A Feasibility Study for Wind/Hybrid Power System Applications for New England Islands

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Abstract

This paper presents the results of a feasibility study of potential wind energy developments on the islands of New England. The study included the compilation of an inventory of New England coastal islands, a categorization of the islands according to energy related criteria, and an overview of the current energy supply situation on those islands where energy demanding activities take place. This paper summarizes that study and presents two case studies of wind driven hybrid power systems on selected islands, together with an estimation of the technical performance and economic merits of these systems.

1.0 Introduction/ Background

There are more than 3000 islands near the New England shoreline. About 150 of these islands support activities that require some sort of energy supply. These activities range in kind from unmanned automatic lighthouses to entire communities living year round on some of the islands. A significant number of islands support summer populations that use the islands for recreational, scientific and educational purposes. Since the type of activities varies from island to island, the energy systems that presently provide electricity and heating to the islands also vary. Of particular note is that some islands are connected to the mainland grid via underwater power transmission cables while other islands are isolated and generate their own electricity.

The wind resource off the New England shore is quite favorable with wind speeds averaging from 7 to 9 m/s (at 50 m) from the Connecticut to Maine coasts. Therefore, this region could be appropriate for suitably sited wind power systems, especially wind/hybrid systems. A feasibility study, carried out at the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts/ Amherst was carried out with the objective of investigating the feasibility of such systems.

This work, summarized in this paper, was carried out under a U.S. Department of Energy contract and included the following six components:

1) A New England islands inventory and classification
2) A wind resource assessment for offshore New England
3) A summary of the current energy supply status of the islands
4) Power system options for the islands
5) Analytical modeling of potential hybrid power systems
6) Case studies of representative island systems.

The term "hybrid" usually refers to an isolated power system in which there is more than one immediate source of energy. Thus wind/diesel and photovoltaic (PV)/gasoline generator combinations clearly fit into this category. As used in this study, the definition has been expanded to include multiple sources of energy, or multiple types of power converters, used in a regionally distant or quasi-isolated setting. By quasi-isolated we mean an application partially served by a distinct external supply (such as an island connected to the mainland by a cable).

2.0 Inventory and Classification of Islands

2.1 Inventory and Statisitics

As documented by the U.S. Geological Survey [1], there are a total of 3,284 islands in New England. They are divided by state as follows: Maine (1902), Massachusetts (669), Connecticut (346), New Hampshire (270), and Rhode Island (97). Most of the islands are within 20 miles of the mainland, with a few exceptions such as Matinicus Rock in Maine (22 mi) and Natucket Island in Massachusetts (30 mi).

As shown in Figure 1, the islands range in size from 70,000 acres (Martha's Vineyard) to very tiny, rocky outcropping of less than an acre.

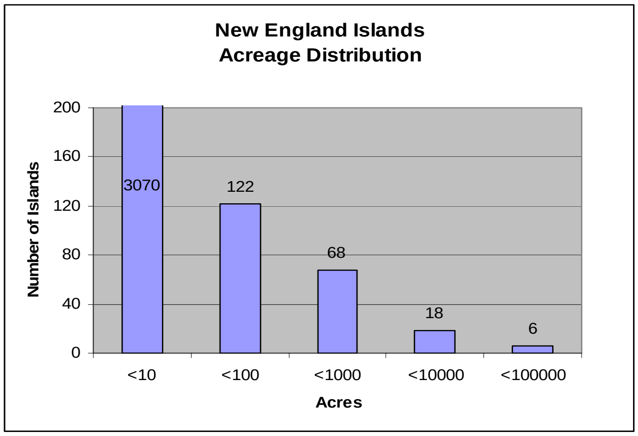

Figure 1 Acreage distribution of New England Islands

Among the islands, about 150 of them have been identified with activities that require some form of energy supply. The activities and population of these islands vary widely ranging from uninhabited meteorological stations to large year-round communities. For the populated islands, the population distribution fluctuates substantially, with the summer population typically increasing by a factor of three or more. Some islands, however, present a more dramatic variation. As an example, Star Island (one of the Isles of Shoals), NH, sees its population increased 200 times over the summer due to a conference that is held every year on the island. Another example, Block Island, RI, has a year-round population of approximately 1,100, but the summer population increases up to 14,000.

The wide fluctuation in the number of people living on the islands at different times of the year creates design challenges for the use of renewable energy resources in these sites. An example of the influence of the population fluctuations on the electric load can be seen in Figure 2. This shows the actual electric load profile for Cuttyhunk Island, where the population varies from 25 during the winter to more than 100 during the summer [2].

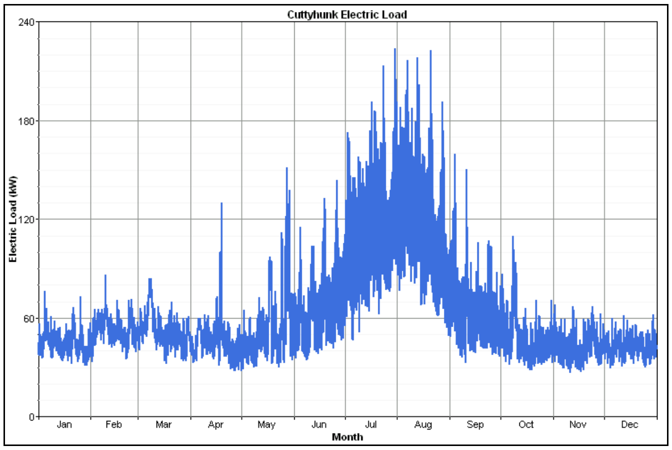

Figure 2   Cuttyhunk Island Yearly Electrical Load

To compare the islands in terms of their potential energy consumption, an average monthly population, Pop_{avg} , was defined as follow:

$$Pop_{avg} = \frac{3(Pop_s) + 9(Pop_w)}{12}$$

where Pop_s is the average monthly population during the summer months and Pop_w is the average monthly population during the rest of the year.

Figure 3 presents the monthly average population distribution among the energy consuming islands.

