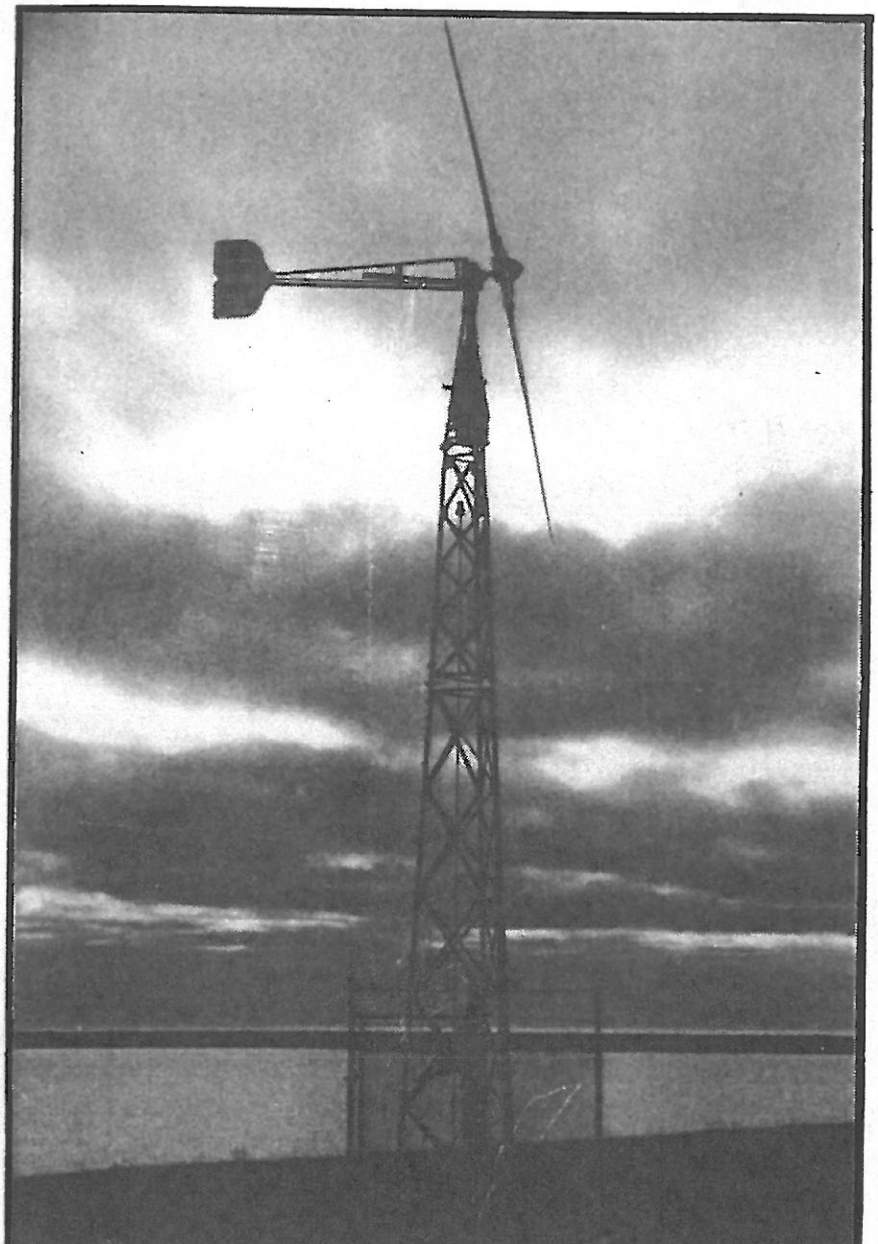
Alaska's Wind Energy Systems



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& Economic Development
Finance and Economics

Inventory and Economic Assessment

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ALASKA'S WIND ENERGY SYSTEMS:
Inventory and Economic Assessment

by

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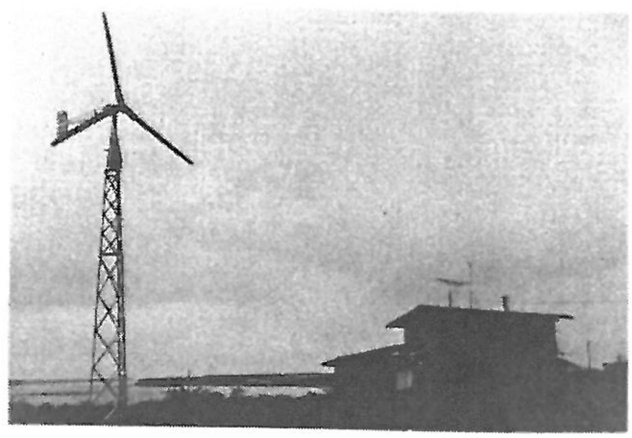
The economic analysis depends on information collected or reported in the last quarter of 1983: although it is the best information available on wind generation, it is recognized that implementing a dynamic system could improve the data base. Reference to a company or product does not imply a recommendation or approval. The contents of this report reflect the author's views rather than official policy of DCED.



WIND GENERATOR in Bristol Bay, adajacent to the Nak-uek River.

ALASKA'S WIND ENERGY SYSTEMS

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Executive Summary

A January, 1984 inventory of wind generators in Alaska with details on the location and technical characteristics of the machines--such as manufacturer, rated kilowatt (kW) capacity, and whether the machine was a battery charger or intertied with the local utility--has been completed. Information on the working status, model, and kilowatt-hour (kWh) production of each wind generator was verified by site visits or in a phone survey of wind generator owners, municipal officials, and equipment dealers. By 1984, there were at least 140 wind generators rated at .5 kW or larger that had been installed in Alaska, a sizeable increase over the 82 wind generators listed in a previous survey (Alaskan Wind Energy Handbook, March, 1981).

To put wind generator ratings (kW) for production into perspective, consider the kWh production from a 1 kW wind generator operating in Platinum. This wind generator has produced 2400 kWh in the period from January through October, 1983. This machine has achieved a capacity factor of 32.8 percent (2400 kWh divided by 1 kW times the product of 24 hours per day and 365 days per year). At 8760 kWh the Platinum machine would achieve a capacity factor of 100 percent. This machine is producing an average of 240 kWh per month. This exceeds the 1982 Alaska Village Electric Cooperative (AVEC) village average residential consumption of 184 kWh per month.

The kWh data base for this preliminary economic assessment was limited, in some cases containing only three months of meter readings and in one of the best cases not more than a cumulative reading at the end of 24 months. Estimates of annual kWh production were made for 24 of the 140 machines included in the inventory.

Many machines have gone through an initial period of adjustment after installation, which has affected their reliability and production. Increased production can subjectively be attributed to improved blade, tail and inverter designs. These design changes have also resulted in a decrease in down time. By contrast, a machine installed in Unalakleet in June, 1983 has been operating for 7 months with no down time.

UNALAKLEET #4-- Excellent winds and good planning results in high performance.

The economic assessment presented in this report is based on a comparison of the fuel and operation and maintenance costs of diesel-fired electrical generation to the capital, installation, and operation and maintenance costs of wind generators. The value of diesel-fired electrical generation is calculated by multiplying the kWh of production times the per kWh cost associated with diesel fuel and operation and maintenance. This is affected by the fuel conversion of the diesel generators in the community. The analysis excludes investment in the diesel generators because these are necessary to provide reliable capacity for meeting electrical loads on demand. If wind generators are able to demonstrate capacity factors of 30 percent or more, then there may be a basis for crediting them with a capacity value in addition to the fuel savings.

Economic analysis was used on the limited kWh data to estimate the per kWh cost and value of wind generator production. Three techniques were used to put the costs into perspective. These include 1) first year costs of the wind generator compared to the value of the diesel fuel savings in the first year, 2) perspectives on the year that wind generator costs will be lower than the value of the fuel and operation and maintenance savings from the diesel generators for several of the better producing wind machines, and 3) the present value of the diesel fuel savings over the 15 year production period of the wind generator.

