Alaska Isolated Wind-Diesel Systems: Performance and Economic Analysis

Prepared for
Alaska Energy Authority
and
Denali Commission

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DEFINITIONS

Alaska Energy Authority (AEA): A public corporation of the state with a separate and independent legal existence, with the mission to construct, acquire, finance, and operate power projects and facilities that utilize Alaska's natural resources to produce electricity and heat.

Alaska Village Electric Cooperative (AVEC): A non-profit electric utility serving rural locations throughout Alaska.

Alternating Current: An electric current that reverses its direction at regularly recurring intervals, usually 50 or 60 times per second.

Banner Wind Project: A joint venture in Nome between Bering Straits Native Corporation and Sitnasuak Native Corporation, consisting of 18 wind turbines.

British Thermal Unit: The British thermal unit (BTU or Btu) is a traditional unit of energy equal to about 1.06 kilojoules. It is approximately the amount of energy needed to heat 1 pound (0.454 kg) of water 1 °F (0.556 °C). It is used in the power, steam generation, heating and air conditioning industries. In North America, the term "BTU" is used to describe the heat value (energy content) of fuels, and also to describe the power of heating and cooling systems. When used as a unit of power, BTU per hour (BTU/h) is the correct unit, though this is often abbreviated to just "BTU."

Capacity Factor: The amount of energy a facility generates in one year, divided by the total amount it could generate if it ran at full capacity. A capacity factor of 100% implies that a system runs at full capacity the entire year; a typical wind farm will operate at 30%.

Capital Cost: The cost of field development, plant construction, and equipment required for generating electricity.

Denali Commission: An independent federal agency designed to provide critical utilities, infrastructure, and economic support throughout Alaska; projects thus far exemplify effective and efficient partnership among federal and state agencies and the private sector.

Department of Energy (DOE): A federal agency that oversees programs, such as Wind Powering America, with the mission of advancing national, economic, and energy security; promoting innovation; and ensuring environmental responsibility.

Energy Information Agency (EIA): An independent agency within the U.S. Department of Energy that develops surveys, collects energy data, and analyzes and models energy issues.

Federal Aviation Administration (FAA): An agency within the U.S. Department of Transportation with the authority to regulate aerospace.

Generator Set (gen-set): The aggregate of one or more generators, together with the equipment and plant for producing the energy that drives them.

Grid: The layout of an electrical distribution system.

Independent Power Producer (IPP): A wholesale electricity producer (other than a qualifying facility under the Public Utility Regulatory Policies Act of 1978) that is unaffiliated with franchised utilities in the area in which the IPP is selling power and that lacks significant marketing power. Unlike traditional utilities, IPPs do not possess transmission facilities that are essential to their customers and do not sell power in any retail service territory where they have a franchise.

Kilowatt-hour (kWh): A unit of energy equal to one kW applied for one hour; running a one kW hair dryer for one hour would dissipate one kWh of electrical energy as heat. Also, one kWh is equivalent to one thousand watt hours.

Kilowatt (kW): One thousand watts of electricity (See Watt).

Kodiak Electric Association (KEA): A non-profit electric utility serving Kodiak and the rural area surrounding Kodiak.

Kotzebue Electric Association (KEA): A non-profit electric utility serving Kotzebue and the rural area surrounding Kotzebue.

National Renewable Energy Lab (NREL): A federal laboratory dedicated to research, development, commercialization, and deployment of renewable energy and energy efficiency technologies, operating under the jurisdiction of the U.S. Department of Energy.

Nome Joint Utility System (NJUS): An electric utility serving the community of Nome.

O&M: Abbreviation for operations and maintenance

Pillar Mountain Wind Farm: Kodiak wind project consisting of three GE 1.5 MW turbines. It has become a statewide model for integrating renewable energy into isolated grid systems.

Power Cost Equalization program (PCE): State of Alaska program under which participating utilities receive state funding to reduce electricity rates for consumers in rural areas, where prices can be three to five times higher than prices in urban areas.

Power Purchase Agreement (PPA): A legal, long-term, contract between an electricity generator and a power purchaser to purchase ongoing power at rates with pre-determined annual increases; such agreements clearly designate maintenance responsibilities.

Railbelt: The portion of Alaska that is near the route of the Alaska Railroad, generally including Fairbanks, Anchorage, the communities between these two cities, and the Kenai Peninsula.

Real power: The component of electric power that performs work, typically measured in kW or MW; sometimes referred to as active power.

Renewable Energy Fund (REF): Created by the Alaska Legislature and administered by the Alaska Energy Authority, which awards grants to competitive and qualified applicants for renewable energy projects.

SCADA: Supervisory control and data acquisition; it generally refers to an industrial control system, such as a computer monitoring system.

Transmission System (Electric): An interconnected group of electric transmission lines and associated equipment for moving or transferring electric energy in bulk between points of supply and points at which it is transformed for delivery over the distribution system lines to consumers, or is delivered to other electric systems.

Turbine: A machine for generating rotary mechanical power from the energy of a moving force (such as water, hot gas, wind, or steam). Turbines convert the kinetic energy to mechanical energy through the principles of either impulse or reaction, or a mixture of the two.

Watt (Electric): The electrical unit of power; the rate of energy transfer equivalent to one ampere of electric current flowing under a pressure of one volt at unity power factor.

Watt (Thermal): A unit of power in the metric system, expressed in terms of energy per second, equal to the work done at a rate of one joule per second.

Watt-hour (Wh): The electrical energy unit of measure equal to one watt of power supplied to, or taken from, an electric circuit steadily for one hour.

Western Community Energy (WCE): A company from Bend, Oregon, that is the developer and manager of the Banner Wind Project in Nome.

Wind Powering America: A program funded by the U.S. Department of Energy that is committed to dramatically increasing the use of wind energy in the United States in order to establish new sources of income for American farmers, Native Americans, and other rural landowners, as well as to meet the growing demand for clean sources of electricity.

EXECUTIVE SUMMARY

Most remote rural communities in Alaska use diesel to generate electricity. But the recent rapid development of a worldwide commercial wind industry, along with the rise in diesel fuel prices, has increased interest in wind power in rural Alaska—both to reduce energy costs and to provide local, renewable, sustainable energy.

Wind is abundant in Alaska, and a growing number of rural communities are building wind-diesel systems, integrating wind into isolated diesel power plants. These systems have moved from the initial demonstration phase a decade ago toward a technology available for many communities. Even in places that have not yet added wind, some rural utilities are planning for the possibility. For example, Alaska Village Electric Cooperative (AVEC) has committed to making new diesel power plants "wind ready" by designing its electrical systems so that wind turbines can be incorporated in the future without major reconfiguration.

But it is not clear under what rural Alaska conditions wind-diesel systems are more economical than conventional diesel plant operations. The Alaska Energy Authority asked the Institute of Social and Economic Research (ISER) and the Alaska Center for Energy and Power (ACEP) to assess the performance of existing rural wind-diesel systems. We analyzed data available for existing wind-diesel systems as of spring 2010.

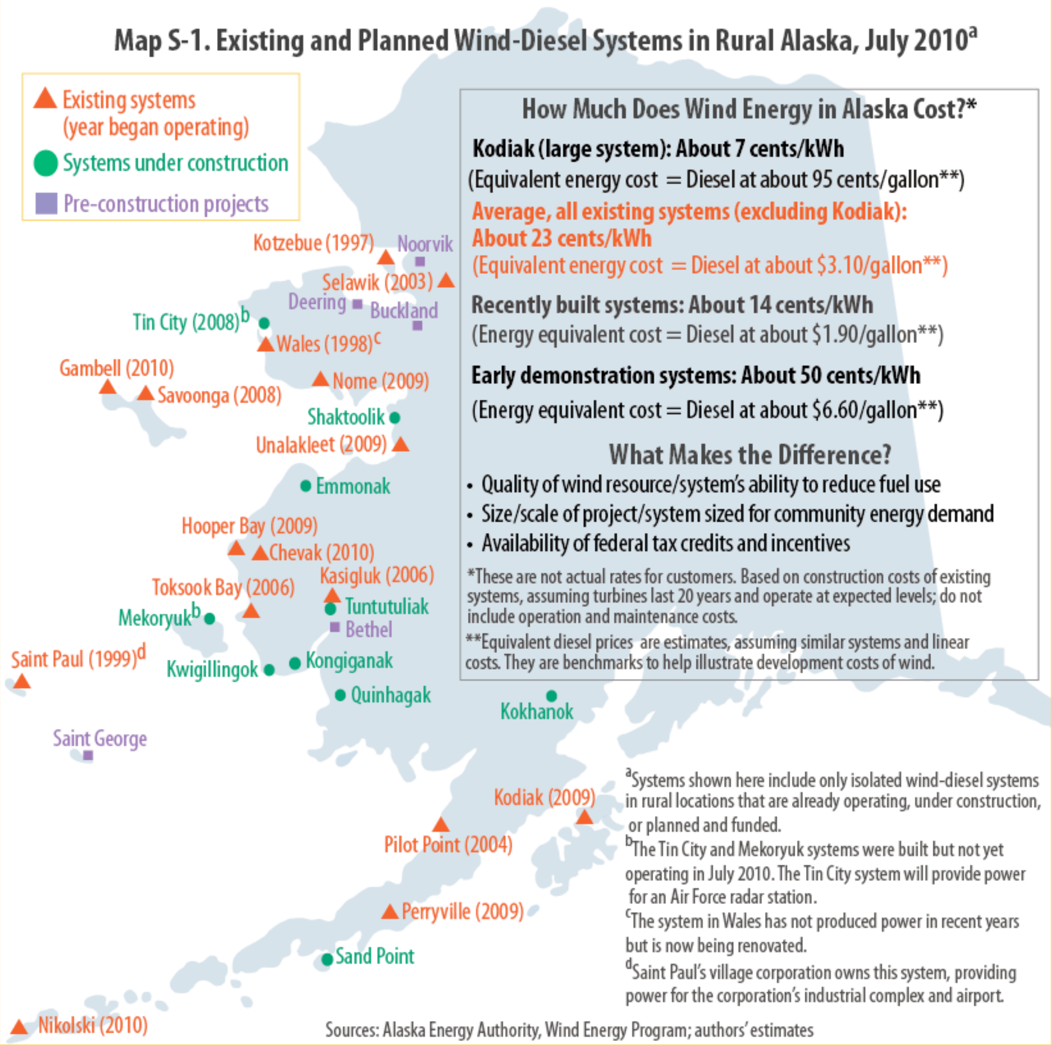
Keep in mind that our analysis is preliminary; most rural wind-diesel systems are very new, and more time is needed to evaluate them fairly. Only three wind systems (Kotzebue, Wales, and Saint Paul Island) have been operating for more than a few years. Initial funding for the Kotzebue and Wales projects came from the U.S. Department of Energy, which funds research but does not subsidize utility operations. These early projects, built in the late 1990s, faced problems but demonstrated there is hardware that can operate in arctic environments. The Saint Paul village corporation funded the system on the island; it provides power for an industrial complex and airport the corporation owns. It is a high-performing system, and the most successful of the early demonstration systems, as measured by its capacity factor. However, it should be noted that both the Kotzebue and Wales systems have provided valuable experiences and lessons learned while integrating wind on a community-scale grid.

Beginning in 2004, the Denali Commission funded projects in five communities (Selawik, Hooper Bay, Kasigluk, Savoonga, and Toksook Bay). In 2008, the Alaska Legislature created the Renewable Energy Fund, a competitive program intended to invest in renewable energy. That fund, which is administered by the Alaska Energy Authority, paid for construction of six projects listed as completed in spring 2010.

The total installed capacity at the time of our analysis was approximately 11,856 kW, from an investment of about $82 million (exact figures for many of these projects are uncertain) in both public and private funds (at least $23 million in Alaska Native corporation and utility funds).

Approximately ten projects were under construction in spring 2010; those will add about four MW (megawatts) of capacity. Another twenty-three projects were in feasibility studies or negotiating contracts to begin work. Many more projects were in the proposal stage.

Map S-1 shows rural wind-diesel systems operating, under construction, and funded but not yet built, as of July 2010. Systems planned but not yet funded are not shown, nor are wind systems that are or will be connected to power grids in urban areas.



Map S-1. Existing and Planned Wind-Diesel Systems in Rural Alaska, July 2010[a]

How Much Does Wind Energy in Alaska Cost?*

Kodiak (large system): About 7 cents/kWh

(Equivalent energy cost = Diesel at about 95 cents/gallon**)

Average, all existing systems (excluding Kodiak): About 23 cents/kWh

(Equivalent energy cost = Diesel at about $3.10/gallon**)

Recently built systems: About 14 cents/kWh

(Energy equivalent cost = Diesel at about $1.90/gallon**)

Early demonstration systems: About 50 cents/kWh

(Energy equivalent cost = Diesel at about $6.60/gallon**)

What Makes the Difference?

- Quality of wind resource/system's ability to reduce fuel use
- Size/scale of project/system sized for community energy demand
- Availability of federal tax credits and incentives

*These are not actual rates for customers. Based on construction costs of existing systems, assuming turbines last 20 years and operate at expected levels; do not include operation and maintenance costs.

**Equivalent diesel prices are estimates, assuming similar systems and linear costs. They are benchmarks to help illustrate development costs of wind.

[a] Systems shown here include only isolated wind-diesel systems in rural locations that are already operating, under construction, or planned and funded.

[b] The Tin City and Mekoryuk systems were built but not yet operating in July 2010. The Tin City system will provide power for an Air Force radar station.

[c] The system in Wales has not produced power in recent years but is now being renovated.

[d] Saint Paul's village corporation owns this system, providing power for the corporation's industrial complex and airport.

Sources: Alaska Energy Authority, Wind Energy Program; authors' estimates

Scope of Analysis

Despite more than ten years of experience with wind generation in rural Alaska, evaluating its economic benefits proved difficult. Installing wind systems frequently requires upgrading other electrical systems in the village (Wales was rewired almost entirely to add wind) and construction of roads and transmission lines, making it difficult to place a cost on wind power only. Early demonstration projects required some arctic adaptation (for example, the Saint Paul installation lost two gearboxes to cold-weather issues and Kotzebue has struggled with tip brakes), which requires additional engineering support. Foundations in discontinuous permafrost have proved significantly more expensive than foundations in more temperate climates. These higher costs, however, are offset by the rising cost of diesel-generated power.

The Alaska Energy Authority's 2009 Power Cost Equalization report indicates the success of Northwind 100 (NW100) turbines in Toksook Bay and Kasigluk, as these turbines have produced levels of energy consistent with the energy projected in the modeling used to justify the projects. These data verify both the robustness of the hardware and the legitimacy of the modeling.

Data to date, however, are insufficient to complete a comprehensive economic evaluation. Most projects justify their economics based on a steady output of power for 20 years, but no installations have yet operated for that length of time. As of spring 2010, 87% of the installed wind capacity in Alaska had less than four years of operation, and 76% had less than one and a half years. More time is needed to fairly and fully evaluate these systems. This report includes case studies of several of the wind systems currently operating in Alaska. It also explores the reasons why some systems have failed to operate or are operating at levels below what wind models had projected.

Investment in wind energy for rural Alaska is currently $20 million to $30 million per year through the state's Renewable Energy Fund. It seems prudent to collect and analyze information from these wind systems to determine their cost effectiveness, especially as compared with the cost of continued operation of the network of diesel generators. But for such a detailed analysis, a more robust system for collecting construction and performance data needs to be established.

Configuration of Wind-Diesel Systems

The percentage of electricity wind power supplies in a wind-diesel system is known as wind penetration. Wind-diesel systems can be classified into low, medium, and high penetration systems. All three types of systems have been built in rural Alaska. The amount of wind power on the grid determines what ancillary equipment is needed for power control and energy storage. Figure S-1 shows the basic configuration of conventional diesel-only systems and examples of low, medium, and high penetration systems—but there are also many other variations in configurations. Also, the numbers shown in Figure S-1 are approximate. The broad differences in systems with different levels of wind penetration are:

- Low-penetration systems cost less to build and do not overly complicate the existing power plant. But wind energy generates only up to 20% of electric demand and does not reduce fuel use as much.

- Medium-penetration systems are costlier to build and more complex to operate, but wind energy generates up to half of electric demand, displaces up to half the diesel, and potentially provides energy for space heating or other uses—like electric cars.

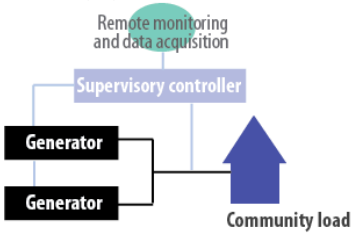
- High-penetration systems are the costliest and the most complex to operate, but wind generation has the potential to supply a large percentage of electric demand and also provide considerable energy for heating or other uses.

Figure S-1. Configuration of Diesel and Wind-Diesel Systems

Information	blue line
Electricity grid	black line

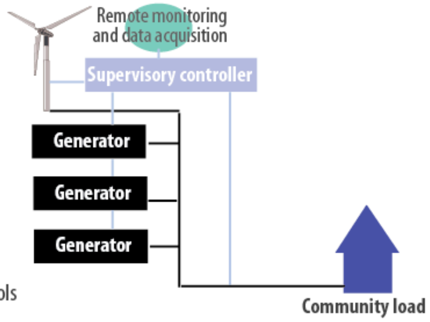
Diesel-Only System

- Diesel generates all electricity
- System simpler to operate



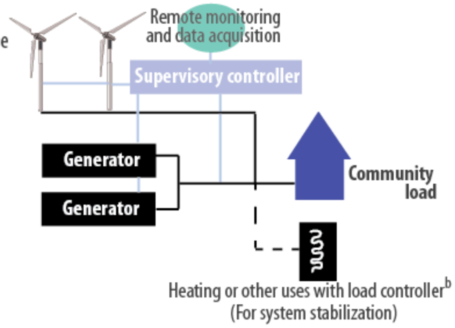
Wind-Diesel System, Low Penetration[a]

- Diesel generators must run at all times
- Wind power reduces load on generators
- All wind energy goes to primary community electrical load
- Annual average wind penetration under 20%
- Fuel savings up to 15%
- Lower installation costs, because system requires less complex controls



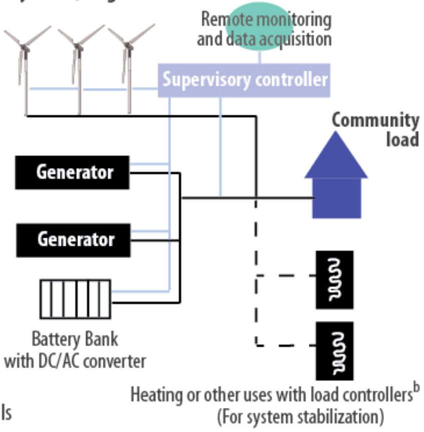
Wind-Diesel System, Medium Penetration[a]

- Potential exists for diesel generators to run under lower, less efficient loads; this should be considered during design
- At high wind power production, part of wind energy diverted for space heating, or wind generation is curtailed
- Annual average wind penetration 20% to 50%
- Fuel savings 15% to 50%
- System controls must be more advanced, which increases installation costs



Wind-Diesel System, High Penetration[a]

- If properly configured, diesel generators may be shut down when wind power exceeds electrical demand
- Auxiliary components regulate voltage and frequency when needed
- Power in excess of what is needed for primary electrical load can be used for space heating or stored in batteries
- Annual average wind penetration 50% to 150%
- Fuel savings 50% to 90%
- Higher installation costs, because system requires sophisticated controls
- Operators must be highly skilled



[a] Wind penetration is the percentage of electricity supplied by wind.
[b] Besides residential or commercial heating, possible other uses include charging electric cars.

Note: These are examples of systems; other configurations exist.

Sources: Authors' compilations

Types and Construction Costs of Existing Systems

The wind-diesel systems built in rural Alaska as of mid-2010 vary considerably in their construction costs and the size and installed capacity of the turbines, as Figure S-2 shows. The installed capacity varies from 24kW at Perryville to 4,500kW at Pillar Mountain on Kodiak Island. Construction spending for existing rural systems as of mid-2010 varied from $4,000 to $15,000 per installed kilowatt, with an average of about $9,600.

Smaller projects in remote places are more expensive, corresponding with the local cost of power, logistics, and construction. Long-term routine maintenance must be conducted to assure that hardware provides the high availability and service life needed for economical operation. Integration of a wind system into an isolated village diesel power plant is a challenge because of the fluctuating nature of wind. As wind turbines provide a larger fraction of the total system power, integration becomes increasingly complex.

Figure S-2. Types and Construction Costs of Existing Wind-Diesel Systems (July 2010)

Size of Turbines/Installed Capacity

2.4 kW/24kW (Perryville) - 1,500 kW/4,500kW (Kodiak)

Construction Costs

(Per installed kilowatt)

$4,000 - $15,000

Types of Systems

(Based on annual average wind penetration)

Low	*Medium*	*High*
Kotzebue	Toksook Bay • Hooper Bay	Saint Paul
Nome	Kasigluk • Savoonga	Wales*
Selawik	Unalakleet	
Perryville		

*Wales' wind system has not generated power in recent years, but it was designed as a high-penetration system and is being renovated.

Notes: Figure does not include systems currently under construction.
About 80% of Kodiak's electricity is from hydroelectic. The new wind system displaces about half the diesel previously used to supplement local electricity, but it does not meet the standard definition of a "high-penetration" system because most of Kodiak's electricity is generated by hydropower, with diesel and now wind supplementing as needed.

Sources: Denali Commission; utilities; wind-developers; Alaska Energy Authority

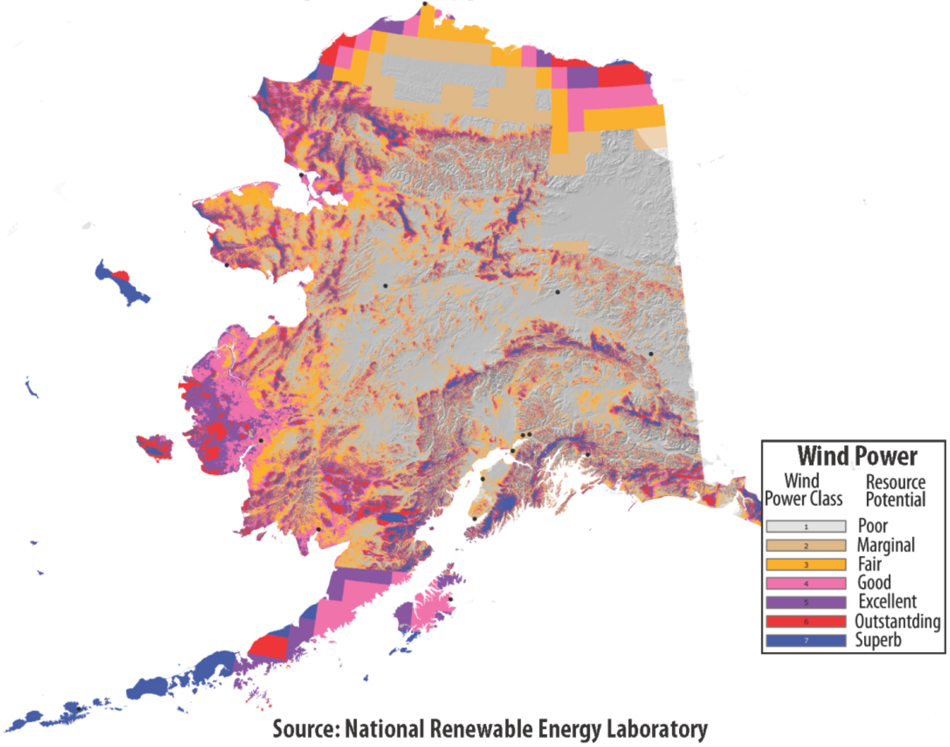
The cost of planned urban or road-connected wind projects is considerably less, averaging $3,100 per installed kW. Planned urban projects may offer the potential for expanding the Alaska wind market and building in-state system development and maintenance expertise that could potentially benefit rural systems.

For projects to be economical there is a need to streamline project construction. Increasing project size and using excess wind energy that is not required to meet the electric load for space heating will likely improve project economics. A standardized system to track construction costs is needed for a thorough analysis of project costs. Additional attention to training local operators and building community capacity is likely to increase project sustainability and protect public and private investments.

Performance of Installed Wind-Diesel Systems

Many areas of Alaska—especially along the coast—have an abundant supply of wind, as Map S-2 shows. But installing wind turbines in a remote arctic environment, and integrating them into isolated diesel power plants, was not considered commercial when the first projects were initiated in Alaska in the late 1990s. A number of people believed that wind turbines and other hardware could not stand up to arctic conditions.

Map S-2. Wind Map of Alaska



Source: National Renewable Energy Laboratory

How does the performance of Alaska wind-diesel installations to date compare with what wind-models projected? By "performance" here we mean the actual kilowatt-hours produced by wind, compared with how much electricity wind models estimated they could produce.

Systems operating in mid-2010 can be categorized into demonstration-phase development—including pilot projects in Kotzebue, Wales, and Saint Paul—and modern-phase development, including the installations in Kodiak, Toksook Bay, and Kasigluk.

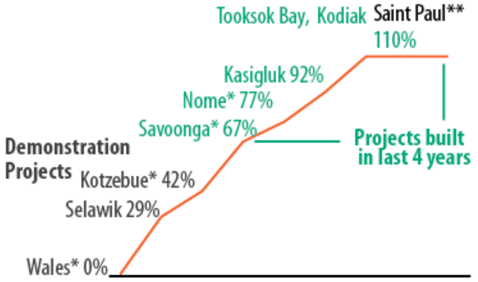
Pilot projects are intended to demonstrate a new technology, improve an existing technology, or prove that an existing technology will work in a new application or environment. Wind turbines have been a commercial technology worldwide for decades. The installations in Kotzebue, Saint Paul, and Wales brought wind-diesel technology through the demonstration phase and into a more modern period of development, in which installations are being optimized and penetration levels are exceeding what was previously thought possible.

Today, Saint Paul is the only high-performing demonstration project, generating more kilowatt-hours than wind models predicted. Systems at Kotzebue and Wales were intended first as arctic test sites and are not performing at expected levels. By contrast, several more recent installations are performing at or above expected levels; some had not yet ramped up to full operation by mid-2010.

Figure S-3 shows the continuum of improving performance of existing wind-diesel systems, from demonstration projects to those built in the past four years. Figure S-4 compares actual versus expected performance of systems for which we have data—adequate data are not available for all existing systems—and summarizes factors affecting the performance of individual systems. (The actual kilowatt-hours produced by wind shown in Figure S-4 are from the Power Cost Equalization program, for communities in that program, and by utilities themselves, for communities not in the PCE program.)

Figure S-3. Improved Performance of Newer Wind-Diesel Systems

(Actual Kilowatt-Hours Produced by Wind, as Percent of Wind-Model Estimates)



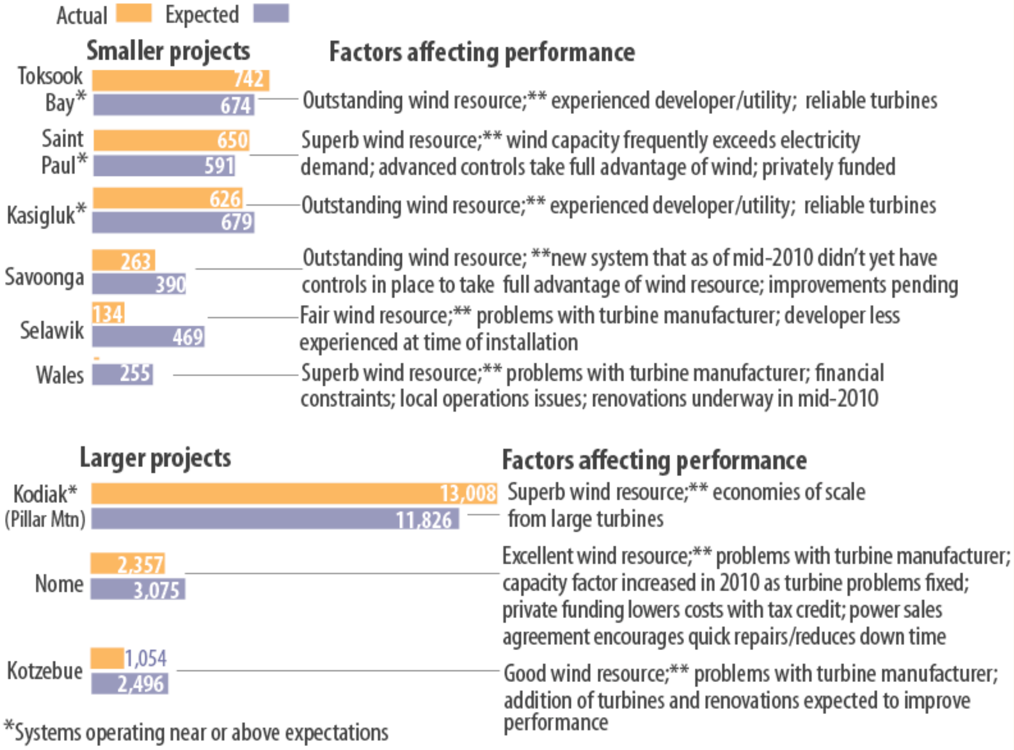
*System being renovated or still ramping up to full operation; see Figure S-4.

**Built in 1999, this system is the exception: an early but high-performing system; the developer had significant experience in wind-diesel systems.

Source: Utility information, Power Cost Equalization Program data

Figure S-4. Actual versus Expected Performance, Existing Wind-Diesel Systems

(In Thousands of Kilowatt-Hours per Year Produced by Wind— Reported Hours versus Wind-Model Estimates)



*Systems operating near or above expectations

**Wind resources are divided into seven classes, from those with the least to the best potential for generating power: Class 1: poor; Class 2: marginal; Class 3: fair; Class four: good; Class 5: excellent; Class six: outstanding; Class 7: superb

Note: Adequate data aren't available for all existing systems.

Sources: Utility information, Power Cost Equalization Program data; HOMER model estimates

Critical factors affecting system performance are the available wind resource and the level of wind penetration—low, medium, or high—into the system. Each system requires different levels of engineering support and capital outlay. Low-penetration systems are lower risk from an operational standpoint, because the technology is relatively seamless to incorporate into an existing diesel power plant. However, the existing low-penetration systems in Alaska, such as those in Kotzebue, Nome, and Selawik, appear to also have low capacity factors; capacity is the percentage of time during the year when a wind turbine is producing energy. It should be noted that there is no direct correlation between penetration level and capacity factor, other than the fact that a better performing system, which yields a higher capacity factor, will have a higher penetration of wind into the existing system.

