Leading Edge Projects Inc.

A Report on the State-of-the-art and Economic Viability

of

Wind Power Development in Arctic Communities

Prepared for

Aurora Research Institute, Aurora College

Inuvik, Northwest Territories

By

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EXECUTIVE SUMMARY

The technology of cold weather wind turbines in the 50 kW to 300 kW range and the available wind-diesel integration technology is ready for sequenced installation in the north. There have been some advances in wind turbines recently and there are also some good quality European wind turbines in the market and a new model by US manufacturer about to enter the market. For some wind turbines tall guyed towers are still lacking. Wind-diesel integration technology has been maturing in other countries and is available and applicable. This equipment is available in both sophisticated prepackaged modules or in less costly formats.

In the author's opinion both the wind turbines and wind-diesel equipment has progressed beyond the experimental. However, further improvements and cost reductions, will, in part, be dependant on the installation of projects to increase the sales volumes for the suppliers. This will also provide project owners an opportunity to work with equipment suppliers to overcome any difficulties. For the suppliers there is a window of opportunity opening up because the higher oil prices and the net metering opportunities are increasing the market for this equipment.

Under a range of conditions wind energy projects can be economically viable in the north at oil prices in the order of $US60 per barrel. The main requirements for economic viability for the initial "leader" wind-diesel projects include: locations with economies of scale, availability of local equipment, availability of local technical human resources, access to reasonable transportation, committed community and project proponent, and a wind resource of 6.5 m/s or higher (depending on local diesel plant fuel cost) at turbine hub height. It is recommended that projects be kept as technically simple as possible to start with, either low or medium penetration. High penetration projects can be expensive and technically complex.

Leader project proponents will require adequate financial and human resources to overcome any difficulties encountered and keep the projects operating. Because wind technology is relatively new and unfamiliar to most people, the provision of training for operating and maintenance staff is important, and time will be required to gain experience. These first projects are likely to cost $5,000 per installed kW or more if done well with good equipment. Following the success of leader projects, and based on the knowledge and experience gained in them, the same proponents could install projects in smaller more isolated communities.

Ideally wind projects should be owned by the diesel plant owners as this will minimize the potential for conflicts (especially in trouble shooting problems) and will provide technical, operational, and management economies of scale.

Good quality wind resource information is lacking for most northern communities. Wind resource data from towers at least 30 meters high with anemometers at 3 levels collected over a period of at least one year (preferable 2 or more) located on potential project sites is required.

Government support for wind energy in the north can make an enormous difference. Programs such as the CanWEA proposed ReCWIP would provide very valuable financial support and would expand the potential for viable wind energy projects to many more northern locations.

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1.0 Background

The Aurora Research Institute (ARI) has found that there is not as much support for the arctic wind power related initiatives that they wish to undertake as they had expected. ARI wished to know if the reason for this weaker than expected level of support was that the wind power generation and wind-diesel integration technology was not yet adequately advanced to make wind diesel projects in the arctic economically viable.

Leading Edge Projects Inc. (Leading Edge) was retained by Aurora College, Aurora Research Institute to assess the feasibility of wind power in diesel dependant arctic communities. Leading Edge researched available materials related to wind energy development in arctic communities, consulted with various wind power developers in Canada and Alaska, consulted with a wind resource assessment specialist experienced in the north, and consulted with various wind turbine and wind-diesel integration equipment manufacturers in preparing this report.

2.0 Wind Resource Assessment

The wind resource available within reasonable distance of any community will be one of the key factors determining the economic viability of any wind diesel project. When screening diesel served communities for the potential to host a wind power project to displace diesel power generation, it is thus one of the key factors used in decision making.

Since the energy content of the wind is proportional to the cube of the wind speed, even small increases in the wind speed a wind turbine is exposed to can make a noticeable improvement in project economics, or vice versa. The wind speed distribution can have a similar although less pronounced effect. It is thus of critical importance that accurate information on the actual site for a possible wind farm be available. Airport wind speed data and wind atlas data can be used as a preliminary screening tool to rule out unsuitable sites or to identify possible sites but any final site selection should be based on actual data.

This also underlines the importance of wind farm site selection near a candidate community. In some locations there are geographic and topographic variations that can be used to advantage in selecting a site. A location on a hill or a ridge can make a significant difference in the wind resource to which the wind turbines would be exposed. These local topographic and geographic differences cannot be picked up by the Canadian Wind Atlas calculation programs, so significant differences between Wind Atlas predictions and actual data, positive or negative, may be encountered. Similarly data from an airport located either in a flat valley or on top of a higher ridge could lead to overly pessimistic or optimistic assumptions.

A January 2005 report by Terriplan Consultants of Yellowknife said: "*Wind energy has been measured in only 15 NWT communities so far. Most of these measurements come from airport-related weather equipment and may not represent the ideal wind energy sites in the community. More detailed assessment work is required to determine if grid-connected small wind systems could provide cost-competitive electricity in diesel-electric communities.*"

The author's experience in wind monitoring (mostly in treed areas) also indicates that lower level (e.g. at 10 meters) wind speed data (at airports or elsewhere) can lead to significant underestimation of the actual wind speed at 30 meters or higher.

Appendix A consists of a table of NWT, Nunavut, Yukon (2 only), and Nunavik (14) communities displaying, as available, various data sets such as the wind speeds at 30 and 50 meters above ground levels (AGL) as predicted by the Canadian Wind Atlas for NWT and Nunavut. In general NWT communities have a lower indicated wind resource than Nunavut communities do. A first screening that could be considered is to 'screen out' any community with a wind speed of less than 5 m/s at 30 m AGL and to 'screen in' any community with a wind speed of 6 m/s or greater at 30 m AGL. Communities with wind speeds of between 5 and 6 m/s could be screened in if taking advantage of the local topography might yield a significant increase in wind speed for a turbine to harvest. The communities passing this test would then be the focus of further work.

A number of the communities in Nunavik (northern Quebec), especially those along coasts, also have significant wind resources. For 14 of these communities some wind speed information was found and these have been added to the table in Appendix A.