The approach of including all of the costs of production and comparing them to the value of the diesel fuel and operation and maintenance savings is appropriate in evaluating utility investment in wind generators. However, from the wind generator owner's point of view, the production from the wind generator displaces kWh that the owner would normally buy from the utility at residential or commercial rates--rates considerably higher than the cents per kWh estimated from the utility "fuel savings". For example, the Alaska Village Electrical Cooperative (AVEC) rate is 37.2 cents per kWh for residential customers.

The results of the present value analysis indicate that there are places where the best wind generators can lower the cost of electricity over the next 15 years--both at their locations and possibly at other sites if the experience proves transferable. The economics for Naknek, Unalakleet, and Sand Point are favorable--with improvements in kWh production the wind generators can generate enough power to supplement existing diesel-fired generation at competitive prices. Gambell and Hooper Bay also appear to have the favorable conditions of high diesel fuel costs and existence of good wind regimes. Increases in production are necessary to improve the economics of the four machines at these two locations. Bethel, Kodiak, and Nome appear to have less potential than the locations noted above. There are many other places in rural Alaska that have good wind regimes and high diesel fuel prices, where feasibility studies may show wind generation to be one of the best alternatives based on the present value of costs to meet electrical loads.

A. Introduction

Electrical energy costs in rural Alaska are very high when compared with Juneau, Fairbanks, and Anchorage. There are numerous reasons. First, it is expensive to supply electricity for small demands. It is also difficult to match generator size to loads. To provide reliable backup often requires a standby generator which can carry the load in the event of a major mechanical failure. Therefore, there are large percentages of idle equipment. A single generator must frequently be run at inefficient loadings. The cost of buying and installing a generator in a rural community is expensive, as is operation and maintenance. Over the years diesel generators have proven to be a reliable source of electricity and when oil was relatively inexpensive they comprised virtually all of the generation capacity in rural Alaska.

Transportation charges from the regional centers of distribution, like Dutch Harbor, Nome, Barrow, Bethel, Kotzebue, and Kodiak, are significant--for example, it costs the utility about 43 cents a gallon to transport diesel fuel from Nome to Gambell. Total diesel fuel costs to rural utilities frequently exceed $1.50 per gallon--as is the case in over one-half of Alaska Village Electric Cooperative's villages in 1983--whereas the costs to individuals for heating oil often exceed $2 per gallon.

In recent years, the abrupt increase in oil prices, coupled with high transportation costs of bringing oil to communities, has caused the price of electricity to rise substantially. In 1979, AVEC's average diesel fuel price was $.97 per gallon; it was $1.56 in 1983.

The State of Alaska has addressed the problem in several ways. First, through the Energy Program for Alaska, it has implemented alternative energy projects, waste heat utilization projects, interties, and hydroelectric projects. Second, there have been a variety of energy conservation projects, including weatherization, audits and grants, and retrofits of institutional buildings. Third, it has subsidized electricity costs through the Power Cost Assistance program. Fourth, it has looked for economically and technically viable alternatives to replace oil used in electric generation.

There are alternative sources of energy for electric generation that are renewable, indigenous, and appear to be compatible with cultural values and socioeconomic preferences of residents. Wind is one such resource. Interest continues to grow because in many cases it may be the best alternative to diesel-fired electric generation, especially where microhydroelectric or major regional projects are not feasible. Wind generation continues to evolve as a practical technology, although there have been numerous challenges to overcome. The commentary from a science teacher at Hooper Bay was typical of the nature of this challenge in some communities: "Everything had to be done by hand, and because it was a learning experience, almost everything had to to be done twice before it was correct."

In the conclusion, there is a brief discussion of the implications of the findings, a discussion of steps that could be taken to improve the performance of and knowledge about WECS, and a discussion of options for future action. The discussion covers only the experiences with wind generators smaller than 20 kW, as the viability of larger machines in Alaska has not been demonstrated to date. Further details on sensitivity analyses, the data base used in the economic assessment, and the status of individual wind installations are available from DCED.

B. Inventory

There are 140 wind generators included in the January, 1984 wind generator inventory (see the Appendix). There are about a dozen wind generators which are smaller than .5 kW and some in remote areas of Alaska that are not listed in the inventory. This information is dynamic, so that the working status may be expected to change according to machine performance and conditions at the site. Local knowledge is invaluable in assessing the experience at a specific installation.

Although there are installations throughout the State, Southwestern Alaska has the most wind generators (30) that are in operation, planned, or were previously installed. The inventory contains at least 20 wind generators over 10 kW that are known to be working on a consistent basis: there are another 30 working wind generators with rated capacities of from 1 to 4 kW. There are wind generators in all regions of the State, as shown below:

Region	Number of Wind Generators
Northern (Arctic)	• 5
Northwest	• 27
Western	• 19
Southcentral	• 23
Southwestern	• 30
Southeastern	• 11
Interior	• 9
Aleutians	• 16
Total	140

THREE 10kW WIND generators in use at Unalakleet are barely visible behind the fish drying rack.

C. Methodology

Estimates of annual kWh production were made for 24 of the 140 machines included in the inventory. Of the 24 wind generators, all data was based on records for 3 to 24 months of operation. Utility managers were contacted to update information on diesel fuel costs and fuel efficiency of diesel generators provided by the Alaska Power Authority. Information for 15 wind generators at nine locations was validated on site visits. The 15 machines are identified in Appendix B, which also lists the months of data used to estimate total annual kWh production.

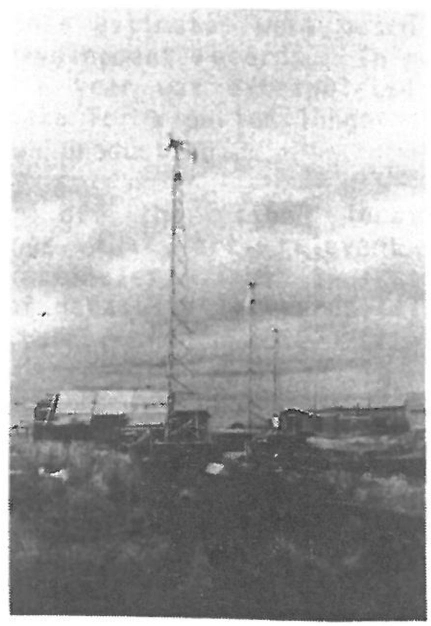
Site visits were planned to collect kWh data and validate information on the cost of generating electricity from existing diesel generators. Eleven of the 15 machines were working at the nine locations: the locations are Bethel, Nome, Gambell, Hooper Bay, Chevak, Kodiak, Naknek, King Salmon, and Unalakleet. These communities have several things in common: the bulk of their electricity is generated by diesel-fired generators, there is an adequate to excellent wind regime for the machines, and the communities have had individuals who were willing to tackle the challenge of making the wind generators work.

The following methodology was used in evaluating the economics of wind generators. The cost of diesel-fired electrical generation, using projected diesel fuel costs in 1984 for the analysis, is compared to the first-year cost of generating the same number of kWh with a wind generator. The results of the "First-Year Case" are summarized in Table 1 in subsection 1 of the Economic Analysis section. In all cases the 1984 cost per kWh of diesel fuel is lower than the cost per kWh calculated using the capital, installation and estimated operation and maintenance costs for the wind generator. This is typical of capital-intensive technologies, such as wind generators and hydroelectric projects. In both cases, the initial investment is traded against the value of the fuel costs incurred by using diesel generators.

This comparison is followed in the economic analysis, subsection 2., by calculations showing the crossover year when diesel fuel and operation and maintenance costs are greater than the wind costs on a per kWh basis. For the crossover analysis oil is inflated at 6% per year (or 0% in real terms assuming a 6% inflation rate) and 8.5% per year. Operation and maintenance costs for both diesel generators and WECS are inflated at 6%. The recovery of the capital and installation costs of WECS assumes a principal and interest payment based on 10 percent interest.