A common reason why early systems are not performing as well as expected is that they have had problems with specific brands of turbines. The systems in Kotzebue, Nome, Wales, and Selawik use Entegrity turbines and have experienced turbine operational problems. These installations would benefit from having a regional maintenance program, with an entity that could support all the systems and improve availability. There are other, more recently installed low-penetration systems that do not use the problematic Entegrity turbines, but there is insufficient operational experience to fully evaluate them.

The medium-penetration systems installed by the Alaska Village Electric Cooperative (AVEC) have been more successful, demonstrating high availability of over 95%, year after year, and higher capacity factors, such as 24% at Toksook Bay. Any excess wind penetration is delivered to a secondary boiler, to optimize the available wind, stabilize power quality, and further increase economic benefits.

High-penetration systems offer large potential for future development, including the ability to store excess electricity in a battery system, offset residential and commercial space heating, or enhance alternative transportation such as electric vehicles. The deployment of wind power in Alaska communities can be enhanced by matching load to the availability of the wind energy. At least one company has developed an open protocol Smart Grid load management system to achieve the full integration of wind power, diesel generation, and the electric load. Discretionary loads such as water heating, space heating, and pumping can be coordinated with wind power availability. Annual fuel savings could potentially be increased by 10% through employing Smart Grid solutions, when this technology becomes economically viable.

In summary, there is a clear difference in performance between the early demonstration projects, which all used the same turbine (AOC/Entegrity), and the modern installations in Kodiak and Toksook Bay. There is also a commissioning phase, where newer installations have experienced reduced turbine availability for the first couple years of operation. Nome is an example of a system that has been working through problems and increasing its capacity factor.

And while conditions are different for each system, several factors are common among the top-performing systems: wind resource of class 6 (outstanding) or 7 (superb); reliable turbines; experienced wind developers and utilities; and skilled local system operators.

Cost of Wind Power

Critical questions for agencies and communities investing in wind power are how much does wind energy cost, and how does the cost of wind energy compare with that of diesel, on an energy-equivalent basis? Using available information on construction costs of existing systems and amortizing those costs over an assumed 20-year life for wind systems, we estimated the cost of wind energy for existing systems. There is currently not enough data on operations and maintenance costs to incorporate those kinds of costs into our estimates.

As Figure S-5 shows, the estimated cost of wind energy from existing systems varies from about 7 cents/kWh for the large system at Kodiak to about 50 cent/kWh for early demonstration projects. On an energy-equivalent basis, the least expensive wind energy is comparable to diesel priced at less than $1 per gallon, and the most expensive wind energy is comparable to diesel priced at around $6.60 per gallon. The average cost of wind energy for recently built systems is about 14 cents/kWh—on an energy-equivalent basis, that is comparable to diesel priced at about $1.90 per gallon. To put those costs in context, many rural utilities that report diesel prices to the Power Cost Equalization program reported in 2009 that average diesel prices were in the range of $4 to $5 per gallon, with a few reporting prices around $7 per gallon.

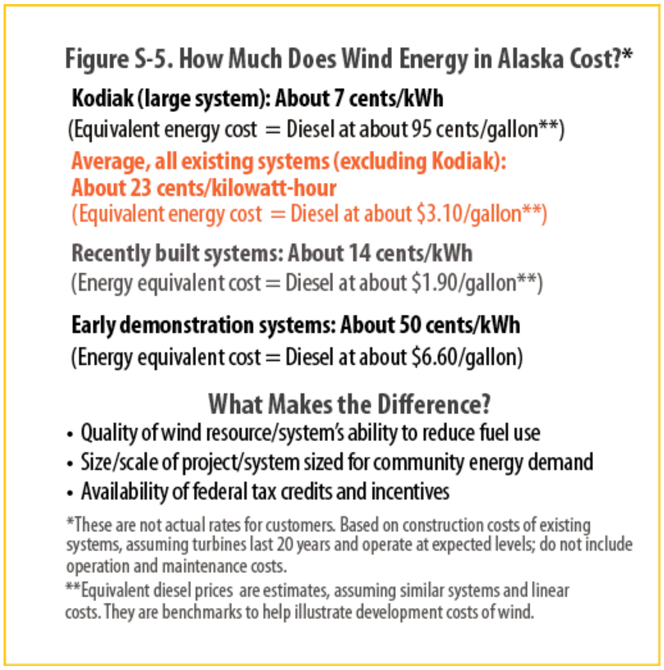


Figure S-5. How Much Does Wind Energy in Alaska Cost?*

Kodiak (large system): About 7 cents/kWh
(Equivalent energy cost = Diesel at about 95 cents/gallon**)

Average, all existing systems (excluding Kodiak):
About 23 cents/kilowatt-hour
(Equivalent energy cost = Diesel at about $3.10/gallon**)

Recently built systems: About 14 cents/kWh
(Energy equivalent cost = Diesel at about $1.90/gallon**)

Early demonstration systems: About 50 cents/kWh
(Energy equivalent cost = Diesel at about $6.60/gallon)

What Makes the Difference?

- Quality of wind resource/system's ability to reduce fuel use
- Size/scale of project/system sized for community energy demand
- Availability of federal tax credits and incentives

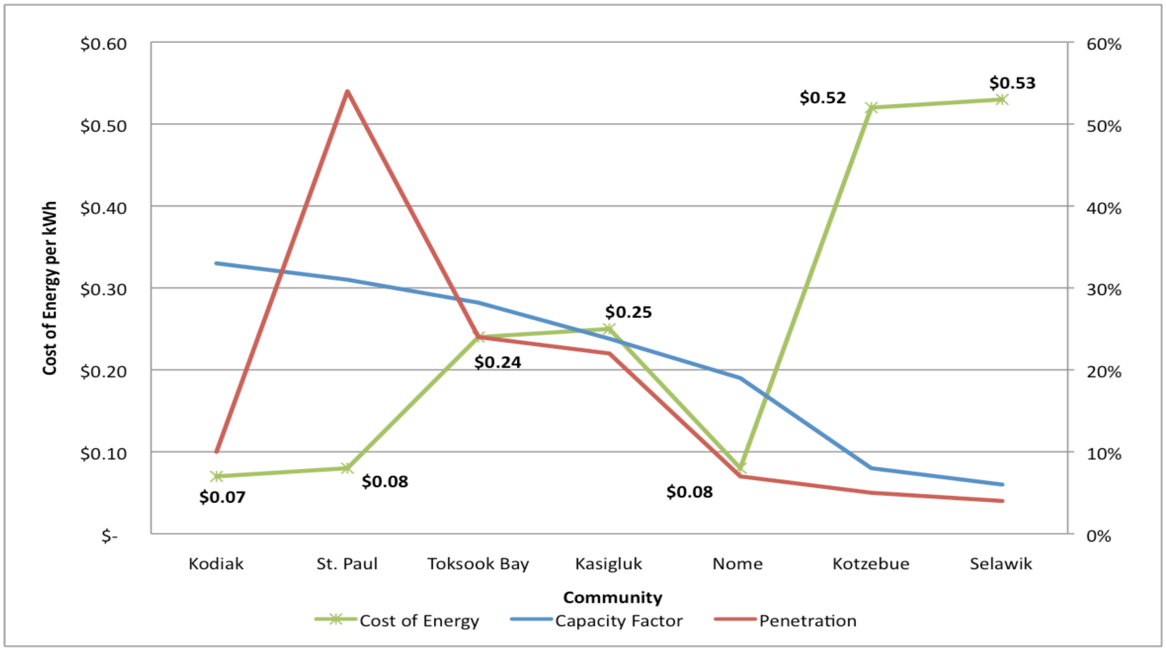
*These are not actual rates for customers. Based on construction costs of existing systems, assuming turbines last 20 years and operate at expected levels; do not include operation and maintenance costs.

**Equivalent diesel prices are estimates, assuming similar systems and linear costs. They are benchmarks to help illustrate development costs of wind.

It can be broadly stated that as systems perform better (higher capacity factor) the cost of wind decreases. It can also be broadly stated that the cost of wind decreases with higher levels of penetration. Also, economies of scale can reduce the cost of energy. For example, the Kodiak system employs the first large-scale wind turbines in rural Alaska (three 1.5 MW GE turbines), and the cost of wind from that system is at the low end of the range.

The cost of wind does not always directly correlate with the capacity factor and penetration level. Nome (a low-penetration system) is an example. As a privately funded project, it qualified for federal production tax credits that significantly reduced installed costs of wind, thereby lowering the cost of wind energy.

Figure S-6. Impact of Penetration and Capacity Factor on Cost of Wind



Source: Alaska Energy Authority, Power Cost Equalization and utility data; authors' compilations and estimates

Except for the Nome system, the cost of wind energy for communities with existing low-penetration systems ranges from 32 cents/kWh to more than 50 cents/kWh, over a 20-year project lifespan. Nome has a current capacity factor of 22%, but an estimated cost of wind energy that is significantly lower than that of other low-penetration systems, as Figure S-6 shows.

The cost per kWh is lower for the medium-penetration systems, coming in at around $0.25/kWh. While the capital cost is higher per installed kW—because of the increased capital cost of the NW100 turbines, the secondary-load controller, and a more complex SCADA system—existing medium-penetration systems are performing well, with high capacity factors.

Higher-penetration systems, such as the ones at Kodiak and Saint Paul Island, have the lowest lifetime wind costs—less than 10 cents/kWh.[1] Both systems have capacity factors of over 30%, indicating that the wind resource is ideal, the turbines are well maintained, and the project developers have a stake in maximizing the benefit of the installed systems.

Overall, as modeling predicts, it does appear that higher penetration systems equate to higher capital costs but greater fuel savings—which directly lowers the cost of energy. Again, with the small number of installed systems this correlation is based on limited data points. The calculated

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[1] Kodiak's system is wind integrated with hydroelectric and diesel generation. It is a "high penetration" system in terms of offsetting diesel generation, but wind actually provides a relatively small portion of total power, which is mostly hydro. Kodiak is a unique system in Alaska and not directly comparable to any other rural system.

lifetime savings do not include the potential economic benefit of directing excess power to thermal loads. While higher penetration systems can provide greater benefit, training and support infrastructure is crucial for long-term sustainability of these more complex systems.

Wind Energy and the Power Cost Equalization Program

The state government established the Power Cost Equalization (PCE) program in the 1980s to help bring the cost of electricity for rural Alaskans closer to what urban residents pay, and to help small rural utilities, which struggle with high costs. PCE pays eligible utilities part of the cost of the first 500 kilowatt-hours of use per residential customer per month and also subsidizes the first 70 kWh of use per person per month for community facilities in eligible communities. Communities eligible for PCE subsidies are determined by state statute, based on costs of electricity; currently 184 small communities are eligible.

Some utility operators and analysts told us they think this PCE formula penalizes rural utilities that add wind power. In response, we constructed a comparative cost model to assess the effects of the current PCE formula on wind-diesel and diesel-only systems; we analyzed how adding wind energy to a rural power system affects potential utility reimbursements.

Figure S-7 describes the issue and illustrates it with an example. Essentially, under the current PCE formula, communities with wind-diesel systems receive less benefit from the program at times of increasing fuel prices than communities generating electricity with diesel fuel alone. That's because the formula was developed for diesel-power generation utilities—and it responds to higher fuel prices by increasing the rate of subsidy, based on diesel fuel used for generating electricity.

So when rural utilities add wind power they may not get the full economic benefit—because when they reduce the price of electricity by reducing their fuel use, they lose part of their PCE subsidy. And at the same time, they increase their operating and maintenance costs, because operating and maintaining wind-diesel systems is more complex and expensive than operating diesel-only systems. Installing wind power likely adds in the range of 4 cents to 8 cents per kilowatt-hour to utilities' costs. That is a very rough estimate, because data about and experience in operating wind-diesel systems are limited.

We estimate that to make up for the smaller PCE subsidy and higher operating costs, utilities would have to cut their fuel costs very substantially—by generating about 40% of their electricity with wind. But most existing systems generate less than 25%.

To provide more incentive for rural utilities to use renewable energy —a goal of the state Renewable Energy Fund—and to encourage energy conservation, we suggest the state consider a different PCE formula. Instead of paying part of the cost of the first 500 kWh per month, the state might cover the entire cost of a smaller amount—perhaps in the range of 200 to 300 kWh.

That is just one option to consider. More analysis is needed to determine the optimal PCE system, including an analysis of a larger sample of communities and individual ratepayers' monthly electric bills. But policymakers should consider ways to structure PCE to work in concert with the state's renewable energy goals—and reward rural utilities that make the substantial effort to reduce costs for their customers. Also, while we modeled only the effects of adding wind energy to a diesel utility, it is likely that the results would be similar for a hydroelectric or any other non-fossil fuel generation system.

Figure S-7. Why Might the Power Cost Equalization Formula Discourage Rural Utilities from Adding Wind Power?

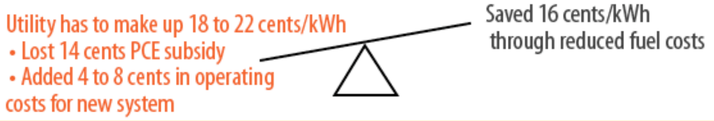
Current PCE formula pays part of the cost for first 500 kWh per residential customer per month*

- Assumes that eligible utilities use only diesel to generate electricity
- Pays utilities more as they use more fuel or as fuel prices increase
- Gives customers little incentive to conserve until use reaches at least 500 kWh per month

Example: Kasigluk Utility

	Old System (Diesel-Only)	New Wind-Diesel System (Wind generates 22% of electricity)	Changes
Price of electricity (per kWh)	70 cents	54 cents	↓ Down 16 cents: wind power reduces fuel use
PCE subsidy (per kWh for first 500 kWh per residential customer)	53 cents	39 cents	↓ Down 14 cents: fuel use and electricity price drop
Non-Fuel costs	Operating/maintaining diesel-only system	Operating/maintaining more complex system	↑ Up 4 to 8 cents/kWh

Model Estimates for Kasigluk Utility, with Wind Generating 22% of Electricity



Utility has to make up 18 to 22 cents/kWh

- Lost 14 cents PCE subsidy
- Added 4 to 8 cents in operating costs for new system

Saved 16 cents/kWh through reduced fuel costs

How Might PCE Provide More Incentive but Still Help Offset High Electricity Costs?

Consider changing PCE system to cover entire cost of a much lower baseline amount of electricity—for example, 200 to 300 kWh per month.

- Would give utilities more incentive to reduce fuel use and allow them to fully capture economic benefits from adding wind power, even at lower wind-penetration levels
- Would give customers more economic incentive to conserve energy and support use of wind power

*Communities eligible for PCE subsidies are determined by state statute, based on costs of electricity; currently 184 small communities are eligible. The PCE program also subsidizes the first 70 kWh of use per person per month for community facilities in eligible communities.

Sources: Utility PCE and RCA filings and ISER model estimates

Wind Energy Financing Options

By publically funding construction of many rural wind-diesel systems, Alaskans are potentially passing up a substantial amount of federal tax credits and other opportunities for funding of wind energy projects. It may be that the Alaska Renewable Energy Fund could be used to leverage rather than replace these other funding opportunities, some of which include Production Tax Credits, Clean Renewable Energy Bonds, and Small Wind System Tax Credits.

Lessons Learned

Economies of Scale. It is important to take advantage of geographically aggregated projects to make development and maintenance more financially viable. Working in several communities simultaneously would help reduce maintenance and equipment costs and allow expenses to be shared among several project budgets. Coordinating equipment and logistics across more than one project and sharing expenses would help decrease construction costs. In addition to geographic clustering, "technical clustering" in the form of technical standardization may help to reduce costs. This need not be a formal standardization, but the application of similar technical and system concepts in communities with similar needs and conditions would greatly enhance the efficiency of applying wind-diesel technology. AVEC is applying these concepts.

Clear, legally defined benefits and obligations for all project parties. When the Wales project was implemented, the Memorandum of Understanding (MOU)—or written long-range plan—between the interested parties was not optimal for Wales. Similarly, the power purchase agreement (PPA) was not in place for the Nome Banner Wind project until one year after the installation. Similar issues related to a PPA have plagued the Saint Paul Island TDX Power project. It is critical to have these agreements in place before projects are constructed.

Importance of trained, skilled, and motivated operators. The training level of operators varies significantly from community to community. Projects need to have operators willing to learn about and adapt to new technologies. Equally important, however, is the fact that wind-diesel systems are more complex then diesel systems—so operators need the right incentives to ensure that the new systems operate as they were intended. Operators also need to have a commitment to and a sense of responsibility for operating the systems. Projects in small communities are likely to require skilled laborers from outside the community to perform repairs and advanced-level maintenance for the lifetime of the project.

Need for skilled and dedicated engineers. Adequate resources need to be invested in developing skilled engineers trained in wind energy. In the end, however, it may not be the utilities that maintain the wind systems. A more optimal and cost-effective system may be development of a regional service organization. Coordinating maintenance visits to several communities during one trip could also help reduce costs. To protect the public investment in projects, warranty and service agreements that include operator training should be required for two to five years.

Good remote monitoring. Remote monitoring alerts the project manager if there are problems and therefore enables better support of wind systems. But it cannot solve problems that are operator-related, as was the case for the Wales system. Remote monitoring can help log the system's maintenance and help preserve a record of performance. Developers should not consider developing a project that does not have good remote connectivity.

Alaska expertise. Past and current projects rely heavily on the expertise of people from outside Alaska. However, people who claim to have expertise in wind-diesel systems may not have the appropriate knowledge required for projects in Alaska.

Data Needs and Reporting Requirements

There are currently few requirements for reporting construction costs or system performance for projects receiving public funds. This analysis was hampered by this lack of data, as will future analyses. A consistent reporting system needs to be developed to enable a thorough review of individual projects. The Alaska Energy Authority will be requiring both performance and economic reporting for the Renewable Energy Fund projects, so the state can better assess the success of the program.

State Investment in Wind

The feasibility of wind projects is very vulnerable to construction and operating costs, and the state has a considerable investment and role in projects—so there are obvious incentives to improve efficiencies. Several cost-containment measures could be facilitated by the Alaska Legislature and state agencies:

- The NW100 is now the most frequently installed utility-sized wind turbine in rural Alaska. Negotiating the purchase of multiple turbines for grant recipients of Renewable Energy Fund wind projects might help to lower costs.

- It would be helpful if the Alaska Department of Natural Resources expedited the land lease process for cooperatives and nonprofits. One utility manager recommended that the State of Alaska set a priority on using public lands for energy projects and make land available.

- Projects able to provide their own financing or cash-flow construction are better able to manage and minimize construction costs. Projects in smaller communities that depend on Renewable Energy Fund invoice reimbursements reportedly suffer delays and cost increases. The invoice reimbursement process is not an efficient way to manage project construction.

- Wind resources vary from place to place, and a better wind resource can provide more benefit from the same investment in equipment. Given limited funding, investments should be made in places with the best wind regimes. More extensive placement of met towers to evaluate wind resources would better focus project investment.

- Smaller installations cost more per installed kW, but smaller communities also tend to have higher energy costs—so the economics of each place must be evaluated to make sure that the wind power is cost-effective in that market. Larger wind turbines cost less per installed kW, and the excess energy produced can be used to offset diesel used for heating. Demonstration projects are needed to develop this technology. Based on the wider wind industry development curve, installation costs should decline as the number and variety of wind manufacturers supplying both new and refurbished equipment and the number of trained service technicians increase. These improvements, in turn, will decrease investment risk.

- Current installed costs of $4,000 to $15,000 per kW for small communities with good wind resources (30% capacity factor) correspond to a capital cost of 7 cents to 50 cents per kWh (assuming a 20-year system life), or a diesel price of about $1.00 to $6.60 per gallon (assuming other utility costs remain the same). The economic calculations done to evaluate wind assume a 20-year life for the equipment, which requires the attention and commitment of the local entity to keep systems operational. Some communities are better equipped for this responsibility than others.

- From a technical point of view, well-managed modern systems are providing the expected or a higher level of electrical power, based on the wind resource and turbine parameters—which provides greater confidence in investment decisions.

- The current rate of growth in the number of wind installations supports the in-state development of wind energy expertise. Less activity may be insufficient to create a robust market; too great an increase might result in importation of expertise. At the same time, there may be economies of scale with larger clustered development. Attention and increased investigation of this balance is warranted. In addition, the current structure of PCE provides disincentives for renewable energy. Better mechanisms to incentivize renewable expansion should be considered.

Conclusion

The successful performance of the few available modern wind systems is an important observation—because it was not clear whether wind projects in Alaska achieve the level of generation estimated by wind models, indicating a potential mismatch between model assumptions and Alaska conditions. Based on the findings of this analysis, the models appear to reliably forecast performance in Alaska.

But for projects to be economical there is clearly a need to ensure that an adequate wind resource is available. Indicators of success in communities with wind-diesel systems meeting model expectations include the use of reliable turbines, a very high wind class—6 (outstanding) or 7 (superb), and competent utilities or operators.

Systems in communities with the strongest wind regimes, Saint Paul and Kodiak, have high capacity factors and are meeting model expectations. On the other hand, Selawik has a lower wind class—3 (fair)—so that system has a lower capacity factor. It is critical for developers to complete a full and detailed wind site assessment when planning a project, because a strong wind resource is necessary for any project to succeed.

It is also critical to streamline project construction, especially for smaller rural projects. Increasing the size of projects and using excess wind production for space heating may also improve project economics. A required and standardized system of tracking construction costs is needed, so public agencies or private developers can analyze project costs. In addition, a consistent reporting system needs to be developed now—so in the future there can be a more thorough review of the program, when more systems have been operating long enough to have more consistent records.

1 INTRODUCTION

Wind power has developed over the past 40 years, as large-scale commercial generator technology matured to provide electricity generation at commercial rates in grid-connected environments. This has resulted in large wind-farm developments in the U.S. and Europe. The economics of wind-power systems improved as turbine size grew larger, and the market for wind-generated power increased. Installed turbine size grew from less than 100 kW to more than 1 MW over this time, significantly reducing the capital cost per installed kW.

The success of wind systems sparked interest in using this technology to provide power in Alaska's remote communities, especially given the excellent wind resource many of these places have and the high and rising cost of diesel, which is the major source of energy for remote Alaska communities. Several successful demonstration projects in Alaska provided hope that use of wind power might be possible. In 1997, Kotzebue Electric Association pioneered the installation of the first three 65 kW wind turbines and demonstrated that these commercially available turbines could survive arctic conditions and provide usable power for Kotzebue residents—though the wind turbines provide only a small fraction of the total power required by the community.

This test project was followed by a demonstration project in Wales, intended to show that augmenting the wind turbines with a modest battery system could allow operation of the utility in a diesel-off mode when the wind was sufficiently strong. The battery could absorb variations in both generated power and village load. This system operated well when supported by National Renewable Energy Lab (NREL) engineers, but never won the confidence of the local operator. A third system installed by TDX Corporation on Saint Paul Island used a refurbished 225 kW Vestas turbine to provide both electrical and thermal energy to the TDX facility, with a reported payback on the investment of less than eight years. The success of this project depended both on strong management support and investment, as well as the dedication and skills of the system operator.

These successes were encouraging and proved that wind power could be used in Alaska. However, both the Kotzebue and Wales systems were pioneering systems and required significant engineering support for design and operation, as expected in initial demonstration projects, making economic analysis of the projects difficult. The hope of all involved in the development of wind power is that it will prove more economical than the current diesel-only generation infrastructure. Cost of energy from these wind systems will be reduced if:

- Installation costs are minimized
- Systems are maintained to maximize the working life (similar to hydro, the major investment is in upfront capital, and the power becomes cheap only after the capital investment is recovered)
- Usable power from the system is maximized to displace as much diesel fuel as possible

Alaska's Renewable Energy Fund legislation, passed by the state legislature in 2008 and implemented by the Alaska Energy Authority, pushed the deployment of wind systems to a new level, as several dozen wind projects were funded throughout the state. These funds provide for capital equipment purchase and installation, but not for O&M (operation and management) costs beyond the initial warrantee period.

The economics of wind in remote Alaska communities is significantly different from that in more developed places. Some of the reasons for these differences include the following:

- The arctic climate presents challenges, including cold weather operation, icing, and very dense air, for which some turbines are not designed.
- Most remote communities do not have ready access to cranes or other construction equipment required for installation.
- Transporting turbines and necessary construction equipment adds logistical costs.
- Small communities may lack people with the skills needed for maintaining the systems.
- Permafrost and other soil conditions raise the cost of foundations to anchor turbines.
- Operation of wind turbines may destabilize the operation of diesel engines, reducing the heat recovered from these engines, and may increase diesel O&M expenses due to operating in low-load conditions.
- Many small communities require less electricity than is provided by a single large-scale generator, so smaller, more expensive turbines are required.
- There is no grid to absorb excess power, which raises costs of integrating wind into existing diesel systems.

Many of these issues vary significantly among villages, making it difficult to estimate project costs for any given place.

Worth noting is that the economics of diesel-power generation is also difficult to evaluate, given that many capital projects—such as the recent diesel-plant upgrades and bulk-fuel storage tanks—are funded by grants from the Denali Commission. Therefore, customers never see the costs of these investments. In order to receive funds through the PCE program, village utilities report costs associated with the generation of diesel power, including both fuel and non-fuel costs. The fuel costs are relatively straightforward, based on actual costs incurred by each village utility, but the non-fuel component varies greatly, and includes labor, administration, and capital recovery. Compared with costs for wind-power generation in rural Alaska, costs for diesel-power generation are relatively well understood, because capital costs, efficiencies, and O&M costs have been established for remote communities over the past 40 years.

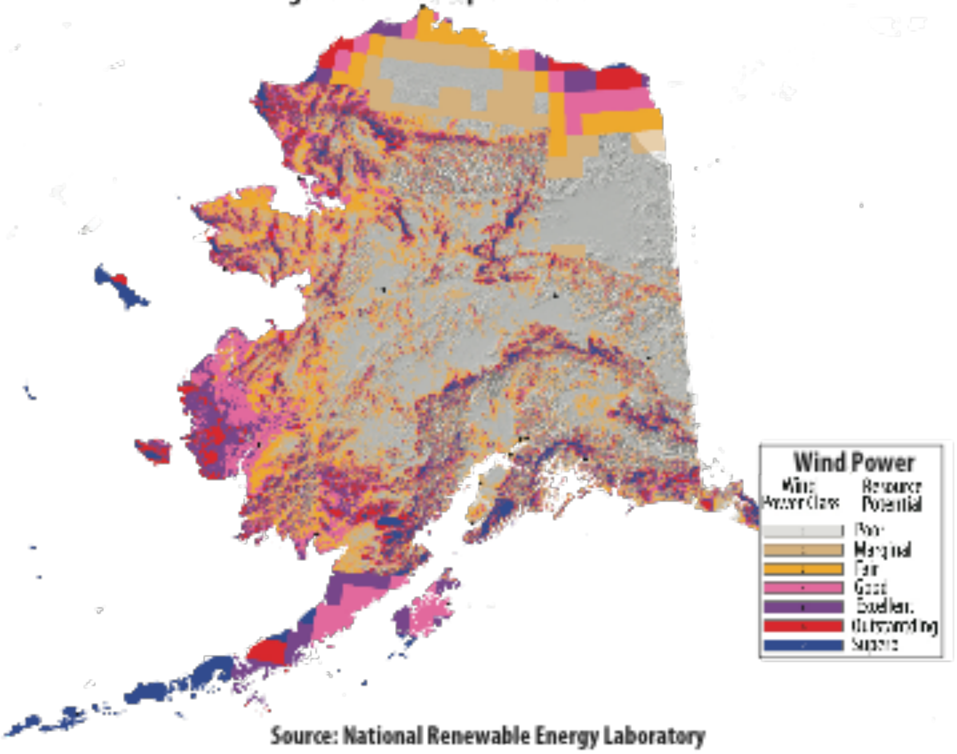
Given these uncertainties, the modest goals of this study were to:

- Survey existing wind-diesel installations for lessons learned, including best-effort estimates of the cost of power

- Compare wind-diesel modeling projections of electricity wind could generate with statistics on actual production from available sources, including PCE reports
- Identify communities that have received Renewable Energy Funds for installation of wind-diesel projects, calculate capital costs per installed kW, and establish a baseline for evaluating the cost of power over the lifetime of each project
- Assist the wind industry in Alaska by identifying both successful and unsuccessful deployment strategies in order to help maximize the benefits of wind
- Identify data needs to allow Alaskans to make well-informed, economically defensible decisions about the future deployment of wind energy

Wind energy is abundant in many remote communities, and currently represents an attractive, locally available energy source for both electricity and heat (Figure 1).[2] While fuel costs for wind power are zero, the energy is not free; it takes significant funds to purchase, install, and maintain these systems. This study shows that wind can provide energy at costs lower than the existing energy infrastructure, if the system is well designed and has a sufficient wind resource, based on diesel and heating fuels at current 2010 prices.[3]

Figure 1. Wind Map of Alaska



Source: National Renewable Energy Laboratory

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[2] National Renewable Energy Laboratory. http://www.windpoweringamerica.gov/images/windmaps/ak_50m_800.jpg

[3] Energy Information Administration. 2009. Annual Energy Outlook 2009, November.

1.1 CURRENT INSTALLED CAPACITY AND WIND GENERATION

Wind energy, which is abundant in Alaska, is being incorporated in more and more community energy systems, moving from the initial demonstration phase toward a technology being considered for many communities. Alaska's first utility wind farm was installed in 1997, when three Entegrity (formerly Atlantic Orient Corporation or AOC) turbines were erected in Kotzebue. In the next six years, the Kotzebue farm increased its capacity from 195 kW to 1.14 MW. Kotzebue was the proving ground for many of the technological challenges that Alaskans would face as additional wind turbines were erected over the next ten years. Since that first installation, significant development and innovations have occurred. The Alaska Village Electric Cooperative (AVEC) has committed to making new diesel power plants "wind ready" by designing electrical systems so that wind turbines can be incorporated in the future—which is indicative of the trend toward incorporating wind in more remote rural systems.

As of spring 2010, nineteen wind projects had been completed in various communities around the state, but only three (in Kotzebue, Wales, and Saint Paul Island) have been operating for more than a few years. Initial funding for Kotzebue and Wales came from the U.S. Department of Energy (DOE), which funds research but does not subsidize utility operations. Beginning in 2004, the Denali Commission funded projects in five communities (Selawik, Hooper Bay, Kasigluk, Savoonga, and Toksook Bay). In 2008, the Alaska State Legislature created the Renewable Energy Fund, a competitive program established to invest in renewable energy. Wind projects have received a substantial portion of the funds available through this program, which the Alaska Energy Authority administers.

