council administrator all working together. Quarterly meetings with free food were held to engage community members, who appreciated the effort. Those championing the project set down roots in Galena and hired locals to accomplish it, which also built community support. Biomass resource data collection, although challenging, was performed to help secure funding.

4.1.3 Execution

The tribe, city, and school district created Sustainable Energy for Galena Alaska (SEGA) (SEGA undated) with $100,000 in funding from each to operate the biomass system for the first 3 years. Tim Kalke, a part-time teacher who was getting a natural resource management degree at Oregon State, was hired to help set up SEGA. Forest planning and Alaska's Renewable Energy Fund (REF) provided a $3-million grant for the 4.5-million British-thermal-unit biomass boiler. The existing domestic water lines and steam distribution system were abandoned, with a new hydronic distribution system funded by the Alaska Energy Efficiency Revolving Loan Fund and new water lines funded by a $1.5-million Alaska Department of Environmental Conservation loan. A $500,000 governor's grant funded mechanized wood-harvesting equipment, Figure 2. The boiler came online in December 2016. In 2018, the project was expanded to energy education, with additional renewable energy and energy efficiency projects. SEGA managed the district heating system for 3 years in a contract with the city. Construction, labor, and a growing capacity for system maintenance were kept internal to Galena. By 2022, the community had a 5,000-square-foot shop and the experience to keep the system running.

Figure 2. SEGA's self-propelled chipper and self-loading log truck harvesting wood for the biomass boiler. ***Image from Orr (undated)***

4.1.4 Results

Biomass now meets 75% of the boarding school’s heat load, displacing 90,000 gallons of diesel annually. The hydronic system upgrade displaces another 100,000 gallons, leaving just 40,000-50,000 gallons of diesel necessary for heating annually. If the diesel price is over $3.30/gallon, biomass is the cheaper heating option. The distribution system works well, and the fuel quality is good. SEGA expanded from timber harvesting and operating the biomass district heating loop to independent power production and construction. It shouldered project risk to benefit the community. SEGA’s board has members from the city, school, tribe, and community, constituting one full-time-equivalent employee. Timber is harvested from September through March, employing 6−7 people. SEGA is now building energy-efficient, low-income housing, employing 6−8 employees. Its total payroll in 2021 was over $400,000. With increased technical capacity, SEGA is considering installing a 26-kW solar PV system on Galena’s electric grid.

4.1.5 Challenges and Lessons Learned

Galena’s biomass system has endured technical challenges. Wood-harvesting equipment breaks down frequently while operating at -30°F. The boiler’s automated feed system has occasional problems. Employees must clean the heat exchanger frequently due to mill scale (a magnetite coating that can form on hot steel surfaces). On the social side, SEGA did not enter the local firewood market (which could have been a revenue stream), to avoid competition with the local, native wood-cutting industry.

One key takeaway is the importance of community engagement and empowerment. From the beginning, community health and well-being were an important focus. The use of local deciduous wood has long been part of Galena’s culture and economy, so it made sense to burn wood instead of diesel. Including community members in discussions with the SEGA board, along with educating and hiring an all-local workforce to complete and maintain the projects, both empowered and enriched the community. SEGA has provided meaningful, satisfying work, and created new jobs as it expands. Education and tools have allowed the community to tackle new projects and maintain existing systems independently. Building local capacity was a huge factor in the project’s success. This capacity building has strengthened the community, provided a sense of purpose, and shifted the focus from the individual to the collective.

4.2 Kotzebue (Kotz)

4.2.1 Background

As Kotzebue grew from 1975 to 1995, its diesel fuel use increased from 1.0 to 1.5 million gallons per year. In the early 1990s, Kotzebue was 100% diesel-powered. Kotzebue’s community mindset, which is inquisitive and innovative yet practical, motivated the exploration of wind energy. With a concern that PCE subsidies would go away, the community began to realize that local wind power could eventually become cheaper than diesel power.