In the author's view it is vitally important that wind monitoring using up to date methods and procedures be conducted at candidate wind farm sites. The minimum height of monitoring should be 30 meters and anemometers should be located at a minimum of 3 different heights (for example 10, 20, and 30 meters). Without this information a credible assessment of the viability of a potential project is not possible.

3.0 Wind Power Technology Review

On a global basis smaller scale wind power generation technology, in particular the wind turbines themselves, is relatively mature. However, the bulk of the market at present is in moderate to warm climate applications and the cold climates of the north (or far south) bring their own special requirements to wind turbines and their towers. The special cold weather requirements are less well developed in the smaller turbines and towers, and there is considerably less choice on the market for these products.

Overall the much more sophisticated electronic / digital technology that has made wind-diesel integration possible will require different operating, trouble shooting, and maintenance skills than the comparatively simpler and better known diesel plant technology in use today. Training programs for the operating and maintenance staff is thus important for the success of wind-diesel projects.

There are many wind-diesel systems working around the world, including a report of 8 high penetration wind-diesel systems in Australia. There are several wind-diesel projects in Scandinavia, several in Alaska, but only a very few in Canada. The number of failures of wind turbines in Canada's north has resulted in a justified concern about the viability of these systems.

Those directly involved in wind-diesel project operations contacted by the author consistently stated that the wind power technology was ready for the north, however all did allow that there was still a need for the technology to mature further. A view expressed regularly was that in order for the technology to mature, in particular the cold climate aspects of the technology, more wind turbines would need to be installed and operated in the north. Improvements would come with time and experience.

3.1 Wind Turbines

Wind turbine technology in the 50 to 300 kW size range, and for cold climate applications in particular, had, until very recently, undergone very little modernization over a period of 15 to 20 years. This was likely due to the limited sales in this market segment. Fortunately this trend has been reversed recently with both Entegrity Wind Systems Inc. and Atlantic Orient Canada Inc. spending time and effort overcoming the well known problems in their machines (controls, yaw dampening, and tip brakes included). Those who successfully deploy these machines consider the fundamental components of the machine (generator and gearbox) to be robust and have put considerable effort into their controls as well as their operation and maintenance. Further improvements are coming. An established manufacturer, Bergey WindPower, has recently entered the field and is about to start selling its new XL.50 (70 kW peak) direct drive, permanent magnet generator, wind turbine. It will be available with a range of guyed towers up to 82 meters tall. However, it is not yet known whether there will be a cold weather version available right away. Wind Energy Solutions (WES), a successor to Lagerwey, has recently re-entered the Canadian market with the WES 18 (80 kW) and the WES 30 (250 kW).

The advent of net metering across much of the USA and Canada will increase the market for this size range of turbine. It expected that this increase in sales volume will allow manufacturers to further improve their turbines and potentially reduce prices.

Enercon (a German manufacturer) has a 330 kW turbine, the E33, which is probably the “Cadillac” of turbines in this category. It is a direct drive unit with tubular tower heights of 43 and 49 meters. There are three of these units operating in the Antarctic. Its main disadvantages are the need for a significant concrete foundation and the need for a substantial crane for its installation. Up to now the cold weather operation has been limited to -30°C.

Northern Power Systems have now sold 10 of its first run of the NorthWind 100 wind turbine. It too is expensive and comes with a tubular tower (and the need for a substantial concrete foundation), but it is designed to operate in temperatures down to -40°C.

Fuhrlander of Germany, through its agent Lorax Energy Systems, LLC of Rhode Island USA, manufactures and sells turbines of 100 and 250 kW (as well as a 30kW unit). They have a cold weather design package that will allow operation down to -40°C. These turbines also have tubular towers and thus a need for substantial foundations as well as a crane for installation.

Bergey WindPower has been indicating that they will soon be marketing their new direct drive XL.50 wind turbine. They indicate that it will have two different rotor diameter options and a peak output of 70 kW. Tower heights of 28 meters to 82 meters (reportedly guyed towers) are to be available. At this time it is not known if a cold temperature version suitable for the arctic will be available.

WES Canada (office in Smithville, Ontario) has two turbines of interest. The WES 18 (80 kW) available with a 40 meter guyed tower, and the WES 30 (250 kW) which uses a 50 meter tubular tower. Company officials are concerned about the failures that have occurred in NWT in the past and have said that without a guarantee of professional maintenance they would not sell turbines into northern Canada.

One general trend in the wind industry that could benefit the north too is the development of wind turbines more suited to lower wind speeds. These turbines have a greater swept area than usual for the specified capacity. A relevant example is the new Bergey XL.50 for which both 14 and 16 meter rotor diameters are available. Existing turbines such as the Entegrity EW15 and Atlantic Orient's AOC 15/50 equipped with a larger rotor diameter would generate more energy in moderate wind speeds.

Present potential suppliers for the north are:

Atlantic Orient Canada Inc., AOC 15/50, 60 kW
Entegrity Wind Systems Inc., EW 15, 60 kW
Northern Power Systems, NorthWind 100, 100 kW
Enercon GmbH, E33, 330 kW
Fuhrlander / Lorax Energy Systems LLC, FL100, 100kW; and FL250, 250 kW
Wind Energy Solutions Canada, WES 18, 80 kW; and WES 30, 250 kW

3.2 Towers

Tower designs can be a significant portion of the cost of northern wind projects. Free standing tubular towers usually require a substantial concrete foundation. Concrete in isolated communities is expensive and, in some Alaskan communities at least, aggregate has to be barged in (seasonally) which further adds to costs. Free standing towers also, most often but not always, require a crane for their installation. Crane mobilization and demobilization presents both logistical and cost challenges. Guyed tubular (or lattice) towers, such as those developed by wind turbine manufacturer Vergnet of France (and more recently WES and Bergey), result in greatly reduced foundation and anchor loadings and are thus cheaper to install. Guyed towers are not yet available from turbine suppliers such as Atlantic Orient Canada Inc., Entegrity Wind Systems, and Northern Power Systems, but are available from WES Canada and are reportedly to be available for the Bergey XL.50 turbine. Lattice towers are less desirable in locations where icing is a problem as they provide a great deal more surface area onto which the ice can adhere.

