Leading Edge Projects Inc.

Technical Aspects of a Wind Project for Tuktoyaktuk, NWT

Prepared for

AURORA RESEARCH INSTITUTE
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By

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FOREWORD

The work described in this report was completed by a team of four professionals, Carl Brothers P.Eng., of Frontier Power Systems; J.P. Pinard, P.Eng., Consulting Engineer, Tim Weis, P.Eng., of Pembina Institute, and John Maissan P.Eng., of Leading Edge Projects Inc. John Maissan provided the coordination of the work and the consolidation of the components into a single report. John Maissan would like to acknowledge the significant contribution of each of the professionals to the overall project. Collectively we thank the Aurora Research Institute (ARI) for the opportunity to work on this project. Also, we would like to thank the many government, non-government organizations, and private enterprise people we contacted for their helpfulness in providing us with information and data necessary to the completion of the report. The task would have been so much more difficult without their assistance.

The document ***Framework for the advancement of a wind development project in Tuktoyaktuk, NWT*** (Appendix 1) listed six sections, each with a number of topics for further work that would assist in the advancement of a potential wind development project in Tuktoyaktuk. This work represented in this report covers the four technical sections but does not cover “Communications / social” and “Governance” as these are considered to be proponent specific. For convenience, this report is arranged into the four technical sections, but some the topics have been rearranged or consolidated to improve the overall “flow” of the report.

EXECUTIVE SUMMARY

The regulatory processes that a wind project in Tuktoyaktuk would need to follow include an Environmental Impact Screening Committee process, as well as land use and community zoning issues. The requirements appear to be relatively straight forward but will require some time for community input. Since the suitable wind development sites identified are within 4 km of the airport, Nav Canada and Transport Canada requirements and processes will need to be followed. These are likely to require a number of months. The realistic earliest completion date for a project in Tuktoyaktuk is the spring of 2010.

The history of failed wind-diesel projects in NWT (and Nunavut) is probably foremost of the identifiable risks to a wind development project. Only two projects operated longer than 8 years, and Ramea is presently the only operating wind-diesel project in Canada. Capital and / or operating cost overruns are also a possibility due to the limited experience in the north.

One of the keys to success will be a strong project manager (or business partner) to keep tight management control over a project from start to finish. Carefully managing the tendering processes, including tendering for the project turbines and developing project supplier partners, will help with cost management. The NTPC RFP and interconnection guidelines lay out requirements that appear to be manageable and within the capability of the available technology; however, some specific issues will need to be discussed or negotiated.

Tuktoyaktuk has in its favour its reasonable size (for some economies of scale), its human resources, and its proximity to reasonable, if seasonal, transportation. Training of project personnel for maintenance and operations, as well as involvement in project installation, will be required. Its challenges will be its very modest wind resource which limits its economic strength.

The optimum size for the project appears to be in the 250 to 300 kW range, equal to or slightly above NTPC's specified maximum of 250 kW. The three turbine models that the authors selected for analyses include the Entegrity EW15 (65 kW), the Distributed Energy NW100 (100 kW), and the Wind Energy Solutions WES18 mk1 (80kW). Analyses were completed at four different wind penetration levels for each of the three candidate turbines.

The 4 turbine EW15 project was projected to cost $1.375 million or $5,288 per kW, the 3 turbine NW100 project $1.694 million or $5,645 per kW, and the 4 turbine WES 18 project $2.221 million or $6,942 per kW. The estimated capital costs have generally been a bit lower than the prefeasibility study indicated; however, there are still a number of uncertainties in the capital cost estimates. O&M costs are dominated by capital repayment (cost of capital was estimated to be 8.4%).

Only sale of electricity was considered in project revenues, but there are other potential revenues to be pursued. These include government wind support programs, the sale of carbon credits, the sale of surplus wind energy, and sources such as training and R&D opportunities. The projected cost of energy was $0.49 per kWh for the NW100 project, $0.55 for the EW15 project, and $0.66 for the WES project, compared to the present diesel fuel cost of about $0.30 per kWh.

Foundation design will be challenging and may be expensive in the ice rich permafrost of Tuktoyaktuk. There are companies in the north with the required geotechnical experience to deal with these conditions using adfreeze piles.