In spring 2010, nineteen wind projects had been completed in various communities and are displayed in Figure 2. The total installed capacity in these projects is approximately 11,856 kW, from an investment of about $82 million (exact figures for many of these projects are uncertain) in both public and private funds (at least $23 million in Alaska Native corporation and utility funds), giving an average installed cost of about $9,600 per installed kW (smaller rural systems). The largest and cheapest of these projects, per installed kilowatt, is the Pillar Mountain project on Kodiak (4500 kW at $21 million). Smaller projects in remote places are more expensive, corresponding with the local cost of power, logistics, and construction. Most of these projects started before the state REF began in 2008, and were funded by the Denali Commission, the U.S. Department of Energy, or private sources. The REF was used for seven projects listed as completed in Table 1.

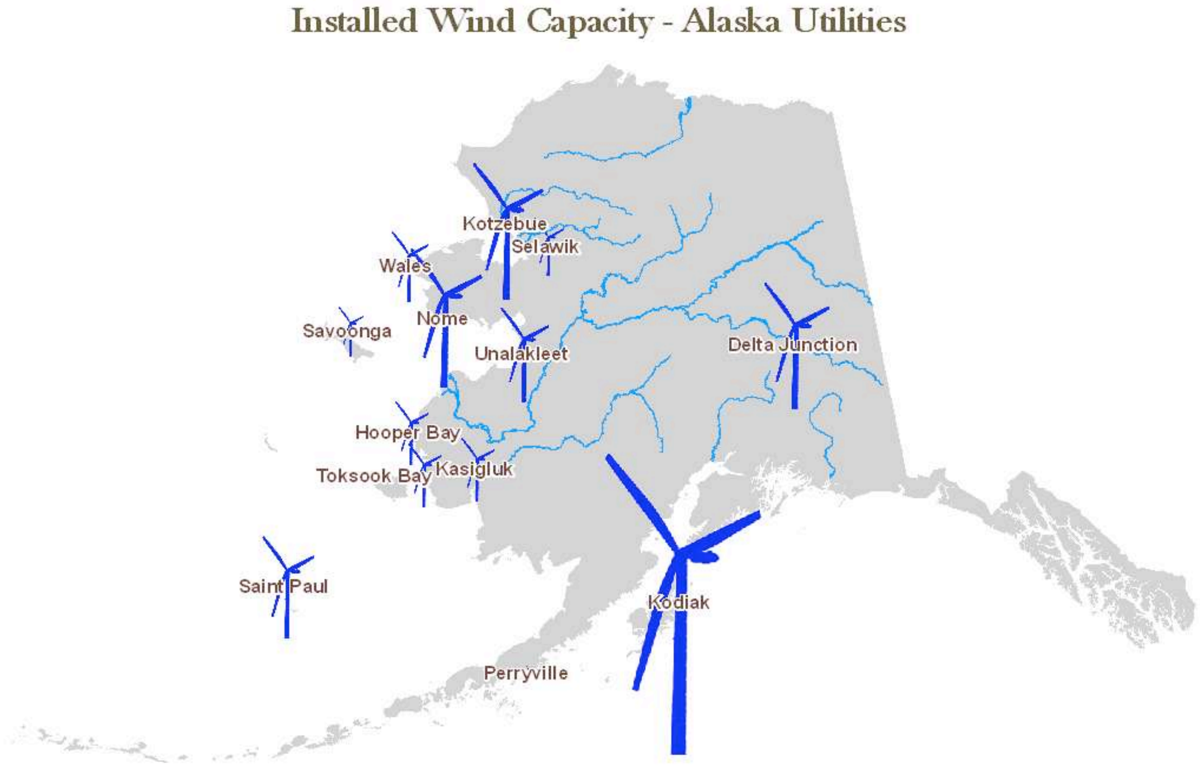
1.2 PLANNED WIND PROJECTS

Through the Alaska Energy Authority's Renewable Energy Fund (REF) and Denali Commission grant programs, a number of new or expanded wind-diesel energy projects are planned or under development in Alaska. The REF, planned as a five-year program, is currently entering its third year with $125 million allocated to projects, including wind projects, during years 1 and 2 (also called Round 1 and Round 2). Some Round 1 projects, constructed in 2009, are listed in Table 1.

REF has provided a significant source of new funds for wind projects in rural communities. Data on ongoing project construction provided by the AEA indicate 13 projects are in construction for approximately $47 million in public funds, adding 4 MW of capacity. Another $40 million is funding preconstruction phases of projects in seven additional communities. Many more projects are in feasibility studies, in the early stage of negotiating contracts to begin work, or still in the proposal stage.

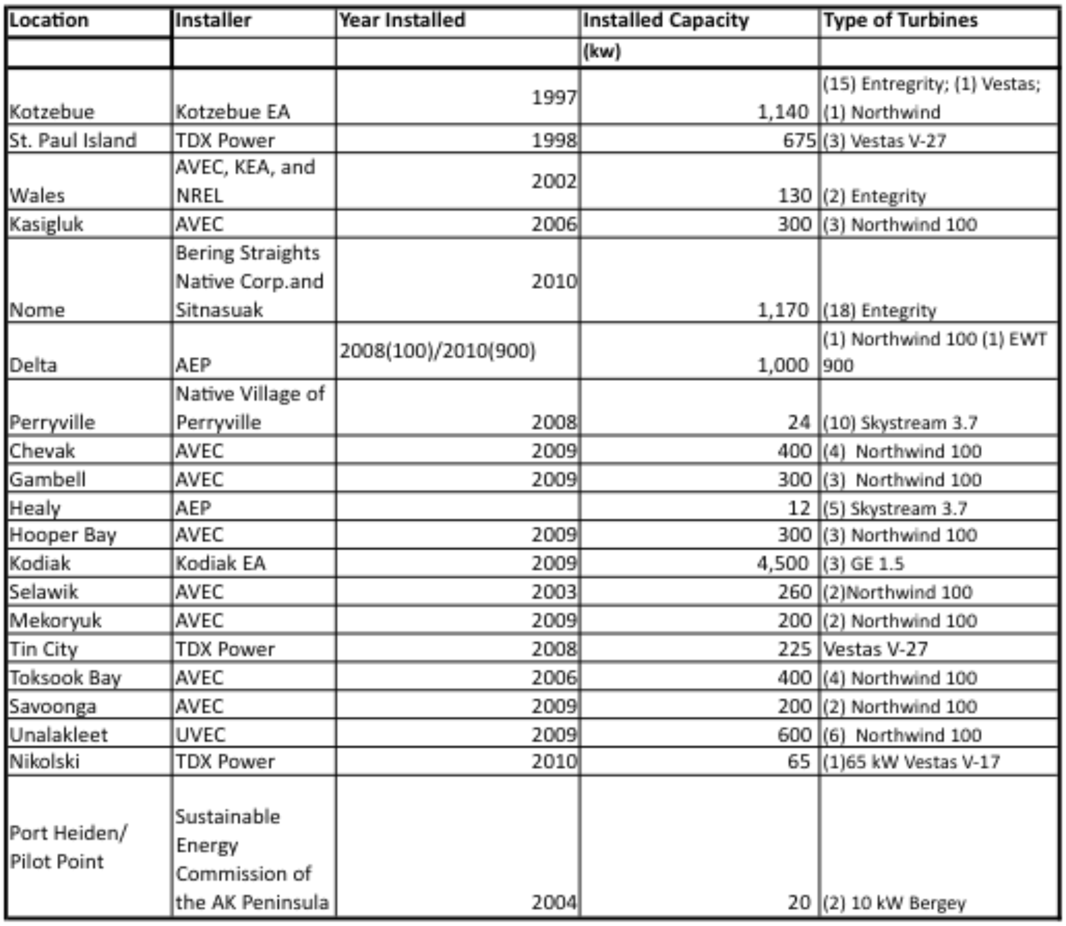
Figure 3 shows communities with meteorological (MET) towers in early 2010, assessing local wind to determine suitability of locations for wind systems.

Figure 2. Existing Wind-Diesel Systems, Spring 2010



Source: Alaska Energy Authority

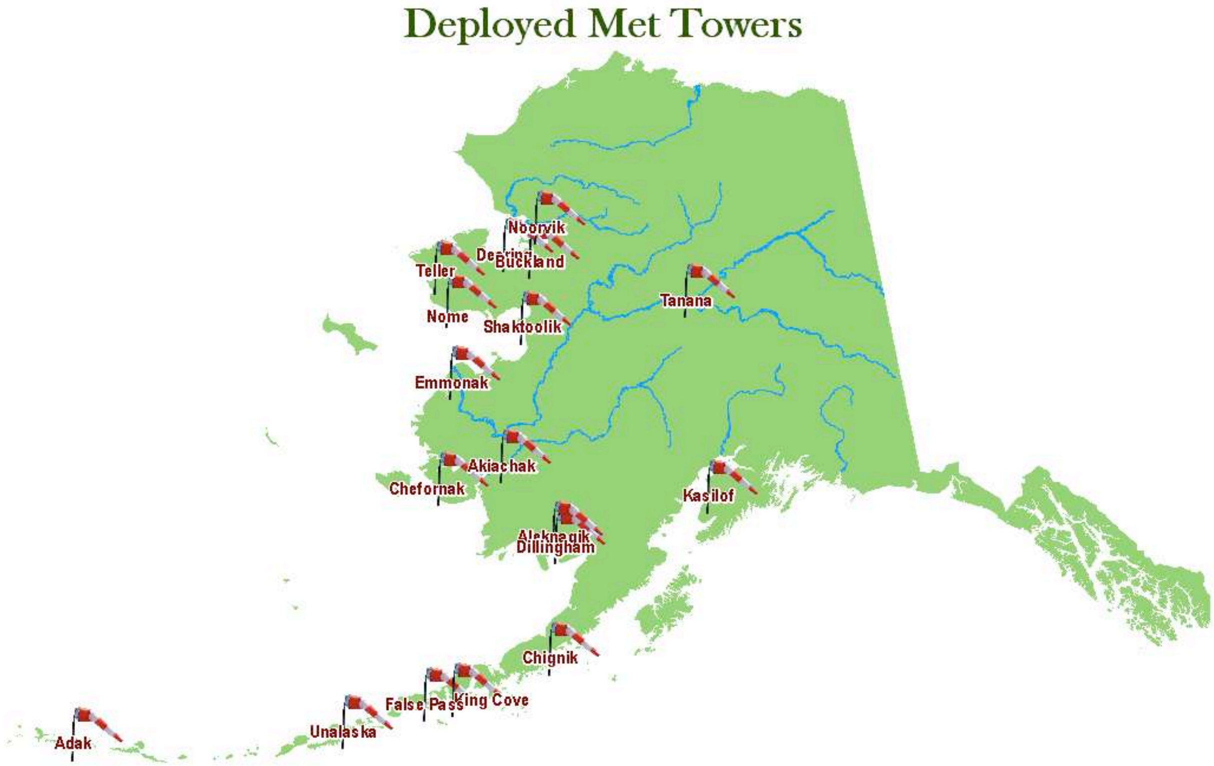
Table 1. Installed Wind Capacity in Alaska



Location	Installer	Year Installed	Installed Capacity	Type of Turbines
			(kw)	
Kotzebue	Kotzebue EA	1997	1,140	(15) Entregrity; (1) Vestas; (1) Northwind
St. Paul Island	TDX Power	1998	675	(3) Vestas V-27
Wales	AVEC, KEA, and NREL	2002	130	(2) Entegrity
Kasigluk	AVEC	2006	300	(3) Northwind 100
Nome	Bering Straights Native Corp.and Sitnasuak	2010	1,170	(18) Entegrity
Delta	AEP	2008(100)/2010(900)	1,000	(1) Northwind 100 (1) EWT 900
Perryville	Native Village of Perryville	2008	24	(10) Skystream 3.7
Chevak	AVEC	2009	400	(4) Northwind 100
Gambell	AVEC	2009	300	(3) Northwind 100
Healy	AEP		12	(5) Skystream 3.7
Hooper Bay	AVEC	2009	300	(3) Northwind 100
Kodiak	Kodiak EA	2009	4,500	(3) GE 1.5
Selawik	AVEC	2003	260	(2)Northwind 100
Mekoryuk	AVEC	2009	200	(2) Northwind 100
Tin City	TDX Power	2008	225	Vestas V-27
Toksook Bay	AVEC	2006	400	(4) Northwind 100
Savoonga	AVEC	2009	200	(2) Northwind 100
Unalakleet	UVEC	2009	600	(6) Northwind 100
Nikolski	TDX Power	2010	65	(1)65 kW Vestas V-17
Port Heiden/ Pilot Point	Sustainable Energy Commission of the AK Peninsula	2004	20	(2) 10 kW Bergey

Note: The Tin City and Mekoryuk systems were built but not commissioned as of July 2010.
Source: Alaska Energy Authority

Figure 3. Deployed Met Towers, Spring 2010



Source: Alaska Energy Authority

2 ALASKA WIND-DIESEL SYSTEMS

2.1 TURBINE SIZE

There is a general movement away from smaller turbines such as the Entegrity 65 kW and 50 kW Vestas toward slightly larger turbines such as the 100 kW Northern Power Northwind100 and 225 kW Vestas V-27. In addition, larger village hubs such as Kotzebue and Nome are considering larger turbines, such as the 900 kW Emergya Wind Technologies DirectWind 900 and the 1.5 MW GE. The first MW-scale turbines were installed by the electric utility in Kodiak. Interest in large-scale systems is driven partially by the reduced cost per installed kW, as well as interest in offsetting diesel in space heating applications with wind energy.

2.2 ARCTIC FOUNDATIONS

Designing foundations in permafrost is a challenge. Permafrost can be defined as ground that remains at or below 0°C for at least two consecutive years. The upper layer, which thaws in summer and freezes in winter, is called the active layer. The permafrost table is a moisture-rich layer that remains frozen in frost-susceptible soil. However, when warmed from the surface, a pond appears within a short time because of water that is trapped at the surface by frozen ground below. Thawing permafrost has the structural integrity of pudding. In addition, the temperature of the permafrost can affect its strength. Warming the permafrost, even without complete thaw, reduces its load-bearing strength. Continuous permafrost on the North Slope of Alaska has warmed 2.2–3.9°C over the last century.[4] A 5°C increase in temperature would ultimately result in the thawing of permafrost everywhere except on the North Slope.[5] This level of warming is quite possible, as temperatures in the Arctic, which have increased by 4°C over the past 60 years, are expected to increase between 3°C and 8°C in the next 100 years.[6] This warming poses a serious issue for those designing turbine foundations and developing wind projects.

A wind turbine foundation must not settle, tilt, or lift. In permafrost, AVEC uses pile foundations that may extend into the ground one-third to two-thirds the height of the tower.[7] Permafrost foundations add significant capital expense to the overall installation cost. To compound this problem, climate-change trends are causing thaw zones to increase, making foundation design less predictable. These temperature increases will lead to thawing in the underlying permafrost. Frozen ground must remain frozen, so many wind turbines are designed with an aboveground “point of fixity” (the point where the wind turbine meets a solid and secure base) to allow cold air to pass over the ground. Figure 4 depicts such a foundation style on an Entegrity turbine in

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[4] http://landsat.gsfc.nasa.gov/pdf_archive/cape_halkett_4web.pdf

[5] http://www.carc.org/pubs/v15no5/3.htm

[6] William L. Chapman and John E. Walsh. Simulations of Arctic temperature and pressure by global coupled models. http://arctic.atmos.uiuc.edu/ February 2006.

[7] http://www.akenergyauthority.org/Reports%20and%20Presentations/2007Weats_Wind_Turbine_Foundation_Design.pdf

Kotzebue. In parts of Alaska, this point of fixity may vary throughout the year depending on how deep the thaw zone migrates. When thawing occurs, uplift risk for the tower is created and the extended foundation can result in destructive frequencies. AVEC counters these frequencies by putting over 100,000 pounds of dampening mass on its NW100 foundations.[8]

Figure 4. Above Ground Point of Fixity-Kotzebue

Photo courtesy of Northern Economics, Inc. 2006

2.3 WIND TURBINES IN ARCTIC CONDITIONS

Wind turbine technology developed in more temperate climates is not always well suited for arctic environments. In Alaska, wind turbines must be engineered to withstand temperatures of minus 40°C or colder, with heavy rime buildup. As more wind-turbine manufacturers become accustomed to working in arctic environments, more specialized cold-weather turbine packages are being developed. Modifications are made to many turbine components, including the blades, heating components, controls, and other materials. For example, the lubrication in a gearbox needs to be changed to enable performance at minus 40°C. GE Energy offers a Cold Weather Extreme package on its 1.5 MW turbine, allowing operation down to minus 30°C and survival down to minus 40°C.

Northern Power Systems, which uses a hydrophobic polymer coating on its blades to ensure a smooth finish that prevents easy build-up of ice, has employed passive de-icing techniques. This is combined with a black coating that helps shed ice—through solar assistance—once ice does

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[8] http://www.confmanager.com/communities/c680/files/hidden/Papers/Ren-13,%20Foundation%20Design%20of%20Wind%20Turbines.pdf

form on the blade. Certain active de-icing techniques—including rotor blade heating—are not yet common in Alaska because they have not proven economical on smaller scale projects.

Often modifications need to be made to compensate for the increased air density found in cold conditions. This increase in air density is a benefit that can allow for greater power production than the predicted power curve. If the controls are not adjusted to compensate, however, this increased production will cause an over-current error that will shut down the wind turbine.[9]

2.3.1 REFURBISHED TURBINES

Some Alaska utilities prefer to purchase refurbished wind turbines in order to reduce the initial capital cost of a wind project. The global wind market is moving toward larger and more efficient turbines that replace smaller turbines, which require more land to produce the same amount of power. In large wind farms in other parts of the world, smaller turbines are being taken down, overhauled, and resold. A new wind turbine (not including installation) costs between $1,400 and $1,600 per kW (or $5,500 per kW for a NW100). A re-manufactured wind turbine of the same size will cost between $700 and $800 per kW. A properly rebuilt wind turbine can be restored for 20 years of service. Many components of the wind turbine, such as the nacelle, do not see any wear; these can be refurbished and reused. Parts that do see wear are replaced completely. The problem with a refurbished wind turbine is that the warranty guarantee is limited at best, and more maintenance is likely to be required to ensure proper operation. In addition, there is no regulating entity ensuring that remanufactured turbines meet industry standards.

Several Alaska wind developers, including TDX Power, Marsh Creek, and IES, use refurbished wind turbines to increase economic benefit for the end user. These companies also have the engineering expertise to ensure successful operation of the units. Saint Paul Island has two refurbished Vestas V-27 (225 kW), Tin City has one refurbished Vestas V-27 (225 kW), and Kongiganak has five refurbished Windmatic 17S (95 kW).

2.4 DIESEL GENERATORS

Only approximately one-third of the energy from diesel power plant fuel is normally available for generating electricity from conventional four-stroke diesel engines. The remaining two-thirds is turned into heat, noise, and mechanical losses. However, the excess thermal energy from the exhaust stack and the engine-jacket water system may be captured by using conventional heat exchangers and used for space or water heating. Overall, by using the thermal energy, up to two-thirds of the diesel injected for power generation can be used while maintaining plant performance and meeting Environmental Protection Agency (EPA) air quality standards. This

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[9] Laakso, T., Baring-Gould, I., Durstewitz, M., Horbaty, R., Lacroix, A., Peltola, E., Ronsten, G., Tallhaug, L., Wallenius, T. State-of-the-Art of Wind Energy in Cold Climates. http://arcticwind.vtt.fi/reports/StateOfTheArtOfColdClimate2009.pdf

extremely high-value captured thermal energy must be considered when estimating the benefits of offsetting diesel with wind.

Conversely, the excess wind energy from high-penetration installations can also be used for space heating. In rural Alaska, most space heating uses diesel, independent of electric power generation. A conversion of home heating from these auxiliary boilers to electric heating from excess wind power increases the potential diesel offset by wind power. The energy balance, however, between the use of waste heat from the diesel electricity generation plant, burning of fuel oil directly for space heating, and the use of excess wind energy for space heating is complex and requires detailed economic and engineering analysis at each site. It makes no sense to electrically heat homes from the diesel electric generator sets, because the direct thermal Btu content of diesel for space heating is three times higher—so a careful balance must be reached based on the available excess wind power.

Other modifications to the diesel generator control systems may be more cost effective than installing wind turbines. For example, a 20% increase in diesel efficiency is possible when using new electronically controlled fuel injected engines, with automated paralleling and dispatching switchgear.[10] Expected gains through energy efficiency improvements are outlined in Table 2.[11]

Table 2. Efficiency Recommendations and Expected Gains, Diesel Generator Sets

Technology	Efficiency Gains
Electronic Engine Controller and Fuel Injection	10%-20%
Water Jacket Heat Recovery Receptors	18%
Exhaust Stack Heat Recovery	15%
Constant Load Monitoring and Automatic Generator Dispatch	10%-15%

Source: Authors' compilations

While diesel generator sets have been commercially dominant for many decades, the technology continues to evolve rapidly. Recent related developments include:

- Installation of automatic paralleling switchgear and electronic fuel injection
- Control of remote SCADA for improved system monitoring
- Stack heat exchangers and custom-built marine manifolds for enhanced waste-heat recovery
- Efficiency improvements from the installation of charge air coolers and variable frequency drives on cooling fans
- Reduction of diesel consumption and emissions through alternative fuels such as fish oil and other bio-fuel blends.

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[10] Alan Fetters, 2009, personal communication

[11] Alan Fetters, 2009, personal communication.

These modifications need to be accounted for when communities are considering installing wind power onto an existing diesel power plant, because they will influence ultimate performance.

Also, to be fully optimized, a wind-diesel system must have appropriately sized diesel generator sets, to avoid running at an inefficiently low load when wind energy is being incorporated.

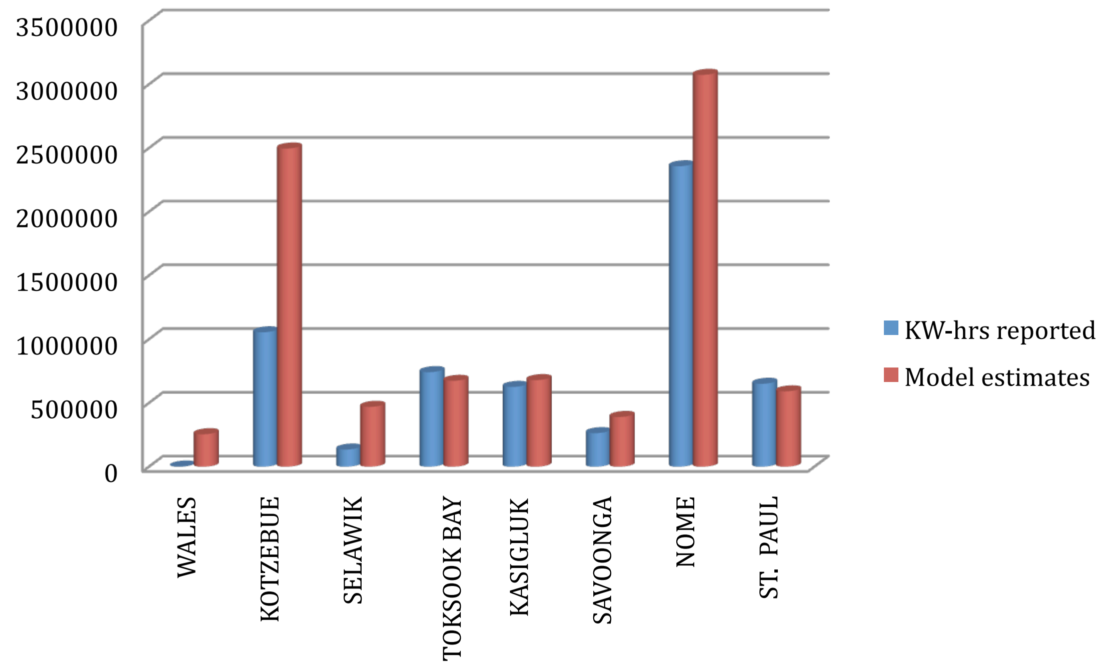
2.4.1 LOW-LOAD DIESEL

Usually, diesel generators must run at greater than 40% of their nameplate rating to avoid inefficient operation and combustion-related maintenance problems. Powercorp Pty Ltd developed a Low-Load Diesel (LLD)™ to allow for operation down to <10% of the nameplate rating, without an increase in maintenance or a significant loss in efficiency. Instead of limiting wind penetration to allow the 40% engine loading, the LLD remains online and provides the spinning reserve coverage along with voltage and frequency regulation. This concept has the advantage of being able to quickly support the network for extended periods should the available wind power suddenly decline. The system is not as fast acting as the flywheel inverter system for grid stabilization (see 5.5 High Penetration); it requires an engine to continue running and increases the capital cost of the generator set. The LLD is a viable alternative to battery storage as a long-term back up for a renewable energy plant. It is not clear if the LLD would be able to meet the Environmental Protection Agency's tier III emissions requirements, and more testing is needed for Alaska applications.

3 TECHNICAL DATA COLLECTION

Figure 5 compares total non-diesel-generated kWh reported to the Alaska Power Cost Equalization (PCE) program for several communities. Wind model estimates are based on the 2009 Rural Energy Plan estimates for these same communities, adjusted for actual installed capacity. Several communities, notably Wales and Selawik, are significantly underperforming based on model expectations, and are discussed in the case study section of this report. However, Saint Paul, Toksook Bay, Kasigluk, and others are performing close to or exceeding expectations.

Figure 5. Modeled Production versus Actual kWh (Reported to Power Cost Equalization Program, 2009)



Sources: Utility information; Power Cost Equalization program data; HOMER model estimates

Collecting basic wind-diesel system performance information is not an easy task. While PCE communities are required to report diesel and non-diesel generation, the variance from year to year is difficult to track. For example, a low-production year could result from a lower than average wind year, or reduced turbine availability due to maintenance. To gain a greater understanding of system performance, it is necessary to consistently collect more detailed information. Such reporting should be required for any projects receiving public funds and should include turbine downtime, O&M expenditures, and total annual output.

The initial scope of this project included an analysis of high-resolution (two-second) data to determine how adding wind power to a diesel power system affects power quality. We discovered, however, that access to existing data is difficult to obtain and that in most cases there was a lack of stored data. Typically, utilities such as AVEC and TDX Power store fifteen minutes of data on average, unless there was a system error—at which point higher-resolution data are captured before, during, and after the event. Utilities then use the fifteen-minute data to compile monthly reports. This methodology is outdated; without a systematic approach to data collection, a more in-depth analysis is not possible.

3.1 OPERATION AND MAINTENANCE

Operation and maintenance costs on wind farms are typically broken down into four categories:

- Regular maintenance
- Repair, or non-regular maintenance
- Spare parts
- Ongoing expenses such as administration, insurance, and travel

Insurance, regular maintenance, and administration are all predictable and relatively constant throughout the design life of the turbine, which is estimated to be 120,000 hours or 20 years. These costs can be reduced by creating economies of scale through use of multiple units of the same model in one installation. However, the costs for repair and spare parts are less predictable and can increase significantly over the lifetime of the turbine.

Diesel O&M is relative to the size and model of the generator set. It is also more easily quantifiable than wind O&M. For example, a Caterpillar 3500 series will cost $7.40/operating hour and a Detroit Diesel 60 (rated at approximately 380 kW) will cost $6.20/operating hour. For a Caterpillar 3516 series diesel generator set (rated at approximately 2000 kW), O&M is estimated at less than $0.01/kWh. When considering the costs of a wind-diesel system, the wind costs and diesel costs should be treating separately.

Challenges to collecting wind O&M cost data include data not being collected uniformly across utilities. For example, some utilities combine diesel and wind O&M costs, others assign marginal costs to wind, and still others apportion costs based on kWh produced, regardless of actual costs. To understand long-term O&M wind-diesel costs, developing and applying a consistent methodology for data collection across utilities is critical.

4 ECONOMIC ANALYSIS

4.1 ALASKA WIND CAPITAL CONSTRUCTION COSTS

A recent study by the National Renewable Energy Laboratory (NREL) indicates that wind project construction costs play a critical role in determining the conditions under which small rural wind projects in Alaska are economically feasible.[12] The NREL study was a modeling exercise, largely because there was insufficient data at the community level for completed integrated wind-energy production systems on isolated rural Alaska grids. There was not enough data on site-specific wind resources, total community energy use (especially fuel use for space heating that could potentially be offset with wind power), and construction and operation costs. The NREL study had to rely on relatively general data and then extrapolate from those data points to fill gaps. However, the study did identify wind-class information and total electrical consumption by community, and attempted to size a wind installation for each village. Capital costs were estimated by a linear function of the installed wind size. The results from the NREL study were most useful for defining the scale of effort needed if wind were to be installed in every community, but the lack of detail on cost and community resources limits its utility.

The initial intention of this study was to move beyond NREL project modeling and use community-specific data from developed wind projects to analyze system performance and estimate development and construction costs. However, this goal has proved difficult, because to date there is insufficient operational data from newly constructed wind systems to evaluate performance adequately. Furthermore, tracking and identifying construction costs has proved extremely difficult. Some of the early wind-demonstration projects have been reconfigured or expanded over time in multiple phases. Project development in these early phases is not likely to be the most cost-effective method to achieve the optimum system and is unlikely to be a reliable benchmark. In addition, we were not able to account fully for all project phases and respective costs, which proved true of all projects funded before the Denali Commission began funding wind projects.

Given the limited data available, we used information on economics and performance to identify potentially optimal systems. We asked people actively involved in wind-project development to share their experiences, including their recommendations about ways to improve efficiencies and lower costs. The goals of this analysis are to identify ways to lower development costs and improve project performance and economics as additional wind systems are developed, and also to identify circumstances in which it does not make economic sense to install wind facilities.

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[12] Nigel, NREL

Cost Categories and Reporting

In reviewing information on projects constructed to date with Denali Commission and Renewable Energy Fund (REF) grants, we found that many rural wind-diesel projects have unique development characteristics attributable to specific site characteristics and the condition of the initial diesel generation facilities. Not all wind-development projects have these additional costs. In the cases that do, most construction-cost reporting has not clearly separated such costs. To more clearly understand and manage costs for future construction, these costs need to be identified more accurately. Separation of capital equipment (turbines and towers) from construction (building foundations, erecting towers, and raising turbines) and transmission (running wires to the power plant) would also greatly assist cost analysis, but we could separate these items from the existing project documentation.

Despite the fact that most projects are at least partially funded with public grants, there are minimal project reporting requirements for both construction and performance measures. For construction cost reimbursement, there are no specifications on cost categories. In an attempt to analyze construction costs, we sorted them into five categories—site development, pre-development, construction, integration, and project administration (Table 3). Site-development costs, such as roads, tended to vary considerably across projects. By identifying these costs, we hoped to provide more consistency across projects. How transmission-line extensions were accounted for in invoicing is unclear. We identified eighteen pre-development, four site development, twelve construction, nine integration, and five project administration cost categories reported on project invoices or reports for grant funding.