Another tower aspect that is of significant importance is the height. Since the capital costs of building roads and power lines in remote northern communities is expensive, it is generally not practical to go far from these communities to take advantage of local topography to develop the best wind site. As a consequence the only alternative for increasing the wind resource which the turbine is harvesting is to put it on a taller tower. While taller towers cost more than shorter towers, the percentage increase in energy capture is usually in excess of the percentage increase in project cost. Bluntly speaking it is cost effective. However the turbine manufacturers that have the smaller turbines suitable for the north have not yet designed such towers, mostly they still have 25 and 30 meter towers. The exceptions are the Enercon E33 330 kW, the Fuhrlander FL250 250 kW, and the WES turbines which have towers between 40 and 50 meters available. In a location with a modest wind resource a 50 meter tower would increase the energy output of a turbine by about 20% over a 25 meter tower (wind shear coefficient of 0.16).

Taller, guyed towers can be designed (Vergnet of France and WES have done so) – it is simply a case of vendors needing customers for them to justify designing and building them.

3.3 Wind-Diesel Integration

Key components of wind-diesel integration include, depending on a whether low, medium, or high penetration system is installed, some or all of the following: controllers for the wind turbines, an overall master controller for the wind plant, modern digital governors for the diesel plant if not already so equipped, an overall modern controller for the diesel plant if not already so equipped (ideally one that combines the control of the diesel plant and the control of the wind plant into one), a dump load boiler or equivalent, a low load diesel, and a synchronous condenser. Other components may also be required or desirable.

The wind-diesel integration equipment is less weather dependant than wind turbines as this equipment is normally housed in a heated building such as the diesel plant or in temperature controlled enclosures. In practical terms this means that the development and maturation of this technology anywhere in the world is applicable anywhere else. The north can thus benefit from the development work done elsewhere. This is readily apparent in the relative maturity of the wind-diesel integration equipment from The Powercorp Group of Australia. Australia has many isolated regions, much like northern Canada, except that their climate is hot. Powercorp wind-diesel equipment is available in North America through its subsidiary, Powercorp Alaska, LLC, located in Anchorage, Alaska.

Another company with relatively mature wind-diesel integration equipment is Northern Power Systems (NPS) of Vermont USA. They have been in the wind-diesel and alternative energy business for many years. This company has also designed and built for the north a 100 kW direct drive wind turbine, the NorthWind 100. It can operate in temperatures down to -40°C. Ten of these wind turbines are now deployed, or about to be deployed, in Alaska. These machines tend to be expensive and require a crane for installation. Foundations for free standing towers can also be expensive, see comments under foundations and civil works.

Frontier Power Systems (FPS) of Prince Edward Island (PEI) also has a wind-diesel integration system, one that is more economical that those of Powercorp and NPS. This system is based on FPS's principal Carl Brothers' experience in wind diesel integration work at the Atlantic Wind Test Site, and in cooperation with the wind-diesel test bed work done at IREQ (Quebec Hydro's research group) in Varennes. The FPS system has been installed in their own wind-diesel project in Ramea (on an island off Newfoundland). This system can be replicated for other projects but FPS does indicate that their system, while lower in cost, may not be as mature as Powercorp's or NPS's systems.

Modern digital governors for the diesel generators will be required to ensure that the diesel generators can respond as quickly as the wind fluctuates. This is required since the output of wind turbines will change quickly with changes in the wind (gustiness). Without fast acting governors there will be fluctuations in the frequency and / or voltage of the power system.

The overall diesel plant control needs to accommodate the control of the wind turbines either directly if the power plant controller has the capacity to do so (or if a new one that can do this is installed), or by interfacing with the wind plant controller. Digital governors and plant controllers are existing mature technology. However any given diesel plant may require modernizing to accommodate a wind plant.

Low load diesels, those with the ability to operate effectively at a very low percentage of their rated capacity, may be required if the existing diesels in the plant are not capable of doing so. These may be purchased as a complete package such as provided by Powercorp, or may be purchased directly from manufacturers and installed as any other unit in the diesel plant fleet. Some modern diesels are capable of carrying a load that is a relatively low percentage of their rated capacity. Low load diesel technology is available but is relatively new and any given diesel plant may or may not be equipped with these units.

Boilers equipped with a large number of small capacity heating elements are often used as a means of leveling out the fluctuations of wind power. A fast acting controller will add or drop heating elements (or otherwise vary the load on larger heating elements) as the power output from the wind plant increases or decreases. In projects with a substantial wind penetration a specified minimum capacity kept on at all times can help smooth the effect of a turbine trip. Boilers and their heating elements are standard off-the-shelf technology. The Controllers are also fairly standard electronic pieces of equipment, but their programming and speed of action are aspects that will require special attention. Details will vary from project to project. Dump loads, such as electric air heaters, will function in the same manner as a boiler (which is essentially a dump load too) but these may or may not be situated so that the dumped energy can be recovered. The purpose of a boiler is to capture and make use of the energy that would otherwise be wasted.

If a diesel plant is to be shut down to allow a wind power plant to service all of the electrical load (high penetration system), the grid frequency needs to be maintained by a device such as a synchronous condenser. Synchronous condensers have been around for a long time and are quite "standard" although typically designed for each specific application. They do consume power in their operation, power which would be produced by the wind plant and which will then not be available to displace diesel fuel. A generator can be decoupled from its diesel engine (with the use of a clutch) to serve as a synchronous condenser.

An energy storage device such as a battery bank (or a spinning flywheel) will also be required in a high penetration system. The energy storage device is typically designed to serve the electrical load while allowing the diesel plant time to start up and pick up the load if the wind suddenly drops off or if a wind turbine shuts down or if the power line from the wind plant trips off. It can also absorb significant fluctuations in the output of the wind plant that do not involve trips. Energy storage devices tend to be relatively expensive and they consume power (wind power). Battery banks with their charging systems and inverters to store and draw out the power are standard common and mature technology. Other energy storage devices such as Powercorp's PowerStore™ flywheel storage system, represents newer, less mature technology. It is also more expensive technology than batteries at present, but it does have a significant capacity and some advantages.