4.2.2 Upgrade Story

Wind energy development occurred in two main phases, as follows.

Phase 1: Pre-REF, 1995−2008

In the first phase, Kotzebue Electric Association installed several meteorological towers in 1995 to measure wind and solar energy resources, with a second collection campaign in 2000. The community succeeded at getting grants, receiving funding from the STEP program in 1995 for the first three 50-kW Atlantic Orient Corporation (AOC) 15/50 wind turbines that were installed in 1997. These machines were not particularly reliable but were a stepping stone to increasing Kotzebue's capacity to handle bigger wind turbines. Over the next decade, fifteen 50-kW wind turbines, one Vestas V15 (75 kW), and one Northwind NW100 (100 kW) were installed, for a total of 925 kW of wind capacity. The community worked with the National Renewable Energy Laboratory to verify the power curves of the Northwind and AOC machines. Operators were hesitant to use the wind turbines because wind variability and turbine faults caused short load shedding outages, prompting the need for a battery. In 2005, Kotzebue Electric Association installed new switchgear and a supervisory control and data acquisition (SCADA) system to minimize fuel consumption and automate the power system to maximize wind energy capture.

Phase 2: With REF, 2008-present

The REF was established by the Alaska State Legislature in 2008 to develop renewable energy projects, with a focus on the most energy-burdened communities in the state. Since 2008, 244 REF grants have been awarded, totaling $284 million. Those state grants leveraged approximately $250 million in private and federal funds to complete project funding. Over 100 operating projects have been built with REF support, collectively saving more than 30 million gallons of diesel each year.

Kotzebue's second phase of development began with a zinc-bromide flow battery installed in 2010. The battery did not meet the required specifications, was not tested for the application or transported properly, and ultimately did not work. As a replacement, REF funding was used to procure a 950-kWh Saft Li-ion battery coupled to a 1.2-MW ABB PCS100 inverter, commissioned in 2015. The battery regulated the electric grid's frequency, keeping the power stable and preventing load shedding, which allowed more wind turbines to be installed. A 450-kW electric boiler was installed at the hospital to further smooth over variability from the wind turbines, absorbing 750 megawatt-hours of excess generation per year.

In 2012, two Emergya Wind Technologies (EWT) DW54-900 wind turbines (900 kW each) were installed. These machines were chosen because they had direct drive (no gearbox and less moving parts that would require a crane to fix) and EWT had a good track record. Eight of the AOC wind turbines were decommissioned. In 2020, eight solar PV arrays were installed that used the AOC's existing infrastructure; the solar inverters had the same rating as the AOC's inverters (66 kW). The arrays were placed next to the wind turbines and their inverters were set in the AOC shelters and plugged into their power cables to minimize cost, Figure 3. There is now 576 kW of total PV capacity.

Currently, only the two EWT wind turbines are operating, but Kotzebue Electric Association would like to operate seven of the AOC wind turbines and the Northwind 100 again, given the recent doubling in fuel prices. When the diesel generators are on, they stick to the minimum load fraction recommended by the manufacturer. Future plans include installing:

- Vertical, bifacial solar PV arrays facing east-southeast and west-southwest to capture more sunlight during the high morning and evening loads

- A high-speed SCADA system to better understand what is happening during grid events like outages
- Two more EWT wind turbines with large rotors to increase energy capture at low wind speeds
- Larger batteries and thermal energy storage systems (Bergan 2021) to increase renewable energy utilization and reduce the need for diesel generators to provide spinning reserve
- A diesel rotary uninterruptible power supply (possibly) to provide grid support.

4.2.3 Capacity Building

For this project, lots of information technology, electrical, and mechanical technician work was needed, and it took several years to learn the technical skills to successfully operate these projects. Kotzebue has received remote support to supplement growing local knowledge. The community has a local wind energy technician, but no local BESS technician, so it has had to learn to troubleshoot issues with remote support. Kotzebue has transitioned funds from buying diesel to training staff, which creates local jobs.