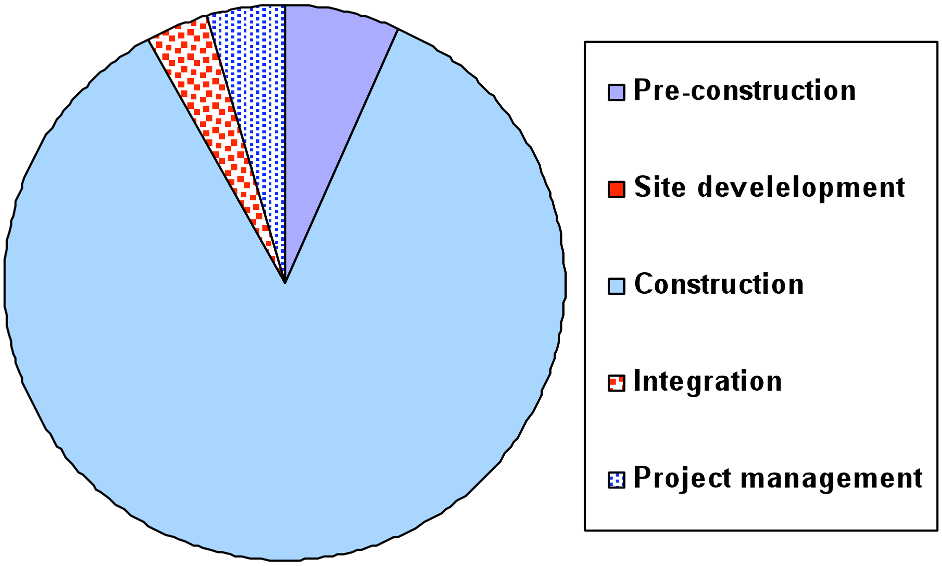
And within the five major categories, costs were not broken out by labor and materials. Many of the invoices were not segregated into these cost categories, but we attempted to parse them as such. There is likely crossover between pre-construction and project management costs, especially for large projects that use attorneys to draft power purchase agreements. So costs within the five categories should be viewed as estimates and used only to provide relative proportions across categories. Developing a standard system for identifying costs in invoices is critical for analyzing costs of future project development.

Figure 6 shows the estimated relative proportions of the five categories of costs in wind-project construction. Table 4 shows the estimated costs in each category for specific projects; the blanks reflect unknown information. An Alaska Wind Working Group data subcommittee has been formed to improve data collection.

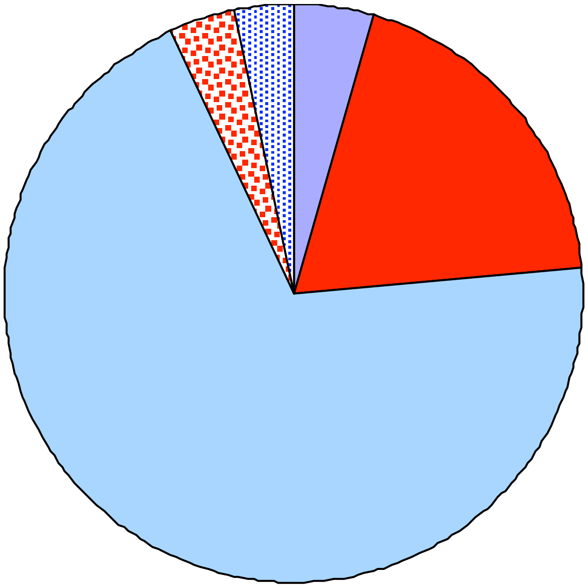
Table 3. Costs Identified in Construction Invoices Parsed into Five Categories

Pre-Construction	**Construction**
(Permits, Environmental, Design Studies)	Control & Maintenance facilities
Wind studies	Site roads & pads
Avian Studies	Foundations
Feasibility	Turbines
Reconnaissance	Turbines, Towers & Commissioning
Permits	Turbine, Tower & Rotor Shipping
Geotechnical studies	Spare parts & supplies
Road & line easement acquisition	Crane and Turbine Construction
State land permit	Transformer Station to 138KV
Land lease	Underground Power Collection
Topographic mapping	Hookup
Wetlands mapping	
Archeological review	**Commissioning/Integration**
Preliminary design	Install and Commission
Final design	Test turbines, controls, transmission
Power Purchase Agreement	Heat Recovery and Metering
Business plan	Generation sets/switch gear
Design/Mgmt	SCADA
	Integration and Control
Site development	Evaluation and Support
Land purchase	As-built surveys/ close out
Site Dev/Transmission & road	
Control/electrical	**Project Administration**
	Financing Costs, Legal, Closing
Most projects do not distinguish these	Construction Insurance
preconstruction site development	Contingency
costs from wind turbine facility construction	Project management
costs. This has skewed construction costs	Scheduling/logistics
estimates or at least not permitted clear	Reporting
comparisons across projects.	Quality control

Figure 6. Estimated Proportions, Cost Components of Wind Project Construction



Small Rural < 1,000 kW



All Rural
Source: Authors' estimates

It is also unclear what is included in construction costs for each project. For example, AVEC includes diesel generator renovations and system optimization in the cost of wind projects; those together most likely account for its higher costs per installed kW. As mentioned above, many projects were completed in stages and from multiple funding sources. As a result, we may have incomplete and/or inaccurate construction cost estimates. Table 4 provides our best estimates. We hope that our errors will be identified and corrected in the review process.

Table 4. Estimated Wind-Diesel Construction Costs by Category

Project	Turbine type	# turb	kw/ turb	Total instl. kW	Permits, Environ., Design Studies	Site devel	Construction	Integration	Admin	Total costs	Cost/Instl. kW
Perryville	Skystream 3.7	10	2	24						100,000	4,167
Wales	Entegrity	2		130							
Kotzebue*	Entegrity	3	65	195						782,700	4,014
Hooper Bay	NW100	2	100	200	113,788		1,954,061	46,230	106,063	2,859,088	14,295
Mekoryuk	NW100B	2	100	200						3,506,406	17,532
Savoonga DC	NW100	2	100	200	180,016		2,266,353		122,319	3,005,794	15,029
St. Paul*	Vestas-27	1	225	225						1,291,800	5,867
Tin City	Vestas-27	1	225	225							
Selawik DC	Entegrity	4		260	198,755		1,066,783	57,028	49,474	1,557,320	5,990
Gambell	Northern	3	100	300						3,716,506	12,388
Hooper Bay DC	NW100	3	100	300	180,803		2,542,137		136,148	2,859,088	9,530
Kasigluk DC	NW100	3	100	300	240,635		2,564,761	113,605	154,651	3,271,439	10,905
Quinhagak	NW100B	3	100	300						4,313,603	14,379
Chevak	Northern	4	100	400						3,471,978	8,680
Tooksok Bay	NW100	4	100	400	189,215		4,003,121	182,744	189,384	4,564,464	11,411
Unalakleet	NW100	6	100	600						5,550,000	9,250
Banner Wind	Entegrity	18	65	1,170	138,443	753,209	4,603,398	343,808		6,390,000	5,462
Kodiak	GE 1.5	3	1,500	4,500						21,400,000	4,756
Average Small Rural					**183,869**		**2,399,536**	**99,902**	**126,340**	**2,917,870**	**10,245**
Average All Rural					**177,379**	**753,209**	**2,714,373**	**148,683**	**126,340**	**4,290,012**	**9,603**

*Phase one only.

Sources: Denali Commission; Alaska Energy Authority; project developers

Table 5. Summary of Average Cost of Wind Projects per Installed kW

	Average total cost	Cost/Installed kW
Small rural	$2,917,900	$10,200
All rural	$4,290,000	$9,600

Source: Sources: Denali Commission; Alaska Energy Authority; project developers

Based on best available data, we estimate that rural non-road-connected projects have cost approximately $9,600 per installed kW (Table 5). We did not have sufficient information to estimate costs excluding site development costs. Smaller rural projects averaged $10,200 per installed kW. Separating rural projects by size, projects with an installed capacity of 1,000 kW or larger showed that these larger rural hub projects averaged $4,700 per installed kW including site development costs.[13] The recently installed Pillar Mountain project in Kodiak had a similar cost (Table 4). A large portion of construction costs in remote rural Alaska is relatively fixed, so due to economies of scale, larger installations have lower costs on an installed-kW basis. Integrating wind into remote off-grid systems is a large component cost that is relatively absent from urban grid-connected systems. Such integration is needed in large part to assure system stability as the wind turbines achieve higher-penetration levels in small communities. Dump loads, control systems, and power-quality stabilization equipment are required.

There are no currently completed and operating urban wind projects, with the exception of the turbines installed at Delta Junction. The planned urban projects are projected to average $3,100 per installed kW with site development costs, and $2,800 per installed kW without site development costs—costs consistent with similar-sized wind farms in the Lower 48. These urban/road-connected projects will potentially benefit from the spreading of costs across larger capacities, as well as from lower costs due to easier access for both equipment delivery and construction. These urban projects may offer the potential for expanding the Alaska wind market and build in-state system development and maintenance expertise that could benefit rural systems.

Factors Affecting Capital Costs in Alaska

Interviews with a number of wind-project developers provided insights into factors that influence project development costs and actions that could potentially help control or lower costs and improve project economic viability. Most developers identified project logistics and the small scale of projects as the biggest factors driving up costs for Alaska projects. Larger projects and larger turbines provide economies of scale.

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[13] However, Kotzebue and Saint Paul only include phase one construction costs.

Logistics, Project Timing, and Budgeting

Rural Alaska's remoteness, lack of transportation infrastructure, and severe climate collectively contribute to complex project logistics and timing issues, such as the need to over-winter cranes.

A further complicating factor is that many projects are publically funded—so there are the added complexities of government budgeting, accounting, and procurement. Numerous wind-project developers mentioned that the start of the state fiscal year (July 1) budget cycle is in the middle of the construction season. The effective date of the budget authorizing REF project grants determines when invoiced costs can be reimbursed and, thus, construction initiated. The July 1 start date may cause the loss of a construction season or the protraction of project activities, both of which increase costs. It appears that the projects with the most efficient construction schedules and resulting costs are those that have cash-flowed construction and can be reimbursed when projects are completed—AVEC projects and the Kodiak project, for example. However, these financing costs add to the cost of project development. Project construction would be more efficient if, once approved, the entire grant was released. Otherwise, the smaller and already more costly projects tend to have delays that increase costs while waiting for reimbursements. The invoice reimbursement process is not an efficient way to manage project construction. But at the same time, AEA has a fiduciary responsibility for the accountability of public funds.

Project Permitting

Although avian issues are often thought to be the most significant permitting challenge, most developers we talked with cited Federal Aviation Administration (FAA) permitting as the greatest challenge—because of the prevalence of rural airports that tend to have roads leading to them, drawing development in their direction. It is economically advantageous to develop projects closer to the community. However, the closer the turbines are to the community, the greater the likelihood that there will be issues related to erecting the turbines close to the airport. In addition to turbines, the meteorological/wind assessment (met) towers often create FAA problems, since met towers are not routinely lighted while turbines towers are. Lighting met towers could help resolve this issue.

While numerous wind developers mentioned FAA permitting problems, one mentioned having to apply for an FAA permit twice due to internal FAA problems and a lapsed time frame for FAA to issue the permit. Once the permit was issued, there was a required 15-day interagency review process, which ultimately took 45 days. This interagency review process was followed by a required 39-day public review period, which ended up taking an extra week. Wind projects, similar to other projects, are often vulnerable to being delayed by glitches, particularly in the permitting process, and there are no existing mechanisms to make agencies more accountable. Delays can cause a project to incur additional costs, particularly if the turbine installment is delayed. The State of Alaska should work with the FAA to establish a clear permitting process and timeline and use state permitting agencies to facilitate the timely issuance of permits. This role used to be fulfilled by the Division of Governmental Coordination. The state has developed a best-practices guide for all wind power-related permits.[14]

Land Leasing

Another project-development issue raised was land leasing. In many rural areas, available land suitable for wind projects and close to villages is limited to Alaska Native allotments, land owned by Alaska Native corporations or village tribal organizations, or land owned by local or state governments. Some developers mentioned that Native allotment lands are difficult to lease due to issues with working through the Bureau of Indian Affairs processes—which make them less attractive as potential project sites. At times, Alaska Native corporate or tribal lands have been leased at relatively high rates that, in turn, have to be included in local electrical rates paid by shareholders.

Kodiak Electric Association's Pillar Mountain project was the first wind project developed on state land. This permit process was lengthy. The State of Alaska could develop a streamlined state land permitting and lease process for community wind projects.

Project Size

Based on our review of numerous REF project applications, it appears that on average larger projects reduce the cost per kilowatt and increase benefit/cost ratios. This is especially true when marginal or surplus power can be used for space heating. Some wind-project developers think projects that have received state funding are an order of magnitude smaller than optimal. Research is needed on the economics of developing larger projects versus smaller projects, to determine cost effectiveness. It is difficult to create economies of scale for installation, construction, financial management, and O&M in rural Alaska. However, larger wind turbines may supply sufficient kilowatt-hours to make the project more economically viable, especially if heat can also be produced and sold.

Community Capacity, Training, and Sustainability

According to some wind developers, communities that are not part of a larger utility frequently do not have residents with sufficient skills to develop, manage, and operate

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[14] James Jensen, wind project manager, Alaska Energy Authority, Commerce, Community & Economic Development, personal communication, April , 2010.

wind-diesel systems. Also, if a small community does have a skilled operator, retaining that operator is often a challenge. In thinking about such cases, it is important to address who will provide the backup maintenance. If a village is not served by AVEC, the fallback is often AEA. However, AEA is not responsible for providing maintenance to rural utilities. Wind-diesel systems are more complex to operate than conventional diesel systems. Doug Vought, owner of V3 Energy, believes that we need to be focusing on development of more sophisticated high-penetration systems to maximize benefits to rural communities—but these types of systems are also more complicated and thus harder for local operators to maintain. When considering high-penetration systems, response to blackouts or failures in communities also becomes a more serious concern.

A common theme that emerges in discussions about energy with rural residents is the need for less expensive energy—for both electricity and space heating. How that is actually accomplished is usually less important to rural Alaskans than the result, and it can be difficult to keep people fully engaged to successfully sustain a wind project. It is similarly difficult to get local residents to keep track of and be interested in data from projects after they are installed. According to many village project developers we interviewed, all projects need to have a local champion. Jim Saint George—owner of STG, the company constructing both AVEC and TDX wind facilities and most of the currently installed wind capacity in Alaska—stressed that electric loads and costs are only a part of the rural energy problem. Space heating in villages uses a significant amount of energy and costs a lot of money, and state programs are not adequately addressing the heating load issue.

Local utility operators need to have specific training for wind operation and maintenance. Consequently, people from outside the community are often hired to do the work, causing project and maintenance costs to increase dramatically, and reducing the local sense of ownership in the project. For communities that are not part of a utility group such as AVEC, a regional approach to maintenance could still be used to reduce the costs and provide more local training. There could be agreements among communities or utilities to share resources, such as equipment, training, and information. The administrative structure does not necessarily need to be consolidated; it would be more of a virtually consolidated structure that could increase the effective size of the group, to create economies of scale for maintenance and training. Many local operators are willing to receive advanced training.

According to Jim Saint George, the technical and physical aspects of project development are rather straightforward and addressable. He believes that the bureaucratic and permitting issues create the most difficulty for wind projects in rural Alaska. Many people identify the difficulty of getting cranes as a significant barrier to wind development. However, Mr. Saint George stresses that cranes are just a single piece of any project, and that people who focus primarily on logistics and the economics of moving cranes are missing the bigger picture. Cranes and equipment are moved into and out of rural communities for projects all the time; STG has 17 or 18 cranes commissioned for projects around western Alaska. High fixed-costs are associated with wind development projects, and the price per kilowatt-hour will decrease dramatically if larger systems are installed and the timing of multiple installations is coordinated.

Operator training and continued O&M are critical to sustaining systems over time. To ensure that local operators are sufficiently trained and that developed projects succeed, John Lyons with Marsh Creek requires that communities sign a five-year O&M contract, agreeing to work with the developer through the startup phase. It may be that these types of contracts should be required for all publically funded projects, if the community is not part of a larger organization such as AVEC. The Alaska Energy Authority requires all such smaller utilities to have five-year operation and maintenance contracts for Renewable Energy Fund projects.[15]

4.2 EFFECT OF POWER COST EQUALIZATION ON WIND ENERGY SUSTAINABILITY

This section presents the results of our analysis of how adding wind energy to a rural power system affects potential utility reimbursements under the Power Cost Equalization (PCE) program. It addresses the question raised by some utility operators and analysts about whether the current structure of the PCE program undermines incentives for rural utilities to increase alternative energy production.

Costs and challenges of operating an electric utility in rural Alaska are very high. The PCE program is critical in lowering the cost of electricity for rural Alaskans and supporting the viability of rural electric utilities. There are a large number of rural electric customers who do not qualify for PCE, so both they and their utilities have incentives to lower costs and rates. The question posed in this analysis is whether the structure of the PCE program provides disincentives to add wind energy in PCE communities and thus works at cross purposes with other state programs, such as the Renewable Energy Fund, developed to promote renewable energy. The analysis includes a test of an alternative structure to the PCE program and its effect on renewable energy development, as well as the long-term sustainability of wind projects developed with state funds.

Since 1980, energy subsidies such as Power Production Cost Assistance and Power Cost Assistance have been approved by the Alaska Legislature to help Alaskans burdened with high power costs. The Power Cost Equalization (PCE) program, which became effective in October 1985, is the most recent effort directed at helping residents of rural Alaska faced with extreme electric costs. The program is intended to lower electric rates

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[15] James Jensen, Alaska Energy Authority, Wind Energy Project Manager, personal communication, May 2010.

statewide to levels somewhat comparable with rates paid by residents in the larger population centers of Anchorage, Fairbanks, and Juneau. The PCE program is funded through the PCE Endowment Fund, which is invested to earn 7% over time. Power Cost Equalization payments are distributed to eligible utilities, which are then able to lower monthly bills for individual customers. Thus, the PCE program helps to ensure the long-term viability of local utilities in rural Alaska.[16]

Eligibility and monthly PCE payment amounts are determined by formula specified in state statute (AS 42.45.110-150), and are based either on non-fuel and fuel costs (cost-based PCE) or utility rates (rate-based PCE). The PCE level, or in other words the PCE payment per kilowatt-hour, applies only to the first 500 kWh for residential customers and 70 kWh per community resident for community facilities and streetlights. Additional components used in calculating the PCE rate include:

- Ninety-five percent of a utility's costs are eligible if these costs are between
    - Minimum eligible cost currently at 14.12 cents/kWh[17]
    - Maximum eligible cost currently at $1.00/kWh
- The maximum PCE level currently at 81.59 cents/kWh[18]
- The current funding level of the PCE program[19]

The effective PCE rate is determined by whichever is smaller—the formula above, or the difference between the utility's residential rate and the average rate for Anchorage, Fairbanks, and Juneau.

During fiscal year 2009, approximately 77,500 residents living in 184 communities benefited from the program, at a total cost of $37 million.[20]

Current PCE Subsidy Structure

The PCE program structure reduces incentives (1) for customers consuming less than the 500 kWh/month cap to conserve electricity; and (2) for electric utilities to minimize costs. The PCE program removes some of the incentive for community residents to reduce their energy use or invest in energy efficiency, because residential customers do not pay the full cost of electricity on the first 500 kWh they use each month. Similarly, utilities see their PCE payment decline as they increase efficiency. In addition, use of alternative energy systems will reduce fuel expenses and have the same effect on utility

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[16] Alaska Energy Authority, Statistical Report of the Power Cost Equalization Program, Fiscal Year 2007, February 2008.

[17] This is called the base rate, which is the average rate for Anchorage, Fairbanks, and Juneau.

[18] The maximum was changed in 2009 by the legislature. Alaska Energy Authority, Statistical Report of the Power Cost Equalization Program, Fiscal Year 2009, March 2010.

[19] PCE-levels are reduced if there are not enough funds available to pay for the cost of the PCE program.

[20] Alaska Energy Authority, Statistical Report of the Power Cost Equalization Program, Fiscal Year 2009, March 2010.

PCE payments as increasing efficiency. The current PCE formula structure does not give utilities incentives to reduce their non-fuel costs.[21] The current structure of the PCE program makes payments to utilities without the need for them to overhaul, maintain, or bring new equipment on line—which some PCE-eligible utilities find attractive.[22]

Based on the effects of the subsidy structure on consumer and utility incentives, we tested the effect of adding wind energy production to a community's energy portfolio. We specifically tested:

- How wind-penetration levels affect electricity rates and bills paid by residential customers

- How fuel prices in conjunction with wind penetration affect PCE-levels

- How an alternative PCE structure could affect residential customers' energy bills.

This analysis should not be considered a definitive assessment of the effects of wind or other alternative energy sources on utility costs. Given the customer and utility disincentives caused by the current structure of the PCE subsidy formula, our objective was to identify the program's potential impact on wind-energy sustainability. We also wanted to determine who the beneficiaries are of potential rate reductions resulting from reduced fuel costs from alternative energy systems such as wind. The sensitivity analyses are intended to bracket the range of likely scenarios. We used the best available data. This analysis does not propose any specific change to the PCE program or its structure, but instead considers how the subsidy structure potentially affects economic incentives and wind-energy sustainability.

Methods

We developed a spreadsheet model for calculating PCE levels for utilities with wind-diesel systems. The model divides fuel and non-fuel costs into diesel and wind components. While the cost of wind generation is fully captured in the non-fuel part of the PCE calculation, the cost of diesel generation is comprised of non-fuel and fuel costs. Note that non-fuel costs include generation, distribution, general and administration, PCE-eligible depreciation, interest, and other expenses. Fuel costs are equal to the amount of diesel used for generation, multiplied by the average annual price per gallon, including the cost of transportation.

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[21] Lockard, David, Technical Engineer, Alaska Energy Authority, Commerce, Community & Economic Development, personal communication, April , 2010.

[22] William, Jeffery, PCE program administer, Alaska Energy Authority, Commerce, Community & Economic Development, personal communication, April , 2010.

With cost records available from the Regulatory Commission of Alaska (RCA) and wind-penetration[23] data reported by the utilities themselves, we modeled the cost structure for a low and a medium wind-penetration system. This analysis is specifically based on 2008 wind and diesel generation data from Kotzebue Electric Association and AVEC in Kasigluk and Toksook Bay.

Assumptions

We assumed values of 4 cents and 8 cents/kWh for wind O&M, and then calibrated the model to reflect the RCA data on fuel and non-fuel costs accordingly (Table 6). The assumed wind O&M costs compare with 5 cents and 6 cents/kWh nationally.[24] Recent reviews of applications for Renewable Energy Fund (REF) grants indicated that the average O&M cost for these projects is equal to 3.6 cents/kWh, with a maximum of 11 cents/kWh and a minimum of .2 cents/kWh. We note that there remain inconsistencies in reporting separate wind and diesel components for O&M on wind. In addition, we felt that assuming higher costs in Alaska, compared with the national average, is warranted due to smaller project size, site remoteness, lack of maintenance personnel, and harsh conditions.

Table 6. Assumptions Used for PCE-Level Calculations

	Kotzebue	**Kasigluk**	**Toksook Bay**
Wind			
average annual wind penetration [%]	3.9%	22.4%	24.0%
wind O&M – base case / alt. case [$/kWh]	$0.04 / $0.08	$0.04 / $0.08	$0.04 / $0.08
Diesel			
* non-fuel cost [$/year]	$0.17	$0.34	$0.35
*average annual price of fuel [$/gal]	$3.85	$3.62	$3.62
*efficiency [kWh/gal]	14.7	10.6	10.6

Wind penetration is from 2008 PCE data.

* These values are calculated by the model based on wind O&M assumptions and RCA information.

Results

Our analysis indicates that both utility rates and PCE levels for wind-diesel systems decline as wind penetration increases, as shown in Figure 7, using the Kasigluk wind-diesel system as an example. The black solid line shows utility rates calculated if diesel generators supplied 100% of electricity. The solid orange line illustrates how rates

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[23] Wind penetration is net wind production as a percentage of net total production. Net wind production is equal to gross wind production minus station service power such as electricity used to run the wind turbine, lights, computers, and other equipment.

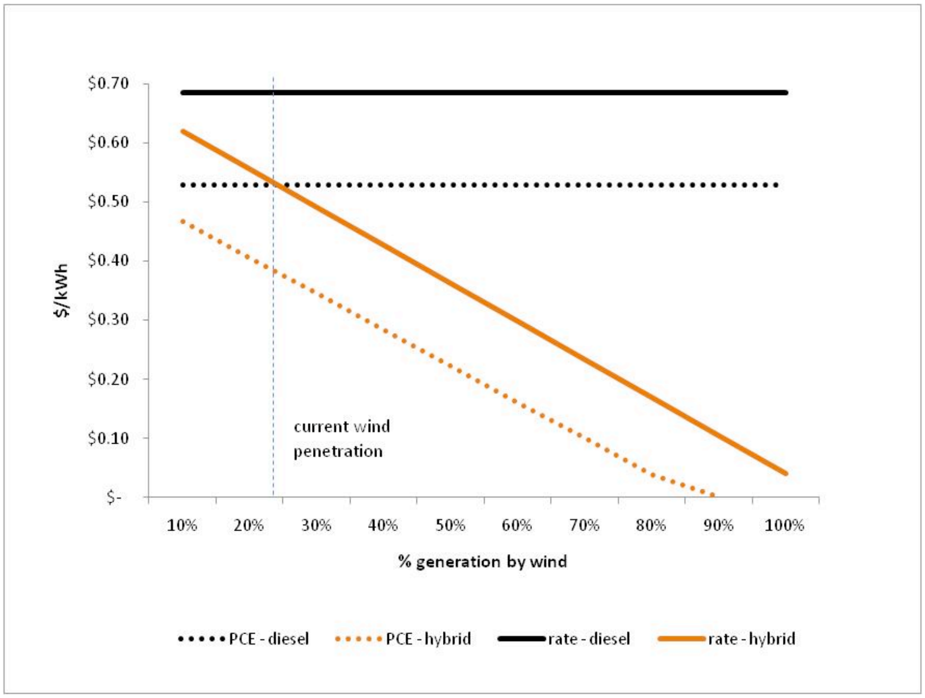
[24] Christopher Walford. "Wind Turbine Reliability: Understanding and Minimizing Wind Turbine Operation and Maintenance Costs" March 2006. Prepared for Sandia National Labs.

change with increasing wind penetration—that is, with wind power supplying more of the electricity—assuming all other variables are kept constant.

Currently the community generates about 22% of its total electricity from wind power (blue vertical line). Had the community ***not*** invested in wind generators, the non-subsidized rate for electricity would be 70 cents/kWh, and PCE would subsidize 53 cents/kWh for the first 500 kWh of use per customer (dashed black line). But the current wind penetration decreases Kasigluk's reliance on fuel, and thus lowers the residential rate to 54 cents/kWh. By lowering the rate by more than 16 cents, the wind generators also decrease the costs eligible for the PCE subsidy—and therefore decrease the PCE level by 14 cents, to 39 cents/kWh (dashed orange line).

Clearly, as a community increases its wind-generation capacity, its utility receives a lower subsidy through the PCE program. This, of course, assumes that the technology is performing consistently. This decline in PCE subsidies could serve as a disincentive for rural communities to conserve energy and invest in alternative energy projects.

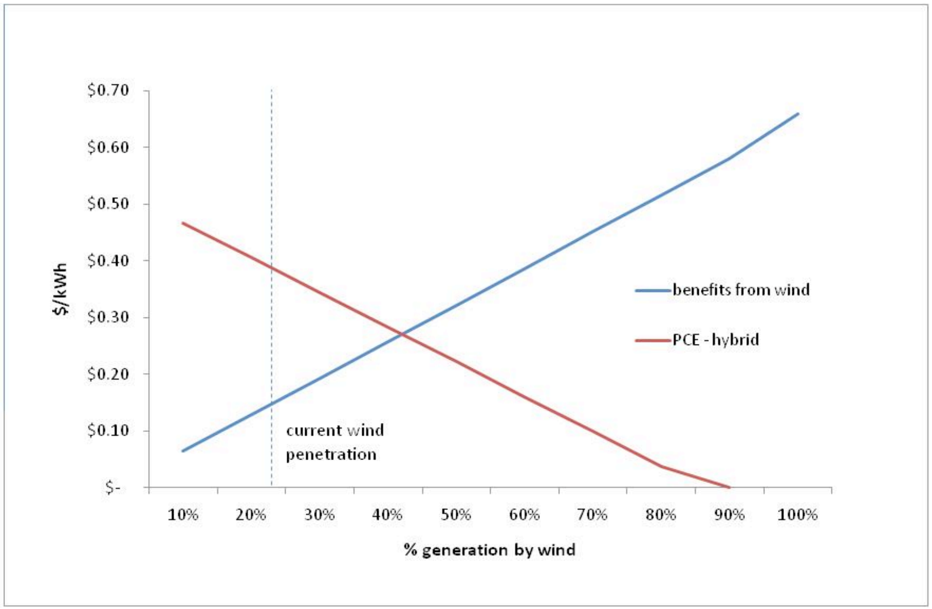
Figure 7. Comparing Rates and PCE Levels for Kasigluk



Source: Authors' estimates

If the percentage of electricity from wind power were increased beyond current levels, the community would continue to benefit from rate reductions associated with wind generation (Figure 8, solid blue line). But at the same time, the PCE subsidy (red line) would decrease linearly due to falling costs of electricity, hypothetically going to zero if wind-penetration levels exceeded 90%.