When a wind plant is providing for all of a community's energy requirements and the diesel plant it shut down, it will need to be kept in a state of readiness for restarting at any time. This means that the building will need to be kept at a reasonable temperature and that the individual engines will need to be kept hot and ready to start and pick up load within minutes. In diesel power plants the heat from the engines (including from their block cooling and exhaust systems) is typically used to keep the building warm and any non-operating engines on hot standby. With the diesel plant shut down this heat will need to be provided by a boiler system that uses either wind energy or is oil fired or a combination of the two. This technology is common, known and "off-the-shelf", however it does represent a capital and operating cost to the wind project because it would not otherwise be needed.

Appendix D contains some literature on wind diesel integration systems produced by Powercorp of Australia. This is not to indicate that the author promotes Powercorp's products over other suppliers, it just indicates that Powercorp has some well written and presented information.

3.4 Wind penetration levels

The level of diesel energy displacement by wind energy is called the wind penetration level. Penetration levels are typically simply categorized into low, medium, and high. Low penetration is the displacement of up to about 10% of the diesel energy by wind, and would usually be accomplished in a small community by connecting one (or more) wind turbines, the "wind plant", to the system. The wind plant would need to be small enough so that the diesel plant can continue to operate as it previously would have. The only difference is that the diesel plant will "see" a slightly lower electrical load. The low penetration option requires a minimum amount of wind-diesel integration equipment. The diesel governors need to be able to respond to the fluctuating output from the wind plant, but aside from that only the physical connection and electrical protection are needed. The wind plant will have its own controller which is a normal part of a wind turbine package. The disadvantage of the low penetration approach is that the cost per kW of installed wind capacity may be high because there would be no economies of scale in the size of the project. Operations and maintenance (O&M) costs per kWh of energy produced will be higher for the same reason while the savings on diesel fuel are limited.

In medium penetration wind projects the installed wind capacity will be such that there will be more wind power than the diesel plant can accommodate at windy times. This occurs when the available wind power would reduce the diesel plant loading below the minimum allowable level on the smallest available diesel generator. When this happens the excess wind energy will need to be dumped. Overall diesel fuel displacement can be up to 25%. The equipment required to achieve medium penetration includes a dump load, a dump load controller, and a more sophisticated diesel plant controller, or an overall diesel and wind plant controller, to accommodate the higher level of wind energy and its fluctuations. A low load diesel may also enhance the achievable penetration level. Advantages of a medium level of penetration include a greater economy of scale in the purchase and installation of the wind plant capacity (a larger turbine or a greater number of smaller turbines), reduced O&M costs per kWh for the same reason, and a greater diesel saving.

A high penetration wind project would typically displace from 25% to 40% of the diesel energy and possibly as much as 50% in a wind rich region. In practical terms this requires, at windy times, the diesel plant to be entirely shut down but maintained in a state of hot standby so it can start very quickly again as needed. A high penetration project requires the greatest amount of integration equipment and the most sophisticated equipment. There will be an excess of wind energy at windy times and for the project economics to be optimized, the excess wind energy will need to serve a useful function – such as space heating. In addition to the equipment described in the medium penetration case, required equipment includes a diesel plant heating and engine hot standby system, an energy storage system, a frequency regulation system such as a synchronous condenser, a boiler or other useful dump load system, and a sophisticated overall power system controller that regulates all of the equipment listed and maintains power quality and reliability to the community.

The advantage of a high penetration system is that it provides the greatest economy of scale in the purchase and installation of the wind plant (size and number of turbines) and the greatest level fuel saving. Wind energy O&M costs would be minimized for the same reason. The disadvantages are that the amount and sophistication of the equipment needed can drive up the capital cost significantly and the power requirements for this equipment detracts from the diesel displacement. The smooth operation of this equipment and its maintenance will be a challenge until operating and maintenance staff become very familiar with them. There is also a power requirement for the operation of the integration equipment which must be supplied by the wind plant, directly or indirectly. This power requirement is sometimes called a parasitic or station service load.

3.5 Anti-icing technology

There are some locations in which the icing of wind turbines, which can cause a reduction in power output, is a significant concern. The icing is due either to the proximity of open water under cold conditions, or extended extreme cold weather and ice fog, or because of the altitude at which the turbines are to be located to access a good wind resource. There are some effective mitigation measures available. For turbines that require wind instruments (anemometers and wind vanes) for their control, heated instruments are readily available and are proven, mature technology. There is also a black blade coating available (StaClean™) that has a low adhesion surface for ice and that absorbs solar energy (when available) to assist in blade de-icing. This coating has been shown to be effective in the north. Again this is an “off-the-shelf” product that can be applied by qualified painting contractors.

Where the icing is severe and the “passive” mitigation features described above are not adequate the only option is a blade heating system. Blade heating systems have never been produced in any quantity, and until one supplier came to the author’s attention recently (located in Finland), there had been no known commercial suppliers. A second potential supplier is located in the US but this supplier still needs a significant customer to help bring the product to market. There are custom designed blade heating systems in operation in Finland, Sweden, and in Yukon. However, this technology cannot be considered “off-the-shelf” at this time; but there is at least the appearance of light at the end of the tunnel on this matter. The cost and overall economic benefit of such a system would need to be demonstrated in actual performance in the north.

3.6 Suppliers of wind-diesel integration systems

There are a several wind-diesel integration system equipment manufacturers. Those known to the author include Powercorp, Northern Power Systems, Frontier Power Systems, Enercon, Sustainable Automation, PitchWind, and Wind Energy Solutions. There are probably others.

3.7 Wind turbine manufacturers promote wind-diesel systems

There are several wind turbine manufacturers that supply wind diesel systems or that promote their turbines for wind-diesel systems. Those with wind diesel systems include Enercon, Northern Power Systems, PitchWind (not sure if they make products suitable for the north), and Wind Energy Solutions (the author has no detailed technical information on their products at the time of writing). Those that promote their products for use in wind-diesel systems include Entegrity Wind Systems Inc., Atlantic Orient Canada Inc., Fuhrlander, and Vergnet (does not have suitable products for cold climates at present).