In the final part of the Economic Analysis, as summarized in Table 3 in the "Life-Cycle Cases", the present value of the diesel fuel and operation and maintenance costs over 15 years is compared to the present value of total costs for the wind generation system: the total wind generation costs include the capital, installation, and operation and maintenance costs. Both alternatives produce the same power output. The table shows the results based on a 10 percent interest rate (6% inflation plus a 4% real discount rate). Costs are inflated at the inflation rate and then discounted back to 1984 $ using a 4 percent real discount rate. For example, fuel and operation and maintenance costs are inflated at 6 percent (0% in real terms) and then discounted at 10 percent (4% in real terms).

As the economic analysis is very sensitive to changes in oil prices and kWh production from the wind generators, it should be interpreted as an initial forecast rather than as an evaluation based on extensive reporting and analysis. The result is that the economic viability of WECS may be understated. It would be useful to update these estimates based on new information from wind generator owners.



THREE WIND MACHINES are part of utility demonstration project in Unalakleet.

D. Economic Analysis

1. "First-Year" Case

The sites chosen for the economic analysis all have working wind generators. Unalakleet has the largest number of working machines (4) in this assessment; whereas Sand Point and Naknek have two machines which rival Unalakleet for the location with the best performing wind generator in Alaska for which kWh data is available.

This part of the economic evaluation of production from the wind generators compares the first-year diesel fuel costs to the capital, installation, and operation and maintenance costs of wind generators. The value of diesel-fired electrical generation is calculated by multiplying the kWh of production times the per kWh cost associated with diesel fuel and operation and maintenance. The analysis excludes investment in the diesel generators because these are necessary to provide reliable capacity for meeting electrical loads on demand. Findings are presented in Table 1.

Of the 24 working wind generators for which annual kWh data is available, there are four different manufacturers' machines. The analysis includes one Bergey, four Enertechs, one Grumman and eighteen Jacobs machines. The 10 kW Jacobs is the most common working wind generator in Alaska. The kWh listed in Table 1 is estimated from actual readings taken off the mastermind of the wind generator during the site visits--or these estimates were based on owner or Division of Energy and Power Development records. In many cases, data for a period of less than a year was extrapolated to calculate an annual figure; in others, data for a period longer than a year was averaged to estimate annual kWh production.

Appendix B contains indicators of the site location characteristics and machine performance that are relevant to interpreting the annual kWh production estimates. These indicators include average wind speed, the months of data used in extrapolating or averaging annual kWh data, working status, and capacity factors. Capacity factors vary for the wind generators included in the economic analysis. The capacity factors for Jacobs units ranges from 1 to 19 percent, whereas the Enertech units have experienced capacity factors of 8 to 34 percent. The 1 kW Bergey has had a capacity factor of 32 percent. The Grumman 20 kW machine has had a 12 percent capacity factor.

Annual production for the 10 kW Jacobs machines varies by location and reliability of the equipment. It includes a low of just over 1200 kWh per year in Ketchikan. At the high end of the range are Naknek at 16,900 kWh per year (based on 24 months of operation), 17,020 kWh per year at the Sand Point location (based on 12 months of operating experience and including a large amount of down time), Unalakleet #2 at 16,520 kWh per year (based on 8 months of data) and Unalakleet #4 at 22,780 kWh per year (extrapolated from 6 months of operation from July through December, 1983).

A reference case is valuable source for projecting costs at different locations, especially when one examines the range of capital and installation costs. Reference case costs for wind generators are based on the four machines installed at Unalakleet. The reference case was identified based on the following criteria: the location should have more than one machine installed and operating, both private and public investments should be evident, and the wind machines should be producing at least 15,000 kWh per year. The private capital and installation cost (in 1984 dollars) for a 10 kW Jacobs wind generator and 60'-80' Rohn tower is $31,500. The cost (in 1984 dollars) for a 10 kW wind generator may be increased to $41,400 if the site requires additional interconnection equipment. These documented costs exclude siting and planning costs, such as installing and reading an anemometer. Operation and maintenance costs were estimated at $250 or $1200 a year based on actual experience, again at Unalakleet.

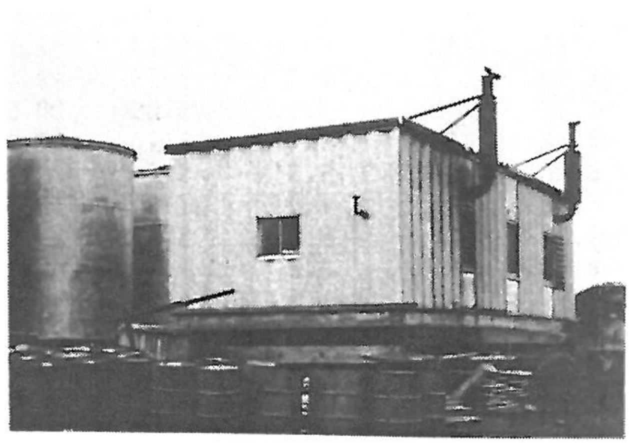
The kWh production figures in Table 1 include significant periods of time when the machines were out of operation. This implies that the annual kWh estimates are probably not overstated. In some cases, one may expect significant improvements in performance now that some of the previous problems affecting the blades, inverters, governors, and feathering tails have been overcome through design changes. For example, in Unalakleet the production from the best producer of the three machines owned by Unalakleet Valley Electric Cooperative surpassed 2900 kWh in November of 1983. This is up 50 percent over the comparable two-month period last year. If this becomes a trend, then the benchmark calculations shown in Table 1 will prove to substantially underestimate the benefits obtainable from wind generation over the 15 year analysis period.

The wind generator costs in Table 1 may also be overstating per kWh costs if the kWh production exceeds the estimates in Table 1. A good case in point is Unalakleet #2, a machine estimated to produce 16,520 kWh per year. At a 10 percent interest rate, the capital and interest charges on Unalakleet #2 are equivalent to an annual payment of $4950 a year for 15 years-- equivalent to 30 cents per kWh. This falls from 30 to 25 cents per kWh if production increase to 20,000 kWh per year. It falls further, to 21.7 cents per kWh, for production of 22,780 kWh per year.

Diesel fuel delivered in bulk to the utility is estimated to cost $.90 to $2.05 per gallon in December, 1984 at the 17 locations with 24 wind generators that have been included in the following economic analysis. The diesel fuel prices for Dec., 1984 are shown in Table 1. Diesel fuel prices for Dec., 1984 were projected to be 8.5 % higher than the price in Dec., 1981. For example, AVEC's "average" diesel fuel cost per gallon was $1.61 in Dec., 1981: the forecast of Dec. 1984 prices at 6% over this average results in an average fuel price of $1.70 per gallon. An 8.5 % fuel price escalation over the Dec., 1981 price yields an estimate of $1.74 per gallon for the average fuel price. The historical price has shown some volatility, illustrated by the July, 1981 price for AVEC of $1.33 per gallon before the increase later that year to $1.60 per gallon.

AVEC's average fuel cost for diesel generation in 1982 was 19.2 cents per kWh--indicating that many of AVEC's 48 villages probably have higher fuel costs than the average of those shown in Table 1. According to Alaska Power Authority calculations, AVEC may receive 22.4 cents per kWh in FY 1985 for power cost assistance to help defray the burden these high fuel costs place on rural residents. There is a potential to reduce this cost, especially over a multi-year period, by improving generator efficiencies and implementing cost effective alternative energy projects.

Wind generators are likely to be expensive to install in remote communities with high diesel fuel prices. However, if the kWh production and reliability of the most successsful wind generator projects could be replicated in these locations, wind could supplement the diesel-fired electrical generation and lower total electrical generation costs. Individual diesel generators serving a single residence are even more expensive than larger community generators; thus a comparison of isolated wind costs may yield some interesting results.



DIESEL GENERATOR house and bulk fuel storage at Gambell.