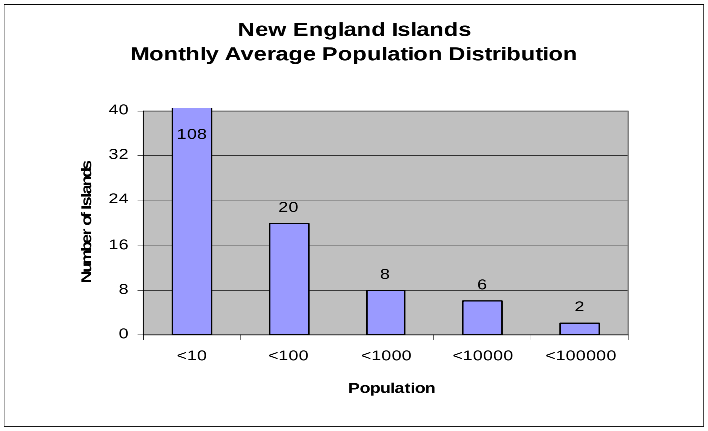

Figure 3 Population Distribution of Energy Demanding Islands

2.2 Classification of New England Islands

A particularly important factor in the classification of the islands is whether or not the islands are connected to the electric grid on mainland. Eighteen islands are linked to mainland through road bridges; all of these are also connected to the electrical grid onshore. Another 16 islands are connected to the electrical grid via underwater transmission cables running from mainland.

Within these two classifications, the yearly population pattern and the type of activities carried out on the islands were used to further subdivide the islands classification. These two categories were selected because of their direct relationship to the annual electrical and heating energy load profiles. Thus, the six classification groups established (and number of energy demanding islands) included:

Grid Connected Islands
1. Island communities grid connected to the mainland via underwater cables (33)
2. Other islands with small or no population, but with equipment that requires a year-round energy supply. (2)

Islands Isolated from the Mainland Grid
1. Islands with significant year round population, but isolated from the mainland (9)
2. Islands with primarily summer-only activities (50)
3. Islands with no population, but with equipment that requires a year-round energy supply (30)
4. Islands preserved for their ecological value. (23)

Information about annual energy –electricity and heating- consumption and supply, electricity rates, fuel costs, underwater cable capacity and other energy related data was not available for many of the islands. For the islands for which the energy use was not available, correlations were performed in order to estimate this value as well as the annual and daily electric and heating load profiles.

For the electric load, correlations were based on population patterns and type of activities from islands whose electricity consumption and load profiles were known. To estimate heating loads on islands where that information was not available, correlations based on standard values for the ratio between energy required per household and degree-days were used [3].

3.0 Estimation of Offshore Renewable Energy Resources

For the hybrid systems studied in this report, most included wind turbine generators. Some systems also used PV panels as a power source. Thus, both the wind and solar resource were considered for the various islands.

3.1 Wind Resource

The most complete existing source for offshore wind data in New England is a network of buoys and stations operated by the National Oceanic and Atmospheric Administration (NOAA) [4]. Moored buoys and C-MAN (Coastal Marine Automated Network) stations located on islands record data on wind, waves, temperature and barometric pressure. Figure 4 shows the location of buoys and stations off the New England coast.

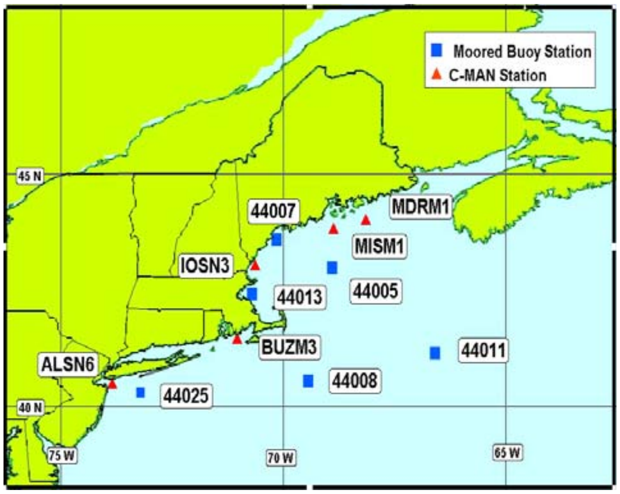

Figure 4 NOAA C-MAN and Buoys in Northeast

For this work data sets for the year 2000 were chosen, since complete data sets were available for each station for that year. In order to estimate the average wind speeds in buoys and stations over a longer period of time, a correction factor was introduced to adjust the data sets for year 2000 and to adjust for coastal or island sites as compared to ocean based sites. The factor was calculated by using the ratio between the average wind speeds for year 2000 and the 10-year average both at Logan International Airport in Boston Harbor and a conservative estimate of an 8% reduction in wind speed for potential island sites.

Also, the data was adjusted so that it would be representative of the wind resource at the hub height of a typical wind turbine (e.g., 50 m). This was accomplished by scaling the wind data by the well known "power law". Assuming the islands to be located in the open ocean, a power law exponent of 0.12 was used. Table 1 gives values for the average wind speed, its scaled value at 50 m, and the adjusted 10-year average island value.

Buoy/Station	Elevation	Average Wind Speed 2000	50 m correction	10-year adjusted average
	m	m/s	m/s	m/s
Boston Harbor 44013	5	6.1	8.0	7.4
Buzzards Bay BUZM3	24.8	8.4	9.1	8.4
Isles of Shoals IOSN3	19.2	7.3	8.2	7.5
Matinicus Rock MISM1	16.5	8.2	9.3	8.6
Mt. Desert Rock MDRM1	22.6	8.4	9.2	8.5
Nantucket 44008	5	7.3	9.6	8.9
Portland 44007	5	5.5	7.3	6.8
Portsmouth 44005	5	7.4	9.8	9.0

Table 1 Average Wind Speeds at NOAA C-Man Stations and Buoys

It can be seen from the table that the offshore wind environment consists of class 5 and 6 sites, indicating that the area has an excellent wind resource.

In addition to this data, other wind data collected by the University of Massachusetts (e.g., see Reference 5) at a number of sites on islands and offshore was used as a data source for this work.

3.2 Solar Resource

For cases where PV hybrid systems were considered, an estimate for the solar resource on selected New England islands was needed. The solar radiation for the studied islands was estimated based on the geographical location (i.e., latitude) of the island and the monthly average clearness index, $\overline{K}_T$. Monthly $\overline{K}_T$ values were obtained from Duffie and Beckman [6] for various locations along the New England shore. Since the islands where PV systems were proposed are less than 20 miles from mainland, the given $\overline{K}_T$ values were used.