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1 ENVIRONMENTAL AND PERMITTING

1.1 Environmental Impact Assessment

A wind development project in Tuktoyaktuk will need to go through the Environmental Impact Screening Committee (EISC) (see http://www.jointsecretariat.ca/EISC/aboutus.htm). This committee has the legal obligation to screen all proposed developments inside the Inuvialuit Settlement Region (ISR) that may negatively impact the environment and / or Inuvialuit wildlife harvesting. They are one of the co-management boards at the Joint Secretariat and they screen all projects/ developments in the ISR. The information required in the application to the EISC includes:

1. Title
2. Contact name and address
3. Regulatory approvals
4. Location
5. Development summary
6. Development timetable
7. New technology
8. Alternatives
9. Traditional and other land uses
10. Community consultation
11. Environmental overview
12. Proposed mitigation and anticipated environmental impacts
13. Cumulative effects
14. Emergency response plans
15. Cleanup, reclamation, disposal, and/or decommissioning plan
16. Other environmental assessment

The guidelines for the application are found at http://www.jointsecretariat.ca/EISC/doc.htm.

As a development is likely to be within the municipal lands of Tuktoyaktuk the proponent will be consulting with the HTC (Hunters and Trappers Committee) as part of the EISC process. The expected turn-around time is 45 days although it may require two months to process the application. The resource person for the Screening Committee is Barb Chalmers (867) 777-2828.

There will likely be a requirement for meetings with the local public regarding the development of the wind farm. Citizens may have concerns about potential impacts such as aesthetics, noise, and effects on birds which will need to be addressed. A short text of these is included in Appendix 2.

1.2 Potential Impact Study Requirements

EISC will consult with the Canadian Wildlife Services (CWS) regarding wildlife impact studies. CWS will likely have concerns with impacts on the bird population in the area. According to Craig Dockrill, habitat biologist with the CWS in Inuvik, a wind farm of the size that is being proposed (less than 500 m long) within the hamlet boundary may not require a permit from CWS since it is within the hamlet boundary, it is not in an ecological reserve, and it is relatively small in size.

A guideline called "Environmental Assessment Best Practice Guide for Wildlife at Risk in Canada" can be found at the following link: http://www.cws-scf.ec.gc.ca/theme.cfm? lang=e&category=12. (**Note that spaces are put into web site addresses to provide for reasonable line spacing**.) Specifically for wind turbines there are two guidelines that should also be consulted: "Recommended protocols for monitoring impacts of wind turbines on birds" and "Wind Turbines and Birds A Guidance Document for Environmental Assessment" are found at http://www.canwea.ca/Government_Resources.cfm?subID=13. Copies of these documents are included on a resource CD accompanying this report.

If project construction were to take place in the summer there may be concerns for birds breeding in the area. If a CWS permit is required then a study will need to be done, which will require research time, a site visit, and a written report. This type of study will likely cost approximately $15,000 to carry out. Consultants from Inuvik or Yellowknife are available to carry out this type of research.

1.3 Land Use Permitting

The proposed project sites are situated on land that is within the Municipal Boundary of Tuktoyaktuk. The application for land use needs to go through the Government of Northwest Territories (GNWT) Municipal and Community Affairs (MACA) office in Inuvik (contact Joanne MacNeil 867-777-7123). MACA requires the coordinates of the project site, the size of the proposed site, and a sketch of the site as well as information on the applicant. An application for land use within the Tuktoyaktuk Municipal Boundary requires approval by the Hamlet of Tuktoyaktuk.

A project proponent can acquire a lease or a land use permit but not title to the land. If the project owner / land use applicant is a private business then a $7 per square meter per year fee may be charged for the land. If the applicant is a government agency (i.e. the hamlet) then they can reserve the land free of charge.

According to the report "Hamlet of Tuktoyaktuk Zoning Bylaw #258" (this document can be found at http://www.maca.gov.nt.ca/lands/community_planning/index.html on the web) the project potentially falls into one of two types of zones: Open Space, and/or Urban Reserve, see Figure 1 (also see Appendix 3) below. Copies of the bylaw and the Tuktoyaktuk Community Plan are also provided on the resource CD with this report. Open Space zoning allows for conditionally permitted developments, including telecommunications towers, the nearest match to a wind farm (see Schedule A Sec. 2.3.2 in Appendix 4). Urban Reserve zoning allows for conditionally permitted developments that include municipal or public utilities (see Schedule A Sec. 2.6.2 in Appendix 4). In these zones other supplementary developments that are allowed include electrical power lines and public roads.