4.2.4 Results

The large amount of renewable energy generation has reduced Kotzebue's need for diesel storage, allowing the utility to lease excess fuel storage to other local energy providers. As a result, the local fuel market can now compete with an existing monopoly, and thereby reduce the cost of living. The winter peak load has been cut by more efficient lights and appliances, improved weatherization, and consumer mindfulness. Prior to wind energy installation, there were occasional diesel-engine-related power outages. After installation, there were additional wind-turbine-related outages. Now that the battery is installed, it has prevented most outages from both.

Residential electric bills have not decreased because their savings are countered by reduction in the PCE subsidy. However, nonresidential customers who are not eligible for PCE (e.g., stores, hospitals, schools, and so on), have seen large electric bill reductions. The installation of renewables has increased community technical capacity, wealth, and pride, and allowed Kotzebue to become a leader in renewable energy development that is able to support other communities that are new to developing renewables through cost and knowledge sharing.

Figure 3. Kotzebue's wind turbines and solar PV arrays, which use the old wind turbine's inverters. ***Image from Misbrener (2021)***

4.2.5 Challenges and Lessons Learned

Kotzebue has found that the wind, solar, and battery technology of the future is here, and recommends going "all in" on renewable energy. A community's inquisitiveness, innovation, and practicality can combine to create clean, cost-effective solutions. Representatives from Kotzebue have several specific recommendations:

- Treat renewable energy technologies as the prime sources of power, and diesel as a supplement.
- Ensure that all equipment is suited for the application, and work with suppliers who will test, ship, and install it properly.
- Overbuild so that there is more than enough wind and solar energy to cover both baseload and contingency scenarios (such as fast load ramp ups or generator trips).
- Use a battery large enough to meet the system's load for an hour or two during the winter, when heat is especially critical.
- Seek grant funding as much as possible; when local money is not at stake, people will be less risk-averse.

- Communicate the benefits of the new renewable system clearly to the community. For example, in Alaska, the question, “Why didn’t my home electric bill go down?” can be answered with, “Because you’re using less PCE, which preserves more of the subsidy for future generations. Also, nonresidential customers without PCE, like your general store, school, and hospital, will have lower electric bills, which will translate to lower prices on the shelves and lower taxes, to the benefit of the whole community.”

4.3 Shungnak and Kobuk

4.3.1 Background

Shungnak and Kobuk were joined by a 10-mile-long intertie originally built in 1980 (Alaska Village Electric Cooperative [AVEC] 2014). A fiber-optic telecommunications cable was added in 2021. Before joining AVEC, Shungnak’s diesel generators powered Kobuk. Then, the river flowing through these villages changed course and the water level decreased. This change prevented barges from reaching the villages, which had been used to supply diesel fuel to the area. As a result, the communities were motivated to move quickly: a solar PV array and battery were planned to displace diesel, and heat pumps were planned in Shungnak to increase building energy efficiency and reduce the use of diesel-fueled furnaces which were common for heating.

4.3.2 Preparation

To prepare for renewable installation, Shungnak and Kobuk joined forces as an independent power producer (IPP). The Northwest Arctic Borough (NWAB) used its experience and data collected from a project it had developed in Buckland and Deering to create a more efficient and less costly project in Shungnak and Kobuk. Funding for the Shungnak and Kobuk solar-battery IPP came from the United States Department of Agriculture ($1.3 million) and the NWAB ($800,000). An energy audit, costing about $1.02 million and funded by the Borough’s Village Improvement Fund, was performed on 80 households in Shungnak and Kobuk to understand the benefit of heat pumps. A pilot heat pump project was also conducted with grants from the Coastal Impact Assessment Program to demonstrate that the technology would work in local conditions.