Table 1
Diesel Fuel Price, "First-Year Case"
Comparing Diesel to the Total Cost Per KWh of the Wind System

Project	WECS kWh per yr (1)	Diesel fuel $/gal (2)	Fuel ¢/kWh in 1984 (3)	Diesel Fuel & Operation& Maint. ¢/kWh (4)	WECS Total Cost Cents per kWh: O+M (5)	WECS Total Cost Cents per kWh: Capital +Instlln (6)	WECS Total Cost Cents per kWh: Capital Installn and O+M (7)
GAMBELL	4120	$1.50	15.8	21.8	29	103.3	132.3
GAMBELL	9940	1.50	15.8	21.8	12	42.8	52.8
GAMBELL	13800	1.50	15.8	21.8	9	30.8	39.8
KIVALINA	4800	1.51	18.9	24.9	5*	39.8	44.8
NOME	11970	1.28	9.7	12.7	2*	31.5	33.5
UNALAKLEET#1	4000	1.37	12.1	15.1	30	123.7	153.7
UNALAKLEET#2	16520	1.37	12.1	15.1	7	30.0	37.0
UNALAKLEET#3	5460	1.37	12.1	15.1	22	90.6	112.6
UNALAKLEET#4	22780	1.37	12.1	15.1	1*	16.5	17.5
BETHEL	1350	1.26	10.2	13.2	19*	58.4	77.4
BETHEL	4400	1.26	10.2	13.2	27	73.9	100.9
CHEVAK	5400	1.60	17.8	23.8	5*	56.2	61.2
HOOPER BAY	10840	1.58	13.2	19.2	2*	29.0	31.0
PILOT STATION	7200	1.69	17.4	23.4	17	68.7	85.7
PLATINUM	2875	2.00	20.0	26.0	9*	56.1	65.1
PALMER	6800	1.00	7.7	10.7	4*	34.6	38.6
KING SALMON	9290	1.28	9.2	12.2	3*	39.8	42.8
KODIAK	7320	0.91	7.1	10.1	3*	32.3	35.3
NAKNEK	16900	1.28	9.2	12.2	1*	18.1	19.1
KETCHIKAN	1220	0.90	6.4	8.4	20*	247.9	267.9
KETCHIKAN	2600	0.90	6.4	8.4	10*	116.3	126.3
SKAGWAY	10370	0.94	7.8	10.8	12	118.0	130.0
NELSON LAGOON	21560	2.05	22.8	28.8	8	58.8	66.8
SAND POINT	17020	1.05	10.5	16.5	7	18.5	25.5

(1) WECS kWh per year was extrapolated or averaged. Note caveats in paragraphs two and three of subsection 1., section D. Economic Analysis.
(2) Diesel fuel $/gal.--Dec. 1984 price, delivered to the utility.
(3) Fuel ¢/kWh in 1984 is calculated by dividing the diesel fuel $/gal in column #2 by the kWh per gallon (column 3, Table 3 herein).
(4) Estimated by allocating AVEC's 1982 operation and maintenance costs over total kWh sold. Transmission and distribution costs were subtracted from the results. Some of the O+M costs for regional centers were derived from Rural Electrification Administration data forms (REA form 12f).
(5) *Wind operation and maintenance (O+M) costs were estimated at $250 per year for wind generators that had experienced very high reliability or had individuals on-site that did the O+M work (designated by a * above). High O+M costs were estimated at $1200 per year for those without an *.
(6) Data on the capital and installation costs of wind generators was escalated to January, 1984 $ using the Anchorage Consumer Price Index. There are some problems with this index (ISER Research Summary No.14, Jan., 1984.
(7) The capital and installation cost was amortized over a 15 year period using a 10 percent interest rate (or "cost of capital"). Actual costs are different than these costs, since the machines were installed before 1984.

2. "Crossover-Year" Calculations

The graphs of the cost of wind generation show a comparison of the cost of wind generation, calculated on a per kWh basis, compared to the per kWh value of the diesel fuel and operation and maintenance savings. The comparisons show that one of the wind generators at Unalakleet and the machines at Naknek and Sand Point are producing power at a rate that would make them attractive compared to diesel generation at or above 20 cents per kWh in 1984.

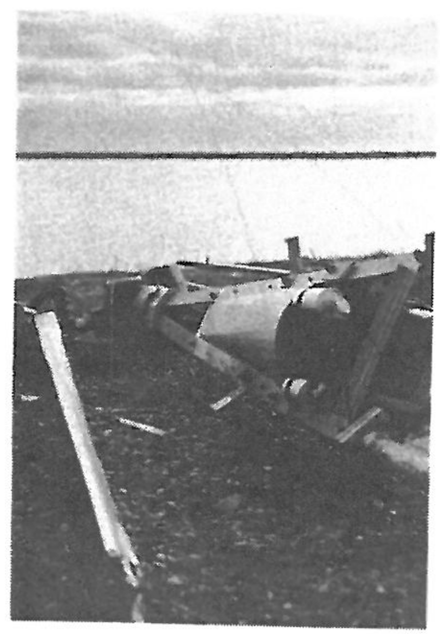
Table 2 shows the crossover year of projected diesel fuel and operation and maintenance costs and wind costs for ten of the wind generators. It is interesting to note that Unalakleet #2, one of the "reference case" wind generators and the machine with one of the best performances so far, does not have the earliest crossover point. This occurs because diesel fuel costs are greater in many of the other communities. While wind generator units in Nome and Kodiak are moderately good producers, the crossover analysis is not favorable for wind because of the relatively low diesel fuel prices. This may not always be the case in the same geographic region, especially when there is no local utility. Also, the crossover analysis indicates that if the Sand Point wind generator had the same estimate for operation and maintenance costs as the Naknek wind generator, its crossover point would improve considerably.

Table 2
Number of Years for Wind-Diesel Crossover, on a Per kWh Basis

	Diesel Fuel Cost with Diesel Operation and Maintenance Costs	
Project	Oil Inflated at 6%	Oil Inflated at 8.5%
Chevak	none	14
Hooper Bay	10	7
Naknek	9	7
Sand Point	12	8
Unalakleet #2	none	15
Unalakleet #4	3	3
Platinum	none	none
Kodiak	none	none
Nome	none	14
Gambell #3	14	11

Figure 1 displays the basic relationship between wind and diesel fuel and operation and maintenance costs graphically. The crossover points in Table 2 are shown at the intersections (scales vary; points are rough approximations). A significant increase in the kWh production of wind generators would lead to a downward shift in the wind curves, since they are very sensitive to this factor. On the other hand, tower or equipment failures resulting in destruction or dismantling of the wind generator would result in much higher costs than those shown. The likely shift in the wind generator cost curve, based on actual experience, demonstrates the need to develop better data for projecting kWh production.

The average fuel costs for AVEC villages illustrate the fact that there are many places in rural Alaska with diesel-fired electrical generation costs greater than those at communities portrayed in this report. However, this average comparison indicates a potential for wind generation based solely on diesel fuel costs--in order to present results in terms of project feasibility, the wind regime and wind generator costs need to be evaluated for individual villages at specific sites.



TOWER FAILURE in Gambell results in a shambles.