An application form for a development permit is found in Schedule C – Form A (see Appendix 5) of the Zoning Bylaw report noted above. The application for development is expected to be accompanied by a non-refundable fee that is based on the project cost or contract price, which for projects over $100,000 is $3.50 per $1,000 project price. For a $1.5 M project the fee would amount to $5,250. Information such as legal lot description, setbacks and lot lines, access points, and foundation elevations will be required by the local Development Committee (see Appendix 5 or visit the website noted above for more details).

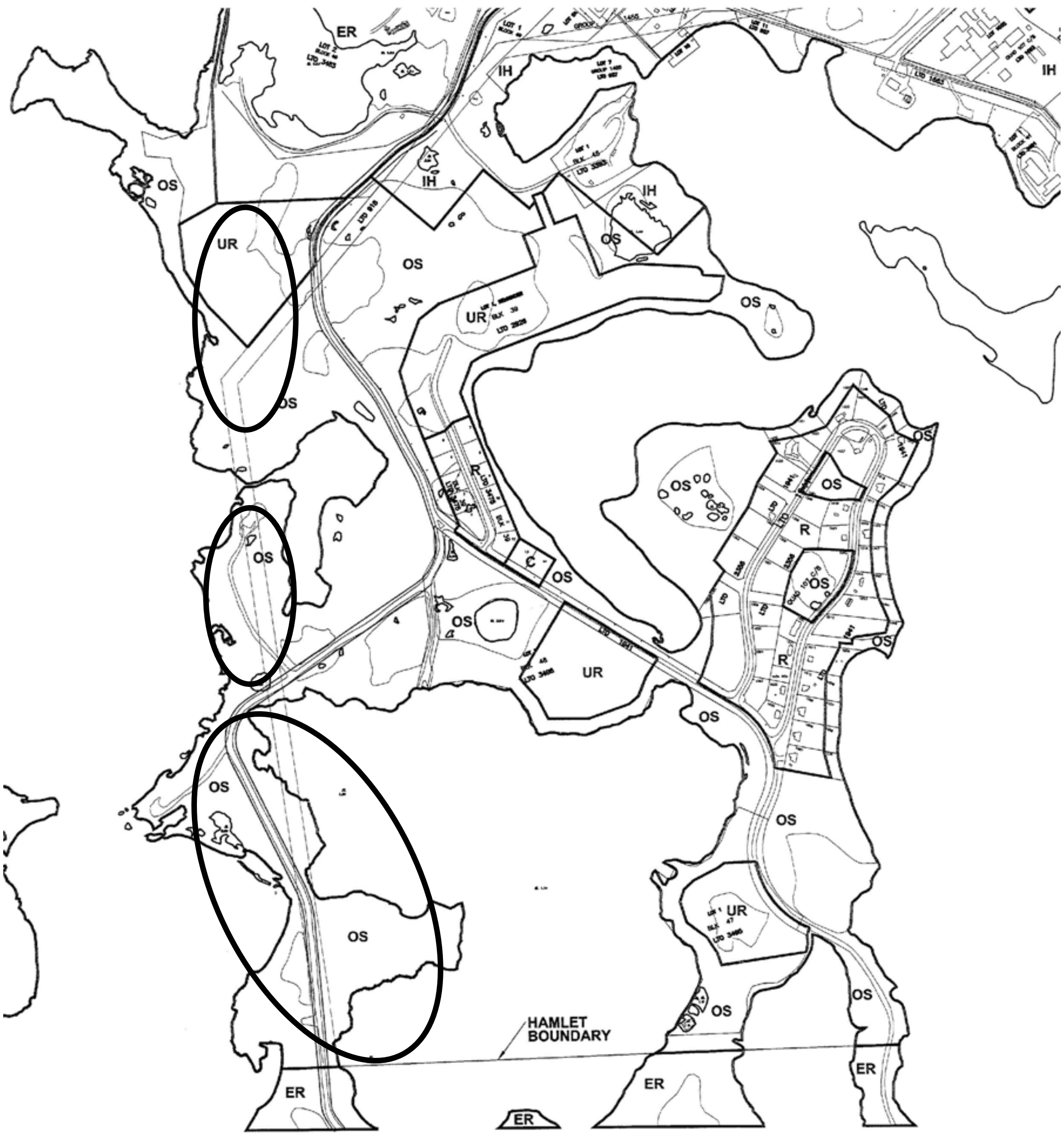

Figure 1: Zoning map for the Hamlet of Tuktoyaktuk. The ovals show the possible sites for a wind power development project. See Appendix 3 for full map.