The values for $\overline{K}_T$ in New England shore varied from 0.49 in summer to 0.40 in winter. These values yield an annual average radiation for the region of approximately 3.7 kWh/m^2/day.

4.0 Power System Options

4.1 Current Energy Supply Status

Island communities isolated from the mainland electrical grid are generally supplied by stand-alone diesel generators. This is the case of islands such as Monhegan, ME; Cuttyhunk, MA; and Block Island, RI. In all cases, the local utility takes care of the maintenance and operation of the generators. This work has an annual cost comparable to the cost of the fuel itself, according to several reports from local utility companies. The cost of fuel, in turn, is an unpredictable variable that represents approximately 25% percent of the cost of energy in these types of power systems. The logistics of fuel transportation not only add to this cost, but also create uncertainty in the energy supply. On the isolated islands, heating fuel is periodically delivered from the mainland.

At present, some of the grid-connected island communities (e.g., the islands of North Haven and Vinalhaven in Penobscot Bay, ME) are facing the necessity to replace their old underwater transmission cables. In this case, for instance, fishing practices and other maritime activities have physically damaged the underwater cable. Neither of these islands has any backup power system, relying completely on the external electricity supply.

For those isolated islands where much of the activities are concentrated during the summer, the power is usually provided by either diesel generators (e.g., Isles of Shoals, NH) or individual PV systems (e.g., Eagle Island, ME), depending on the size of the electrical load. When diesels are used, fuel cost and transportation as well as environmental impacts such as air pollution and noise are a serious concern among the residents. Small, individual PV systems are usually used on the islands with few houses or cabins occupied only during the summer. In many of these cases, refrigeration is not electric, and propane is brought to the islands to power the refrigerators. Here again, the logistics and potential hazards of fuel transportation are present.

Finally, the more than 40 lighthouses and meteorological stations located on the New England islands are typically supplied by stand-alone PV systems, although a few of them incorporate diesel generators as backup power [7]. The US Coast Guard automated most of the lighthouses during the 1980s and 1990s, introducing the PV systems in the process. Scientific laboratories and stations on the islands rely, in general, on PV systems for their electricity supply.

4.2 Power System Options

Based on the current energy supply status, several renewable based power systems for applications on grid or non-grid connected islands were investigated in this study. They included:

Grid Connected Turbines
For grid connected islands, potential economic benefits of grid-connected wind turbines include the use of the large wind energy resource available offshore, increasing the energy output of the system for the same installed power capacity, and the possibility to transmit and sell the excess energy (i.e., the power generated by the wind turbines that exceeds the load at any given moment) to the utility grid on mainland. The installation of grid-connected wind turbines is not limited to inhabited islands with the underwater cable already in place. There are a number of isolated, deserted islands which do not carry any type of human activities nor have any special ecological value but that could be suitable for wind energy development. The latter do not fit under our definition of hybrid system, so while they may be of interest, they are not discussed here in any detail.

Isolated Wind/Diesel Systems
For both groups of island types, wind/diesel hybrid systems were studied as a second option. These systems could supply not only electricity, but also heat to the community, decreasing the amount of heating fuel shipped to the islands every week. At present, many islands are facing the cost of replacing the existing underwater cables because of damage caused by fishing and other nautical activities. For some of these islands, a stand-alone wind/diesel system could be a viable alternative, as it is shown later in this paper. For the isolated islands, wind/diesel systems were compared to existing diesel only power systems.

Isolated Wind/PV/ Systems
Wind/PV systems were considered for a number of islands where there is electrical equipment and a small year-round population and a stable energy demand over the year. In this case, the systems are to provide power to communication equipment, meteorological stations, lighthouses and the like, that require a fairly constant and highly reliable source of energy. For these remote systems, the design included the option of energy storage.

5.0 Description and Modeling of Potential Power Systems

Based on the work of the previous section, technical and economic performance models were used to analytically model the following island power system options:

1) Grid-connected Wind Turbines with Underwater Cables
2) Isolated Wind/Diesel Power Systems
3) Isolated Wind/PV Systems with Storage

For all the cases considered, the modeling required specific data from each island, or group of islands for an analysis of energy performance, loads (electrical and heating) and economics (including administrative and distribution as well as life cycle costs).

In order to accurately model these systems, either the Hybrid2 computer code, developed at the University of Massachusetts and the U.S. National Renewable Energy Laboratory (NREL) [8], or Homer (Hybrid Optimization Model for Electric Renewables), developed by NREL [9], were used. A full description of the individual component performance and economic models is beyond the scope of this paper, but more details are given in the final report on this work [10]. For this study, special attention was placed on the technical and economic modeling of the following power systems components:

1) Wind Turbine Generators
2) Underwater Power Transmission Cables
3) Diesel Generators
4) Electrical Loads

6.0 Overview of Selected Case Studies

During this work, a number of islands were the subjects of case studies for potential renewable energy power systems. Two of these case studies will be summarized here: 1) a grid connected island community: Fox Islands and 2) an isolated island community: Monhegan Island.

6.1 Grid Connected Island Community: Fox islands

6.1.1 Description of the Islands

The Fox Islands are a group of islands located in Penobscot Bay, in mid-coast Maine, at about 12 miles from the mainland. The two major islands in the group are Vinalhaven and North Haven. Vinalhaven is the largest island, and is approximately 9 miles long and 6 miles wide. Most of the island is covered with dense spruce forest, but there are several large areas of barren granite outcroppings. The coastline is rocky. Vinalhaven is the site of one the largest island communities in New England, with a year-round population of 1,300 and a summer population of approximately 6,000. Commercial lobster fishing makes up the largest segment of the island’s economy [11].

North Haven, second largest island of the group, has an area of 9.8 square miles and a year-round population of 350 that increases during the summer to approximately 2,000. North Haven has a small snack bar/restaurant, a post office, a library, two gift shops, a general store, a market, a school, a church, a gym and many large private summer residences located along the shore [12]. Figure 5 shows Vinalhaven and North Haven as well as other islands of the Fox Islands group [13].