4.3.3 Execution

The communities moved quickly, executing the solar PV, battery, and heat pump projects in 2021. Deerstone Consulting, with project experience in Deering and Buckland, provided technical assistance. A 223.5-kW solar PV array on two strings with a 100-kW inverter each, coupled with a 352-kWh battery and a 250-kW inverter were installed, Figure 4. The IPP signed a power purchase agreement with AVEC and NWAB to complete the project. The PV arrays were only installed in Shungnak because sufficient gravel needed to build above flood level in Kobuk could not be found. The panels are bifacial, with no tracking and an 11% capacity factor. The arrays are pointed in different directions to better distribute their power generation throughout long Arctic summer days. System microcontrollers turn the diesel generators off during the summer when they drop to 30% load and provide real-time visibility to AVEC. Solar and battery operators were trained by the contractor, Alaska Native Renewable Industries.

Figure 4. The 223.5-kW solar PV array that powers Shungnak and Kobuk. ***Image from DeMarban (2022)***

4.3.4 Results

The solar PV produces 200 megawatt-hours of electricity per year, offsetting 14,300 gallons of diesel. The battery is capable of energizing Shungnak and Kobuk for a few hours, ensuring stable, reliable power in the case of a diesel generator or PV array shutting down. The communities expect a renewable fraction of 11%−15% and want to get to 30%. They expect households to save $2,000−2,500/year from heat pumps alone. No pushback was received from community members, and NWAB is waiting to see how members respond to the project before moving forward. The future goal is to displace more diesel. Plans are to upgrade the inverter to 500 kW to meet a winter peak load of 300 kW and add a 100-kW wind turbine to the system. The communities are searching for funding to install more household heat pumps and lower the electricity rate of customers. There is less heat recovery now that the diesel generators are running at a lower level, so there is an inquiry into harnessing battery heat. In addition, there are plans to build an intertie to the nearby village of Ambler, and then investigate installing wind energy and hydropower, which are available along the potential intertie route.

4.3.5 Challenges and Lessons Learned

Good relationships with suppliers, consultants, and contractors are essential to the success of a renewable energy project. Shungnak and Kobuk have an excellent relationship with Box Power (supplier of the solar-battery system), who worked with contractors on-site to tailor the installation of their products to the location.

This rapid project was streamlined by good planning and the whole project being controlled by the Native Village of Shungnak (the local tribe), thereby simplifying land and equipment ownership.

Fuel prices must be high enough for heat pumps to be financially helpful. These pumps make more sense when building a new house, and less when removing existing equipment and replacing it. Increasing the energy eligible for PCE per household (from 500−750 kWh) increases the financial benefit of electrical heat pumps.

4.4 Kodiak

4.4.1 Background

In 2000, roughly two-thirds of Kodiak's power came from the Terror Lake hydropower plant. The rest was covered by diesel generators. Hydropower was far cheaper than diesel power, and its availability was dependent on rainfall, causing significant swings in power prices that were difficult for customers to budget for. This unpredictability motivated the utility, Kodiak Electric Authority (KEA), to pursue a system that was 95% renewable and provided power at a cost equal to or lower than diesel.

4.4.2 Preparation

KEA bought the Terror Lake hydropower plant from the Four Dam Pool Power Authority in 2009 (Southeast Alaska Power Agency 2022) for $38 million, mostly with a United States Department of Agriculture loan. This funding gave it the flexibility to modify and operate the plant as required for a high-renewable-fraction system. The utility planned to couple hydropower with wind energy. To maximize chances of success and increase local control, it engaged the local community as much as possible, both in engineering studies and with community concerns. For instance, KEA partnered with the local Audubon society to study the effect of wind turbines on local birds. The utility also performed rigorous wind resource assessment campaigns. The initial campaign had to be redone to consider the vertical wind component caused by the ridge where the wind turbines were sited. Whatever engineering work that could not be performed locally was outsourced.