1.4 Navigational Obstructions

The proposed areas for the wind farms are within the 4,000 m radius of the airfield. According to Transport Canada (TC), see http://www.tc.gc.ca/publications/EN/TP312/PDF%5CHR/TP312E.PDF, (also on the resource CD) the wind turbines will exceed the height limit of 45 m under the obstacle limitation surface (see Figure 2): (tower + blade heights vary from 44.5 m for the Entegrity EW 15 to 49 m for the Wind Energy Solutions WES 18/80). Therefore they will likely be (should be assumed to be) subject to obstruction marking and lighting requirements.

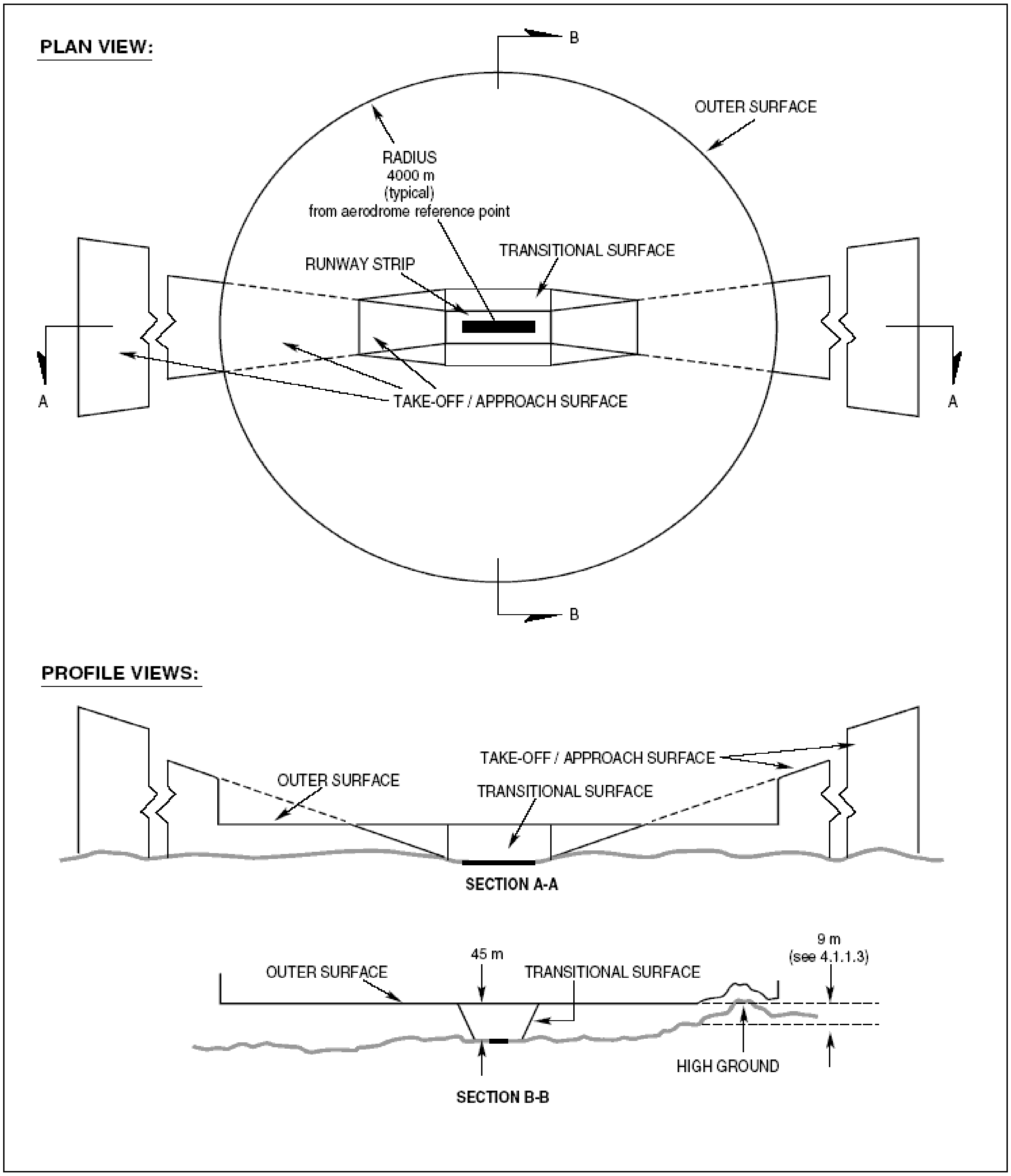

Figure 2: Obstacle limitation surface near an airfield.