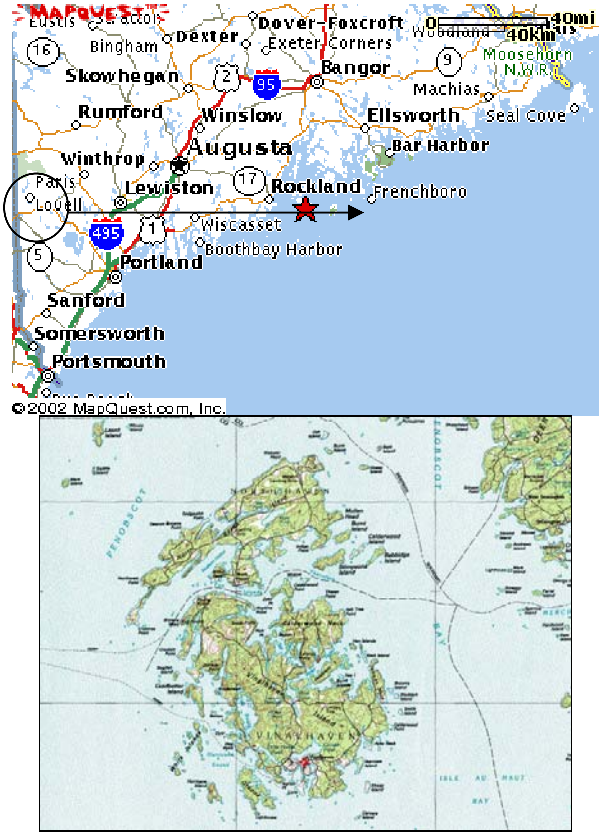

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Figure 5 Map of Fox Islands in Penobscot Bay, Maine

Fox Island Electric Cooperative has provided the electricity for both islands since 1975. In 1977 the cooperative installed a submarine cable between North Haven and Central Maine Power Company’s lines at Rockport, on the mainland. Today, Fox Island Electric Cooperative is facing the need to replace the existing cable that has been damaged over the years by fishing and other nautical activities. The combined annual electric energy use on the islands is approximately 8,500,000 kWh (corresponding to an average load of about 1000 kW), according to data given by the Island Institute [14]. Figure 6 shows the estimated hourly average electric load, and the influence of population fluctuations is evident. The annual peak electricity demand is approximately 5,000 kW. It occurs in August.

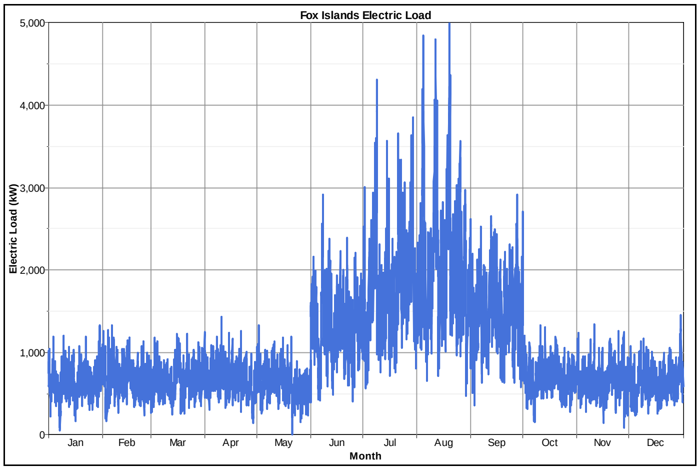


Figure 6 Fox Islands Electric Load

The estimation of the wind resource was based on the two NOAA stations close to Fox Islands, one is the MDRM1, located in Mount Desert Rock Island, and the other one is MISM1, at Matinicus Rock. Both stations have similar wind speed annual averages. In this study, data from MDRM1 station was used, since this station is about the same distance from mainland as the Fox Islands. Figure 7 shows the hourly wind speeds. The annual average wind speed at 50 m is 8.34 m/s.

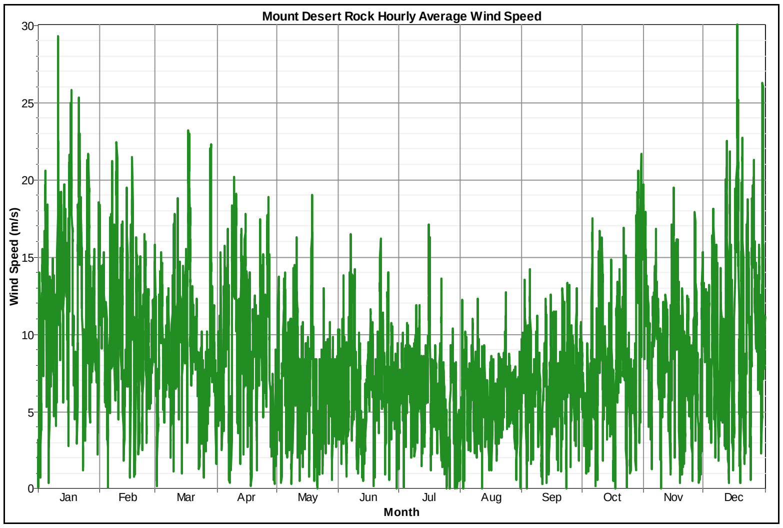


Figure 7 Mount Desert Rock Hourly Average Wind Speeds

6.1.2 Performance of Proposed Power Systems on Fox Islands

The first type of power system proposed for the Fox Islands consisted of one to six grid-connected wind turbines. Two different wind turbines were considered, the Vestas V52/850 and the Nordex N60/1300, with 850 and 1300 kW rated power outputs respectively. The turbines were assumed to be attached to the local electrical grid that, in turn, is connected to the grid in the mainland via an underwater cable.

Figure 8 shows the annual wind energy production as a function on the number of turbines for two different turbines. The values were calculated on an hourly basis by using the wind speed time series and the turbines' power curves. The annual electric load in Fox Islands is also included for comparison purposes.