4.4.3 Execution

To address the significant risks of integrating the amount of wind energy required to achieve KEA's ambitious goals, system upgrades have been carefully performed in stages over 16 years. Each stage grew confidence and capability and answered questions that supported the next stage. The 33.6-MW Terror Lake hydropower plant was outfitted with a faster control system, so that it could quickly adapt to variable wind power. Three General Electric (GE) 1.5-MW wind turbines were installed at Pillar Mountain in 2009, Figure 5. In 2012, three more GE 1.5-MW wind turbines were installed, along with two 1.5-MW battery energy storage systems. Two ABB

Powerstore 1-MW flywheels were installed in 2014. The batteries and flywheels maintained system stability, and the flywheels provided stable power to a 2-MW Matson electric shipping crane at the port. Roughly half of the $145-million total funding (Scott 2022) received for upgrades was from Alaska state and REF grants, and the other half was loans from the CoBank, National Rural Utilities Cooperative Finance Corporation, clean renewable energy bonds, and other sources.

Figure 5. Three GE 1.5-MW wind turbines in Kodiak's Pillar wind energy project overlook the flywheel-powered electric shipping crane. ***Image from Kodiak Electric Association (undated)***

4.4.4 Results

KEA has exceeded its goals, with a system that uses 99% renewable energy and is significantly cheaper than diesel power. About 85% of the community's electricity now comes from hydropower, and the rest from wind. The diesel generators only run when maintenance on the renewable resources or the transmission infrastructure is necessary. Generator operation is so infrequent that they are turned on quarterly to make sure they still work. KEA found that the wind turbines are much cheaper to run and maintain than the diesel generators, and easier to operate overall. Even high-quality diesel generators have costly regular maintenance and break frequently. The wind turbines do trip often, but usually can be reconnected quickly. Hydropower costs 6.8¢/kWh, wind energy costs 11¢/kWh, and diesel power costs 28.9¢/kWh (given a diesel price of $3.50/gallon, which is about half of the current price) (Hobson 2016). Overall, $100 today buys the same amount of electricity as in 2000. The community loves renewable energy, which is a source of pride (e.g., wind turbine art can be seen regularly around the city). Moving forward, KEA is doing a detailed study on projected load growth caused by electric heat pumps, electric vehicles, and U.S. Coast Guard ships docking in Kodiak. KEA also plans to increase the size of the wind turbine and BESS deployments accordingly when they reach the end of their expected lives. A diversion from Hidden Lake was added in December 2019 to boost the hydropower resource so it can handle the variability of more wind capacity while maintaining its water level.

4.4.5 Challenges and Lessons Learned

Previous failed projects provided lessons that set up other projects for success. In the past, a water boiler was a waste of funds because it took so long to build that the surplus water it was built to use ran out. Also, a power plant heat recovery system was poorly designed. Overall, these lessons taught KEA the value of solid engineering, management, and data collection.

KEA's independence from other communities, regulators, and the federal government provided it with the flexibility to operate a high-renewable-fraction system. It decided not to become an IPP so that it would not be beholden to any external customers. Competitive mentalities between communities can ruin otherwise-promising projects. Also, because the wind turbines are exclusively owned by and benefit Kodiak, there was no community resistance.

Ongoing community engagement and support were crucial to the success of the project. For example, a healthy understanding of risk was important. KEA's board was willing to accept risk and understood the risk of doing nothing. This understanding, combined with careful engineering and a progressive development approach, built confidence in the community and mitigated risks. Furthermore, the board stuck to the original goals of the system (providing at least 95% renewable energy at a cost less than or equal to that of diesel power).

Establishing good relationships with reliable equipment manufacturers who provided ample support was important. KEA typically does closed bids to companies that they trust, instead of just accepting the lowest bid they can find.

4.5 Kongiganak (Kong)

4.5.1 Background

In the past, Kongiganak was powered entirely by diesel. The fuel price spike of 2008 motivated its move toward renewable energy.