Day markings and lighting are subject to be reviewed at the time of application but the following are general guidelines based on TC guidelines as found in http://www.tc.gc.ca/CivilAviation/Regserv/Affairs/cars/PART6/Standards/Standard621.htm see also Figure 3. However, TC has changed their requirements regarding marking, they will no longer require marking on wind turbines (conversation with Linda Melnyk 780-495-7694); however, lighting may still be required.

For lighting requirements, on a structure 45 m (150 feet) above ground level (AGL) or less, two or more steady burning lights should be installed at the top of the tower. For structures between 45 m and 107 m tall both a steady light at mid-point and a flashing beacon on top are required. The guideline specifies that in a group of obstructions, if there is no prominent centre obstruction, then an Aeronautical Evaluation will be performed to assess the location of the applicable beacons.

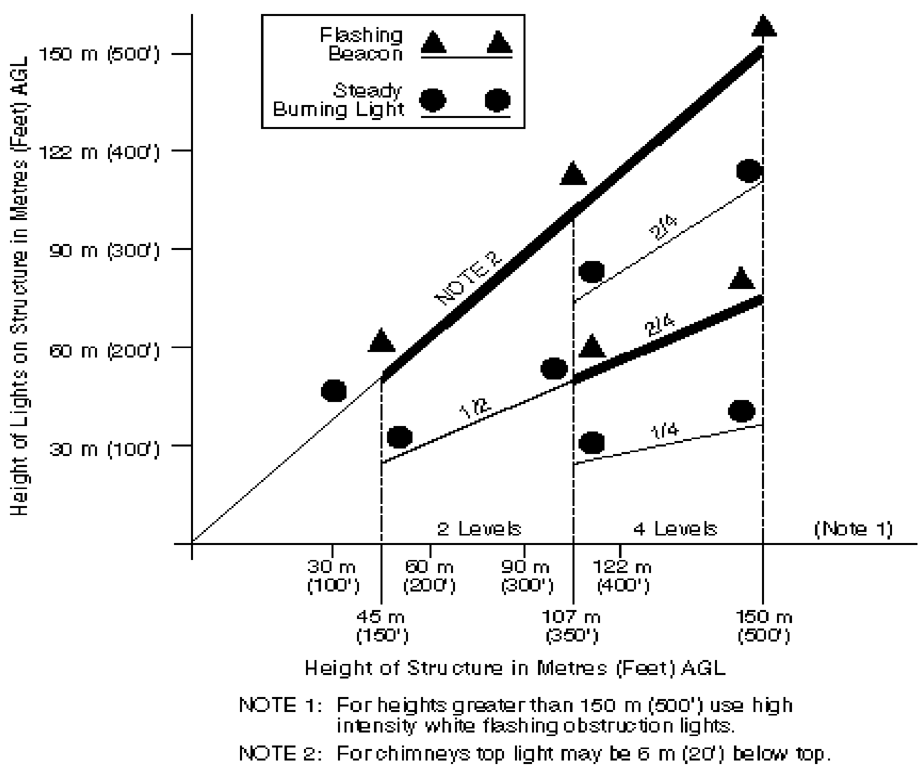

Figure 3: Lighting type requirement for a tower with respect to its height.

A new guideline that TC is proposing is found in Appendix 6. It states that a set of lights are required every 900 m in a row of wind turbines. For a row shorter than 900 m a light may be required at each of the end structures. The lights at both ends are required to flash simultaneously. These requirements are, according to the new guidelines, for wind turbines over 90 m. The new guidelines are open to changes, and a discussion with TC should take place at the time the project enters into the planning stage. A contact person can be found in Appendix 6, and further information can be referred to Linda Melnyk, of Transport Canada, Edmonton 780-

495-7694. Permission will be required from both Nav Canada and Transport Canada. The forms are listed in Appendix 7 and 8 and can be found at http://www.navcanada.ca/NavCanada.asp?Content=ContentDefinitionFiles%5CServices%5CANSPrograms%5CLandUseProposal%5Cdefault.xml and at www.tc.gc.ca/pdf/26-0427.pdf. Typically it takes several months to process the navigational permits, calling Linda Melnyk when filling and sending the forms should help to speed up the application process.