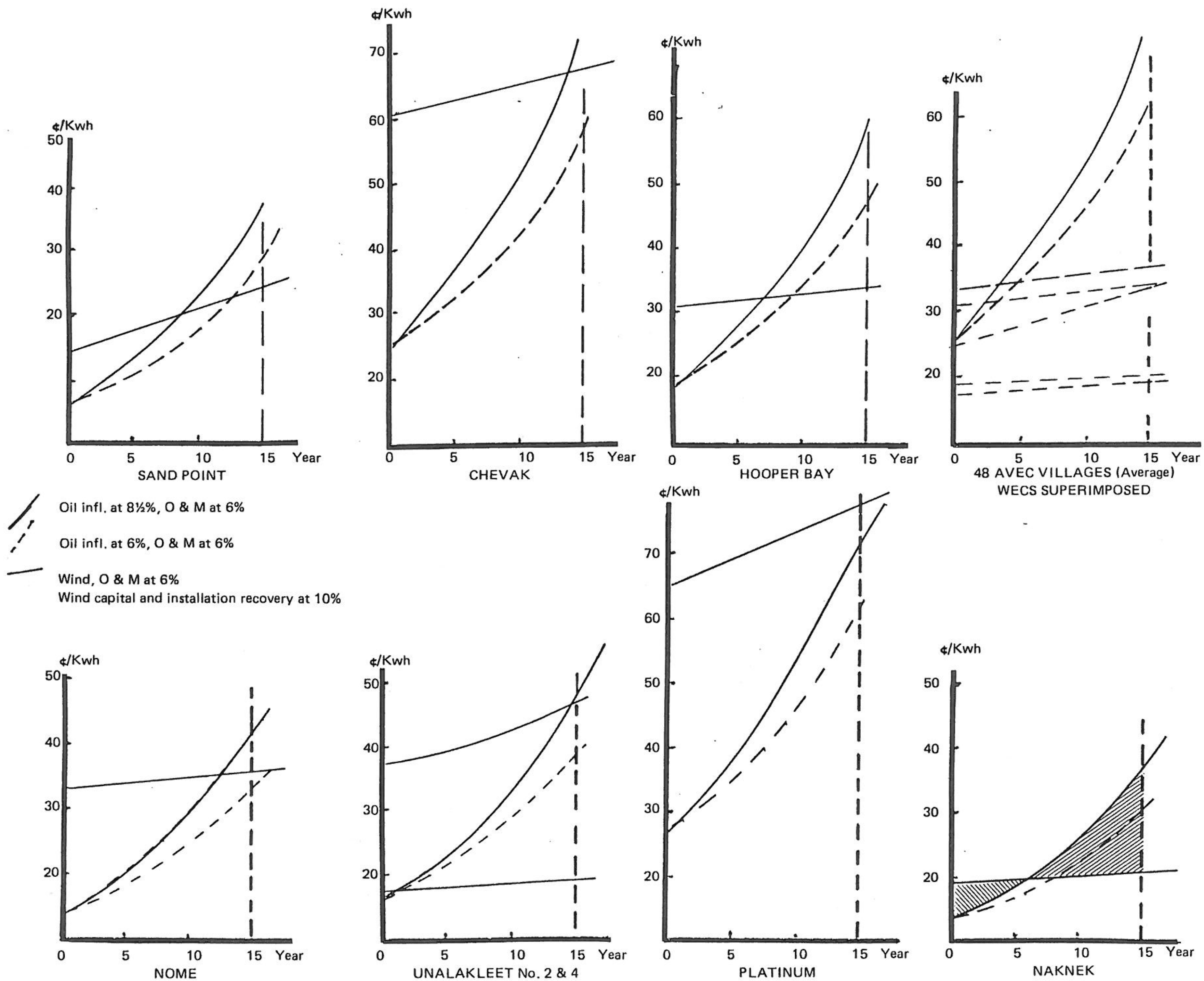


Figure 1. Crossover Analysis (Diesel Fuel and Wind)

3. "Life-Cycle Cases"

The present value of the fuel savings must account for the fact that a dollar benefit received or cost incurred in the future is not considered to have the same value as a dollar that is invested today. The present value approach allows the decision maker to compare projects, with costs or benefits occurring at different times in the future, on a comparable basis. This is especially useful when projects will provide identical benefits. In order to make this analysis as useful as possible to the Alaska Power Authority, which has the major responsibility for conducting reconnaissance and feasibility studies for electrical energy in Alaska, the project evaluation criteria used here are almost identical to those being considered by APA analysts for the 1984 fiscal year. The economic analysis criteria used in this analysis are:

inflation	• 6%
real discount rate	• 4%
diesel fuel escalation above inflation	• 0 to 2.5%
implied opportunity cost of capital	• 10 percent

Also, in this economic assessment the present values of wind generators are "inflation free"--that is, it does not escalate todays dollars ($1984) to reflect general changes in the price level for goods and services produced in the economy. This is identical to the Alaska Power Authority project evaluation procedure. The analysis focuses on price changes relative to the general increase in prices due to inflation.

Sensitivity analysis is an appropriate method to use to evaluate the effect of changing major assumptions, such as the kWh produced, real escalation of fuel prices, and real discount rate. A 25 percent increase in kWh production over the baseline, no real diesel fuel price increase over and above inflation, and a 3.5 percent real discount rate would be one interesting case to evaluate for specific installations. As another example, consider that if production from the Naknek wind machine increases 20 percent over that shown in Tables 1 and 3 and diesel fuel increases at a 6 percent rate instead of the forecasted 8.5% rate (showing no real price escalation), then the present value of diesel fuel (column 3 in Table 3) decreases from $20,820 to $20,770, less than a one percent change.

Table 3 lists the present value of the diesel fuel savings over the 15 year period. This assumes that the historical kWh production for each wind generator would be produced instead by running the existing diesels--the value of the fuel savings is calculated using the diesel generator efficiency (kWh per gallon) shown in this table and the cents per kWh for fuel and operation and maintenance costs shown in Table 1.

Qualitative factors are also important in evaluating wind generation. Wind generators are the only practical alternative in many villages without hydroelectric generation potential. Issues such as building bulk fuel storage, financing fuel deliveries, allocating operation and maintenance costs, and replacing diesel generators have not been explicitly addressed in this analysis. It is reasonable to assume some of these costs could be reduced, perhaps substantially, if reliable capacity were available to meet electrical loads at wind generator sites. It also appears that transmission losses and the effect of the wind system on diesel generator efficiency deserve attention--although this is perhaps best addressed in a testing facility under controlled measurement conditions. Experience has shown these considerations can be met in a manner that allows the wind generators to effectively function as part of the electrical generation system.

The economic analysis includes a 2 to 6¢ credit for operation and maintenance cost savings associated with an ability to defer these costs because the diesel would not have to meet the load at the wind generator site--over 200,000 kWh of electricity demand in 15 years at 13,333 kWh of production per year. These costs are very dependent on site-specific characteristics, such as the size of the diesel engines and generators. The credit for rural villages, estimated at an average of 6 cents per kWh, is approximately correct, although it does not represent the costs at a particular or even typical village.

One of the aspects of wind generation not addressed in this analysis is the issue of whether there should be a capacity credit for wind. Achieving high kWh production relative to the machines rated capacity depends on the average wind speed at the site. The capacity factors of the 10 kW wind generators at Sand Point, Naknek, and Unalakleet (19, 15, and 19 percent) compare favorably with diesel generators in villages which have 100 percent redundancy in the diesel capacity. The issue of the capacity value of WECS deserves further consideration, especially if data can be collected and analyzed for an on-line Alaskan situation using various load conditions.

Diesel generators in rural Alaska can have total plant capacity factors of 10 to 20 percent due to the need for redundancy in generation capacity and the need to respond to emergency conditions or a mismatch between generator sizes and loads. This indicates that where there is a reliable wind regime, there may be a capacity value credit for the wind generators. Appendix B has statistics on average wind speed and capacity factors for the 24 wind generators evaluated in the economic analysis.

Table 3
Present Value of Diesel Fuel and O&M Savings
versus
Present Value of Costs of Power Generated from Existing Wind Machines