4.0 Foundations, and Civil Works

The foundations for wind turbines can be a significant cost component of a wind project. In particular there are locations where there is ice rich permafrost in silt that is at risk of degradation due to global warming (this is the case in a number of Alaskan coastal communities). This makes the foundation design particularly tricky and expensive. A complicating factor can be the lack of a supply of aggregate, as is the case in some areas of Alaska. Where aggregate needs to be barged in it will be expensive and add significantly to the cost of foundation and road construction. These factors favour the use of guyed towers for which foundations and anchors are less demanding. Unfortunately the environmental regulations (bird impact concerns) in Alaska are such that guyed towers are not an option there at present. This leaves Canada alone to develop these towers as they are not yet available for the cold weather turbines on the market.

The further development of helical screw pile anchoring systems (such as the AB Chance helical screw type of anchors) would reduce the installed costs for the turbine towers now available and the guyed towers that we hope will be designed soon.

The ideal location for wind turbines in isolated communities is on bedrock where standard rock anchoring systems, which are cost effective, can be used. In these locations it is unlikely that aggregate supply would be a problem.

The cost of power line construction for wind turbines located some distance from a community will generally follow the cost trend for wind turbine foundations. In ice rich unstable permafrost the costs will be high, and in dry and rocky locations the costs will be substantially lower.

Other civil works, including buildings and their foundations, will follow similar cost patterns.

5.0 Present Cost Experience

A review of the historical capital costs (adjusted to present value by adjusting for inflation) for the installation of wind projects indicates a wide range has been experienced. In Northwest Territories (NWT), before the formation of Nunavut, the NWT Power Corporation (NTPC) costs for various projects have ranged from about $4,500 per installed kW to over $8,000 per installed kW. Granted there were special circumstances driving up the capital cost in most of these one or two wind turbine projects, however, the costs are significant.

Yukon Energy’s experience with two grid connected turbines, one in 1993 and one in 2000, are inflation adjusted costs of over $5,000 per kW to about $3,400 per kW. In this case there were significant costs for power line reconstruction, road upgrading, and custom anti-icing (blade heating systems) included.

The author’s examination of a potential project in a road accessible small diesel served community (125 to 250 kW load, average about 175 kW) suggested that costs could range from $5,000 per kW to about $9,000 per kW depending on the number of turbines involved and the level of wind penetration in the configuration. Costs would be higher for communities without road access. The author admits to a bias of being quite conservative in cost estimating – estimating higher rather than lower.

A very interesting result of the author’s examination of this potential wind project (wind speed 6 m/s at 30 meters) was that the medium penetration option yielded the lowest cost wind energy. The high penetration option was high cost because of the significant amount of additional equipment required compared to the low or medium penetration options, and the amount of power consumed by this equipment. The author estimated that both the low penetration (one EW15 turbine) and the high penetration (five EW15 turbines) projects would displace diesel power at $0.55 per kWh whereas the medium penetration project (three EW 15 turbines) was projected to displace diesel at $0.44 per kWh. It was calculated that increasing the wind turbine tower height from 25 to 50 meters would reduce the cost of energy in the medium penetration case to about $0.34 per kWh. The lesson from this analysis is that it may not be cost effective in small communities to go to high penetration systems because of the high fixed costs of the wind-diesel integration equipment required. Smaller simpler projects may be more cost effective.

The most recent (anecdotal) information from the wind-diesel projects using 60 and 100 kW turbines in small remote communities in Alaska, seems to be indicating capital costs in the order of $CDN10,000 per kW. These coastal communities suffer from unstable permafrost and a lack of aggregate. Most also have outdated diesel plant controls so a major diesel plant upgrade is typically required and completed as part of the project.

Presentations by Hydro Quebec staff to the International Conference on Wind Energy in Remote Regions in October 2005 described two wind-diesel projects planned by the utility. One will be on Iles de la Madeleine where a 300 kW first phase of a wind-diesel project will be installed in 2007 at a cost of about $8,300 per kW. The second project is a 1,300 kW high penetration (no storage) wind-diesel project planned for Inukjuak for 2008 at an estimated cost of $7,600 per kW.

A 2004 presentation on Hydro Quebec's prospects for wind-diesel projects indicated that for 7 of the 14 Nunavik communities examined, high penetration no storage wind-diesel projects would be economic (these would have positive net present values). And since 2004 fuel prices have increased substantially. Hydro Quebec's discount rate is 5.2%, substantially lower that the 8% used by the author in the preparation of the economic analyses that form part of this report.

The history on maintenance costs also indicates a wide spread in cost experience. Most of the projects by NTPC failed or required an enormous level of technical intervention by NTPC. If the costs were to be fully accounted for on a per kWh basis the figures would be astronomical. Yukon Energy recently indicated in a public utilities board hearing that their O&M costs for wind power were in the order of $0.08 per kWh.

The information available from Alaska indicates that the maintenance costs would probably range from about $CDN0.05 per kWh in smaller projects to less than $CDN0.01 in a larger wind farm applications. No information on the allocation of operating costs other than maintenance was available.

In the author's view it would be realistic to expect O&M costs to be in the order of $0.05 to $0.10 in somewhat larger projects and probably more like $0.10 to $0.15 in smaller projects. The project ownership structure will have a significant bearing on this cost as a small independent power producer with one wind project is likely to have higher overhead costs than a utility that already owns the diesel plant in the community.

6.0 Recommendations from Project Developers

There are a number of recommendations and comments that were received from project developers in Canada and Alaska. Included are the following:

Wind-diesel technology is past being experimental and ready for sequenced installation starting with "demonstration" projects. A prudent approach would see the bugs worked out and experience gained in larger communities, before projects are replicated in smaller and more remote communities. These first projects must be large enough to have some economies of scale in the wind project, a reasonable amount of construction equipment, and some level of technical support available. A suitable wind resource, one that can be expected to yield a capacity factor of at least 25% in a wind plant, is also a necessity. The community must be committed to the project.

For a jurisdiction or a utility to start into wind energy they should begin with a "pioneer" project. This pioneer project should have economies of scale (larger project size), access to local equipment, access to technical staff, and above all have a core project staff that is committed to the success of the project. There will be much to learn (significant training required), experience to gain, and there will be difficulties to overcome. Once this pioneer project is up and running successfully, other smaller and more isolated projects can be planned and installed using the experience gained in the first project and replicating the first project as much as possible.