2. BUSINESS

2.1 Project risks

There have been several wind-diesel projects that have been attempted in Canada since the 1980's, most of which have met with limited success. Projects locations include: Big Trout Lake (ON), Cambridge Bay (NU), Fort Severn (ON), Igloolik (NU), Kasabonika Lake (ON), Kugluktuk (formerly Coppermine) (NU), Kuujjuaq (PQ), Sachs Harbour (NWT), Ramea (NL), Rankin Inlet (NU), and Winisk (ON). The Ramea project was installed about 3 years ago and is operating reliably, but of the others only Cambridge Bay and Kuujjuaq operated for more than 8 years. The majority of the other projects had lifetimes of two years or less. With the exception of Ramea which is a medium penetration project, all of the aforementioned projects were low-penetration systems and as of March 2008 Ramea is the only operating wind-diesel system in Canada.

While there are many specific reasons that individual past projects have failed in Canada, it is not the purpose of this research to discuss these projects and there has been much discussion about the various successes and failures available through recent conferences[1,2] and reports[3]. Nonetheless, the poor track record is cause for concern for any developers of a project in Tuktoyaktuk, in spite of recent successes in Alaska and Ramea. Therefore a discussion of project risks is outlined in this section to highlight specific issues that ought to be considered and addressed. The following is a list of potential difficulties, but is not an attempt to quantify their likelihood.

Capital cost overruns: Both the Sachs Harbour and Kugluktuk wind energy projects suffered from capital costs overruns, in large part due to poor planning that resulted in entire seasons that were missed due to barge shipping constraints. Tuktoyaktuk has the advantage of winter road access, but nonetheless planning mistakes will be costly and the responsibility for potential capital cost overruns needs to be addressed.

Operation and maintenance cost escalation: Inflation, rising labour costs or access to components could lead to long-term, slow but steady increases in operations and maintenance costs that would reduce future profitability unless the power purchase agreement is also indexed to inflation.

Catastrophic failures: Accidents such as the dropped wind turbine in Sachs Harbour, or *acts of God* such as the lightning strike that hit one of the turbines in Kugluktuk could lead to turbine failures beyond repair, at which point a decision would need to be made about replacing such a machine.

Oil price increases: The future price of oil is very uncertain and unpredictable. With the current oil price reaching all-time record highs, it seems likely that the cost of diesel generated electricity will continue to escalate. However, relative oil prices could fall should there be a global

[1] www.eere.energy.gov/windandhydro/windpoweringamerica/wind_diesel.asp
[2] www.remotewindenergy.ca
[3] www.nunavutpower.com/pdf/WindPowerReport_1.PDF

economic slowdown or another major change in the global oil market. A 20-year fixed price inflation indexed power purchase agreement may significantly undervalue the future worth of non-diesel power if the price of oil continues to rise relatively rapidly. Indexing the power purchase agreement to the annual avoided cost of diesel fuel would ensure that any price increase in oil is reaped by a wind project; however, this runs the risk of absorbing price decreases should the price of oil drop.

The relative likelihood of either circumstance must be considered by the wind power developer in preparing business plans and in negotiations for a Power Purchase Agreement (PPA) with Northwest Territories Power Corporation (NTPC). The agreement that developer Dutch Industries Ltd. (previous distributor for Lagerwey wind turbines; Lagerwey has become Wind Energy Solutions) had with NTPC for the output of a Lagerwey 80 kW wind turbine (now updated and called WES18 mk1) in Cambridge Bay beginning in 1994 was an 8 year fixed power purchase rate slightly higher than the avoided cost of diesel fuel at the time of wind project commissioning. This gave the developer a known fixed power rate, and NTPC hedged against future diesel fuel cost increases by accepting a fixed rate for the 8 year agreement. The PPA was set for 8 years and to be re-negotiated after that point.

Access to grid: Unforeseen circumstances could lead to NTPC restricting access to the distribution grid for a period of time. Possible causes for this include control system problems, grid repair, diesel plant operations and maintenance or other issues beyond the control of the wind energy operator. Any electricity that is generated by the turbines during such periods of time will be without a consumer and therefore without an income stream. Grid access and availability therefore needs to be considered when negotiating a power purchase agreement.