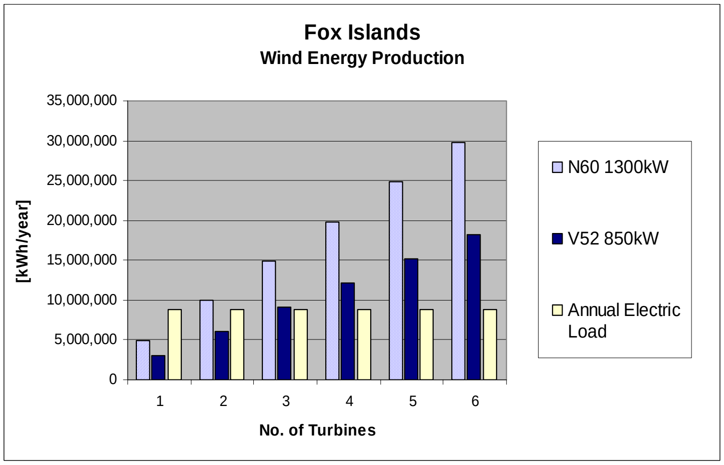


Figure 8 Annual Electric Load and Wind Energy Production vs. Number of Wind Turbines

Due to the temporal mismatch between the wind and the electrical load, only a fraction –from 31 % to 75 % depending on the type and the number of wind turbines installed- of the electrical load would be provided by the wind energy produced, even when this energy is greater than the energy consumption on the islands during a given year. The excess wind energy that is not used to satisfy the load is assumed to be sold into the mainland grid. At the end of the year a net energy flow can be calculated. This is simply the difference between the energy that must be bought from the grid to satisfy the load (i.e., annual electrical load minus fraction of load served) and the excess energy injected into the grid (i.e., total annual energy produced minus fraction of load served). Figure 9 illustrates the net energy flow as a function of the number of turbines for the same two turbines.

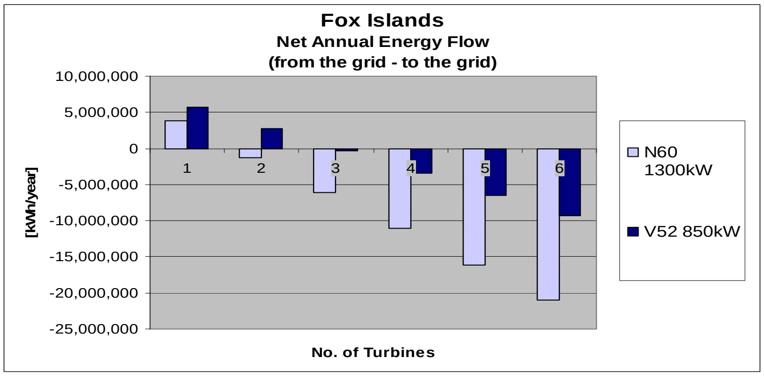


Figure 9 Net annual energy flow from the grid vs. number of turbines

Two different scenarios were studied regarding the replacement of the underwater transmission cable. In the first case, the existing underwater cable is used and no replacement is considered. In a second case, the installation of a new underwater cable is introduced, assuming the initial capital cost to be paid in levelized annual payments over the lifetime of the project. Capital cost, 20-year replacement costs, and O&M costs for the two wind turbines studied were estimated for the economic studies. Administrative and distribution costs are an important part of the annual costs of the power systems, although they may vary substantially from island to island. In this case, the actual administrative and distribution costs are not known, but a cost of $1,200,000 per year was estimated based on reports from two other islands with similar characteristics in terms of population pattern and energy consumption.

Figure 10 illustrates the results of an economic analysis of a proposed power system with six turbines. The cost of electricity from the mainland is varied. The introduction of the wind turbines lowers the increase in the net cost of energy as mainland prices increase.

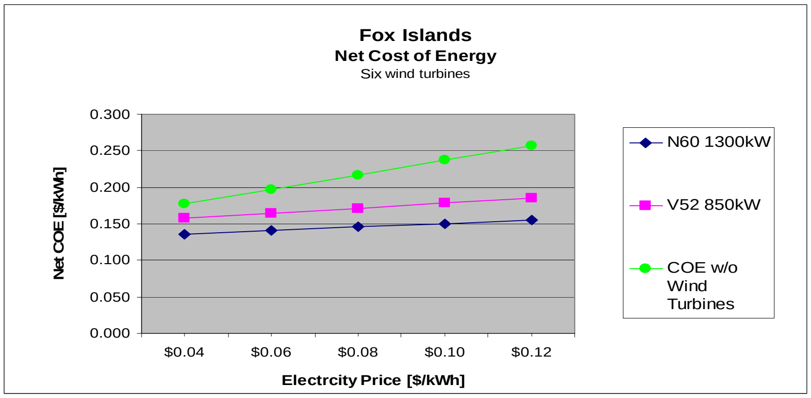


Figure 10 Net Cost of Energy vs Electrity Cost from Mainland and Choice of WTG

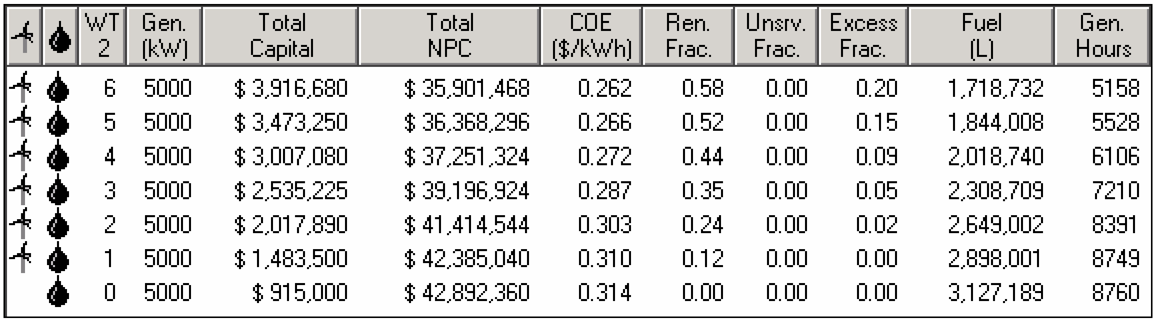
Next, a wind/diesel system, isolated from the grid on shore, was considered as an alternative to the replacing of the existing underwater cable. In this case, the proposed system consists of a choice of three mid-sized wind turbines connected to the local grid and diesel generators as power backup to be used whenever the wind power is not able to provide the total load. Details and assumed costs for the wind turbines are shown in Table 2.