It would be wise to start projects as low or, at most, medium penetration projects if at all possible and to increase the penetration level when experience and comfort in the wind turbines and wind-diesel system permits. High penetration projects are much more sophisticated and are thus much more difficult to deal with, especially with inexperienced operating and technical staff.

There must be a high level of commitment to a wind project in any community where a project is constructed. Without this community commitment there will be problems and the project will either be less successful than it can be or will be a failure.

Stay with consistent equipment technology and equipment suppliers as much as possible so that projects can use similar architecture and the knowledge and experience gained by staff is transferable.

The geographical grouping of projects (including locating subsequent projects near pioneer projects) can help keep cost down, and provide nearby expertise and support when needed.

Ideally install wind projects at the same time as diesel plants are being upgraded (controls at least) so that the controls for the diesel plant and the wind plant are compatible. Modern digital governors for the diesels are a requirement for a wind project to interface successfully with the diesel plant. Wind plants will not work properly with older diesel governors and plant controls.

The required civil works for a wind project can be very tricky and very expensive. Geotechnical investigations and design / preparations need to be started well ahead of time. Innovative solutions may be required. Overall project timing from start to finish can easily be 3 years in an isolated community.

There would be a great cost and practical advantage to having wind turbine towers that are guyed and designed to be easily winched up and down. Guyed towers are not presently allowed in Alaska. As a consequence recent Alaskan wind projects required the use of a crane, and could only be done cost effectively in conjunction with other community projects that also need a crane. There is thus a vulnerability to future major maintenance that requires a crane.

Tubular towers provide more comfortable maintenance access and are less risky for staff compared to lattice towers.

At present AVEC looks for sites with a class 4 wind resource (6.5 to 7.0 m/s at 30 meters above ground level) or better for their potential projects.

There is a need for cost competitive wind turbines in the 100 to 300 kW size range. Enercon has a 330kW turbine but up to now has not been prepared to sell its products into the USA due to patent dispute issues. It was said that Enercon may make an E20 100 kW turbine available again.

Alaska expects costs to be in the order of $CDN10,000 per kW for high penetration projects in the near term and come down to about $CDN6,500 per kW in the longer term. Accepting a higher risk of outages, and somewhat greater permissible voltage and frequency excursions on the power system would likely allow capital costs to be reduced further by reducing equipment costs.

For project success the best wind project ownership arrangement is to have the diesel plant owner also own the wind plant. There has been some experience with an independent power producer (IPP) owning a wind plant and this has resulted in some conflicts between the wind and diesel plant owners and less wind penetration and less diesel savings than would have been possible with the same owner. There must be a very high level of cooperation between the wind plant and diesel plant owners / operators as a minimum.

7.0 Kotzebue, a model to follow

The failures in wind projects in Northwest Territories and Nunavut can lead one to believe that wind-diesel projects can perhaps not be done successfully in Canada’s north. However, the author is of the opinion that wind-diesel projects can be done successfully if done with care and planning and a determination to succeed. If the advice of the experienced professionals quoted above is followed and put together what do we have? In essence we have the successful Kotzebue Alaska wind-diesel project.

Kotzebue, located north of the Arctic Circle on Alaska’s west coast on tundra and permafrost, has about 4,000 people. It serves as a local hub community to 10 other communities. It has a diesel plant with 11 MW of installed capacity. It started wind energy efforts with a small low penetration project and, as experience was gained, it expanded its wind farm in stages. The experience gained here is now being used to assist in the design and installation (and maintenance) of wind projects in the surrounding smaller communities of Wales, Selawik, Toksook Bay, and others.

In putting together their wind-diesel project and its expansions, Kotzebue Electric Association (KEA) made full use of various state and federal support programs to help reduce costs and mitigate risks. Kotzebue first ventured into wind energy in 1997 with the installation of 3 AOC 15/50 wind turbines (about 60 kW capacity). In 1999 7 more AOC wind turbines were installed, in 2002 a NorthWind 100 was installed, and in 2004 another 2 AOC turbines were installed. This year, 2006, another 3 Entegrity EW 15 turbines (a new name for the AOC 15/50 from a new owner) are set to be installed.

KEA's determination to make the project successful is reflected in the positive operational experience with the AOC wind turbine. This turbine and its controls had a number of challenges and the company was, it seemed, in continuous financial difficulty making product deliveries and product support a problem. KEA persevered and has developed considerable expertise in the operation and maintenance of these turbines. Their maintenance costs are in the order of $0.01 per kWh, an exceptional achievement!

Appendix B contains a significant amount of information on the Kotzebue project and its positive effect including two presentations (2002 and 2004), information from their website, extracts from presentations on wind-diesel projects in Wales and Selawik (2004), and a copy of various news releases including one story that appeared in the Juneau Empire on November 13, 2005.

In the author's opinion the KEA wind-diesel project is an excellent example to follow: start with a simple project in a larger community that has some economies of scale, equipment, and expertise and grow from there as experience is gained and problems overcome. With a core of experience and expertise built up, these resources can then be used to establish projects in smaller communities.

8.0 Project site selection criteria

The author believes that the following criteria should be used for the selection of the "leader" wind projects (or "demonstration", or "pioneer" projects if you prefer) that have a high probability of success. They are listed in the author's view of the order of importance with the most important first.

1. A project proponent with the financial and human resources to make the project work and the determination and financial incentive to overcome difficulties to make it successful;
2. A community committed to the wind project (local champions) and of adequate size to provide an opportunity for some economies of scale;
3. Good transportation access;
4. Good access to technical support;
5. Reasonable wind resource; and
6. Reasonable geotechnical conditions.

Once the leader project is up and running well and local staff have been trained and are comfortable with the wind-diesel project, subsequent projects can be selected based on the following criteria, again in order of the author's view of importance.

1. Community commitment;
2. The ability to replicate the leader project;
3. Good wind resource;
4. Reasonable access to technical support; and
5. Reasonable transportation access.