4.5.2 Preparation

Originally, Kongiganak did not have a good hydropower resource or available solar technology. Because there was a community member with experience using wind turbines to charge batteries, the village decided to go with wind energy. In 2005, to qualify for the funding it needed to engage in a wind energy project, share training, build local capacity, and innovate on ways to reduce energy costs, Kongiganak formed CWG, an IPP, with the neighboring villages of Kipnuk, Tuntutuliak, and Kwigillingok (U.S. Department of Energy Office of Indian Energy Policy and Programs, undated). CWG works with the local Puvurnaq Power Company. Intelligent Energy Systems (IES), a local company with extensive Arctic energy experience, funded a wind resource assessment campaign for several years before installing the wind turbines. IES also secured funding from sources including the U.S. Department of Energy, REF, the state of

Alaska, the Alaska Energy Authority, and other legislative appropriations. Technical assistance was provided by IES and Frontier Power, who installed the wind-diesel SCADA system. The resources supplied by CWG meant that the community only needed to hire an outside crane operator and project manager.

Figure 6. Kongiganak's five Windmatic wind turbines, as seen from the town's boardwalk. ***Image from Grainger (2022)***

4.5.3 Execution

Five 95-kW Windmatic wind turbines were installed in 2009, Figure 6. Kongiganak chose these machines because they were inexpensive, reliable, easy to maintain, operate, and erect, and could be winterized to suit the harsh Alaskan environment. Integration challenges were addressed by changing the turbines' brake rotors and pads to last longer, changing to a low-temperature gear oil, and updating the older analog controls to digital to work with the weak grid. Each wind turbine can provide up to 120 kW of power during gusts. The wind turbines were ultimately commissioned in 2012. The Puvurnaq Power Company was $200,000 short, so it worked with the local Calista Corporation to purchase the last two wind turbines with an agreement to buy them back with a power purchase agreement over 7 years. Puvurnaq Power Company now owns the wind turbines. Fifty electric thermal stoves, each with a 6-kW peak charge, 31 kWh of storage, and a smart metering system, were installed in 2011 to take advantage of additional wind generation and reduce reliance on diesel-powered stoves. The stoves are "charged" when the grid is producing excess wind power. The smart metering system helps diagnose electrical issues, has remote reading and disconnect/reconnect control, and provides customers with web portal access. In 2012, Puvurnaq installed an electric boiler to buffer wind variability and provide heat to the local washeteria, a government facility that provides potable water, showers, and laundry facilities to the community. The utility also installed a wind-diesel SCADA system to coordinate the generation and a hybrid system master controller to balance loads with generation, provide redundant, remote control, and record data. Autonomous operation began in November 2012 (Meiners and Brause 2013). In 2018, Puvurnaq installed an ABB lithium-ion battery that can deliver 375 kW for 5 minutes and provides voltage and frequency regulation to reduce wind curtailment. Curtailment is lowering power output, e.g., when wind power is greater than the power demand.

4.5.4 Results

Currently, two of the wind turbines are down, but all of the other system assets are working. Prior to installing renewables, Kong consumed about 80,000 gallons of diesel every year. After the wind turbines were installed, this number was reduced to about 56,000 gallons. Electric thermal stove customers displace up to 50% of their original home heating oil use if their homes have good weatherization. The community members are happy to save on their combined electricity and heating bills, and local technical expertise has been built through good-paying technical jobs. Renewable energy projects have now been installed in each of the CWG communities. Moving forward, Kong has a 5-year strategic energy plan to reach 100% renewable energy. It has received a U.S. Department of Energy grant to build a 200-kW solar farm that must be completed by summer 2023, and REF is funding upgraded wind turbine blades to increase power production. The community now has the technical capability to support installations in other communities.

4.5.5 Challenges and Lessons Learned

One major key to Kong's success is training, using, and retaining its local workforce, which is made up of three wind technicians and a safety professional. Local technicians are well-paid and have electric thermal stoves in their own homes, providing a double incentive to stay in the community. The renewable energy project was done in stages, progressively building local capabilities to take on more complex tasks. Increased local capabilities allowed the community to overcome technical challenges, including:

- At one point, Frontier Power's SCADA system upgrades took the system down, and the local technicians had to figure out how to keep it going until it was repaired.
- ABB upgraded its battery software in 2019, but local technicians had to do warranty work on the inverter capacitors themselves.