Project	WECS kWh per year (1)	Diesel Present Values: Operatn & Maint. (2)	Fuel savings (3)	Fuel + O&M (4)	kWh per gal. (5)	Wind Generator Total Present Value of Costs Range includes low and high wind O&M (6)		
GAMBELL	4120	$2750	$8700	$11,450	9.5	$38,380	to	$48,940
GAMBELL	9940	6630	21000	27,630	9.5	$38,380	to	$48,940
GAMBELL	13800	9210	29150	38,360	9.5	$38,380	to	$48,940
KIVALINA	4800	3200	12120	15,320	8.0	$18,780	to	$29,340
NOME	11970	5320	15530	20,850	13.2	$34,280	to	$44,840
UNALAKLEET#1	4000	1780	6490	8,270	11.3	$44,180	to	$54,740
UNALAKLEET#2	16520	7350	26800	34,150	11.3	$44,180	to	$54,740
UNALAKLEET#3	5460	2430	8860	11,290	11.3	$44,180	to	$54,740
UNALAKLEET#4	22780	5950	36950	42,900	11.3	$34,280	to	$44,840
BETHEL	1350	600	1850	2,450	12.3	$9,380	to	$19,940
BETHEL	4400	1960	6030	7,990	12.3	$29,980	to	$40,540
CHEVAK	5400	3600	12850	16,450	9.0	$28,180	to	$38,740
HOOPER BAY	10840	7230	19100	26,330	12.0	$29,080	to	$39,640
PILOT STATION	7200	4800	16790	21,590	9.7	$44,180	to	$54,740
PLATINUM	2875	1920	7690	9,610	10.0	$16,280	to	$26,840
PALMER	6800	3020	7000	10,020	13.0	$22,480	to	$33,040
KING SALMON	9290	4130	11450	15,580	13.9	$33,680	to	$44,240
KODIAK	7320	3250	6910	10,160	12.9	$22,580	to	$33,140
NAKNEK	16900	7520	20820	28,340	13.9	$28,380	to	$38,940
KETCHIKAN	1220	270	1050	1,320	14.0	$28,080	to	$38,640
KETCHIKAN	2600	580	2240	2,820	14.0	$28,080	to	$38,640
SKAGWAY	10370	4610	10870	15,480	12.0	$105,180	to	$115,740
NELSON LAGOON	21560	14380	65710	80,090	9.0	$125,400	to	$144,700
SAND POINT	17020	11350	23910	35,260	10.0	$29,080	to	$39,640

(1) WECS kWh per year was extrapolated or averaged. Note caveats in paragraphs two and three of subsection 1., section D. Economic Analysis.
(2) See Table 1, columns 3 and 4. Subtract the fuel cost component from the total on the right ("with O&M costs") to obtain diesel O&M. In general, AVEC village costs are set at 6¢ per kWh and Unalakleet, Kodiak, and other regional centers are estimated at 2¢-4¢ per kWh unless specific information was available (REA form 12f). Transmission and distribution O&M was excluded.
(3) Fuel savings were calculated based on multiplying the WECS kWh per year times the diesel fuel $/gal (Table 1, column 2) divided by the kWh per gal. shown above. These 1984 diesel fuel costs were then escalated at 8.5 percent per year for 15 years. The total at the end of each year was discounted back to Jan. 1984 dollars using a 10 percent discount rate. This procedure has the same effect as escalating diesel fuel costs at 2.5 percent real cost escalation over the assumed 6% inflation, and discounting to 1984 $ using a real discount rate of 4%.
(4) Column 2 plus column 3.
(5) kWh per gal. was provided by the Alaska Power Authority.
(6) The estimated capital and installation costs (1984 $), can be derived by subtracting $2780 from the lower end of the cost range for wind generators.

E. Conclusion and Recommendations

The economic assessment concludes that there are places where the best wind generators (those at Sand Point, Naknek and Unalakleet) could lower the cost of electricity over the next 15 years. At Sand Point and Naknek, changing the present value of diesel costs in Table 3 based on higher production levels--say to 20,000 kWh per year--would increase the present value of the diesel fuel and operation and maintenance savings over and above the high end of the total wind generator costs.

Sites with excellent potential based on analysis of this data include Gambell, Unalakleet, Hooper Bay, Sand Point, Platinum, Chevak, and Naknek. There are many other places in rural Alaska with good wind regimes and high diesel fuel costs.

One of the "reference case" wind generators, the Unalakleet #4 wind generator, is producing power at 17.5 to 21.5 cents per kWh. If this experience could be duplicated at Platinum, then the project would be cost effective based on constant diesel fuel prices--and even more attractive with escalating diesel fuel prices. However, it is prudent to check this type of initial analysis in feasibility studies evaluating specific sites, wind generation capital, installation, and interconnection costs, local interest and skills, and financing. In the specific case shown in Table 3, the high initial capital and installation cost for the 1 kW wind generator make it somewhat less attractive than a 10 kW machine at the same site, all other things being equal.

The economic assessment herein suggests that electricity generated by wind generators can displace significant quantities of diesel fuel, providing there is a management emphasis on proper siting and installation. The contribution from the 24 wind generators analyzed in this report amounted to 209,125 kWh in 1983. This is small relative to Alaska Village Electrical Cooperative's total diesel-fired generation in 1982 of 26,121,300 kWh to serve 48 villages: however, the total could reach 1,000,000 kWh a year by 2000 if four 10 kW machines were installed each year during the next 15 years. This would require an investment of approximately $3.0 million in 1984 dollars.

Recommendations concerning advancing wind generator technology in Alaska include developing a program context for wind, building a testing facility or demonstration windfarm, and consolidating technical knowledge of wind generator technology within a division of state government. A programmatic context is needed for wind because there have been many unsuccessful projects built in communites where grants were transferred through the Dept. of

Administration or technical problems were encountered (some of these were Division of Energy and Power Development wind demonstration projects and others were DEPD Appropriate Technology grants). It is more efficient for one state agency to acquire expertise and technical assistance capability than to have wind generator owners and utility engineers addressing all technical problems individually. A windfarm or testing facility could take advantage of economies of scale in machine purchase and operation and maintenance. Production from wind generators could be integrated into the existing diesel-fired electrical generation, and load management options could be tested for the diesel-wind electrical generation system.

Good planning and management are important characteristics of the most successful projects in Alaska. An organized program, similar to the Waste Heat Utilization Program administered by the Alaska Power Authority, has promise as a means of successfully implementing wind generation projects based on economic and siting criteria.

The future of wind generators as a viable alternative to oil in rural Alaska depends on knowledge about the technology in Alaska. The economics could be improved through proper site planning and technical analysis, continuing an on-going monitoring program, and establishing a technical assistance and information program. A well-designed monitoring program would also resolve many of the deficiencies in the kWh production data base. The technology has not been assessed in a manner that technical advances and experience--particularly in Hawaii and California--will result in better Alaskan projects. There are more than 117 megawatts (ie. 1000 kW = 1 megawatt) of capacity in the U.S. according to "Alternative Sources of Energy", consisting of about 1900 systems. Alaska has about 50 projects of 350 kW capacity in working wind generators listed in the inventory. Knowledge of the extensive applications of the technology in Hawaii and California can add insight to decision making and applications in Alaska, provided close attention is paid to Alaskan weather and other special conditions (such as cost, construction techniques, air and barge shipment, and soil conditions) in transfering the most successful applications.

Completion of a technology assessment is a necessary task before full implemention of a testing facility or construction of a wind farm. A testing facility may prove essential to improving Alaskan wind generator reliability, reducing maintenance costs, and addressing technical issues such as capacity credits and voltage levels associated with wind generator production. A testing facility would also lead to improvements in the economics of planned wind generator installations by allowing better estimates of cost and performance.

This report completes an initial step in developing a programmatic context for wind generation. This approach focuses on consolidating technical siting and economic evaluation capabilities. Technical improvements in wind generator technology should result in projects that can lower electrical generation costs in rural communities which have some of the highest electricity prices in the United States.