9.0 Simplified Economic Analyses

The examination of the economic status of potential wind projects was based on calculating the effect of a range of values for key variables. This means that the determination of economic viability requires looking at a multi-dimensional picture. For simplicity's sake some less important variables, or variables that could be determined or predicted with relative ease, were fixed. These include the fuel efficiency of diesel plants, the energy recovery of wind turbines at different wind speeds, implicitly the wind speed distribution (Rayleigh distribution), turbine availability, and wind plant losses (non-diesel displacing theoretically recovered energy). This permitted the effect of key variables to be presented in a series of tables. The key variables include project capital cost, project operating cost, wind speed, and the cost of fuel to the diesel plant. Appendix C presents the spreadsheets used in these calculations.

The values used for the less important variables are as follows. It was assumed that a wind project would consist of three AOC or Entegrity wind turbines representing an installed capacity of 180 kW. The theoretical energy recovery in kWh is based on the manufacturer's curves which in turn are based on standard temperature and pressure, and a Rayleigh wind speed distribution. No adjustments to these figures were made for the purpose of the economic calculations. A turbine availability of 95% was used, perhaps optimistic based on history, but this should be achievable in a good project. Wind system losses (non-diesel displacing energy was assumed to be 10% on the basis that the project would be low to medium penetration. While the energy efficiency of diesel-electric plants varies depending on several factors, a plant efficiency of 3.50 was used as a base case. A table showing how the cost of diesel energy varies with diesel plant efficiency and the cost of fuel is provided so that the reader can see the relationships. The capital cost was amortized over 20 years with annual mortgage style payments at an interest rate of about 8% (20 annual payments of 10% of the initial capital cost).

The key variables presented in each spreadsheet are the capital cost of the project (on a per kW of capacity basis), the wind speed (from 5.0 to 9.0 m/s), and the cost of diesel fuel. A series of three spreadsheets presents the cases of three different levels of annual operating costs, $5,000 per turbine (low), $10,000 per turbine (medium), and $15,000 per turbine (high). As the terms imply, the author believes that an annual operating cost of $10,000 per turbine in a three turbine project should be considered reasonable. With respect to capital costs, however, it is much more difficult to make a definitive pronouncement. Recent experience in Alaska and Hydro Quebec's plans indicate that a well executed project is likely to cost between $5,000 and $10,000 per kW in an isolated community. In the author's opinion a cost in the range of $4,000 and $7,000 should be achievable in a carefully chosen and tightly run project. Based on the experience of the leader project it should be possible to reduce the cost of subsequent projects.

The present cost of fuel in most NWT communities was not available to the author. Using world crude oil prices over a number of years and various data sets that were available, the cost of diesel fuel with crude oil valued at about $60US per barrel was estimated. The cost of diesel fuel in the more accessible communities (accessed by barge) is likely in the range of $0.80 to $1.00 per liter. This means that the cost of diesel generated energy is in the range of about $0.23 per kWh to $0.29 per kWh. In the least accessible communities the cost is likely in the range of $1.00 to $1.25 per liter or about $0.29 to $0.35 per kWh. In the community of Old Crow in Yukon which is accessible only by air, the cost of fuel has recently been running in excess of $1.40 per liter, however the author is not sure that there are any communities in this category in NWT or Nunavut. In the analyses performed by the author it seemed that the increased price of crude oil in $US per barrel resulted in approximately the same increase in cents per liter in diesel fuel. The ratio if increase in Old Crow was slightly higher. Whether this rough relationship would continue to hold for further significant increases in the cost of oil is not known.

The spreadsheets indicate that under a number of realistic values of key variables wind projects in NWT would be economically viable. At a capital cost of $5,000 per kW and a medium operating cost, a wind speed of about 7.5 m/s in a more accessible community would result in an economic project at present fuel costs. For a less accessible project location a wind speed of about 6.5 m/s would suffice to create an economic project at present fuel costs. If the capital costs were to increase to $6,000 per kW the required wind speeds would be about 8.0 m/s and 7.0 m/s respectively for the more and less accessible communities.

The need for a reasonable wind resource for leader projects to be economic and the need to manage capital costs is evident, but the information clearly indicates that economic projects are within reach. While the sensitivity to interest rates was not calculated they do have a significant impact on project economics. A reduction from the 8% used in the analyses to 5% is equivalent to a reduction in capital costs from $5,000 per kW to $4,000 per kW. This is obviously also a variable to be taken seriously in project planning.

An increase in turbine hub height from 25 to 50 meters can increase the accessible wind speed from 6.0 m/s to about 6.7 m/s (wind shear coefficient of 0.16) and increase the energy capture by about 20%. The benefit of the availability of taller towers for wind turbines in remote communities is thus very significant.

Should the federal government implement a WPPI type of program for remote, isolated communities that provided a cost incentive of about $0.10 per kWh (proportional to WPPI for wind farms in the south), the threshold wind speed for economic project viability would drop by about 1 m/s, again very significant. Support for projects by the territorial governments or their utilities would, of course, have similar benefits.

The author would like to note that projects that are poorly done or that use unreliable equipment in an effort to save capital costs are likely to produce expensive energy. Projects that use reliable equipment, or projects that have proponents with the financial resources to make the available equipment reliable, are much more likely to be economically viable, regardless of capital cost.

10.0 Roles of Territorial Governments and their Power Utilities

Given the nature of northern Canada, it would be desirable and advantageous for the three territorial governments and their utilities to get together to develop a single consolidated approach to staged wind development in the north. Coordination would result an organization with some clout and would spread the cost of the early phases of systematic wind project development.

The territorial governments and their wholly owned electric utilities and energy corporations could play a role in the development of a tall guyed tower for smaller wind turbines. The development of more cost effective foundations and anchors for permafrost is another item that can be worked on. Equipment suppliers too can and should be part of the mix, they must stand behind their equipment to ensure it performs up to specification and they must be committed to overcoming the difficulties if it does not.