Figure 8. Benefits from Wind Power and PCE Subsidy in Kasigluk



Source: Authors' estimates

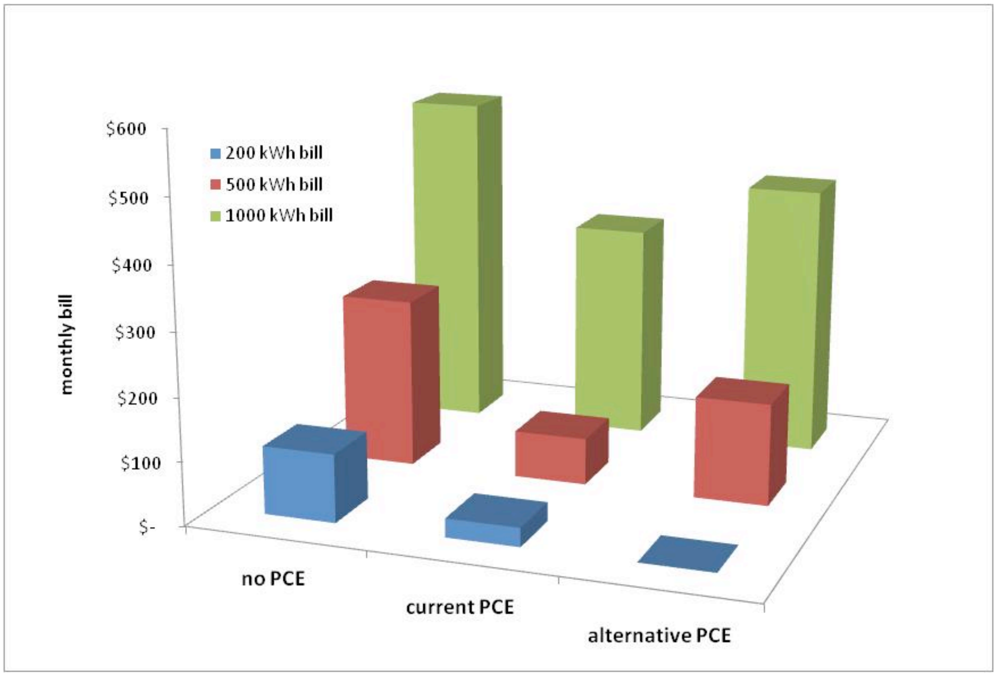
Clearly, even though wind power reduces local electricity costs, the concurrent effect is declining PCE subsidies—which creates a disincentive for communities to invest in alternative energy or energy conservation. That raises the question: should the PCE formula be revised?

In the scenario described below, we tested the effects of a different PCE structure—one that would entirely cover the first 200 kWh/month of use for residents eligible to receive the PCE subsidy—so the first 200 kWh would be free, but any usage above that would be charged at an unsubsidized rate. Figure 9 illustrates how the monthly bill for three different types of residential consumers in Kasigluk would change under this hypothetical alternative PCE scheme. The point here is that energy price signals under the alternative PCE structure would provide the incentives for communities to maximize wind production and sustain their wind systems (or any other renewable energy systems).

In the example, Kasigluk utility customers using less than 500 kWh/month benefit the most from the current PCE formula, which cuts their monthly bill by 72%, from $108 (54 cents/kWh charge) to $30 (15 cents/kWh charge) if they use 200 kWh, and from $270 to $75 if they use 500 kWh. For customers using 1,000 kWh per month, the current PCE program reduces their monthly bills by 36%, from $540 to $345.

We investigated an alternative "baseline" PCE program structure and its potential effect on kWh rates as well as on customer and utility incentives. With a hypothetical 200 kWh/month entirely covered by PCE, customers consuming less than 200 kWh would pay nothing. But residential customers using 500 kWh would see their bill more than double, to $162 per month. Customers using 1,000 kWh would see an increase of 25%, to $432 in their bill. Therefore, this alternative PCE structure would create an incentive for all customers to reduce their monthly use of electricity above the 200 kWh (or any baseline) level.

Figure 9. Monthly Electric Bills for Kasigluk Residential Customers, Under Different Scenarios



Authors' estimates

Any alternative PCE structure with a baseline level would provide an incentive for all residential customers to reduce consumption over the baseline kWh level, so they would directly benefit from increasing wind energy production and, thus, have an increased economic incentive for promoting peak performance and penetration of the community's wind energy system. Commercial customers and public facilities currently have these economic incentives, but they comprise a relatively small portion of the customer base in most small rural PCE-eligible communities. We want to emphasize that the 200 kWh level tested is arbitrary and should receive additional analysis before policymakers consider any changes in the program.[25]

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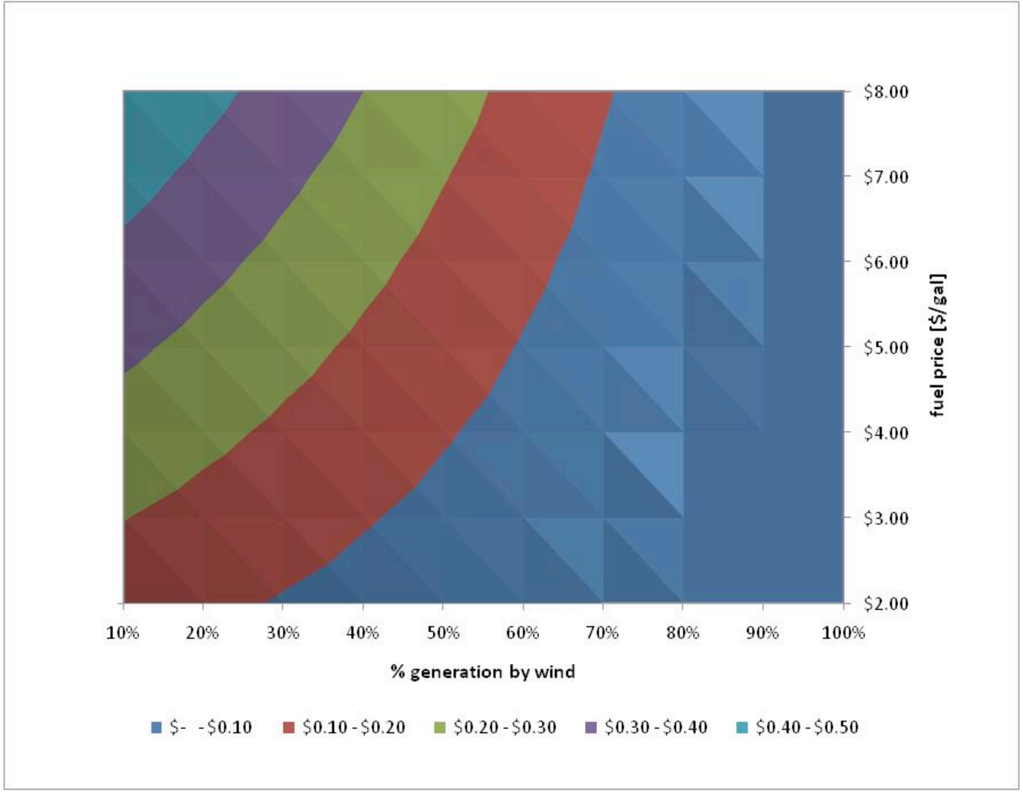
[25] Under a baseline subsidy structure, eligible utilities would be reimbursed by the PCE program for the baseline power provided to customers. This could be a more administratively simple program based on the number of customers and a fuel price index. In addition to better maintaining market signals to consumers, utilities would have more incentive to reduce non-fuel costs and improve operating efficiencies. Filing for reimbursements could also be significantly simplified.

Our analysis also looked at how fuel prices and wind penetration together affect PCE levels, given the current PCE formula. The colored areas in Figure 10 show the combined PCE levels for Kasigluk that fall within a 10-cent interval. For example, the red area is associated with PCE levels of 10 cents to 20 cents/kWh, whereas the green area shows PCE levels between 20 cents and 30 cents/kWh.

The red band identifies all the fuel prices per gallon and wind-penetration percentage combinations that result in a PCE payment per kWh of 10 cents to 20 cents. Similarly, the green band identifies all the fuel price and wind-penetration combinations that result in a 20- to 30 cent/kWh PCE payment.

Notice that the PCE payment per kWh is the same for 70% wind penetration and $8.00/gallon diesel as it is for 30% wind penetration at $2.00/gallon diesel, or 60% wind penetration and $5.00/gallon diesel. Those numbers suggest that as fuel prices increase, the price incentive is to lower wind penetration.

Figure 10. Kasigluk PCE Subsidies, By Fuel Price and Wind Penetration

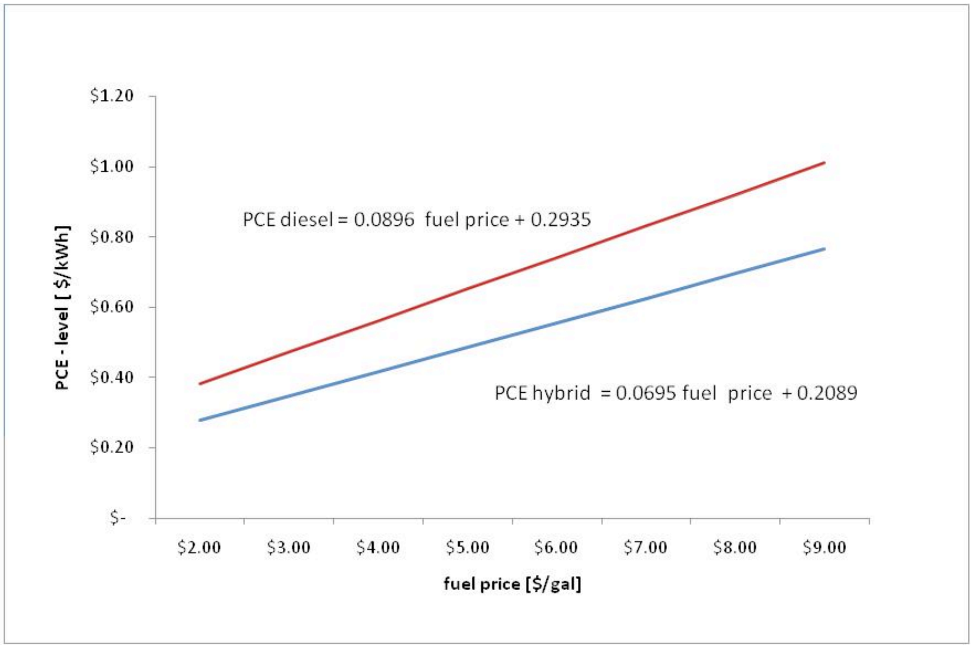


Source: Authors' estimates

It's clear that communities with wind-diesel systems are less sheltered by the PCE program at times of increasing fuel prices. The reason is that an increase in wind penetration by itself hedges against higher fuel prices. The PCE formula, developed for diesel power-generation utilities, thus responds to higher fuel prices by increasing the rate of subsidy, creating a disincentive for development and maximum implementation of renewable energy facilities. That is especially true for off-grid rural systems that are unlikely to be able to operate at the wind-penetration levels that would allow them to reach a break-even point with PCE—which our analysis estimates to be approximately 40% (see Figure 8).

Figure 11 underscores this result for the community of Kasigluk. The red line shows the PCE levels received by a 100% diesel system as fuel prices increase. The blue line illustrates this same relationship for a hybrid wind-diesel system, operating at 22% penetration. Figure 11 conveys two important messages. First, the intercept (initial PCE level at $1/gallon) is lower for the hybrid system than it is for the diesel system. Second, the two curves have different slopes, suggesting that PCE levels for a hybrid system are less responsive to increases in diesel prices than a pure-diesel system. In other words, communities with hybrid wind-diesel systems are less sheltered against high fuel prices than communities that generate power solely with diesel. Specifically, for every dollar increase in the price of fuel, the hybrid system receives 2 cents less in PCE compared with the diesel system (Figure 11 shows betas in the functional relationships —the difference between 0.0896 and 0.0695—which are the slopes of the respective lines).

Figure 11. Kasigluk PCE Levels Depend on Fuel Prices



Source: Authors' estimates

In our model, we tested the effect of varying the assumptions about wind O&M costs, and found that the results are insensitive to wind O&M costs. Additionally, the results are similar for all communities that were part of this analysis.

In conclusion, it appears that the structure of the current PCE program provides a disincentive for long-term functioning of wind-diesel systems. In particular, for systems with lower penetration levels under rising fuel prices, communities could potentially be better off running diesel generators and reducing their reliance on wind—hardly the desired result.

4.3 ECONOMIC ANALYSIS SUMMARY

In summary, the average cost for rural wind projects operating in spring 2010 is approximately $9,600 per installed kW. But the cost difference between small rural projects (about $10,200/kW) and large rural projects (about $4,500/kW) is considerable. By comparison, the cost of planned urban or road-connected wind projects averages $3,100 per installed kW.

For wind projects to be economical there is clearly a need to streamline project construction, especially for smaller rural projects. Increasing project sizes and using marginal production for space heating will likely improve project economics. To be able to analyze project costs, a required and standardized system to track construction costs is needed. Additional attention to training local operators and community capacity is likely to increase project sustainability and protect public investments.

Further research is needed to better understand the effects of an alternative PCE structure on the PCE Endowment Fund, as well as the effects of wind penetration on the PCE Endowment Fund. Analysis of a larger sample of communities and individual ratepayers' monthly electric bills is also warranted.

5 PERFORMANCE ANALYSIS

Even though operation data about rural wind-diesel systems is limited, it is possible to undertake a preliminary performance analysis of select systems. This analysis can be done, in part, by simply comparing actual monthly or annual production of electricity from wind power to expected production, based on wind-model projections. We present such an analysis in this section, but at the same time discuss factors—wind class and others—that affect the performance of the various systems for which we have data. Keep in mind, however, that each system is unique and faces its own challenges. Section 6 presents six case studies of systems, documenting their experiences in detail.

At this point, it's useful to reiterate the definitions of wind penetration and capacity factor—two terms that we routinely use to describe the performance of wind systems. Average net wind penetration refers to the product of total wind turbine energy output (kWh) divided by the total primary electrical load (kWh) over a given period; it provides an idea of the amount of system energy produced by wind. Capacity factor, which is the ratio of actual average power produced to the rated power of the wind plant over a defined period, provides an indication of the wind resource and system efficiencies. Capacity factors above 30% for distributed wind systems would be considered good, although the acceptable capacity factor for a specific community will depend on project and alternative fuel costs.

5.1 CLASSIFYING WIND-DIESEL SYSTEMS

Table 7 shows a wind-diesel system classification that divides wind-diesel systems into low, medium, and high penetration systems and describes operating characteristics for each system type. The percentages detailed in Table 7 are not concrete but serve to provide an understanding of the various operational characteristics of the penetration classes. All three types of systems have been built in rural Alaska.

Table 7. Wind-Diesel Systems by Penetration Class

Penetration Class	Operating Characteristics	Penetration Level	
		Peak Instantaneous	Annual Average
Low	Diesel(s) run full-time Wind power reduces net load on diesel All wind energy goes to primary load No supervisory control system	<50%	<20%
Medium	Diesel(s) run full-time At high wind power levels, secondary loads dispatched to ensure sufficient diesel loading or wind generation are curtailed. Requires relatively simple control system	50%-100%	20%-50%
High	Diesel(s) may be shut down during high wind availability Auxiliary components required to regulate voltage and frequency Requires sophisticated control system	100%-400%	50%-150%

Source: National Renewable Energy Laboratory

Systems are engineered to the demands of a peak instantaneous penetration level, but are typically classified according to annual average wind penetration. The case studies in Section 6 are organized according to this classification system, to enable comparisons across installations. In addition, existing rural wind-diesel installations can be categorized into demonstration-phase development installations (Kotzebue, Wales, and St. Paul) and more modern installations (Kodiak, Toksook Bay, and Kasigluk).

The actual performance of the installations compared with the expected performance is typically lower for the demonstration sites than it is for the modern sites. Pilot projects are intended to demonstrate a new technology, improve an existing technology, or prove that an existing technology will work in a new application or environment. Wind turbine technology, while continually evolving, has been commercial worldwide for decades. However, installing wind turbines in an isolated, remote, and arctic environment onto a diesel-powered island grid system was not considered commercial.

The pioneering systems in Kotzebue and Wales brought wind-diesel technology to a more refined period of development, in which installations are being optimized and penetration levels are pushing the envelope of what previously was thought possible and prudent.

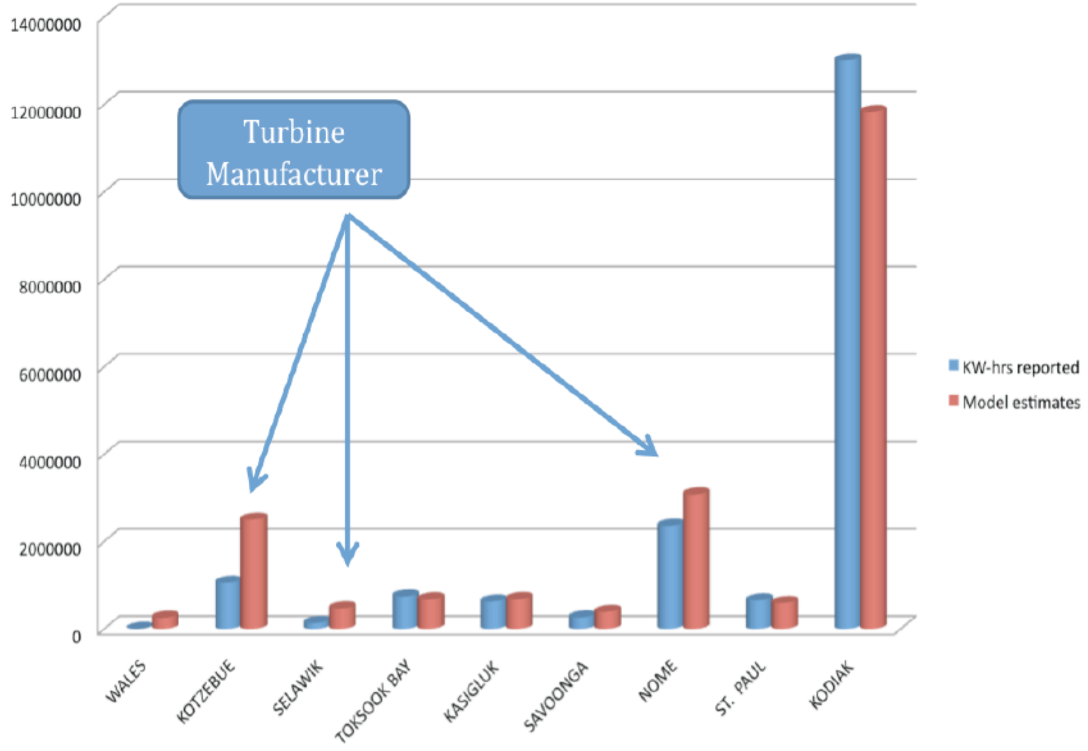
Numerous factors account for how well a system is performing, including wind regime, developer experience, community support, and turbine type. Figures 12 through 16 illustrate how these factors may have influenced the performance of existing rural wind-diesel systems.

5.2 EFFECTS OF TURBINE MANUFACTURER

The communities of Kotzebue, Wales, Selawik, and Nome have all struggled with the Entegrity turbines (see 6.1 Kotzebue Case Study: Turbine Testing). These difficulties have led to reduced capacity factors in all communities.

By contrast, the systems meeting modeling expectations are mostly using NW100 turbines (more expensive than other turbines) in communities with wind classes of 6 or 7 and operating under the watchful eye of a competent utility. However, the remanufactured Vestas on St Paul Island has also performed well. Otherwise, there is insufficient operational time on other turbines in Alaska, such as the 1.5 MW GE turbine and the 900 kW EWT, to determine what availability should be expected.

Figure 12. Effects of Turbine Manufacturer on Performance



Source: Utility information; Power Cost Equalization program data; HOMER model estimates

5.3 EFFECTS OF WIND CLASS

Figure 13 highlights that the communities with the highest class wind regime, St. Paul and Kodiak, have high capacity factors and are meeting modeled expectations. Reciprocally, the communities of Selawik and Kotzebue have lesser wind resources, resulting in a lower capacity factor and lower performance. It is critical to complete a full and detailed wind site assessment when planning a project, because the strength of the wind resource will be critical to the success of the project.

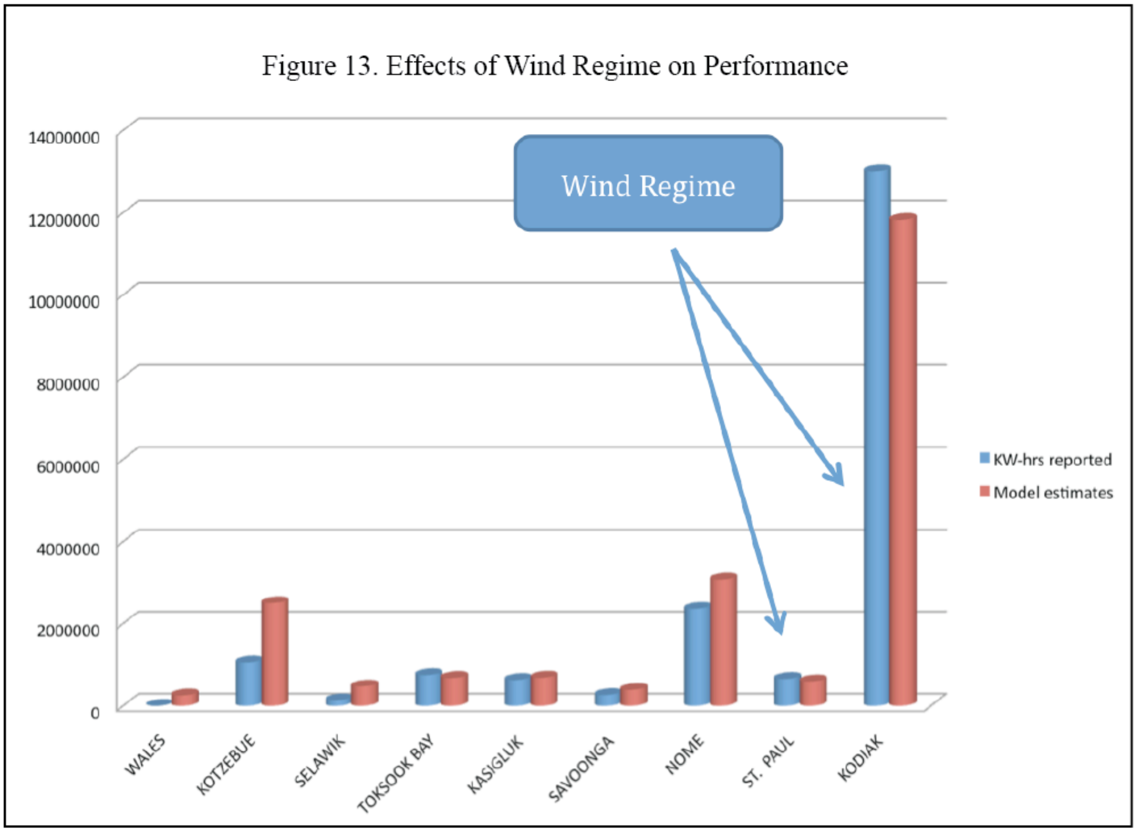


Figure 13. Effects of Wind Regime on Performance

Source: Utility information; Power Cost Equalization program data; HOMER model estimates

5.4 EFFECTS OF EXPERIENCE

Experience of the developers and utilities is another factor affecting performance of wind-diesel systems (Figure 14). The high-penetration system on St. Paul Island was developed by Northern Power Systems in 1997; that developer had considerable previous experience. The Alaska Village Electric Cooperative gained experience during the Selawik installation and numerous systems followed, each improving on the last. AVEC now has a technologically similar system approach, which makes project management more predictable and keeps project development costs within budget.

Besides utilities, other companies are gaining wind-diesel experience, increasing the knowledge base within Alaska. STG construction continually makes improvements on turbine installations with crane utilization and unique foundation design. Electric Power Systems, Inc. has focused on the SCADA system integration and dynamic modeling components. Western Community Energy has become an expert on Entegrity modifications and repairs. The list of experienced developers, utilities, and companies is growing to the point where the wind-diesel design envelope is being expanded steadily.

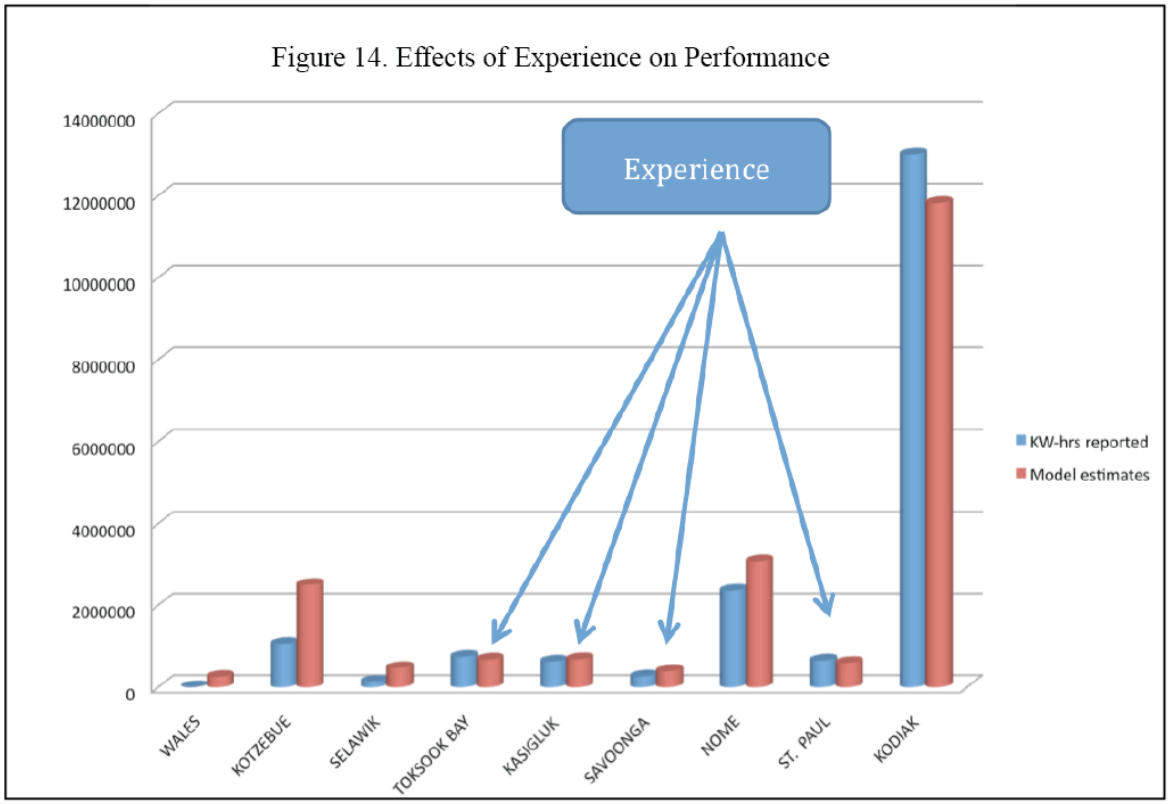


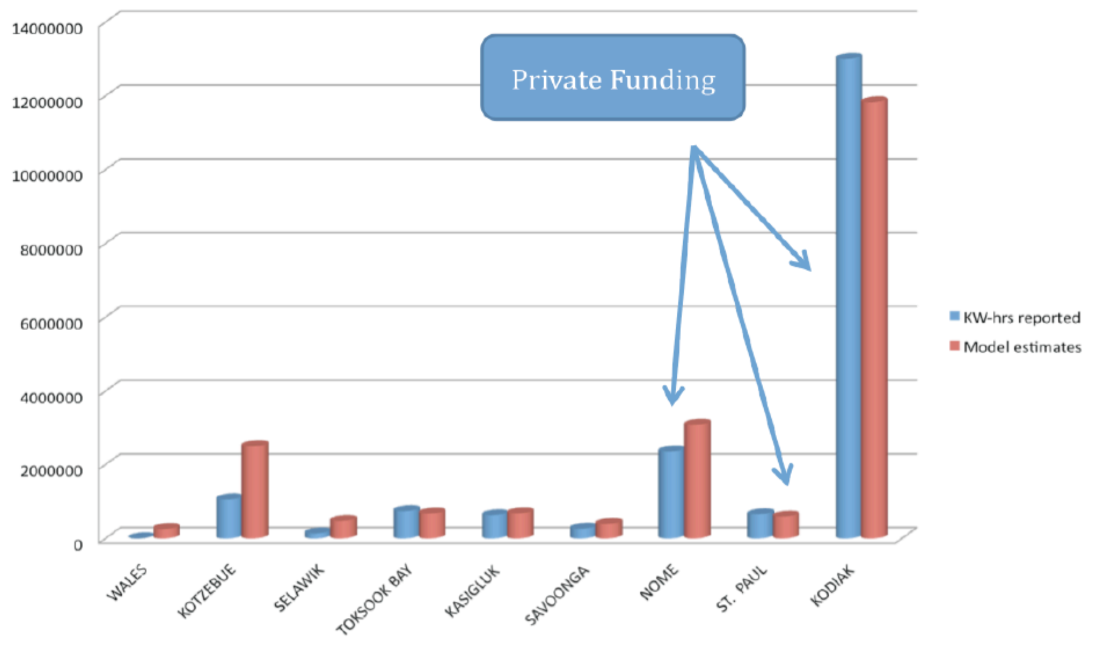
Figure 14. Effects of Experience on Performance

Source: Utility information; Power Cost Equalization program data; HOMER model estimates

5.5 EFFECTS OF FUNDING SOURCE

As shown in Figure 15, private funding for projects can provide increased incentive for strong performance. Private funding can also allow a project to progress more rapidly, without missing construction seasons or waiting for grant agreement. In Nome, for example, the project owners of Banner Wind (Independent Power Producers) report making every low-cost improvement possible on the turbines, to increase the overall capacity factor—which, in turn, directly affects their bottom line. The maintenance crews are out, regardless of weather, repairing a turbine to get it back online as soon as possible; the power purchase agreement requires the developers to compensate the utility and ratepayers for turbine down time and higher costs of diesel-generated power.