Development prior to a federal incentive program: The Canadian Wind Energy Association (CanWEA) has been working with Natural Resources Canada (NRCan) to develop a wind energy incentive program for remote communities and industries in Canada (Remote Community Wind Incentive Program or ReCWIP). The most recent submission to the finance board was a program for a capital subsidy of $900 per installed kW plus a production incentive of $0.10 per kWh for 10 years for small community wind-diesel projects. This program was not included in the 2008/09 Federal budget, and its future likelihood is unknown. Production incentives such as the ecoENERGY for Renewable Power program (formerly the Wind Power Production Incentive or WPPI) apply only to new projects and are not grandfathered for projects that were built prior to program implementation. Commissioning a project in Tuktoyaktuk prior to any Federal incentive would in all likelihood exclude this project from any such incentive program should it come to exist in the future. The potential projects modeled in this report estimate that for each kW of installed wind capacity in the order of 1300 kWh of electricity is generated, or $130 worth of incentive per year. For a 300 kW wind farm, this translates into a potential for an additional $39,000 of annual incentive revenues for 10 years in addition to a capital subsidy of $270,000. Project decisions should thus take into account the near term potential of such a program.

Capital cost, operating cost, and maintenance cost risks can also be managed, to a degree, by optimizing the project from the outset. Based on the modeling results described later in this report (see section 3.3, page 27), the most economic wind project size would be an installed capacity of approximately 300 kW, equal to the minimum load experienced in Tuktoyaktuk.

This would involve 4 (5 would be probably equally good) Entegrity EW 15 turbines, 3 Distributed Energy (formerly Northern Power Systems) NorthWind 100 turbines, or 4 Wind Energy Solutions WES18 mk1 turbines. The authors believe that these are also reasonably practical numbers of turbines from an operational and maintenance perspective. Capital exposure is limited but there are still some economies of scale in purchasing, installing, operating, and maintaining these wind turbines.

2.2 Business and Supplier Partners to share the risks

2.2.1 Business partners

If the proponent for a wind project in Tuktoyaktuk is uncertain about their ability to plan, install, and operate such a project consideration may be given to finding an appropriate business partner or project manager. The business partner may be selected on the basis of their experience in smaller wind development projects or their experience in civil and mechanical projects in the north. This business partner may be responsible for any or all of the key projects steps, including:

- Business plan for the project
- Design of the wind farm
- Selection of a wind turbine manufacturer
- Development of a bid for NTPC's Request for Proposals (RFP) for wind power
- Negotiation of a power purchase agreement with NTPC
- Negotiation of a long-term service agreement for wind farm with manufacturer
- Assuming the RFP bid is successful, project management including construction, commissioning, and operations
- Conceptual design for spoke projects

2.2.2 Supplier partners

There are three likely candidates for wind turbine manufacturers that could supply both Tuktoyaktuk as well as future wind-diesel projects in the region, notably: Entegrity Wind Systems Inc., (www.entegritywind.com), Distributed Energy Systems (www.distributed-energy.com), and Wind Energy Solutions (www.windenergysolutions.ca). There is a potential market not only to service Tuktoyaktuk's project, but also the other communities in the Beaufort Delta in the near term, and more broadly across the North in the longer term. This long-term strategy should be borne in mind when selecting a turbine, to ensure investments in training and replacement parts will be maximized as widely as possible.

A recent study completed by John Maissan and Tim Weis for CanWEA found that there are over 60 remote diesel communities in Canada that have a likelihood of developing a wind-diesel project should the necessary incentives be implemented. The study was based on the $0.10 per kWh production incentive and a $0.05 per kWh equivalent capital cost subsidy suggested in the proposed ReCWIP. From a supplier point of view access to Tuktoyaktuk as an early-adopter does not guarantee a monopoly to these communities, but it would facilitate access to a larger market should a national or territorial incentive program be implemented.

Notably, selecting a turbine that is appropriate for spoke communities will not only facilitate any training undertaken for operations and maintenance, but will also make this investment in local training worthwhile for both the manufacturer and the community.

Key considerations when choosing a supplier:

- History of projects in the North;
- Willingness and ability to work with long-term “hub and spoke” projects;
- Warranty period (aim for 5 years) and extended service agreement;
- Expected turbine performance;
- Cold weather package (operating range down to -40°C);
- Appropriateness of turbine for “spoke” communities, notably Sachs Harbour, Ulukhaktok and Paulatuk;
- Turbine cost;
- Complexity of turbine and O&M risks; and
- Long-term company outlook (likelihood of company to be in business 20 years from the project’s development).

A long-term “hub and spoke” vision should be developed in concert with the chosen manufacturer to maximize mutual benefits and synergies.

Approaches which consider and provide long term benefits (to the hub and spoke wind project development approach) should also be adopted when making arrangements for the design and supply of project components (foundations, electrical control and interconnection modules, etc.), and for the transportation and construction services required.