Manufacturer	Model	Power	Initial Cost	Installation	O&M
		kW	[$]	[$]	[$/ yr]
AOC	AOC 15/ 50	50	75,000	95,000	2000
Northern Power	NW 100/ 19	100	170,000	216,000	3500
Fuhrlaender	FL 250	250	250,000	320,000	4750

Table 2 Rated Power and Cost Assumptions of Three Mid-sized Wind Turbines

Different combinations of wind turbines and diesel generators were analyzed and the optimum configurations, using a number of the larger (Fuhrlaender) turbine are presented here. The initial, replacement and O&M costs of the diesel generators, and the cost of the additional equipment associated with hybrid systems -diesel automation, dump load, synchronous condenser, and the supervisory control- have been estimated and introduced in these calculations as explained previously. Other assumptions used for these calculations include: real interest rate of 4%, administrative and distribution costs of $1,200,000 a year, and fuel cost $0.32 a liter.

The minimum combined rated power of the diesel generators would be 5,000 kW, necessary to deal with a potential peak load when the wind turbines are not generating. Table 3 shows the economic and energy parameters as a function of the number of turbines, including the configuration featuring a stand-alone diesel generator with no wind turbines.



✛	💧	WT 2	Gen. (kW)	Total Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Unsrv. Frac.	Excess Frac.	Fuel (L)	Gen. Hours
✛	💧	6	5000	$ 3,916,680	$ 35,901,468	0.262	0.58	0.00	0.20	1,718,732	5158
✛	💧	5	5000	$ 3,473,250	$ 36,368,296	0.266	0.52	0.00	0.15	1,844,008	5528
✛	💧	4	5000	$ 3,007,080	$ 37,251,324	0.272	0.44	0.00	0.09	2,018,740	6106
✛	💧	3	5000	$ 2,535,225	$ 39,196,924	0.287	0.35	0.00	0.05	2,308,709	7210
✛	💧	2	5000	$ 2,017,890	$ 41,414,544	0.303	0.24	0.00	0.02	2,649,002	8391
✛	💧	1	5000	$ 1,483,500	$ 42,385,040	0.310	0.12	0.00	0.00	2,898,001	8749
	💧	0	5000	$ 915,000	$ 42,892,360	0.314	0.00	0.00	0.00	3,127,189	8760

Table 3 Economic and Performance Parameters for Different Wind/Diesel Systems

The results show that, even with the increase in the total capital cost of the system, the reduction in fuel consumption due to the addition of the wind turbines brings the cost of energy down from $0.314 for the diesel-only system, to $0.262 per kWh when six FL 250 kW turbines are installed. The other two wind turbines yielded higher values for the cost of energy and they were not considered further. According to Table 3, the increasing number of wind turbines, or wind power penetration, reduces the cost of energy. The reduction rate, however, diminishes for a large number of turbines. For example, when the number of turbines increases from 5 to 6 the cost of energy decreases by only 1.5 %, suggesting that there would be no need to increase the number of turbines - and the complexity of the system - beyond this number. A final observation is that it might prove advantageous overall to use fewer but even larger turbines. The possibility of doing so has not yet been analyzed, however.

6.2 Isolated Island Community: Monhegan Island

6.2.1 Description of Island

Monhegan is a small, rocky island located in Muscongus Bay, ME, ten miles from the nearest mainland town [15]. The less than one square mile island is accessible only by boat and there are no cars or paved roads on the Island. Today its economy is based on fishing and lobstering. The year-round population has seldom exceeded 75 in recent times. During the summer, however, cottage owners and one-day visitors bring the population up to 700 or more. Figure 11 shows the topographic map of Monhegan Island, where the black dots represent houses, cottages and several inns [16].

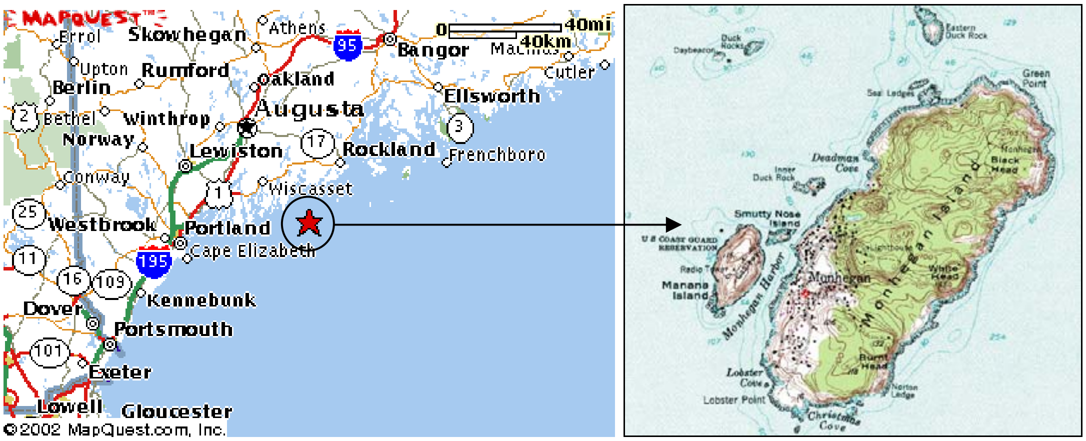


Figure 11 Map of Monhegan Island, Maine

For years, people used their own diesel generators to power their homes, cottages, and the few business in the island, but the generators were noisy and leaking fuel threatened the island's underground water supply. In 1997, the residents voted to establish the Monhegan Plantation Power District with a new centralized power plant that would run on diesel power to generate electricity. In the meantime, the island leased two diesel generators for $7,000 a month until year 2000 when Northern Power Systems installed a 300 kW (nominal) diesel power plant in a location far from the island's primary aquifer. The power plant consists of two 120 kW and one 74 kW rated diesel generators [17]. Along with the power generating station, a 4,160 V distribution system was also installed to replace the existing 208 V system. The retail cost of electricity was $0.50 per kWh in 2001.

The annual electricity consumption on the island is approximately 298,000 kWh (corresponding to an average load of about 35 kW) [14]. The peak demand is about 210 kW. It occurs during the summer. The monthly and daily profiles were estimated and are shown in Figure 12.

The closest NOAA meteorological station to Monhegan Island is the station located in Matinicus Rock, MISM1, at 22 miles to the east and at about the same distance from mainland. Figure 13 shows the estimated hourly average wind speed at a height of 50 m.