References

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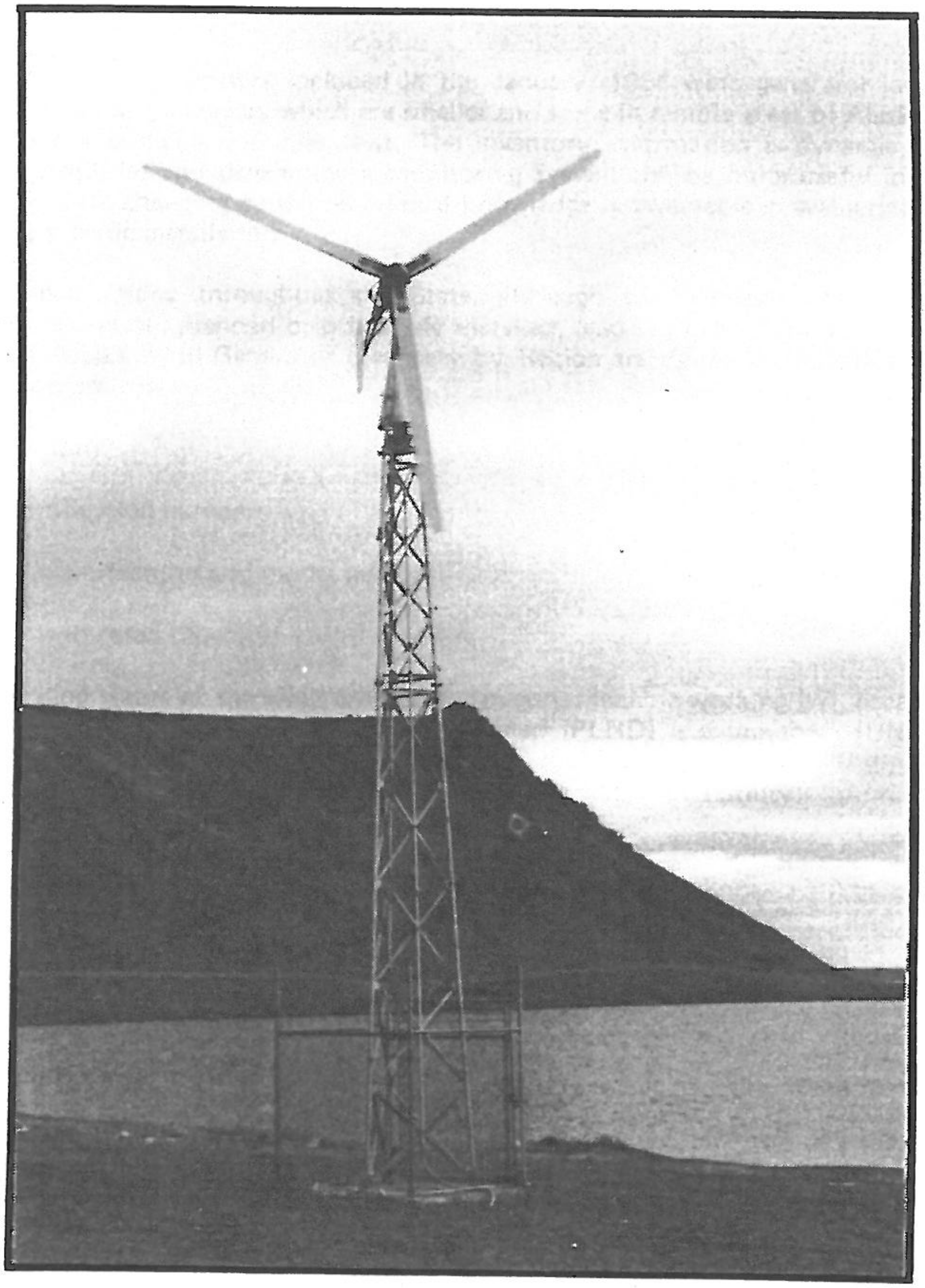
Appendix A
Inventory of Wind Generators

Inventory of
WIND GENERATORS in Alaska



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January 1984

APPENDIX A

INVENTORY OF WIND GENERATORS IN ALASKA

There are 140 wind generators included in the January, 1984 wind generator inventory. There are additional generators which are smaller and some in remote areas of Alaska where owners were not available for interviews. The inventory information is dynamic, so that computer capabilities and developing a monitoring system can be quite useful in making decisions based on changing conditions. Local knowledge is invaluable in evaluating the experience at a specific installation.

There are installations throughout the State, although southwestern Alaska with 29 machines in operation, planned or previously installed, leads all other regions. Included in the attached Alaska Wind Generator Inventory by Region are the following characteristics of the wind generators:

- location;
- identification number;
- the manufacturer and model number;
- kilowatt rated capacity;
- working status of the wind generator: categories include working (W), occasionally working (OW), not working (NW), planned (PLND) and unknown (UNK); and
- whether the machine is a battery charger or intertied with a utility.

KEY

W	= Working
NW	= Not Working or Dismantled
OW	= Occasionally Working
PLND	= Planned
UNK	= Unknown
N/A	= Not Applicable or Not Available
UI	= Utility Intertied
BC	= Battery Charger

ALASKAN WIND GENERATOR INVENTORY
BY REGION

ID	Location	Manufacturer and Model	Size in kw	Utility Intertied or Battery Charger	Status Code
		NORTHERN (ARCTIC) REGION			
1	Barrow	Enertech 1800	1.8	UI	W
2	Barrow	Enertech 4000	4	UI	W
3	Kaktovik	Enertech 1800	1.8	UI	W
4	Kaktovik	Dunlite	2	UI	NW
5	Point Lay	Enertech 4000	4	UI	NW
		NORTHWEST REGION			
6	Ambler	Jacobs	3	BC	W
7	Council	Aeropower SL1000	1	BC	OW
8	Elim	Aeropower	2	N/A	PLND
9	Gambell	IES Skyhawk 4	4	UI	NW
10	Gambell	IES Skyhawk 4	4	UI	NW
11	Gambell	IES Skyhawk 4	4	UI	NW
12	Gambell	IES Skyhawk 4	4	UI	NW
13	Gambell	Jacobs	10	UI	NW
14	Gambell	Jacobs	10	UI	W
15	Gambell	Jacobs	10	UI	W
16	Golovin	Enertech 1800	1.8	N/A	NW
17	Kivalina	Enertech 4000	4	UI	OW
18	Kotzebue	Dunlite	2	UI	W
19	Kotzebue	Enertech 1800	1.8	BC	NW
20	Nome	Aeropower SL2000	2	BC	NW
21	Nome	Bergey BWC1000	1	BC	OW
22	Nome	Jacobs	10	UI	W
23	Selawik	Enertech 1500	1.5	UI	OW
24	Selawik	Enertech 1800	1.8	UI	UNK
25	Shishmaref	Enertech 1800	1.8	UI	W
26	Shishmaref	Enertech 1800	1.8	UI	W
27	Teller	Enertech 1800	1.8	UI	OW
28	Unalakleet	Jacobs	10	UI	W
29	Unalakleet	Jacobs	10	UI	W
30	Unalakleet	Jacobs	10	UI	W
31	Unalakleet	Jacobs	15	UI	W
32	White Mountain	Enertech 1800	1.8	BC	NW
		WESTERN REGION			
33	Alakanuk	Enertech 1800	1.8	UI	NW
34	Bethel	Dunlite	2	BC	NW
35	Bethel	Enertech 1800	1.8	UI	NW
36	Bethel	Enertech 4000	4	UI	OW
37	Bethel	Aeropower SL1500	1.5	N/A	PLND
38	Bethel	Jacobs	10	N/A	PLND
39	Chevak	Enertech 1800	1.8	UI	W
40	Hooper Bay	Jacobs	10	UI	W
41	Hooper Bay	Jacobs	10	N/A	PLND
42	Newtok	Enertech 1800	1.8	N/A	PLND
43	Pilot Station	Jacobs	10	UI	W
44	Platinum	Bergey 1000-S	1	UI	W
45	Sheldon Point	Aeropower SL2000	2	BC	NW
46	Sheldon Point	Aeropower SL2000	2	BC	NW
47	Sheldon Point	Northwind HR2	2	BC	W