Figure 15. Effects of Funding Source on Performance

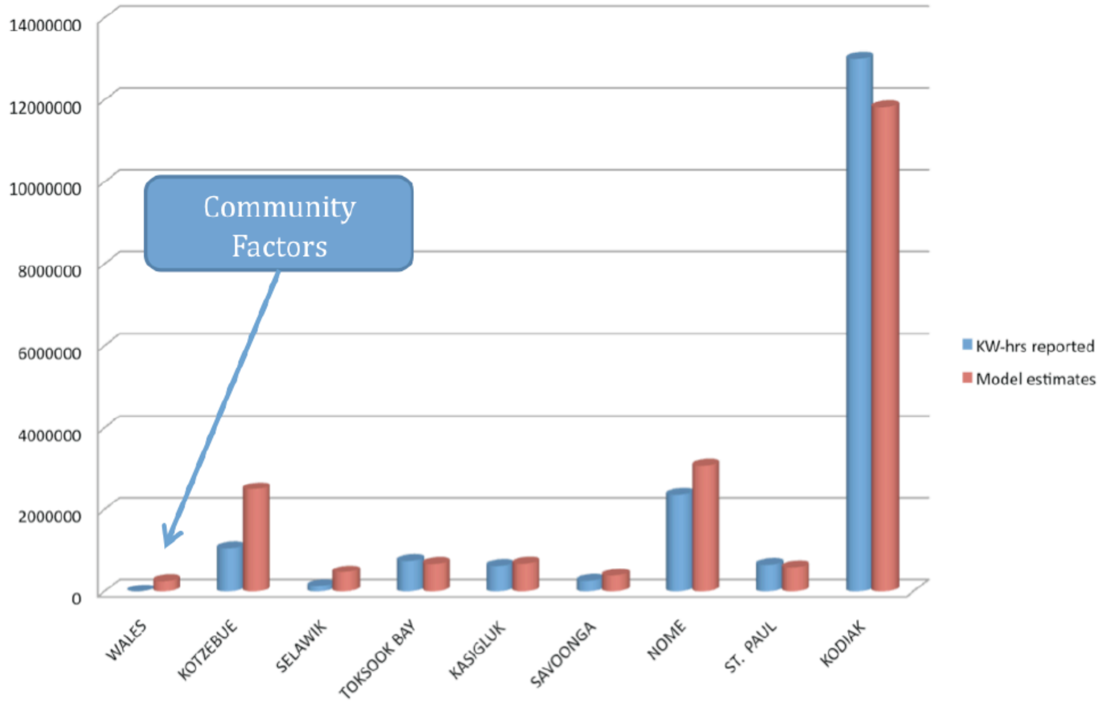


Source: Utility information; Power Cost Equalization program data; HOMER model estimates

5.6 EFFECTS OF COMMUNITY FACTORS

The lack of technical problems is not the only requirement for success in rural Alaska wind-diesel systems. Technical expertise must be accompanied by community support and operator interest. An operator who does not value the more challenging wind-diesel system has the potential to reduce the performance of that system. In other words, when the lights go out-the local operator is blamed and must remedy the situation. The operator needs to be properly supported in order to successfully maintain system stability.

Figure 16. Effects of Community Factors on Performance

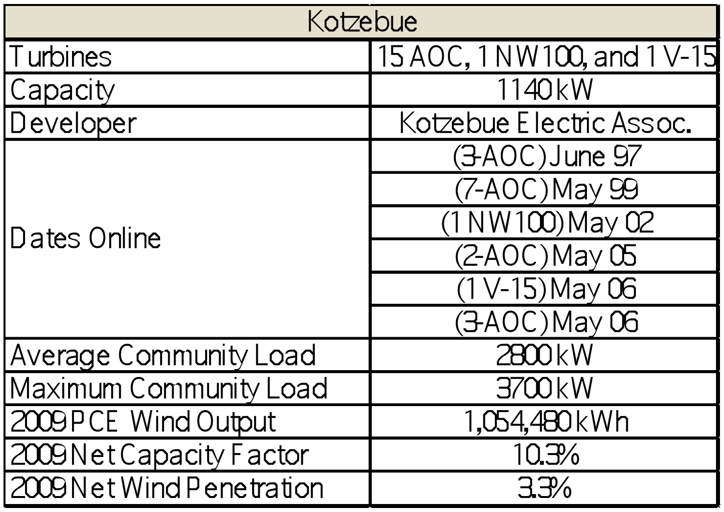


Source: Utility information; Power Cost Equalization program data; HOMER model estimates

6 CASE STUDIES

6.1 KOTZEBUE CASE STUDY

Table 8. Snapshot of Kotzebue Project



Kotzebue	
Turbines	15 AOC, 1 NW100, and 1 V-15
Capacity	1140 kW
Developer	Kotzebue Electric Assoc.
Dates Online	(3-AOC) June 97
	(7-AOC) May 99
	(1 NW100) May 02
	(2-AOC) May 05
	(1 V-15) May 06
	(3-AOC) May 06
Average Community Load	2800 kW
Maximum Community Load	3700 kW
2009 PCE Wind Output	1,054,480 kWh
2009 Net Capacity Factor	10.3%
2009 Net Wind Penetration	3.3%

Source: Authors' compilations

Kotzebue is on the northwestern coast of the Baldwin Peninsula on Kotzebue Spit, surrounded by Kotzebue Sound, Chukchi Sea, Bering Strait, and the Arctic Ocean. Kotzebue is 549 air miles northwest of Anchorage, 26 miles above the Arctic Circle, and 200 miles from the eastern tip of the Soviet Union. The developed portion of the city covers about a square mile. Kotzebue Electric Association, Inc. (KEA) has been operating since the 1950s. An active member of the Alaska Power Association, KEA is a cooperative, nonprofit electrical utility that serves the community of Kotzebue, Alaska, as well as the rural area surrounding Kotzebue. Most of KEA's approximately 1,290 customers are located within a five-mile radius of KEA's power plant. In recent years, KEA has generated up to 22 million kWh per year. Most of Kotzebue's electricity is produced using #2 diesel-fueled reciprocating engine-powered generators, with approximately 10% generated by wind power. Kotzebue is not connected to any other power system or grid.

Project Background

Prior to 1997, electricity for the community of Kotzebue was entirely generated by diesel engines. The diesel power plant has six engine/generator sets and an available output of 11.18 MW. KEA has a peak electric load of approximately 3.7 MW. To help reduce Kotzebue's dependence on fossil fuel, as well as to reduce point-source emissions of carbon compounds, KEA decided to invest in wind power to at least partially replace diesel-generated power.

In 1997, the first three turbines were commissioned on the leased 148-acre project site approximately 4.5 miles south of Kotzebue. Seven more turbines were installed in 1999. As of January 2010, there are seventeen turbines with a total installed capacity of 1.14 MW. These include:

- 15 Entegrity EW50s (AOC 15/50): 66 kW each
- 1 Northwind 100: 100 kW
- 1 Vestas: 65 kW

Through its ongoing development program, KEA expects to eventually increase its wind-generating capacity to 3–4 MW.

Management Structure

To take advantage of its local expertise and knowledge of arctic construction techniques, KEA took responsibility for overall construction management of the project and for project development activities. KEA also conducted or subcontracted for the detailed design of electrical and civil engineering aspects of the wind project.

Construction

The scheduling aspects of this project were particularly challenging because of the unique environmental and climatic conditions at the project site. Certain construction tasks can only be accomplished during specific periods. Tasks requiring the use of heavy machinery typically take place in the winter months (November to April) to minimize impacts on the tundra. However, construction activities are limited during winter months due to extreme low temperatures and limited daylight hours. Brad Reeve, KEA's general manager, estimates that it takes 40% more time in Kotzebue than at wind project locations in the Lower 48 to conduct typical construction and maintenance activities. KEA's experience with the local environment and climatic conditions was extremely valuable in coordinating activities and managing construction tasks.

Turbine Testing

The Kotzebue Wind Farm was and continues to be a turbine-testing site that allowed for the early development of U.S.-made wind turbines. When the project was initiated, the only U.S.-made machine available was the Atlantic Orient Company 15/50 (AOC). The first three turbines were built in a cow barn in Norwich, Vermont, at what was then the headquarters of Atlantic Orient Company. The first twelve turbines were all considered pre-commercial, with co-development occurring at the National Renewable Energy Laboratory, AOC, and KEA. In addition, the pre-commercial Northern Power NW100 was installed in Kotzebue, to develop a cold-weather model. That project was sponsored by the National Science Foundation to develop and commercialize a cold-weather machine that could be deployed in the Antarctic. To illustrate the difficulty that wind turbines and logistics can cause, a few details are provided below.

The installed AOC turbines, as expected, had tremendous difficulties.

> **Delivery:** When the first three turbines arrived in Kotzebue, Lynden Air Freight dropped one of them. It was obvious that some damage had occurred to the dropped unit, so it was sent to Hayden Electric for inspection. Hayden Electric determined that the generator shaft was bent and contacted AOC to supply a replacement. Hayden replaced the damaged generator and Lynden returned it to Kotzebue.
>
> **Blades:** In May 1996, the first blades arrived and were taken to the Kotzebue wind site. When the first turbine was ready to be erected it was determined that KEA had not received the necessary special oval blade washers. These had to be ordered from AOC, causing delay. The delivery of blades for the other two machines was also delayed and the machines were erected without blades. That was necessary because Kotzebue was losing the snow cover on the tundra and needed to move the crane to solid ground to avoid damaging the tundra. Meanwhile, blade production had been moved to Scotland, and the untested blades were delivered to Kotzebue ten weeks later. AOC and KEA personnel came up with a method of installing the blades onto the turbines after the units had been erected. The Scotland blades eventually had to be replaced, due to manufacturing issues. For one AOC turbine, KEA had to purchase a used turbine from California in order to get good blades.
>
> **Tip Brakes**: While the AOC machine had many features that make it cost-effective and reliable, the tip brakes have been a major issue. Kotzebue has tried to resolve this problem in numerous ways. The dampener on the tip brakes eventually caused production of the unit to be discontinued. When the dampener became unavailable, the entire tip brake system was redesigned. The rotary transformer was changed to a slip-ring arrangement in order to supply power to the tip brake. The tip brake again was redesigned to accommodate a coil spring to retract the tip brake into the magnet. KEA and Western Community Energy continue to refine the machine.

Still, despite these major obstacles, the AOC machines (now Entegrity) have survived up to 13 years in some of the most horrendous weather conditions imaginable. In order to keep the pre-commercial machines running, the utility and the manufacturer have had to be completely committed to the success of the wind project.

The early NW 100A in Kotzebue was also not immune to problems.

High Wind-Speed Shutdowns: The programming for the power controller unit caused a significant loss of energy for the unit during its first six years of operation. The problem occurred during the best wind power conditions on a consistent basis. The machine would shut down due to overly conservative programming. The problem was finally relieved in 2008, when a new power convertor was purchased and installed.

Yaw System: The yaw system on the NW100 also needed significant amounts of work. Every six months the yaw brakes needed to be disassembled and cleaned to eliminate brake dust; otherwise a high pitch squeal would develop.

Field Exciter Circuit: The field circuit and the brush assembly have been high-maintenance items. The assembly has failed once and has caused many shutdowns, due to brush dust creating a path to ground—"field exciter fault." The brush assembly needs to be cleaned every six months, which takes about 2 to 3 hours because the assembly is inside the generator and access is tight.

These problems are indicative of the difficulties new turbine manufacturers face, the need for cold weather modifications, and the logistics of getting turbines and parts to remote installations. They also highlight the amount of experience and dedication required of a project developer, such as KEA, in order to maintain an operational wind system.

The Entegrity Wind Systems (EWS) EW50 is based on the well-known and proven AOC 15/50 wind turbine, which was manufactured by Atlantic Orient Corporation in Vermont from 1991 to 2001.

Performance

During the most recent full year of operation (2009), KEA experienced turbine downtime due to problems with the EW50. Two gearboxes needed replacement and numerous tip brake issues resulted in lower turbine availability and a capacity factor of 10.3%. At the same time, Entegrity Wind Systems became insolvent and the procurement of parts was a significant issue. As stated earlier, a tip brake design change caused the discontinuation of a key dampener component that enabled a slower tip brake retraction. KEA tried using a spring system based on the Enertech 14/40 but due to cold weather issues, the springs broke on a constant basis and caused significant loss in production. KEA has been working with EWS for years to improve the machine, but tip brakes have been a constant battle with this machine. With 18 EW50 turbines being deployed at Banner Peak in Nome, methods of collaborative improvements are being discussed.

During the past six years, the Kotzebue wind farm has had a net penetration of 3.5% with an average capacity factor of 10%. With an average wind speed of 5.5 meters/second (m/s), HOMER modeling suggests that Kotzebue could expect an annual capacity factor of 31.5%. This is significantly different from what KEA has experienced. This discrepancy can be explained, however, by turbine downtime and perhaps an overestimated wind resource.

Future Improvements

Kotzebue Electric Association will be expanding the installed capacity of its wind farm during the summers of 2010 and 2011, with the installation of two 900 kW EWT turbines. Since this expansion will significantly increase the amount of wind penetration on the grid, KEA will simultaneously be installing a Zinc Bromide Flow Battery to stabilize the power quality of the grid. In addition to wind-farm improvements, the utility is also in the midst of renovating the waste-heat recovery system to include capture of stack heat. The additional heat will be used to generate power with an ammonia power cycle power plant designed by Energy Concepts. As these modifications are made in Kotzebue, an overall increase in performance should be expected.

6.2 WALES CASE STUDY

Table 9. Snapshot of Wales System

Wales	
Turbines	2 Entegrity EW50s
Capacity	.13 MW
Developer	AVEC/KEA/NREL
Date Online	2000
Community Load	

Source: Authors' compilations

In 1995, AEA, KEA, AVEC, and NREL began collaborating on a technically ambitious project—installing a high-penetration wind-diesel system in Wales. When operating, this community-wide system allows diesel gen-sets to shut off when sufficient wind energy is available. As we'll discuss below, various problems have kept the system from operating in recent years, but in mid-2010 renovations were underway.

Figure 17 depicts the system configuration, which consists of three diesel gen-sets (75 kW, 142 kW, and 148 kW), two 65-kW Entegrity EW50s wind turbines (AOC 15/50), a 130-Ah (31 kWh) SAFT nickel cadmium battery bank, a rotary power converter, and various control components. The system was designed to meet the base electrical load while sending excess wind energy to thermal loads in the village.[26]

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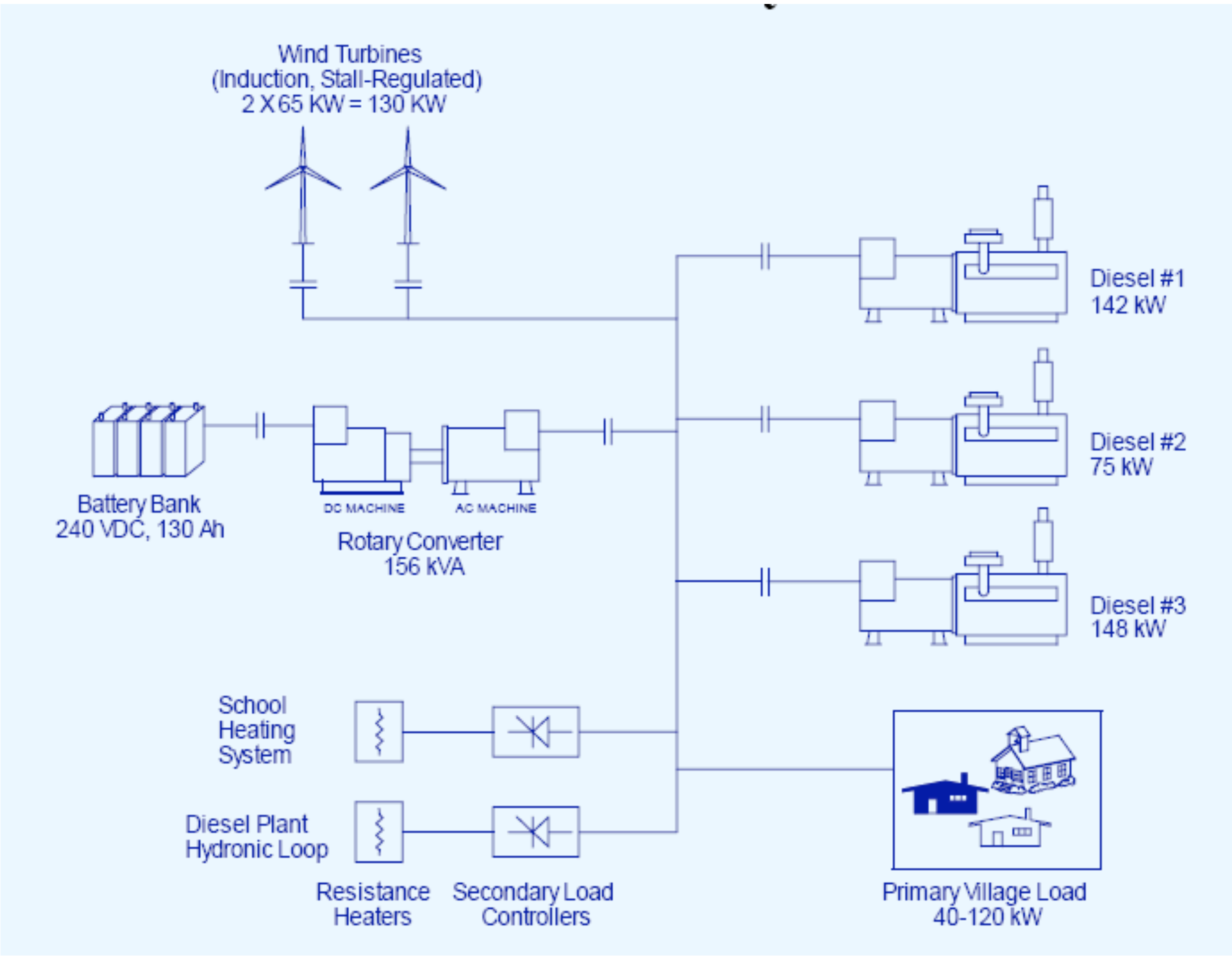
[26] Drouilhet, S.; Shirazi, M. (2002). Wales, Alaska High-Penetration Wind-Diesel Hybrid Power System: Theory of Operation. 77 pp.; NREL Report No. TP-500-31755.

Figure 17. Schematic of Wales Wind-Diesel System



Source: Drouilhet, S.; Shirazi, M. (2002). Wales, Alaska High-Penetration Wind/diesel Hybrid Power System: Theory of Operation. 77 pp., NREL Report No. TP-500-31755

The goal of the project was to demonstrate reliable operation of a high-penetration wind-diesel system, with a focus on providing appropriate component dispatch and smooth transitions between diesel-on and diesel-off operation. This operation needed to happen without a loss in power quality, which meant that good voltage and frequency regulation needed to be available so utility customers would not notice any effect.

In 2002, when the project was receiving adequate support and funding, the system performed sufficiently well that it was meeting its goals. However, the wind turbines have not contributed significantly to Wale's electrical grid for the past five years, because of communications issues with the site and the local operator's lack of confidence about running the equipment. The turbines were available throughout most of this period, but the most recent effort to service them did discover some technical problems, which had not been resolved by spring 2010. Many Alaskans feel that the Wales wind-diesel project has been a failure—but there is no technical reason why the system cannot function as it was originally intended. Table 10 shows operating statistics for the Wales system during part of August 2002, when the system was operating as designed. During that reporting period, wind-penetration levels were such that the diesels were off for 87 hours, or 20% of the time.

Table 10. Wales System Specifications

Wales System Specs August 5-23, 2002			
(427 hour reporting perio		kWh	Fraction of Primary Load
Village Load		26,950	100%
Diesel Energy Output		15,970	59%
Wind Energy		21,080	78%
	To Primary Load	10,980	41%
	To Dump Load	9,430	35%
	To RC Losses	670	2%
Diesel-Off Statistics		**87hrs/427hr**	**20% of time**

Source: Drouilhet, S. and M. Shirazi. Presented at Wind-Diesel Workshop: Anchorage, AK September 23–24, 2002

Capacity factors for the same period in August 2002, shown in Table 11, are high due to the excellent wind regime combined with high availability during the 427-hour sampling period. Table 12 shows the amounts of fuel saved during that period, as a result of wind power.

Table 11. Wales Wind Turbine Production

Wales Wind Turbine Productivity August 5-23, 2002 *(427 hour period)*		
	Turbine 1	**Turbine 2**
Average Wind Speed (m/s)	7.1	6.8
Availability	99%	99%
Capacity Factor	38.20%	37.70%
Project annual energy output	432,000 kWh	

Source: Drouilhet, S. and M. Shirazi. Presented at Wind-Diesel Workshop: Anchorage, AK September 23–24, 2002

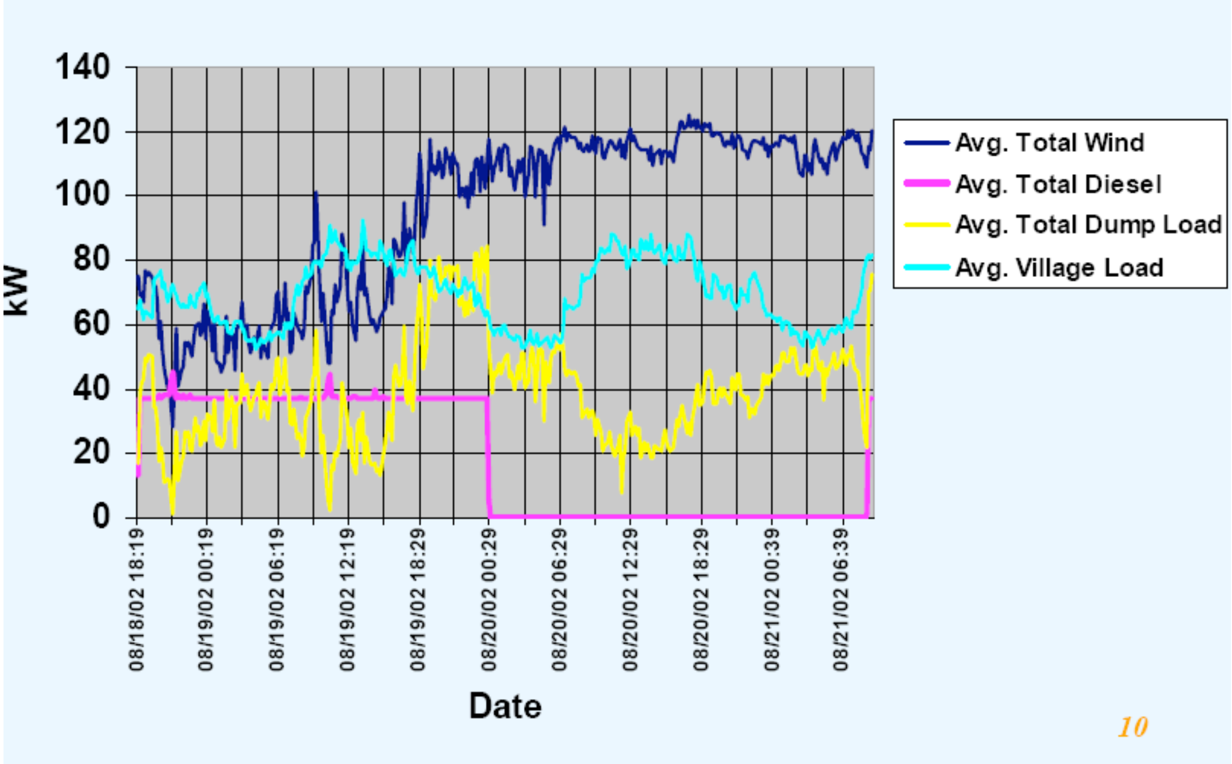
Table 12. Wales Fuel Savings

Wales Fuel Savings		
August 5-23, 2002 ***(427 reporting period)***		**Annual Projection**
Diesel Fuel Saved	845 gal	17,340
Heating Fuel Saved	119 gal	2,440

Source: Drouilhet, S. and M. Shirazi. Presented at Wind-Diesel Workshop: Anchorage, AK September 23–24, 2002

Notice in Figure 18 that the diesel gen-sets were off half the time during a period of several days in August 2002, another indication of how well the system was working in 2002.

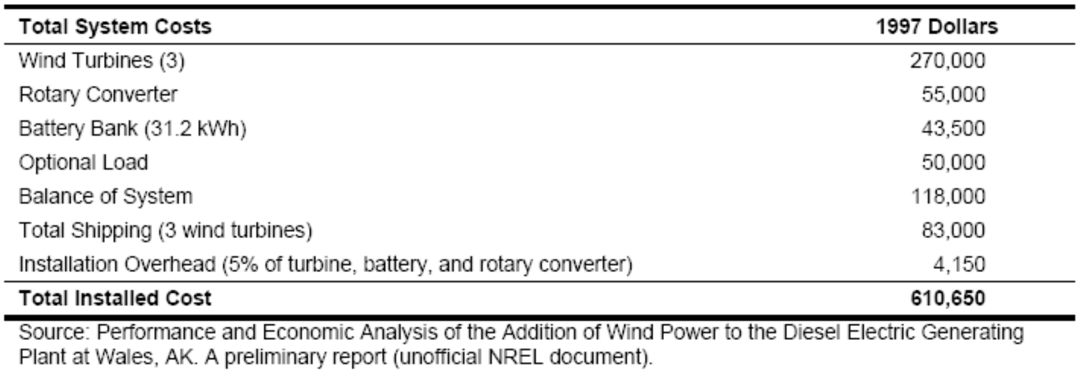
Figure 18. Wales System 10-Minute Power Averages, August 18–21, 2002



Source: Drouilhet, S. and M. Shirazi. Presented at Wind-Diesel Workshop: Anchorage, AK September 23–24, 2002

AVEC owns and operates the Wales power plant. KEA owns and operates the wind farm, and wind turbine upkeep is the responsibility of KEA. But Wales is a significant and costly distance from Kotzebue, and KEA has minimal staff and its own wind farm to maintain. The project was undercapitalized because it did not receive an approved grant, through the Alaska Science and Technology Fund, when that agency went out of business. According to Steve Drouilhet, the initial NREL engineer for the project, many problems can be attributed to lack of ongoing support due to long-term financial constraints, as well as to the lack of a local, technically qualified operator to operate and maintain the system.[27] Table 13 shows a breakdown of costs for the Wales system, in 1997 dollars.

Table 13. Wales System Economic Breakdown



Total System Costs	1997 Dollars
Wind Turbines (3)	270,000
Rotary Converter	55,000
Battery Bank (31.2 kWh)	43,500
Optional Load	50,000
Balance of System	118,000
Total Shipping (3 wind turbines)	83,000
Installation Overhead (5% of turbine, battery, and rotary converter)	4,150
Total Installed Cost	**610,650**

Source: Performance and Economic Analysis of the Addition of Wind Power to the Diesel Electric Generating Plant at Wales, AK. A preliminary report (unofficial NREL document).

In conclusion, without adequate local involvement and without nearby regional support entities, this system was not able to maintain its original functioning status and has remained operational only as a stand-alone diesel power plant. As of mid-2010, the community has begun efforts to revitalize the Wales wind power system and is looking to establish more long-term partnerships. The first priority will be to install satellite communications, so the innovative system can be monitored and controlled remotely as needed. Secondly, the wind turbines need to be repaired. An O&M contract should be renegotiated that benefits all entities. Kotzebue Electric Association was originally responsible for the O&M contract, but flights to and from Wales became prohibitively expensive. KEA has entered into discussion with Western Community Energy to develop a maintenance strategy for the turbines. Western Community Energy holds an O&M contract with the Banner Wind project in Nome and has a regional presence.

Future Improvements

In early 2010, Wales received an Emerging Technology Grant from the Denali Commission, through KEA, that will allow for the necessary modifications to be made. In general, the scope of work will include repair of the Entegrity wind turbines, installation of satellite communications, operator training, and establishment of a functional partnership that does not cause undo strain on any one entity. Having this high-penetration pilot project operational again will be an excellent addition to the growing knowledge base.

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[27] Drouilhet, Steve, 2009, personal communication, owner, Sustainable Automation, September 2, 2009.

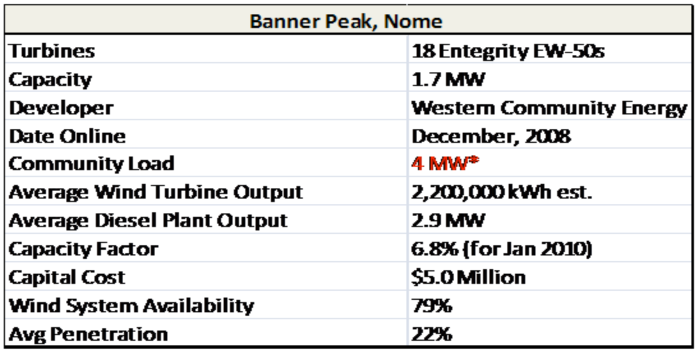
6.3 RECENT INSTALLATIONS

6.3.1 LOW PENETRATION SYSTEMS

Low-penetration diesel hybrid systems are, at this point, a commercial technology. The amount of control technology required is minimal. The diesel gen-sets still maintain the voltage and frequency support of the grid system at all times. There are low-penetration systems operating in Alaska, including in Kotzebue and Selawik. They often seem desirable due to their lower capital cost and simplicity of the controls, which makes them easier to integrate with existing diesel systems. While there are minimal diesel modifications necessary, the fuel savings from these systems is fairly modest—no more than 20%.

NOME CASE STUDY

Table 14. Snapshot of Banner Wind System



Banner Peak, Nome	
Turbines	**18 Entegrity EW-50s**
Capacity	**1.7 MW**
Developer	**Western Community Energy**
Date Online	**December, 2008**
Community Load	**4 MW***
Average Wind Turbine Output	**2,200,000 kWh est.**
Average Diesel Plant Output	**2.9 MW**
Capacity Factor	**6.8% (for Jan 2010)**
Capital Cost	**$5.0 Million**
Wind System Availability	**79%**
Avg Penetration	**22%**

Source: Authors' compilations

Western Community Energy (WCE), a company from Bend, Oregon, is the developer and manager of the Banner Wind Project in Nome. The Banner Wind Project is a joint venture between Bering Straits Native Corporation and Sitnasuak Native Corporation. The project consists of eighteen Entegrity EW-50 turbines. There is one full-time employee on-site and two part-time employees in Nome to maintain the project. Western Community Energy has a five-year O&M contract for the Banner project, with an option for extension. To date, WCE has provided all technical, regulatory, and legal services for the project. WCE is involved with integrating the new wind system with the existing diesel system that is operated by Nome Joint Utility System (NJUS). The project is projected to offset 25% of Nome's power with wind, and it is the first Independent Power Provider (IPP) in the nation operating on a wind-diesel island grid. WCE has been very generous and transparent with production data from the Banner Wind project.

Installation

The installation took seven months from concept (May 2008) to completion (December 2008). Overall, the turbine installation went relatively well and the project had local support, including from the City of Nome and the electric utility (NJUS, which the city owns). WCE had a good local crew but also brought in people from outside the community, with the specific expertise needed to supplement the locally available workforce—such as equipment operators and electricians. WCE worked with Bering Straits Native Corporation to train local operators and phase out the use of outside workers. WCE would like to identify ways to cut installation costs in the future. The company has determined that installing wind turbines in strong wind conditions was only a small hurdle during construction; the crew worked around the clock, during inclement weather, to meet the desired schedule.

Getting equipment from outside the community can sometimes be a challenge for project construction, driving up costs and determining the construction schedule. WCE needed a crane to erect the Entegrity turbines. STG Inc., a construction management and service company based in Anchorage, was working in the area to drive foundation piles at the Rock Creek Mine. WCE contacted STG to do most of the groundwork, including building a three-mile access road. This is one example of coordinating with other local projects to reduce construction costs.