11.0 Role of Federal Government

The federal government can provide very valuable support in several ways. First is to provide, through NRCan, a wind energy support program equivalent to the WPPI for the south. The CanWEA proposed ReCWIP, for example (see Appendix E), would make an enormous difference to the number of northern communities in which wind-diesel projects can be economic. The federal government can also consider providing some capital financial support for leader projects (financing or financing guarantees) through ReCWIP or separately. Indirectly, the CanWEA proposed Small Wind Energy Incentive Program (SWEIP – see Appendix E) to provide purchase incentives for wind turbines for the grid connected net metering market can also benefit the north. SWEIP would increase the market for the size of turbines of interest to the north thus leading to better quality products at competitive prices.

Second, NRCan can increase their level of R&D financial support available to manufacturers to help them develop the products required for north. A 50 meter guyed tower for turbines of 50 to 60 kW (such as the Entegrity and AOC turbines) is one good example.

Third, INAC can be encouraged to ensure that their programs support and encourage the development of wind projects.

Fourth, all federal and territorial government departments pay very high power rates in the north and they can insist on procuring renewable energy wherever possible so that the subsidies that they are effectively paying are channeled into renewable energy forms, including wind.

Leader projects should aim for installed costs of $CDN5,000 per kW or better, and the longer range target should be to install projects at $3,500 per kW.

12.0 Conclusions

Wind-diesel equipment is ready for staged installation in the north. This equipment cannot be expected to “mature” further and come down in cost without the installation of projects to increase the sales volumes of this equipment. Further project installation experience will result in the development of innovative approaches to improving product performance and to reducing costs in subsequent installations.

Deployment of wind energy in the north needs to proceed on a carefully planned and staged sequence starting with “leader” projects and branching out from there. Initial projects are likely to cost $5,000 or more per kW of installed capacity and, depending on other factors, could be economically viable in wind regimes as low as 6.5 m/s annual average. The Kotzebue Alaska wind-diesel project is a very good example to follow.

There is a need for good quality wind resource assessment at potential wind project locations in many communities in the north. Only airport and wind atlas information is presently available for many communities and these are only adequate for the screening of potential wind project sites. Airport and wind atlas data are not adequate to conduct the accurate wind project economic analyses on which wind project decisions must be based. Monitoring should consist of towers of at least 30 meters in height and have anemometers located at three elevations (for example at 10, 20, and 30 meters) to determine the wind shear. These towers should be located at actual potential wind turbine installation sites or be representative of such sites. They should not be located at sites of convenience where neither wind turbine installation nor correlation to a potential wind project site is possible.

The list of communities with potential to host a leader project site based on the suggested screening factors should be highest on the priority list for wind monitoring work if suitable data does not already exist. Other potential subsequent community wind project locations should be next on the list.

Government programs in support of wind energy in the north can make a substantial difference to the viability and expansion of wind-diesel systems in the arctic.

References

Arctic Energy Alliance, personal communication

Arctic Energy Alliance, **"Review of Technical and Economic Viability of Wind Energy Systems in the NWT and Nunavut"** January, 2000

Atlantic Orient Canada Inc. literature and web site www.atlanticorientcanada.ca

Aurora Research Institute, **"Pre-Feasibility Analysis of Wind Energy for Inuvialuit Region in Northwest Territories"**, 2003

Bergey Windpower Company literature and web site www.bergey.com

Brothers, Carl, General Manager, Frontier Power Systems Inc., personal communication

Drouilhet, Steve, **"Overview of the High Penetration Wind-Diesel System in Wales, Alaska"**, Wind Powering America: Wind Diesel 2004 Proceedings, September 2004

Drouilhet, Steve, **"Overview of the Medium Penetration Wind-Diesel System in Selawik, Alaska"**, Wind Powering America: Wind Diesel 2004 Proceedings, September 2004

Enercon GmbH literature and web site www.enercon.de

Environment Canada, Canadian Wind Atlas web site www.windatlas.ca

Entegrity Wind Systems Inc. literature and web site www.entegritywind.com

Fuhrlander AB literature and web site www.fuhrlaender.de

Kotzebue Electric Association web site http://.kea.coop/home/

Maissan, John **"Wind Power Development in Sub-Arctic Conditions with Severe Rime Icing"** Circumpolar Climate Change Summit and Exposition, March 2001

Meiners, Dennis, Senior Project Engineer / Project Manager, Powercorp Alaska, LLC, personal communication

Northern Power Systems Inc. literature and website www.northernpower.com

Northwest Territories Power Corporation, personal communication

Northwest Territories Power Corporation web site www.ntpc.com

Northwest Territories Public Utilities Board web site www.nwtpublicutilitiesboard.ca

Petrie, Brent, Manager, Special Projects, Alaska Electric Village Cooperative Inc., personal communication

Pinard, J. P., J.P. Pinard Consulting Engineer, personal communication

PitchWind Systems AB web site www.pitchwind.se

Reeve, Brad, General Manager, Kotzebue Electric Association, personal communication

Reeve, Brad, **"Kotzebue Electric Association Wind Projects"**, Wind Powering America: Wind Diesel 2002 Workshop Proceedings, September 2002

Reeve, Brad, **"Kotzebue Wind Farm Operational Experiences"**, Wind Powering America: Wind Diesel 2004 Proceedings, September 2004

Roussy, Marie-France, **"Wind Energy in Autonomous Grid Division in Hydro-Quebec"**, International Conference on Wind Energy in Remote Regions, October 2005

Saulnier, Bernard, **"Update on Wind-Diesel Prospects in Nunavik"**, CanWEA Conference, October 2004

Sustainable Automation LLC web site www.SustainableAutomation.com

Terriplan Consultants, **"Distributed Energy in the NWT, Background Paper"** January 2005

The Powercorp Group literature and website www.pcorp.com.au

The Yukon Electrical Company Ltd., personal communication

Vergnet literature and web site www.vergnet.fr

Wind Energy Solutions BV website www.windenergysolutions.nl

Yukon Energy Corporation web site www.yukonenergy.ca

Yukon Utilities Board, personal communication

APPENDIX A

Excel table of communities in the north

APPENDIX B

Information on Kotzebue Electric Association’s wind-diesel project

APPENDIX C

Details of economic analyses

APPENDIX D

Powercorp wind-diesel equipment

APPENDIX E

CanWEA proposed ReCWIP and SWEIP programs