ID	Location	Manufacturer and Model	Size in kw	Utility Intertied or Battery Charger	Status Code
		WESTERN REGION (continued)			
48	Sheldon Point	Northwind HR2	2	BC	W
49	Sheldon Point	Northwind HR2	2	BC	W
50	Sheldon Point	Northwind HR2	2	BC	W
51	Sheldon Point	Northwind HR2	2	BC	W
		SOUTHCENTRAL REGION			
52	Anchorage	Jacobs	1.8	BC	W
53	Chinitna Bay	————————	—	BC	UNK
54	Cordova	Aeropower SL1500	1.5	BC	UNK
55	Homer	Paris Dunn	0.5	BC	OW
56	Homer	Jacobs	2	N/A	PLND
57	Homer	Enertech 1800	1.8	N/A	PLND
58	Homer	Enertech 4000	4	UI	W
59	Homer	Jacobs	3	BC	UNK
60	Homer	Composite	11	N/A	NW
61	Kasilof	Sencenbaugh	1	BC	W
62	Matanuska	Aeropower SL2000	2	BC	NW
63	Ninilchik	Bergey BWC1000	1	BC	UNK
64	Palmer	Bergey BWC1000	1	BC	W
65	Palmer	Bergey 1000-S	1	UI	W
66	Palmer	Aeropower 1500	1.5	UI	UNK
67	Palmer	Jacobs	10	UI	W
68	Palmer	Enertech 4000	4	UI	W
69	Palmer	Jacobs	10	BC	UNK
70	Palmer	Aerolite	11	UI	UNK
71	Seward	Aeropower 1500	1.5	BC	W
72	Wasilla	Jacobs	10	UI	NW
73	Wasilla	Bergey BWC-Excel	10	BC	PLND
74	Wasilla	Dunlite	5	BC	UNK
		SOUTHWESTERN REGION			
75	Afognak Island	Aeropower SL2000	2	BC	W
76	Dillingham	Jacobs	10	UI	W
77	Dillingham	IES Skyhawk 4	4	BC	UNK
78	Egegik	Aeropower SL1500	1.5	BC	W
79	Fox Bay	Jacobs	1.8	BC	UNK
80	Iliamna	Jacbos	1.8	BC	W
81	Iliamna	Dakota Wind & Sun	4	BC	NW
82	Iliamna	Dakota Wind & Sun	4	BC	NW
83	King Salmon	Enertech 1500	1.5	UI	W
84	King Salmon	Enertech 4000	4	UI	OW
85	King Salmon	Enertech 4000	4	N/A	PLND
86	King Salmon	Jacobs	10	UI	W
87	Kodiak	Aeropower SL1500	1.5	BC	W
88	Kodiak	Jacobs	10	UI	W
89	Lake Clark	Dakota Wind & Sun	4	BC	W
90	Lake Clark	Jacobs	3	BC	W
91	Levelock	Northwind HR2	2	N/A	UNK
92	Naknek	Jacobs	12.5	UI	W
93	Naknek	Jacobs	12.5	UI	PLND
94	Naknek	Bergey BWC-Excel	10	UI	PLND
95	Naknek	Bergey 1000-S	1	UI	PLND
96	Naknek	Jacobs	12.5	UI	PLND
97	Naknek	Not Selected	—	N/A	PLND
98	Nannek	Not Selected	—	N/A	PLND

ID	Location	Manufacturer and Model	Size in kw	Utility Intertied or Battery Charger	Status Code
		SOUTHWESTERN REGION (continued)			
99	Naknek	Enertech 1500	1.5	UI	NW
100	Naknek	Enertech 1500	1.5	UI	OW
101	Newhalen	Stormmaster	8	BC	NW
102	Nondalton	Bergey	1	UI	NW
103	Port Alsworth	Jacobs	1.8	BC	W
104	Togiak	Aeropower SL2000	2	BC	NW
		SOUTHEASTERN REGION			
105	Haines	Dunlite	1	UI	UNK
106	Haines	Electro	7	BC	UNK
107	Ketchikan	Jacobs	10	UI	PLND
108	Ketchikan	Jacobs	10	UI	W
109	Ketchikan	Jacobs	10	UI	W
110	Ketchikan	Aeropower SL1500	1.5	BC	UNK
111	Metlakatla	Jacobs	10	UI	OW
112	Petersburg	Jacobs	1.8	BC	PLND
113	Petersburg	Dakota Wind & Sun	4	BC	PLND
114	Port Alexander	————————	—	N/A	PLND
115	Skagway	Jacobs	10	UI	W
		INTERIOR			
116	Cantwell	Dakota Wind & Sun	4	BC	W
117	Cantwell	Jacobs	10	N/A	PLND
118	Cantwell	Bergey BWC1000	1	N/A	UNK
119	Delta Junction	Electro	6	UI	NW
120	Delta Junction	Jacobs	10	UI	UNK
121	Delta Junction	Aeropower SL1500	1.5	BC	UNK
122	Gakona	Aeropower SL1000	1	BC	UNK
123	McKinley Park	Aeropower SL1000	1	BC	UNK
124	Slana	Aeropower SL2000	2	BC	UNK
		ALEUTIANS			
125	Adak	Enertech 1800	1.8	UI	OW
126	Chignik	Aeropower SL2000	2	BC	UNK
127	Cold Bay	Dunlite	2	BC	W
128	False Pass	Dunlite	2	BC	UNK
129	Nelson Lagoon	Grumman Windstream	20	UI	OW
130	Nikolski	Aeropower SL2000	2	BC	UNK
131	Port Heiden	Aeropower SL2000	2	BC	UNK
132	St. Paul	Enertech 1800	1.8	UI	PLND
133	Sand Point	Jacobs	10	UI	W
134	Sand Point	Jacobs	10	UI	W
135	Sand Point	Jacobs	12.5	UI	W
136	Sand Point	Jacobs	15	UI	W
137	Sand Point	Jacobs	15	UI	OW
138	Sand Point	Jacobs	15	UI	OW
139	Sand Point	Aerolite	11	UI	PLND
140	Unalaska	Aerolite	11	UI	PLND

Appendix B
Wind Generator Project Statistics

APPENDIX B

ALASKA'S WIND ENERGY SYSTEMS

Project Site	Average Wind Speed	Capacity Factor
Nelson Lagoon	15E	0.123
Sand Point	19	0.194
Naknek	13	0.154
Unalakleet No. 2	11	0.189
Gambell	18	0.158
Unalakleet No. 4	11	0.173
Nome	10	0.137
Hooper Bay	14	0.124
Skagway	10E	0.118
Gambell	18	0.113
King Salmon	11	0.106
Kodiak	10	0.084
Pilot Station	14	0.082
Palmer	6E	0.078
Unalakleet No. 3	11	0.062
Chevak	15	0.342
Kivalina	13E	0.137
Bethel	12E	0.126
Gambell	18	0.047
Unalakleet No. 1	11	0.046
Platinum	17	0.328
Ketchikan	8E	0.030
Bethel	12E	0.086
Ketchikan	8E	0.014

Note: E = Estimated from data at other sites in the same geographic region. Source for the data is the **Alaskan Wind Energy Handbook.** Capacity factor is calculated by dividing the estimate for annual kilowatt-hour production (KWH/Yr.) by the rated capacity of the wind generator multiplited by 8760 hours per year.

APPENDIX B

ALASKA'S WIND ENERGY SYSTEMS

Wind Generator Project Statistics

Project Site	ID	Size (KW)	Make	Status	KWH/Yr.	Months of KWH Data	On-Site Data Collection
Nelson Lagoon	1	20	Grumman	OW	21560	14	
Sand Point	2	10	Jacobs	OW	17020	12	
Naknek	3	12.5	Jacobs	W	16900	24	X
Unalakleet No. 2	4	10	Jacobs	W	16520	8	X
Gambell	5	10	Jacobs	W	13800	16	X
Unalakleet No. 4	6	15	Jacobs	W	22780	6	X
Nome	7	10	Jacobs	W	11970	3	X
Hooper Bay	8	10	Jacobs	W	10840	18	X
Skagway	9	10	Jacobs	W	10370	10	
Gambell	10	10	Jacobs	W	9940	16	X
King Salmon	11	10	Jacobs	W	9290	7	X
Kodiak	12	10	Jacobs	W	7320	16	X
Pilot Station	13	10	Jacobs	W	7200	3	
Palmer	14	10	Jacobs	W	6800	9	
Unalakleet No. 3	15	10	Jacobs	W	5460	8	X
Chevak	16	1.8	Enertech 1800	W	5400	5	X
Kivalina	17	4	Enertech 4000	OW	4800	3	
Bethel	18	4	Enertech 4000	OW	4400	6	X
Gambell	19	10	Jacobs	NW	4120	16	X
Unalakleet No. 1	20	10	Jacobs	W	4000	8	X
Platinum	21	1	Bergey 1000-S	W	2875	10	
Ketchikan	22	10	Jacobs	W	2600	7	
Bethel	23	1.8	Enertech 1800	NW	1350	21	X
Ketchikan	24	10	Jacobs	W	1220	5	