Commissioning

Immediately post-installation, the blade pitch of the turbines needed to be adjusted to compensate for the increased air density in winter. Due to extreme weather conditions and other delays, this adjustment took until April to complete. At that point, WCE discovered a serial defect in the turbine's drive trains (in the coupling of the generator shaft with the planetary and sun gear in the gearbox). This, again, shut down the entire fleet from April 2009 to August 2009. WCE needed to install appropriate spacers to resolve the problem. WCE was committed to reimbursing its clients for non-operational turbine time. Entegrity turbines, as noted in the Kotzebue case study, have notorious problems with tip brakes. The mechanical springs are prone to break, causing downtime. WCE has replaced all the tip brakes with newer aftermarket versions. WCE was forced to make significant changes in the design of the Entegrity turbine to achieve a single turbine capacity factor closer to the desired and expected 32%. During this time, Entegrity experienced internal financial problems, so WCE needed to initiate repairs on its own, with the hope of being reimbursed by Entegrity later. The cost for WCE to repair the turbines was small compared with WCE's costs to reimburse its clients for turbine downtime. There was significant incentive for WCE to develop innovative solutions to problems the turbine had because of the harsh Nome environment. It was not until September 2009 that the Banner Wind project started producing power.

Performance

During the four months after production started, the Entegrity turbines were tweaked one by one to optimize their performance. Figures 19 and 20 compare average wind power in October 2009 and January 2010, showing an increase in performance during that period. All wind turbine systems experience a breaking-in period; for the first year or two, reduced performance can be expected.

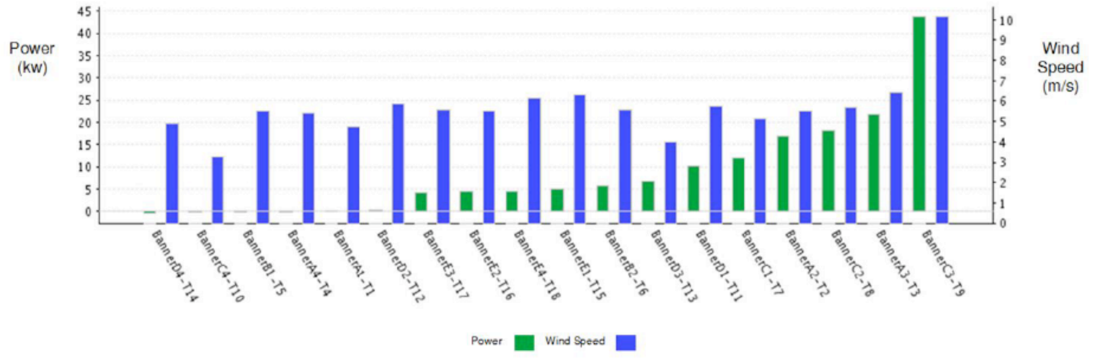


Figure 19. Banner Fleet-Wide Average Power, October 2010

Source: Western Community Energy

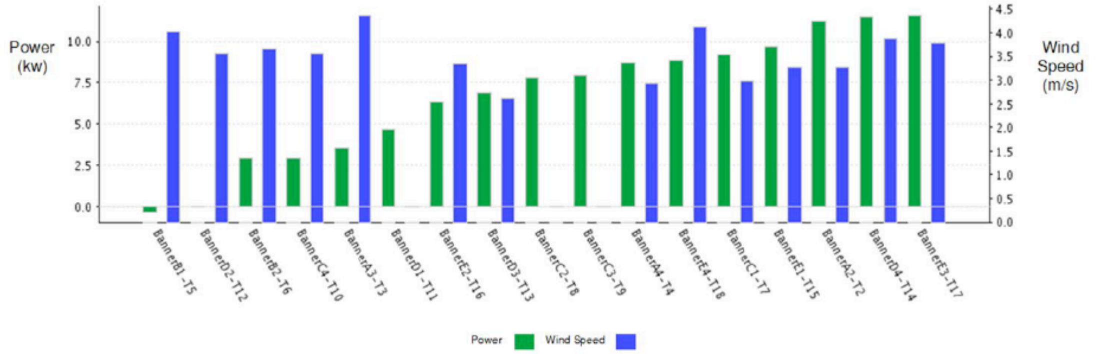
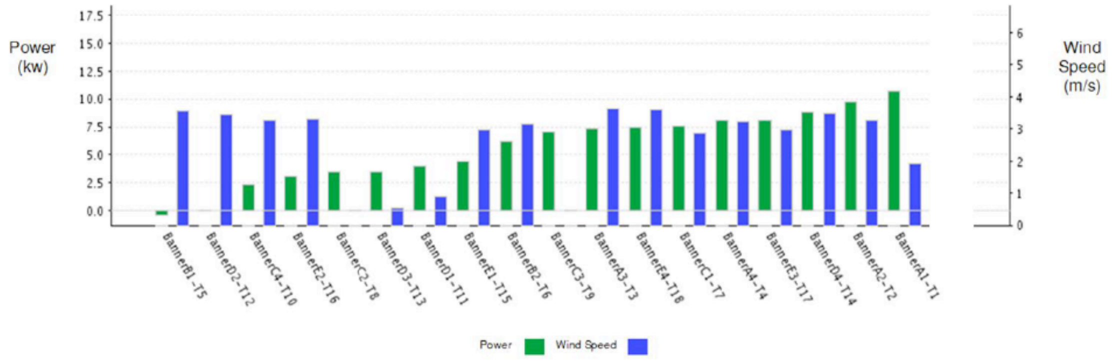


Figure 20. Banner Fleet-Wide Average Power, January 2010

Source: Western Community Energy

While the turbines are still underperforming, WCE expects to see an annual capacity factor of roughly 26% after all turbine modifications have been completed. Between January 1, 2010 and April 1, 2010, the overall capacity factor was 23%—much closer to the expected value (see Figure 21 and Table 15).

Figure 21. Banner Fleet-Wide Average Power, January 1, 2010 to April 1, 2010



Source: Western Community Energy

Table 15. Banner Wind Capacity Factor

January-April 2010	
Turbine Number	Capacity Factor
1	19.74%
2	27.80%
3	27.30%
4	27.97%
6	25.23%
7	18.16%
8	25.42%
9	22.05%
11	21.26%
13	19.60%
14	21.41%
17	21.37%
18	22.82%

Source: Western Community Energy

Operating Agreement and Power Purchasing Agreement (PPA)

WCE established a power purchasing agreement (PPA) with NJUS on December 28, 2009. The PPA is structured to move with the cost of fuel, with the baseline price set to pay off the initial investment and to cover operational costs of the wind farm. To hedge against creating a cost increase to the ratepayer, the PPA brackets a high-value cap on the rate NJUS purchases for wind and a low-value cap for the farm to continue paying off operational costs. With these caps, the structure of the PPA leads to an acceptable return for local investments, a lower electrical cost for the utility to add wind energy, and a reduced cost to the ratepayers of Nome. WCE also has an operating agreement, separate from the PPA, although these two are commonly coupled in the Lower 48. The operating agreement is between WCE and NJUS, and WCE is working to tailor it accordingly. The operating agreement focuses on the cost of integration with the existing diesel system, system efficiency, and monitoring. The revenues from the wind farm will be shared between Sitnasuak Native Corporation and Bering Straits Native Corporation, with 50% of the profits going back into renewable energy projects in communities around Nome.

In conclusion, while the Banner Wind project experienced significant downtime after its installation, many of the hurdles have since been addressed. A source of consternation for all stakeholders in Nome was the PPA, which was not signed until twelve months after the system was commissioned. Though this lack of a PPA created risk, the owner was able to meet the federal DOE Wind Program time requirement to capture the tax incentives.

PORT HEIDEN/PERRYVILLE CASE STUDY (MICROFARM APPROACH)

To avoid some of the construction hurdles, another configuration developers have considered is installing multiple residential-sized wind turbines. Two communities can be used to analyze this approach—Port Heiden and Perryville.

Port Heiden, a community with a population of roughly 120 residents in the Lake and Peninsula Borough on the Alaska Peninsula, has one 10 kW Bergey. This wind system was installed in 2004 by the Sustainable Energy Commission of the Alaska Peninsula, at a cost of $75,000—which equates to an installed cost of $7,500/kW. In a 200-day period of data, this system had a capacity factor of 14.5%. Projecting this data for payback of the turbine in 20 years, the cost of electricity would be $0.87/kWh.[28] This cost can be compared with a diesel-only electricity cost of $0.49/kWh in Port Heiden.

Perryville, another Alaska Peninsula community, was paying $.75/kWh when it contacted Susitna Energy in hopes of installing ten 2.4 kW Skystream wind turbines. Perryville is also in the Lake and Peninsula Borough and has a population of 133 residents. Due to the high cost of energy, these turbines are projected to have a payback of 4.5 years. According to project managers, total installation cost of the 24 kW project was roughly $100,000, equating to an installed cost of $4,100/kW. Gerald Kosbruk, project champion and president of the tribal government in Perryville, has reported that during the first five months of operation, the wind turbines offset $9,143 in diesel fuel. It was not possible to collect more detailed performance data from these systems, as there is no SCADA

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[28] Mark Foster, engineering analysis for the Lake and Peninsula Borough Energy Plan, 2008.

installed to routinely collect and analyze the data. Therefore, these statistics have not been verified independently. Fuel for the community is delivered every six months due to limited storage capacity, and has to be flown in at high cost. While Perryville is an atypical installation, the ten Skystreams have enabled the remote community to offset some diesel with easy-to-install turbines.

6.3.2 MEDIUM PENETRATION SYSTEMS

Medium-penetration systems offer communities the opportunity to reduce fuel use more, while requiring only slightly more complex controls than a low-penetration system. Once peak instantaneous power exceeds roughly 50%, it is desirable to have an automated diesel operation, requiring at least a simple supervisory controller. Also, it is usually beneficial to install and integrate secondary loads, such as an electric boiler. While the capital costs of a medium-penetration system are higher, fuel savings can be up to 40%. Examples of Alaska medium-penetration systems include Toksook Bay and Kasigluk, both of which use electric boilers for their secondary load. Due to the increased complexity of these systems, additional operation and maintenance is required—for secondary-load maintenance and basic control system troubleshooting. That is in addition to the typical wind turbine maintenance required for any wind system.

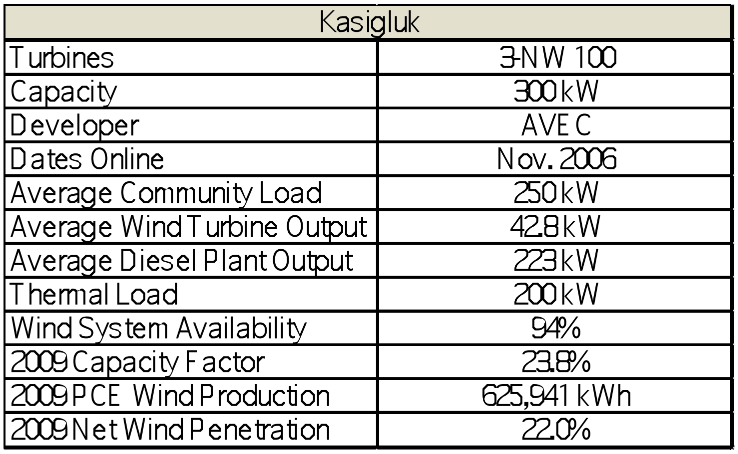
ALASKA VILLAGE ELECTRIC COOPERATIVE CASE STUDIES

The Alaska Village Electric Cooperative (AVEC) is a non-profit electric utility. AVEC received the 2007 Wind Cooperative of the Year Award from the U.S. Department of Energy’s Wind Powering America Program. AVEC has worked hard to develop innovative tower-foundation designs for wind turbines in Alaska’s permafrost conditions. While wind-turbine technology itself is not new, installing turbines in arctic conditions remains a challenge. One difficulty AVEC faces is upgrading its existing power plants—some of which are over 40 years old—to newer and more sophisticated systems that can handle the integration of wind energy. AVEC has chosen not to focus on installation of high-penetration wind systems until the technology reaches a point where the risks to the community are reduced. Selawik, AVEC’s first wind system installation, consists of four Entegrity 65 kW (AOC 15/50) turbines.

AVEC’s second wind system installation was in Kasigluk, a southwestern Alaska village in the Kuskokwim River Delta, 26 miles northwest of the regional hub of Bethel. Kasigluk has approximately 500 residents. The wind project in Kasigluk includes three NW100 turbines and displaces an average of 23% of the diesel fuel previously used for power generation (Table 16).

The turbines were installed in July 2006 as part of a larger construction project that included an upgrade to the existing diesel power plant, a new community bulk-fuel tank farm, and an upgrade to the Nunapitchuk intertie. Funding was provided by AVEC, the Denali Commission, and the U.S. Department of Agriculture's Rural Utility Services, at a total project cost of $16.8 million. The NW100s supply an average of 23% of the electric load to both Kasigluk and the nearby village of Nunapitchuk.

Table 16. Snapshot of Kasigluk System



Kasigluk	
Turbines	3-NW 100
Capacity	300 kW
Developer	AVEC
Dates Online	Nov. 2006
Average Community Load	250 kW
Average Wind Turbine Output	42.8 kW
Average Diesel Plant Output	223 kW
Thermal Load	200 kW
Wind System Availability	94%
2009 Capacity Factor	23.8%
2009 PCE Wind Production	625,941 kWh
2009 Net Wind Penetration	22.0%

Source: Authors' compilations

Another AVEC wind project is in Toksook Bay, a community of about 600 on Nelson Island, northwest of Bethel. Wind contributes 22% Toksook Bay's electric load. As in Kasigluk, AVEC initially installed three NW100 wind turbines in 2006 and is installing one additional NW100 in 2010, for a total installed capacity of 400 kW. To maximize operation in the region, an intertie was developed between Tununak and Nightmute—the other two communities on Nelson Island—and the power plants in those communities were shut down and replaced with standby plants that only operate during outages.

AVEC also installed two NW100s in Savoonga, on St. Lawrence Island, in the fall of 2008. At times, Savoonga has seen instantaneous wind penetrations of greater than 60% without any energy storage or secondary load.

A wind system in Hooper Bay, a community of about 1,100 in the Yukon-Kuskokwim Delta, is another AVEC project that includes three NW100s, installed in 2009. In the same year, AVEC installed four NW100s in Chevak—also in the Yukon-Kuskokwim Delta—and three in Gambell, on St. Lawrence Island.

AVEC has become accomplished at designing these medium-penetration systems, most of which use electric boilers for secondary loads, to stabilize the frequency of the grid system. Over the past couple of years, AVEC has worked to improve the integration of its existing wind-diesel systems. That includes changing set points after the utility has become more comfortable with system operation and response of the controls. In 2008, this change resulted in a 27% improvement in system performance at both Toksook Bay and Kasigluk, without the addition of more equipment. AVEC has also become more comfortable running its diesel gen-sets under low loading, 7% of rated capacity[29], which allows for greater fuel savings. Trainees in each community with a wind system receive a weeklong training session at the Northern Power facilities in Vermont, on servicing and troubleshooting the NW100.

6.3.3 HIGH-PENETRATION SYSTEMS

Unlike low- and medium-penetration systems, high-penetration wind-diesel systems can operate with the diesel generators off, when wind power is sufficiently strong. Developing improved strategies for operating in diesel-off mode is vital to the development of more high-penetration wind-diesel systems both in Alaska and worldwide.

High-penetration wind-diesel systems require a much higher level of system integration, technological complexity, and advanced controls—which increases project costs, but also reduces fuel consumption significantly more than low- and medium-penetration systems.[30]

Power-quality problems have been attracting significant attention as developers and operators of Alaska wind farms strive to increase the level of penetration of wind on isolated diesel grids. Currently, in conventional power systems, the diesel gen-set regulates both voltage and frequency of the grid and provides the needed reactive power, or VAR (Volt-Ampere-Reactive power), support needed for induction motors. However, in a wind-diesel system, continued operation of diesel generators means there are limits on realized fuel savings, particularly as diesel gen-sets are often forced to operate at reduced efficiency as they back off in response to wind availability.

The grid instability caused by high levels of wind power injection has been successfully mitigated by installing high power bi-directional inverter flywheel systems (PowerStore^TM) by Powercorp Pty Ltd. This technology acts as a shock absorber and smoothes the power flow to the load. In order to realize further fuel savings, the long-term goal has been to operate in a diesel-off mode for extended periods. To achieve the required power quality without using a diesel generator, other equipment is needed to provide VAR support. Historically, ancillary components such as a rotary converters and synchronous condensers have been used to perform this function—but these are high-loss devices that can reduce the benefit of running on wind power. Both real and reactive power need to be balanced at all times, and this is done through power electronics, such

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[29] Brent Petrie, project manager, Alaska Village Electric Cooperative, personal communication, September, 2010.

[30] Hunter, R.; Elliot, G. *Wind/diesel Systems*. Cambridge, UK: Cambridge University Press, 1994.

as inverters (the real power can be supplied by a flywheel, for example, while the inverter interface adjusts the phase angle to supply VARs). While standard inverters are a commercial technology, additional development is needed for large hybrid inverters, since only a few have been produced. Various issues such as power quality, voltage and frequency regulation, fault current supply, and load compatibility need to be addressed. The PowerStore^TM unit is able to provide seamless voltage/frequency control between the wind farm and the diesel gen-sets, enabling complete diesel-off mode of operation on the wind farm.

There are successful high-penetration wind-diesel installations, such as those at Coral Bay, Mawson, McMurdo, and Flores Island—all built by Powercorp—that have now been running for a number of years. Operating in diesel-off mode has been sought for many years as significant fuel savings can be achieved when all diesels are shut down. To do this with a large battery bank is possible, but to date it has been prohibitively expensive at any real scale.

Several methods, such as flywheels and ultra-capacitors, can provide short-term power stability. None of these listed systems has been successful at consistently operating wind-diesel systems in a diesel-off state, despite numerous attempts. The system on Alaska's Saint Paul Island, in the Bering Sea, is the only currently operating system to do so[31]—but it benefits from the fact that the wind capacity significantly outmatches electric load for sustained periods. Developing improved strategies for operating in diesel-off modes is vital to developing more high-penetration wind-diesel systems, in Alaska and worldwide.

SAINT PAUL ISLAND CASE STUDY

Saint Paul is a remote community on the largest of the Pribilof Islands, in the middle of the Bering Sea about 750 air miles west of Anchorage. The Saint Paul Municipal Electric Utility currently operates a diesel power plant with a total installed capacity rating of 2,125 kW and an average load of 600 kW. In 1999, the high cost of diesel-generated power from the municipal utility motivated Tanadgusix Corporation (TDX), the Alaska Native village corporation on Saint Paul, to install and operate a stand-alone power system at an airport and industrial complex the corporation owns.

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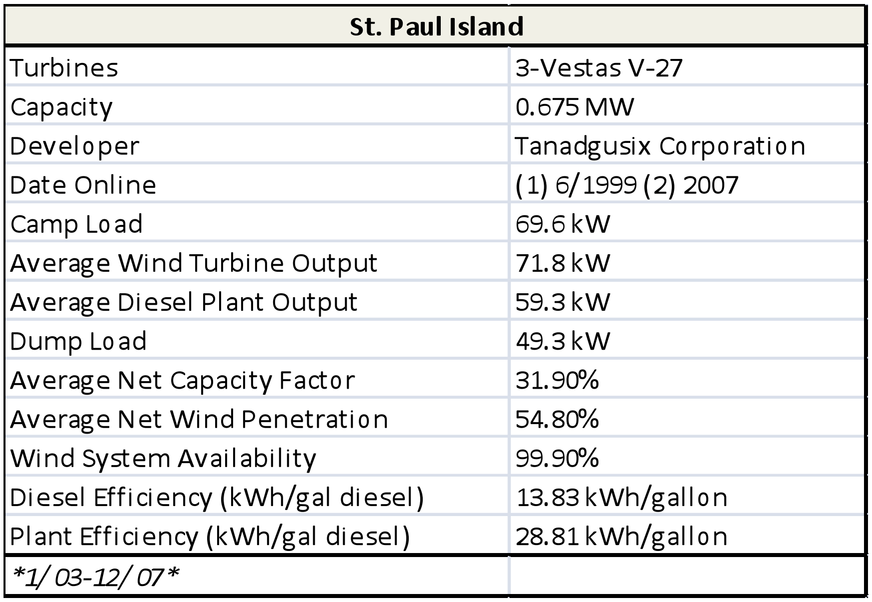
[31] Powercorp recently installed a wind-hydro-solar-diesel system that does run with diesels off when renewable resources are sufficient to meet demand.

Table 17. Snapshot of Saint Paul System



St. Paul Island	
Turbines	3-Vestas V-27
Capacity	0.675 MW
Developer	Tanadgusix Corporation
Date Online	(1) 6/1999 (2) 2007
Camp Load	69.6 kW
Average Wind Turbine Output	71.8 kW
Average Diesel Plant Output	59.3 kW
Dump Load	49.3 kW
Average Net Capacity Factor	31.90%
Average Net Wind Penetration	54.80%
Wind System Availability	99.90%
Diesel Efficiency (kWh/gal diesel)	13.83 kWh/gallon
Plant Efficiency (kWh/gal diesel)	28.81 kWh/gallon
1/03-12/07	

Source: Data from NREL Case Study

The corporation's primary goal was to reduce overall energy costs, while at the same time maintaining stable and reliable power. To take maximum advantage of the available wind resource, TDX installed a system that would enable the diesel gen-sets to be shut off when the level of available wind energy was sufficient. Originally, this high-penetration hybrid wind-diesel system consisted of one 225 kW Vestas V27 wind turbine, two 150 kW Volvo diesel gen-sets, a synchronous condenser, a 6,000 gallon hot-water tank that serves as a dump load for excess power, and a control system capable of providing fully automatic operation of the facility (Figure 22).

The system provides both electricity and primary space heating for the site. From January 2003 to December 2009, wind has offset approximately 183,000 gallons of diesel fuel (Baring-Gould & Dabo, March 16–19, 2009).[32] Recently, two additional 225 kW Vestas V27 turbines have been erected at the site, but they were not yet producing power in mid-2010.

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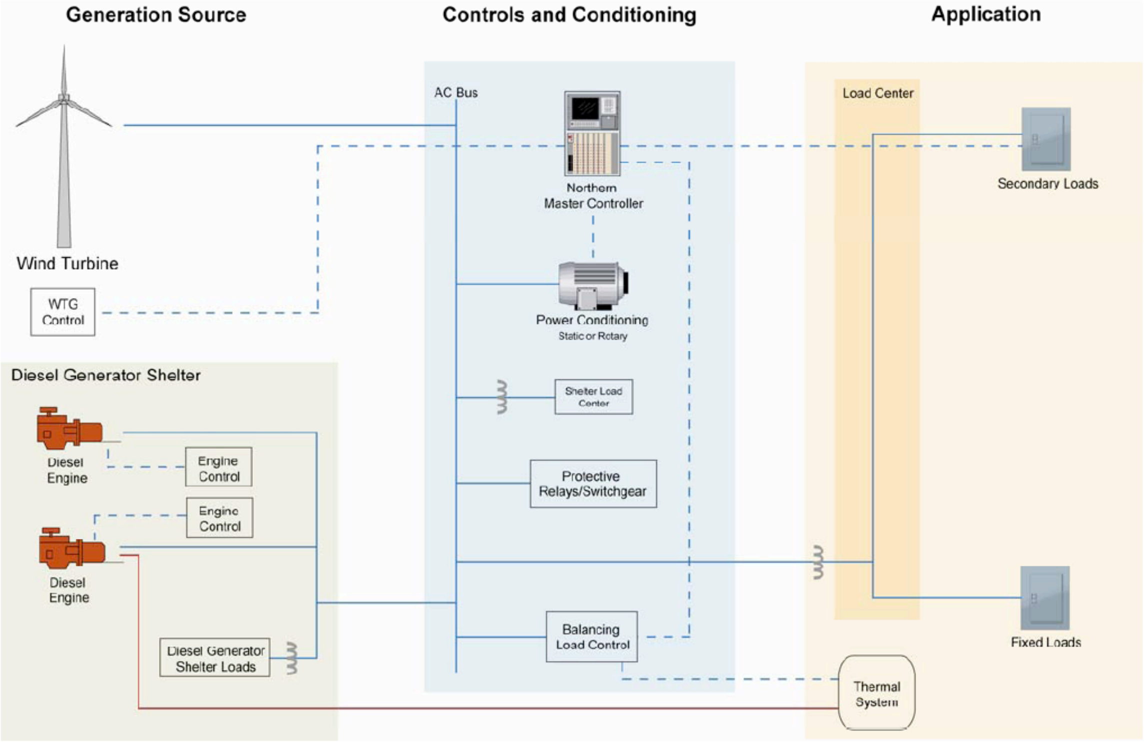
[32] Baring-Gould, I., & Dabo, M. (March 16–19, 2009). Technology, Performance, and Market Report of Wind-Diesel Applications for Remote and Island Communities. *European Wind Energy Conference*.

Figure 22. Saint Paul System Schematic



Courtesy of Northern Power Systems

TDX planned to interconnect the expanded wind-diesel system with the Saint Paul Municipal Electric Utility grid, thus adding 675 kW of installed wind capacity to the system and reducing the community's reliance on diesel fuel. At this time, that interconnection has been delayed indefinitely.

Without a connection to the Saint Paul grid, the hybrid system will produce a significant amount of power beyond what is needed to operate the TDX facility. That facility, the POSS Camp, is an 80,000 square-foot industrial facility with an average load of 65 kW. The system was designed and installed by Northern Power Systems.[33]

Excess electricity can be directed to other loads and used for applications such as space and water heating for commercial and residential applications, air conditioning, water purification or desalination, and ammonia or hydrogen production. Other controllable loads, such as electric vehicles, could be dispatched as needed to absorb peaks in power availability.[34]

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[33] Darrow, K. (no date).525 kW Wind/Diesel Hybrid CHP System. *CHP Case Studies in the Pacific Northwest.* US Department of Energy: Energy Efficiency and Renewable Energy.

[34] Baring-Gould & Dabo, March 16–19, 2009.

The single installed turbine already enables the diesel generators to be shut off for significant periods. Doing that requires advanced controls to dispatch secondary loads. The secondary load consists of resistive heaters mounted in a 6,000 gallon insulated water tank. This configuration has been extremely successful, with a five-year availability of 99.9%. During this period, 70% of the energy needs (including electricity and heat) for the POSS Camp have been met through wind power.[35]

But an important point is that despite the technical successes realized by TDX Power, this is another example of a project that to date has failed to negotiate a Power Purchase Agreement with the local utility, due to competing local interests. However, TDX Power, as an innovative company, has used the excess wind energy for both space heating and electricity in this unique high-penetration system. TDX Power hopes that once the additional two turbines are brought online, the corporation will be able to pass on the benefit to local residents in forms other than grid power—such as through offering an electric vehicle charging station.

KODIAK CASE STUDY

Kodiak Electric Association installed three 1.5 MW GE turbines during the summer of 2009, marking this as the first MW-scale turbines installed in Alaska (Table 18).[36] The wind turbines are anticipated to offset 9% of Kodiak's annual power usage. Kodiak has a mix of generation resources available, including hydroelectric power generated from the Terror Lake hydro project, originally a four-dam pool project. Hydropower supplies firm base-load power and annually accounts for 80% of Kodiak's electric power generation.

In 2002, KEA purchased the Terror Lake facility from the State of Alaska. Original construction cost was $230 million; however, the utility was able to negotiate a purchase price of $38 million. This hydroelectric project serves as energy "storage" for the grid. When wind is available, less water is spilled and this facilitates wind power integration into the system. The remaining 11% of power not supplied by wind or hydro comes from diesel generators.

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[35] Calculated as (total wind kWh produced)/(total diesel and wind kWh produced).

[36] Darron Scott, CEO, Kodiak Electric Association, personal communication, September 2, 2009.

Table 18. Snapshot of Kodiak Island System

Kodiak Island	
Turbines	3-1.5MW GE
Capacity	4.5 MW
Developer	Kodiak Electric Association
Date Online	July, 2009
Average Community Load	16 MW
Maximum Community Load	25 MW
Average Monthly Wind Turbine Output	1,200,000 kWh
Average Annual Diesel Plant Output	10,000,000 kWh
Average Annual Hydro Output	120,000,000 kWh
Est. Annual Average Wind Output	14,400,000 kWh
Dump Load	n/a
Average Net Capacity Factor	33%
Average Net Wind Penetration	10%
Wind System Availability	99%
Diesel Efficiency (kWh/gal diesel)	15 kWh/gal
Plant Efficiency (kWh/gal diesel)	

Source: Authors' compilations

Kodiak's peak load is 25–26 MW and the average load is 16 MW. Wind studies were initiated in 2005. The turbines were ordered in 2007 and the project was installed during the summers of 2008 and 2009, including building the roads, foundations, and substations. The installation was finished in early July 2009, and the system was commissioned in early August 2009.

As of January 12, 2010, the wind system had offset 6,955,870 kWh and 489,850 gallons of diesel fuel.[37] According to the CEO of Kodiak Electric Association, Darron Scott, the project is performing better than the projected power curve estimations. The KEA board set a 95% renewable goal by 2020, as long as the renewable options were economical and did not raise electric rates. Reaching this goal would require installing a fourth turbine, which KEA is considering. Local residents fully support the project and generally feel the turbines have added value to their community, not only by generating electric power, but also by sending a message to visitors that Kodiak promotes sustainability.

The turbines in Kodiak are installed on state land, and Kodiak Electric has a long-term lease with the Alaska Department of Natural Resources (DNR). The state government had never issued a land lease for wind turbines, and the land-lease process was lengthy. The FAA permitting process was also long and challenging.

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[37] Kodiak Electric Association, KEA News Line, February 2010. http://www.kodiakelectric.com/keadocs/Feb_2010_News.pdf

KEA does not have a large bulk storage facility and can only store a few days worth of fuel. KEA purchases fuel from a local supplier that can receive fuel year-round, since Kodiak is an ice-free port. KEA's goal is to operate the diesel generators as little as possible, and rely on wind and hydro to the greatest possible extent. For this reason, and because the generators are located in several different facilities, KEA has elected not to invest in waste-heat recovery.

Kodiak city residents pay 14.8 cents per kWh, which is adjusted monthly based on the inclusion of a diesel fuel surcharge (called a Cost of Power Adjustment, or COPA). The COPA fluctuates with the cost of fuel and the amount of fuel used to generate electricity. Eventually, it is expected that the COPA will decrease due to the amount of diesel being offset, and that rates will decrease slightly over the long term. KEA estimates that wind power costs a diesel equivalent of $1.30 to $1.50 per gallon. As a point of comparison, diesel fuel in Kodiak was selling for $3.05 per gallon during June 2009[38] and sold for over $4.00 per gallon in March 2008.[39]

The utility expects to see continued increases in efficiency during 2010. Despite the short period the project has been operating, the Pillar Mountain Wind Farm has already become a statewide model for effectively integrating renewable energy into isolated grid systems.