Community leader and tribal council support was crucial for proposals. Minimal conflict sped projects forward. The Puvurnaq Power Company is under the local tribal council but has the latitude to act independently.

Critical community trust and relationships were built by doing many presentations in village meetings to communicate the motivations, benefits, and fuel savings of renewable energy projects. At first, some residents had a hard time understanding that although their electric thermal stove increased their electric bill, it reduced their combined heat and electric bill because it was powered by the wind.

5 Conclusions

Integrating renewable energy into existing isolated electric grids holds great promise for remote communities across both Alaska and the Arctic. When done well, renewable energy projects can save a community money, increase the reliability of their heat and power, and build local wealth, skills, and job satisfaction. Such projects have the potential to drive down residents' electric and heating bills, and reduce dependence on expensive imported fossil fuels, insulating communities from the effects of volatile petroleum markets and unpredictable weather.

The case studies highlighted in this report demonstrate that there are a variety of challenges to renewable energy development. However, communities can take steps to address each of them. Community buy-in can be built, and myths surrounding renewable energy can be dispelled, by providing education and communicating through trusted leaders. Financial constraints and risk aversion can be overcome by identifying and seeking the available funding sources, including grants and secured loans. The expense of remote technical assistance can be overcome by training a local workforce to take on more complex renewable energy projects, including cost-sharing and training with nearby like-minded communities. Technical risks can be overcome by rigorous engineering and project management, partnering with trusted project developers and equipment suppliers, and ensuring that a technology is well suited and demonstrated for use in remote, Arctic conditions. Finally, a local "project champion" is critical to cast a vision that all stakeholders can buy into and to push the effort through inevitable difficulties.

To remote Arctic communities considering adding renewable energy to their electrical system: it may seem like a daunting task, but there is help available. Entities such as the Renewable Energy Alaska Project can provide resources that support communities through various development challenges. In addition, other communities that have already successfully installed renewable energy, including those interviewed in this study, are willing to share their experience and what they learned through the process. We hope that this document can provide inspiration and connection for all remote communities that want to take advantage of their renewable energy resources.

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Appendix: Contacts and Data Sources for Each Community

Table A1 provides a contact person, their contact info, and preferred data source for each community interviewed for this report.

Table A1. Contacts and Data Sources for Each Community. Data are available on Github at https://github.com/REAP-Data/Arctic-Case-Study.git. (AEA: Alaska Energy Authority, EIA: Energy Information Administration)

Community	Contact Person	Contact Info	Preferred Data Source
Galena	Shanda Huntington	shuntington@ci.galena.ak.us	PCE 2001–2020
Shungnak and Kobuk	Ingemar Mathiasson	imathiasson@nwabor.org	PCE 2001–2020, 2022 Renewable Energy Inventory
Kotzebue	Matt Bergan	m_bergan@kea.coop	PCE 2001–2020, AEA Renewable Energy Atlas
Kodiak	Darron Scott	dscott@kodiak.coop	EIA 923, AEA Renewable Energy Atlas
Kongiganak	Roderick Phillips	kongppc6@gmail.com	PCE 2001–2020
Utqiagvik	Griffin Hagle	griffin.hagle@tnha.net	EIA 923
Noorvik	Ingemar Mathiasson	imathiasson@nwabor.org	PCE 2001–2020
Angoon	Jodi Mitchell	Jmitchell@insidepassageelectric.org	PCE 2001–2020
Tuluksak	Melony Allain	tuluksak99679@gmail.com	PCE 2001–2020
Tanacross	Dave Pelunis-Messier	david.pelunismessier@tananachiefs.org	PCE 2001–2020, AEA Renewable Energy Atlas
Nikolski	Tanya Lestenkof	Iko.tribe@hotmail.com	PCE 2001–2020