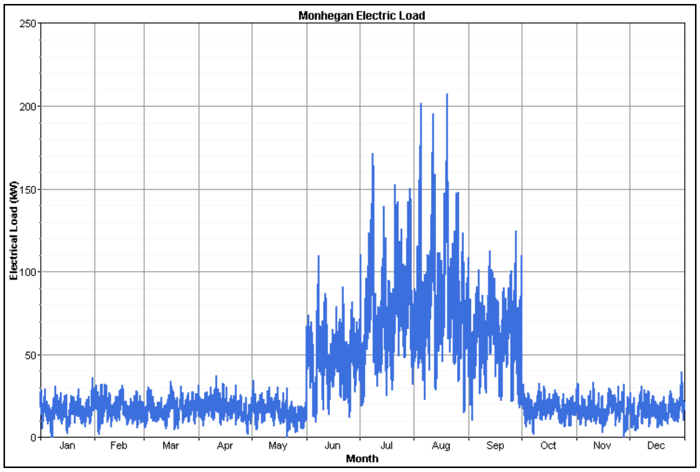


Figure 12 Yearly Electric Load on Monhegan Island

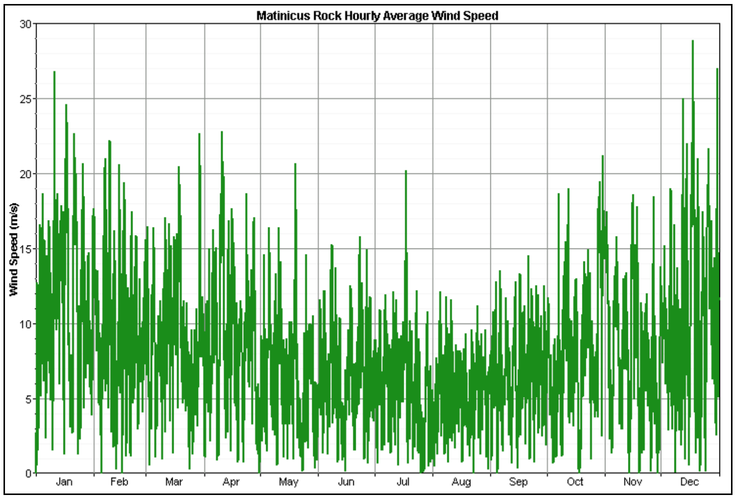


Figure 13 – Matinicus Rock hourly average wind speed

6.2.2 Performance of Proposed Power Systems for Monhegan Island

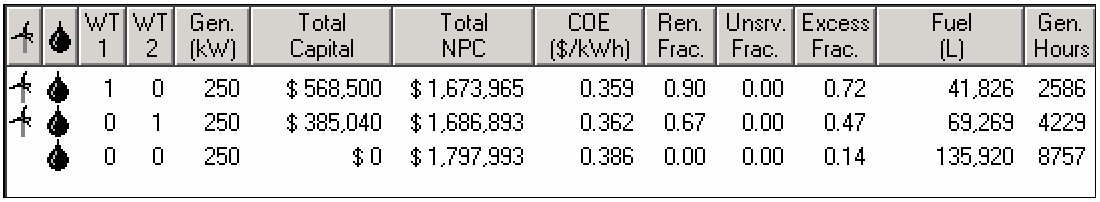
Two different stand-alone power systems were studied and compared for this case study: a diesel-only power plant and a wind/diesel system. Within the latter, an alternative to supply electricity for space heating was also analyzed.

Diesel-only Power System
As discussed above, Monhegan Island currently relies on a diesel power plant for its electricity supply. The following gives a summary of some of the parameters that characterize the performance and economics of the power plant. (Some of the values presented here are real figures obtained from Monhegan Plantation Power District, while others were estimated based on standard information for diesel power plants.)

The fuel consumption of the power plant is approximately 135,000 liters per year, with an annual fuel cost of $43,400 at $0.32 per liter. Other annual operating costs given by Monhegan Plantation Power District are labor: $20,400, payroll taxes: $3,840, insurance: $13,200, phone: $1,080, office supplies: $600, and generators supplies: $4,620, making a total annual operating cost of $44,000 [21]. Other expenses include the maintenance and complete overhaul of the diesel generators that is necessary every two years with a total cost of approximately $52,000. The annual energy production of the diesel generators is approximately 298,000 kWh. Based on the annual costs and the annual energy consumed, the cost of energy was calculated at $0.39 per kWh.

Wind/Diesel Systems
The possible introduction of wind power into the system was examined next. The wind turbines considered were, the AOC 50 kW, Northern Power 100 kW, and Fuhrlaender 250 kW. The initial economic results indicated that the two bigger machines are more appropriate in this case, yielding lower cost per kWh in the life cycle economic analysis.

Table 4 shows the basic economic parameters for three different power systems: diesel-only, diesel and one Northern Power 100 kW turbine (WT2 in the table), and diesel and one Fuhrlaender 250 kW turbine (WT1 in the table). In this case, it was assumed that the existing diesel power plant is used, so no initial capital cost for diesel generators is considered.



🌬	💧	WT 1	WT 2	Gen. (kW)	Total Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Unsrv. Frac.	Excess Frac.	Fuel (L)	Gen. Hours
🌬	💧	1	0	250	$ 568,500	$ 1,673,965	0.359	0.90	0.00	0.72	41,826	2586
🌬	💧	0	1	250	$ 385,040	$ 1,686,893	0.362	0.67	0.00	0.47	69,269	4229
	💧	0	0	250	$ 0	$ 1,797,993	0.386	0.00	0.00	0.14	135,920	8757

Table 4 Performance and Economic Parameters for Hybrid Systems

The results show a reduction in the fuel consumption ranging from 49 to 69 percent when the wind turbines are introduced into the power system. This reduction is the key factor in a drop of the cost of energy from $0.39 per kWh to approximately $0.36 per kWh for the hybrid system. The table shows that 47% of the energy generated by the Northern Power 100 kW turbine would be wasted, while 72% would be dumped if the Fuhrlaender 250 kW turbine were installed.

A possible solution to this problem is to use excess wind energy to supply part of the heating load on the island. Figure 14 illustrates the change in the cost of energy as a function of the fraction of the heating load supplied by the wind/diesel hybrid system with a FL 250 kW wind turbine.