Project Funding

The Kodiak project was projected to cost $23.3 million, but final calculations suggest that true costs were closer to $21.4 million. In 2007, KEA received $1 million directly through state appropriations and, in 2008, received $4 million from the state Renewable Energy Fund. KEA also applied for two Clean Renewable Energy Bonds, which took years to establish. Kodiak Electric reports that process was incredibly cumbersome and lengthy.

Because it had other funding sources, KEA was not dependent on REF grant dollars during project construction, so it was able to independently manage the timing of work.

Road and Transmission Lines

There was an existing road going to the Pillar Mountain site, but the road had to be widened and smoothed at a cost of $2 million. KEA also had to build transmission lines from the turbine to the substation, which totaled approximately 1.75 miles.

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[38] Alaska Department of Commerce, Community and Economic Development, Division of Community and Regional Affairs, Current Community Conditions: Fuel Prices Across Alaska, July 2009.

[39] University of Alaska Fairbanks, Cooperative Extension Service Food Cost Survey, March 2008.

System Integration with Hydroelectric

The Kodiak hydro project is a 20 MW system. KEA replaced the governor controls on the hydro system, which stepped up the speed response and eased integration with the wind system. Terror Lake acts as virtual storage for wind power, so as the wind speed increases, KEA generates less power from hydro. Storage of water resources acts as a battery, creating a well-integrated and complementary system. If additional wind turbines are installed as part of a proposed Phase II, they will allow KEA to manage peak loads with the hydro system and almost completely transition away from using diesel. Kodiak experiences unusual seasonal peaks during the fishing seasons, when some diesel generation may still be needed to meet demand. May and June are the low-demand months; peak loads are the lowest during these months.

In conclusion, KEA is the first utility in Alaska to take advantage of the economies of scale associated with large-scale wind turbine development. As the first utility to do so, KEA experienced significant difficulties, most notably in mobilizing large cranes. Nonetheless, due to good planning and execution, KEA experienced few delays in the construction phase, and the project was completed under budget. As Kodiak continues to seek ways to increase the percentage of renewable energy on its grid, a more complex integration system will be required. At present, Kodiak is undergoing high-resolution modeling to determine the best solution for meeting its future development objectives.

6.4 PERFORMANCE ANALYSIS SUMMARY

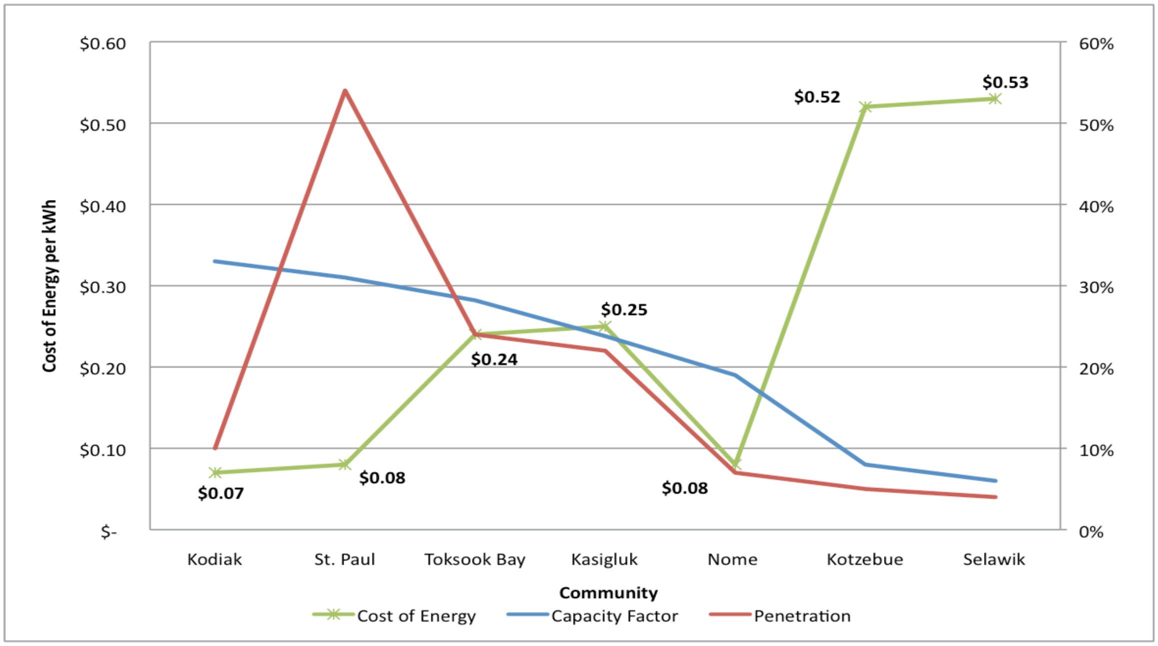
Low-penetration models have been viewed as lower risk from an operational standpoint, as the technology is relatively seamless to incorporate in an existing diesel power plant. However, the existing low-penetration systems in Alaska, such as those in Kotzebue and Selawik, also have lower capacity factors—which indicate that economic benefit of these systems is suspect. All systems using Entegrity turbines have experienced reduced availability from problems with these turbines. These installations would greatly benefit from having a regional maintenance program with an entity, such as Western Community Energy, that can support all similar systems and improve availability. The cost of wind for these communities ranges from 32 cents to 58 cents per kWh over a 20-year project lifespan. The exception is the Nome installation, which has a current capacity factor of 22% but indicates a lower cost of wind, of about 14 cents per kWh as a result of creative financing.

The medium-penetration systems installed by AVEC have been more successful, demonstrating high availability, year after year, of over 95%, as well as higher capacity factors, such as 24% at Toksook Bay. Any excess wind penetration is delivered to secondary boilers, to optimize the available wind and further increase the economic benefit. The cost of wind per kWh, on average, is lower than that of existing low-penetration systems, coming in at around 25 cents per kWh. While the capital cost is higher per installed kW—because of the increased capital cost of the NW100 turbines, the secondary-load controller, and more a more complex SCADA system—these systems are performing better, with high capacity factors.

High-penetration systems offer large potential for future development, including the ability to store excess electricity in a battery system, offset residential and commercial heating, or enhance alternative transportation. High-penetration systems, such as the one on Saint Paul Island, have the lowest lifetime wind costs—less than 10 cents/kWh. Both the Kodiak and Saint Paul systems have capacity factors of over 30%, indicating that the wind resource is ideal, the turbines are well maintained, and the project developer has a stake in maximizing the benefit of the installed systems.

In general, as shown in Figure 23, the cost of wind over a 20-year system lifetime increases as the capacity factor and level of penetration decrease. It is apparent that higher wind-penetration systems equate to higher capital costs but also greater fuel savings—which consumers see directly as a lower cost of energy. This savings does not include the potential economic benefit of directing excess electricity to thermal load, nor does it include the cost to operate and maintain the systems. Operator training and support infrastructure are crucial to long-term sustainability of all such systems.

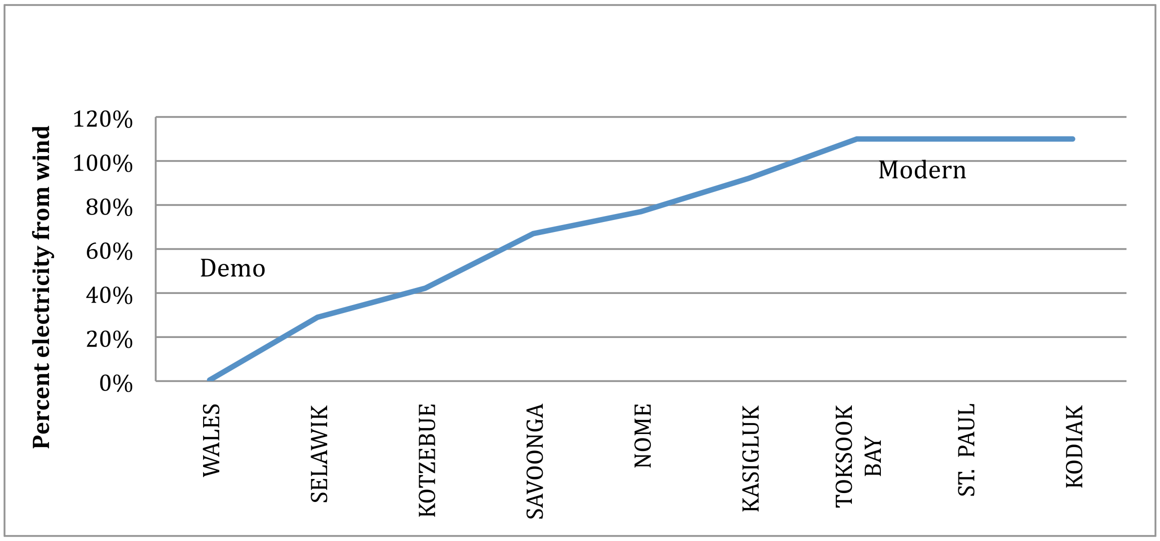
Figure 23. Impact of Penetration and Capacity Factor on Cost of Wind



Source: Alaska Energy Authority, Power Cost Equalization and utility data; authors' compilations and estimates

Overall, with the exception of Kodiak and Saint Paul Island, wind-diesel systems in Alaska are not running at peak efficiency and could benefit from a holistic performance review. Figure 24 shows a continuum of how existing installations are performing in comparison with expected performance. There is a clear difference between early demonstration projects and the modern installations. There is also a commissioning phase, where newer installations don't perform as well when they first begin operating. Moving forward, funding agencies or private developers should set performance standards, to help in the evaluation and optimization of wind-diesel systems.

Figure 24. Improved Performance of Newer Wind-Diesel Systems



Source: Utility information; Power Cost Equalization Program data

7 LESSONS LEARNED

This section discusses lessons we've learned from reviewing project histories and talking to utility operators and wind-system developers.

Geographic and Technical Clustering

Geographically aggregating projects in areas can make development and maintenance more financially viable. Working in several communities simultaneously could help reduce maintenance and equipment costs and allow expenses to be shared among several project budgets. In addition to geographic clustering, "technical clustering" in the form of technical standardization may help reduce costs. This need not be a formal standardization, but the application of similar technical and system concepts in communities with similar needs and conditions would greatly enhance the efficiency of applying wind-diesel technology. Greater standardization would make it much more efficient and economic to perform necessary operations and maintenance, and probably also repairs, of the systems.[40] AVEC appears to be taking advantage of both geographic and technical clustering with the systems it is developing.

Crane Availability

Kodiak Electric Association used a 440-ton crane to erect its turbines. The crane, which came from Wyoming, was barged to Kodiak from Seattle, because no cranes in Alaska were large enough to install these turbines. Fortunately, in-state cranes can be used for system maintenance. KEA spent a significant amount of money on the crane and paid the rental cost while the crane was barged to and from Alaska. As a type of geographic clustering, coordinating crane rental across more than one project and sharing this expense could help decrease construction costs.

It should be noted that crane rental also drove the timeline of the much smaller Banner Wind project in Nome, so this is not an issue solely for large MW-scale turbines.

Agreement Among Entities

When the Wales project was implemented, there was no written long-range plan among the interested parties. NREL eventually relinquished ownership of the turbines to Kotzebue Electric Association (KEA). Presumably, there was a PPA of some sort between AVEC and KEA, where KEA would sell wind power to AVEC. It was implied that KEA would be responsible for maintaining turbines, but there was never a written commitment. Similarly, a PPA was not in place for the Banner Wind project in Nome

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[40] Lundsager, Per, wind-diesel engineer and technical expert, personal communication, May 2010.

until one year after the system was installed, and similar issues related to lack of a PPA with the local utility have plagued the Saint Paul Island TDX Power project.

Having a PPA in place before construction is a critical step in project development. A project development and implementation guide that future developers could draw on would be useful; it should include a checklist and a description of the (sometimes painful) experiences from previous projects.[41]

Operator Challenges

The training level of the operator varies significantly from community to community. Projects need to have operators who are willing to learn and adapt to new technologies, which was a problem in Wales. The operator also needs to have a commitment and sense of responsibility for operating the system. For Wales, this may partly be attributable to the lack of local "buy-in" when the project was initiated. Projects in small communities are likely to require skilled laborers from outside the community to perform repairs and maintenance for the lifetime of the project. The Alaska Vocational Technical Center (AVTEC) in Seward operates a diesel- generator training program and plans to expand its operator training to include wind-diesel systems.

Operation and Maintenance

Projects need to have skilled and dedicated engineers. According to some wind developers, even the larger utilities are not putting adequate resources into developing skilled engineers, trained in wind energy. However, in the long run, it may not end up being the utilities themselves that maintain wind systems. A more optimal and cost-effective alternative may be development of a regional service organization. Coordinating maintenance visits to several communities during one trip could also help reduce costs.

Diesel systems are a mature technology and have many training programs available to operators. Diesel controls have become more sophisticated, but operators receive updated training on a regular basis. Technicians can troubleshoot a diesel system, but wind systems are more complex and need a field engineer to diagnose problems. AVEC relies on diesel mechanics to maintain its wind systems, but that may not be sufficient in the long run.[42]

Kodiak Electric Association (KEA) owns and manages the Kodiak wind project. KEA signed a two-year agreement with GE, the turbine manufacturer, and relies on GE maintenance recommendations. Local KEA staff received training from GE, and the operators will receive additional ongoing training before they take over regular

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[41] Lundsager, Per, personal communication, May 2010.

[42] Drouilhet, Steve (2009), personal communication, owner, Sustainable Automation, September 2, 2009

maintenance of the turbines. KEA employees operate the wind farm; the utility did not need to hire additional staff.

Remote Monitoring and Operation

Good remote monitoring will enable managers to better support wind systems by alerting the project manager if there are problems. But it cannot solve problems that are operator-related, as was the case in Wales. Remote monitoring can help log the system's maintenance and help preserve a record of performance. Developers should not contemplate developing a project without first addressing the need for good remote connectivity.

Limited In-State Technical Expertise

Past and current projects rely heavily on the expertise of people from outside Alaska. But even people with expertise in wind-diesel systems in other places often do not have the appropriate knowledge required for projects in Alaska.

State Involvement

The feasibility of projects depends on construction and operating costs; given the state's investment and role in projects, there are obvious incentives to improve efficiencies. The Alaska Legislature and state agencies could facilitate a number of cost-containment measures.

- The NW100 is currently the most frequently installed wind turbine in rural Alaska. Purchasing multiple turbines for recipients of REF wind project grants could help reduce costs.

- It would be helpful if the state Department of Natural Resources could expedite the land lease process for cooperatives and nonprofits. Darron Scott, manager of Kodiak Electric Association, recommends that the State of Alaska set a priority on using public lands for energy projects and make the land available for free. But that process and price would likely not apply to private for-profit developers. For them, it would be helpful if the state offered financial incentives for renewable projects and provided a renewable energy production credit based on kWh produced. For example, the state could offer 3 cents/kWh for wind projects. If power were not produced, then the utility or IPP would not receive the credit. This means that unproductive projects would not hinder the credit system or public support for renewable energy.

8 WIND-DIESEL RESEARCH NEEDS

There is no doubt that wind power is a mature technology; it has been applied widely across Alaska in recent years. But there are still many significant environmental and technical challenges in deploying wind turbines in Alaska. Critical research is needed to help refine our knowledge of wind-diesel technologies and facilitate future development.

One critical research need is a detailed assessment of current wind projects, focusing on performance, economics, and operations. By simply studying previous projects we can learn what works, what has not, and what still needs improvement. Many projects currently in operation, for instance, may not be running at peak efficiency and could benefit substantially from a holistic performance review. Lessons learned, appropriately documented and disseminated, could provide critical industrial knowledge, and could be applied in future projects both within and outside Alaska. But such an assessment would require that there be standard requirements for reporting construction and operations and maintenance costs and recording performance data. Lack of such detailed data hampered this study.

Beyond lessons from the past, there are many opportunities for future advances, including new and less-expensive foundation designs, new integration concepts that make better use of the wind energy generated, and new blade designs and treatments that minimize icing effects and maximize turbine availability. Not all research is directly wind-power related, but the research will affect the availability and value of wind power on the electrical grid. For instance, research is needed at the nexus of wind technology and energy storage, as wind power can reach higher levels of penetration as energy storage technology improves. Diesel-off hybrid power systems offer the potential to be the next-generation wind-diesel systems. In traditional systems, the diesel gen-set regulates both the voltage and frequency of the grid. To maximize fuel savings, the diesels need to shut off when other renewable resources are available— but to do so, the power electronics must be advanced enough to meet the needs of the system.

Specific identified research needs include:

- Resource assessment
- Identification of statewide high-risk site locations for icing
- Assessment of critical bird flyways that could affect development of wind projects
- Expansion of current resource assessments to consider taller towers

- Grid stability and integration
  - Development and testing of energy storage technology
  - Integration of larger turbines into the Railbelt system
  - Integration in conjunction with hydro installations and related issues
  - Development of high-penetration system configuration standards to optimize performance
  - Better understanding of low-load diesel operation as it relates to wind-diesel dispatching
- Controls
  - Development and proof testing of dispatch strategies for medium- and high-penetration systems
  - Smart grid control and dispatching
  - Plug and play controller logic
  - Investigation and testing of decentralized load controllers for dispatchable loads
  - Increased remote system monitoring and control capabilities
  - Development or implementation of full-system health monitoring
  - Development of standards or guidelines for wind-diesel systems and controllers, including defined commissioning procedures to ensure acceptable system operation following installation
- Deployment
  - Development of low cost foundations and crane-free turbine erection technologies
  - Enhancement of ice-prevention techniques
  - Opportunities to streamline the permitting and land leasing process
  - Incorporation of icing and high wind speed shutdowns in Alaska wind models
- Performance
  - Standardize methods of analyzing wind-diesel economics
  - Standardize methods of reporting and analyzing wind-diesel performance
  - Documentation of comparative environmental impact
  - Facilitation of the availability of performance data for current installations
  - Assessment of systems performance to identify factors considered or omitted in development process

One recent development specific to wind research has been the establishment of the Alaska Wind-Diesel Applications Center (WiDAC), a center to promote excellence in wind-diesel technology. The center analyzes technology options; tests state-of-the-art hardware and control software; educates engineers and trains operators; and provides technical assistance to wind-diesel stakeholders both within and outside Alaska. WiDAC was established by the Alaska Center for Energy and Power (ACEP), together with its partners the Alaska Energy Authority and the National Renewable Energy Laboratory, and focuses on independent analysis and testing, technical support, and workforce development and education.

9 WIND ENERGY FINANCING OPTIONS

Alaskans are potentially missing out on a substantial amount of federal tax credits and other opportunities for funding of wind energy projects. It may be that the Alaska Renewable Energy Fund could be used to leverage rather than replace these other funding opportunities, some of which are briefly described in this section.

9.1 FEDERAL PRODUCTION TAX CREDIT

Production Tax Credits (PTC) are seen by many as a major contributor to the development of wind energy in the United States over the past decade.[43] The PTC is a per kilowatt-hour tax credit for wind-generated electricity. Available during the first 10 years of project operation, it provides a per kWh credit adjusted annually for inflation. Production Tax Credits were enacted by Congress as part of the Energy Policy Act of 1992 and haves gone through several cycles of expiration and renewal. The inconsistent nature of these credits has created uncertainty for long-term planning and hindered steady wind-market development. Under present law, an income tax credit of 2.1 cents/kilowatt-hour is allowed for the production of electricity from utility-scale wind turbines.

Through the American Recovery and Reinvestment Act (passed in February 2009), Congress provided a three-year extension of the PTC, through December 31, 2012. Additionally, wind project developers can choose to receive a 30% investment tax credit (ITC) in place of the PTC for facilities placed in service in 2009 and 2010, and also for facilities placed in service before 2013 if construction begins before the end of 2010. The ITC then qualifies for conversion to a grant from the Department of Treasury, which must pay the grant within 60 days of an application being submitted. Grant applications must be filed through the Treasury Department's online portal.[44] The economic decision-making process for selecting a tax credit can be complex since the value of the PTC is driven by production, while the value of the ITC depends on the installed cost of a project.[45]

Minnesota Flip Business Model

The Minnesota Flip business model was developed in response to a unique combination of federal incentives for wind development and state policies that encouraged

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[43] Wiser, Ryan, Mark Bolinger, and Galen Barbose, 2007, *Using the Federal Production Tax Credit to Build a Durable Market for Wind Power in the United States*, Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division, publication number 63583, November 2007.

[44] American Wind Energy Association, Legislative Affairs website, May 2010, http://www.awea.org/legislative/#PTC

[45] Shaffer, Budd, David Rode, & Steve R. Dean, 2009, Best Among Equals? Choosing Tax Incentives for Wind Projects, *Renewable Energy World North America Magazine*, November/December, Volume 1, Issue 2.

development of community-owned wind projects. The structure has proven a successful model for landowners and equity investors interested in becoming partners in the development of wind projects. This partnership allows the equity investor to take advantage of federal tax credits, while providing local owners the economic benefits of ownership.

Basic Elements of the Minnesota Flip Business Model[46]

Wind projects can involve a sophisticated and complex set of interrelated decisions and agreements among all participants, and the decision to use the Minnesota Flip business model is just one of many important decisions affecting the financing and legal structure of a wind project. The Minnesota Flip model is a business structure developed to allow local owners, including landowners, to own a significant portion of a wind project, while partnering with an equity investor who can use the federal production tax credits generated from the operation of a qualifying wind project.

Under this model, a project limited liability company (LLC) is formed to own and operate the wind project. The LLC owners include the tax equity investor and another LLC made up of local owners. In many cases, the equity investor will reimburse the local owners for their expenses incurred in completing pre-development activities, including permits, wind studies, interconnection and transmission studies, and finance the acquisition of wind turbines and construction of the project. The LLC agreement allocates the wind project's governance and financial rights between the equity investor and local owners. The project is often structured so that the equity investor has a controlling interest in the project for at least the first 10 years to enable the equity investor to use all the PTCs. Then, at a date determined by all the participants, ownership "flips" so that local owners have a controlling interest in the project for the remainder of the project's life.

Limited Liability Corporation Structure. In order to set up a Minnesota Flip wind project, the local owners and equity investor first form a limited liability corporation, or LLC, to own and operate the wind project. Forming an LLC allows the participants to shield their personal and other business assets from liabilities of the project. At the same time, the LLC can elect to be treated like a partnership for tax purposes. This tax treatment facilitates use of the PTCs and allows each member of the LLC to be taxed separately on income from the project. Forming an LLC also allows the members to separate governance and financial ownership rights.

All the terms related to contribution of capital, ownership rights, distributions, and allocations of risk are found in the LLC operating agreement. This document is the key

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[46] Information from the Community Wind Toolbox, May 2010, http://www.windustry.org/your-wind-project/community-wind/community-wind-toolbox/chapter-12-the-minnesota-flip-business-model

contract between participants. The participants negotiate and sign an LLC agreement early in the project development process, to allow the equity investor to finance the acquisition of wind turbines and construction of the project.

9.2 CLEAN RENEWABLE ENERGY BONDS

The Clean Renewable Energy Bond (CREB) program is a financial incentive created in the Energy Policy Act of 2005. It is available to municipal utilities and electric cooperatives and is intended to promote renewable energy development. The Federal Production Tax Credit has been the dominant mode of financing for renewable energy projects since it was made available in the early 1990s. The PTC, however, was designed to benefit the large investor-owned utilities and to track their capital into the renewable energy marketplace. Electric cooperatives and government entities like public power systems and municipal utilities have never been eligible for the PTC. In order to get into the marketplace, they successfully lobbied Congress in 2005 for the creation of CREBs, which are tax credit bonds available only to them and with an interest-free finance rate. The U.S. Treasury pays the entire interest on the bond in the form of a tax credit. Entities that can issue CREBs include:

- State and local governments
- District of Columbia
- Mutual or cooperative electric companies
- Native American tribal governments
- National Rural Utilities Cooperative Finance Corporation
- Non-profit electric utility that has received a loan or loan guarantee under the Rural Electrification Act

9.3 SMALL WIND SYSTEM TAX CREDIT

Under present law, a federal-level investment tax credit (ITC) is available to help consumers purchase small wind turbines for home, farm, or business use. Owners of small wind-systems (100 kilowatts of capacity or less) can receive a credit for 30% of the total installed cost of the system. The ITC, written into law through the Emergency Economic Stabilization Act of 2008, is available for equipment installed from October 3, 2008 through December 31, 2016. The value of the credit is now uncapped, under the 2009 American Recovery and Reinvestment Act.[47]

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[47] American Wind Energy Association, Legislative Affairs website, May 2010, http://www.awea.org/legislative/#PTC

9.4 MODIFIED ACCELERATED COST-RECOVERY SYSTEM

With accelerated depreciation, wind projects can write off the value of equipment on their financial balance sheets over 5 years rather than the typical 20-year projected lifetime of a project. While accelerated depreciation is available to all wind-energy projects, the level at which a project can take advantage of this program is, like the PTC, limited to a project owner's applicable tax burden. Community wind-project owners that typically have a small tax burden may not be able to take advantage of accelerated depreciation, without taking on a tax-motivated investor with a sufficient tax liability to claim the entire incentive.[48]

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[48] Information from the Community Wind Toolbox, Chapter 10: Tax Incentives, May 2010. http://www.windustry.org/your-wind-project/community-wind/community-wind-toolbox/chapter-10-tax-incentives/community-wind-too

10 REFERENCES

Alaska Department of Commerce, Community and Economic Development, Division of Community and Regional Affairs, Current Community Conditions: Fuel Prices Across Alaska, July 2009.

Alaska Energy Authority. (2002–2008). *Statistical Report of the of the Power Cost Utilization Program.* http://www.akenergyauthority.org/PDF%20files/AEA_PCEFY07.pdf

Alaska Energy Authority. (2007). *AEA: PCE Program*. http://www.akenergyauthority.org/programspce.html

Alaska Energy Authority. (2009). *AEA: Wind System Operating in Alaska*. http://www.aidea.org/aea/programwindsystem.html

Alaska Energy Authority. (2010). Statistical Report of the Power Cost Equalization Program, Fiscal Year 2009. March.

American Wind Energy Association, Legislative Affairs website, May 2010, http://www.awea.org/legislative/#PTC

Bakisae, J.; Baring-Gould, I.; Jimenez, T.; Cameron, D. (2004). *Optimization and Regional Cost Analysis for Wind/Diesel Hybrid Systems in Remote Alaska.* Golden: NREL.

Baring-Gould, I.; Dabo, M. (2007). Technology, Performance, and Market Report of Wind-Diesel Applications for Remote and Island Communities. Presented at the European Wind Energy Conference, Marseille, France. NREL.

Baring-Gould, I.; Dabo, M. (2009). Technology, Performance, and Market Report of Wind-Diesel Applications for Remote and Island Communities. European Wind Energy Conference, March 16–19, 2009.

Bureau of Labor and Statistics. (2009). *Bureau of Labor and Statistics Data*. http://www.bls.gov/data/home.htm

Clausen, N.-E.; Bindner, H.; Frandsen, S.; Hansen, J.C.; Hansen, L.H.; Lundsager, P., (2001) Isolated systems with wind power. An implementation guideline. Risø-R-1257(EN) 61 p.

Darrow, K. (no date). 525 kW Wind/Diesel Hybrid CHP System. CHP Case Studies in the Pacific Northwest. U.S. Department of Energy: Energy Efficiency and Renewable Energy.

Drouilhet, S.; Shirazi, M. (2002). Wales, Alaska High-Penetration Wind/Diesel Hybrid Power System: Theory of Operation. 77 pp., NREL Report No. TP-500-31755.

Drouilhet, S.; Shirazi, M. (2002). Wales, Alaska High-Penetration Wind/diesel Hybrid Power System. Presented at Wind-Diesel Workshop: Anchorage, Alaska. September 23–24, 2002.

Energy Information Administration. (2008, June). *Energy Information Administration*. Retrieved August 8, 2008, from EIA – Annual Energy Outlook 2008 – Energy Demand: http://www.eia.doe.gov/oiaf/aeo/demand.html

Foster, M.A.; Fay, G; Lister, C. (2008). *Lake and Peninsula Borough Regional Energy Plan*. Prepared for Lake and Peninsula Borough, October 2008.

Hunter, R.; Elliot, G. (1994). *Wind/Diesel Systems*. Cambridge, UK: Cambridge University Press, 1994.

Kodiak Electric Association. (2010). KEA News Line, February 2010. http://www.kodiakelectric.com/keadocs/Feb_2010_News.pdf

Lundsager, P.; Bindner, H.; Clausen, N.-E.; Frandsen, S.; Hansen, L.H.; Hansen, J.C. (2001). Isolated systems with wind power. Main report. Risø-R-1256(EN) 70 p.

Lundsager, P.; Bindner, H. (1994). A simple, robust and reliable wind diesel concept for remote power supply. Renewable Energy 5 , 626-630

Lundsager, P.; Christensen, C.J. (1991). Main results from Risø's wind-diesel programme 1984-1990. Risø-M-2906(EN) 251 p

MAFA and Northern Economics, Inc. (2004). *Alaska Rural Energy Plan.* Prepared for the Alaska Energy Authority.

National Renewable Energy Laboratory. (2008). *HOMER – Analysis of micropower system options*. (NREL): https://analysis.nrel.gov/homer/

Shaffer, Budd, David Rode, & Steve R. Dean, 2009, Best Among Equals? Choosing Tax Incentives for Wind Projects, *Renewable Energy World North America Magazine*, November/December, Volume 1, Issue 2.

U.S. Department of Energy. (2008). *20% Wind Energy by 2030.* Washington, D.C.: U.S. Department of Energy.

U.S. Department of Energy. (2008). *Wind Powering America: Alaska Wind Resource Map*. Retrieved July 9, 2009, from Wind and Hydropower Technologies Program:

Wind Powering America
http://www.eere.energy.gov/windandhydro/windpoweringamerica/maps_template.asp?stateab=ak

U.S. Energy Information Administration. (2009). *Annual Energy Outlook, 2009*, November.

University of Alaska Fairbanks. (2008). Cooperative Extension Service Food Cost Survey, March 2008.

Wiser, Ryan, Mark Bolinger, and Galen Barbose, 2007, *Using the Federal Production Tax Credit to Build a Durable Market for Wind Power in the United States*, Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division, publication number 63583, November 2007.