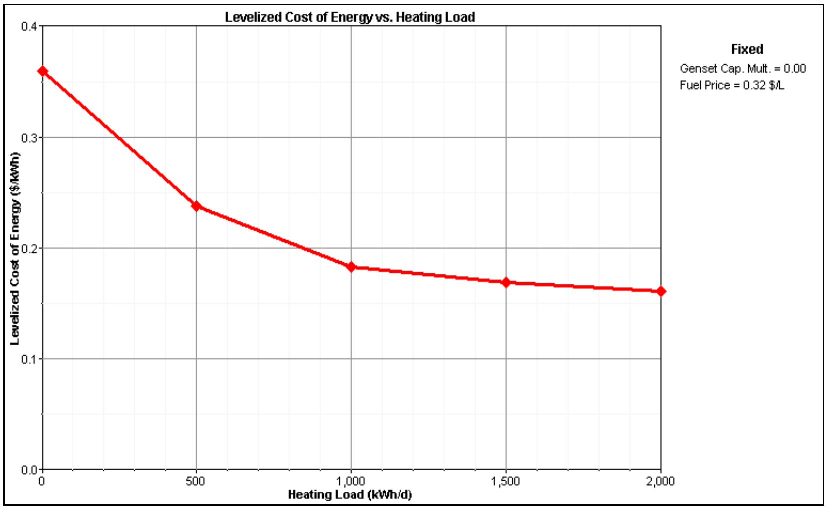


Figure 14 Levelized Cost of Energy as a function of Heating Load

The reduction in the cost of energy is achieved simply by the using of energy generated by the hybrid system that otherwise should be dumped. Besides the better use of the resources that can be accomplished, supplying part of the heating load would reduce the consumption of heating fuel by the same fraction. Monhegan Island uses approximately 140,000 liters of heating fuel (costing about $45,000) per year. If this saved cost were introduced into the calculations, the cost of energy would decrease to below $0.16 per kWh as illustrated in Figure 14. (Note that the use of excess energy for distributed heating on a potential hybrid power system for Cuttyhunk Island is the subject of a separate paper at this conference [19]).

7.0 Discussion and Conclusions

In general, the initial results of this study have shown that there is a great potential for hybrid system energy development in a number of New England Islands. A summary of the most important conclusions follows:

1) The results of the selected case studies presently look good, but the exact system design and economics is still preliminary.
2) If environmental benefits (green certificates, etc.) were added to the picture, the economics of the proposed hybrid systems would be greatly improved.
3) A detailed study of a few selected islands would help to more accurately estimate the potential economic advantages of hybrid power systems.
4) The designing of grid connected wind systems for functioning in an "emergency mode" in the event of cable failure (e.g., Fox Islands) may be worth future consideration.
5) The use of excess energy for distributed heating is an attractive option that should be considered in more detail in future case studies.
6) The inclusion of wind power in hybrid power systems that previously just considered PV only systems could considerably improve the economics of such systems.
7) Attempting to proceed with approvals or permitting would help to identify barriers to the potential deployment of island hybrid power systems.
8) The idea of using small, uninhabited islands as foundations for "quasi-offshore" wind systems is worth future study.

8.0 Acknowledgements

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9.0 References

[1] Geographic Names Information System, *Query Form For The United States And Its Territories*, U.S. Geological Service, http://geonames.usgs.gov/pls/gnis/web_query.gnis_web_query_form, 2001.

[2] Manwell, J. F., Johnson, C., *Wind/Diesel Power System Options Report for Cuttyhunk Island*, Renewable Energy Research Laboratory, University of Massachusetts, Amherst, July 2001.

[3] Energy Information Administration, *Space-Heating Energy Consumption in U.S. Households*, www.eia.doe.gov/emeu/recs/recs97_ce/t2_4c.html, 2002.

[4] National Data Buoy Center, National Oceanographic and Atmospheric Administration, *Historical Data*, www.ndbc.noaa.gov

[5] Rogers A. L., Manwell, J. F., Ellis, A. F., Abdulwahid, U., *Power Plant Options Report for Thompson Island*, Renewable Energy Research Laboratory, University of Massachusetts, Amherst, 1999.

[6] Duffie, J. A., Beckman, W. A., *Solar Engineering of Thermal Processes*, Second edition, John Wiley and Sons, Inc., 1991.

[7] Maine Lighthouses Map and Guide, *New England Lighthouses, a Virtual Guide*, www.lighthouse.cc

[8] Renewable Energy Research Laboratory, *The Hybrid Power System Simulation Model*, University of Massachusetts at Amherst, http://www.ecs.umass.edu/mie/labs/rerl/index.html, 2001.

[9] National Renewable Energy Laboratory, *The Hybrid Optimization Model for Electric Renewables*, http://www.nrel.gov/international/tools/HOMER/homer.html, 2001.

[10] Manwell, J. F., McGowan, J. G., and Blanco, G., *Potential for Wind Energy Development on New England Islands*, University of Massachusetts Renewable Energy Research Laboratory Report, Jan. 2002.

[11] Vinalhaven Historical Society, *A Brief History of Vinalhaven*, http://www.midcoast.com/~vhhissoc/vhistory.htm, 2001.

[12] North Haven Community School, North Haven Island, http://www.midcoast.com/~nhcs/northhaven.html, 2001.

[13] Maps a la Carte, Inc., *TopoZone.com*, http://www.topozone.com, 2000.

[14] Island Institute, *Private Communication*, May 25, 2001.

[15] Monhegan Boat Line, *An Introduction to Monhegan, Maine*, http://www.briegull.com/Monhegan/mibooklet.html, 2001.

[16] Maps a la Carte, Inc., *TopoZone.com*, http://www.topozone.com, 2000.

[17] Northern Power System, *300 kW Diesel Power Plant Supports Monhegan Island*, www.northernpower.com, 2001.

[18] Monhegan Plantation Power District, *Statement of Income and Expenses*, www.monhegan.com/utility, 2001.

[19] Johnson, C., Abdulwahid, U., Manwell, J. F., Rogers, A., Proc Design and Modeling of Dispatchable Heat Storage in Wind/Diesel Systems, AWEA Annual Conference, June, 2002.