2.3 Tender Procedures

This process will be highly influenced by the strategy that the GNWT is willing to undertake as well as the role that a developer within Tuktoyaktuk wishes to pursue in the initial phases of this project. For the purposes of this report we have assumed that a project will be timed to respond to NTPC’s RFP closing date of January 16, 2009. As mentioned later in this section, this timing may not be suitable for an ideal construction schedule if the project is to be complete in 2009.

As was stated by the Tuktoyaktuk Development Corporation (TDC), in its March 17, 2008 Board Paper entitled “Wind Energy Commercialization – Hub and Spoke”, TDC envisions a project being developed in Tuktoyaktuk in two distinct phases: a demonstration phase and a commercialization phase. The transition between these two phases is expected at some point after 12-24 months of initial commissioning. This transition potentially complicates the tendering and operations procedure and ought to be considered carefully early in the process.

The following is a recommended framework, including key dates for a process to develop a regional hub and spoke program. This will be an iterative and evolving process as additional partners become involved in the project.

Context:

- NTPC issued an RFP for wind power with a close date of January 16th, 2009;
- The GNWT is likely to be the major project funding agency;
- TDC has committed to helping to raise supporting funds but is not willing to contribute financially or to own the project in its initial phase; and
- TDC has expressed an interest in acquiring or taking over the project after its operation has been "proven".

Recommended Steps:

- The GNWT issue an initial call for proposals to develop a regional hub and spoke plan, with Tuktoyaktuk as the hub and at least Sachs Harbour, Paulatuk and Ulukhaktok as spoke communities:
  - List project experience in cold and remote communities
  - Preliminary financial quote for "hub" project as well as addition "spoke" additions
  - Outline of potential training requirements and plans
  - Details of warranty and service contracts;
- In consultation with TDC, a supplier/developer is selected by October of 2008. For success the project will need one single owner's representative to take charge of the overall project (the steps outlined below) and to bring it to completion;
- An advanced equipment deposit is posted with the supplier / developer team to complete the detailed project design, including technical engineering as well as development of local training program for the "hub" project only. This will need to be completed by end of year 2008:
  - Wind farm layout
  - Electrical design, including interconnection and control system requirements
  - Detailed quote and business case
  - Permitting
  - Detailed construction plans, including foundation and sourcing necessary equipment
  - Develop training program
  - Develop with TDC and GNWT an intern ownership model and ownership transfer arrangement

    - Detailed list of steps that would need to be taken to develop “spoke” community projects. “Spoke” projects will not be financed or built under the current project, but preliminary planning for them will maximize the mutually beneficial aspects to both the “hub” and the “spoke” projects;

- After completing the detailed design work, the supplier/developer submit an application with the assistance of the GNWT and TDC to the NTPC RFP by January 16, 2009:
    - Finalize financial agreements
- Supporting funding from sources such as Indian and Northern Affairs Canada (INAC), NRCan, National Research Council (NRC) or others are arranged by December 31, 2008. Note that work is not likely to begin until after the end of March, 2009;
- Assuming the RFP is successful, the final details are negotiated with NTPC:
    - Negotiation of terms of PPA (fixed / increasing / indexed / term length / penalties / bonuses)
    - Arrangement of construction plans
    - Interconnection agreements;
- Final permitting;
- Begin technician training program; and
- Earliest possible commencement of construction of the “hub” project summer / fall of 2009 (optimistic; most realistic and minimum cost likely to be the spring of 2010).

Within the details of the project, the tendering of equipment and each of the construction related components is also very important, and must receive due consideration. The selection of the most appropriate wind turbines first of all, tendering for the wind turbines including all of the key options such as warranties, O&M service agreements, training arrangements. Following the final turbine selection foundation design must take place followed by installation, all of which will require time and carefully considered tendering procedures. Transportation of all of the equipment should also be tendered in such a way as to minimize costs.

The overall project timing must be carefully considered. The authors have suggested a time line that would conform to the January 2009 NTPC RFP closing. Beyond this there will be time required by NTPC to consider the submissions it has received, to respond to the submissions and to enter into negotiations if they feel it is appropriate to do so. Realistic completion dates for these arrangements are likely to be at least the end of March 2009. It would also be important for any project proponent to know whether a federal ReCWIP program (or similar ecoENERGY program) is likely to be in place in the near term as those financial incentives can make a very substantial difference to the viability of a project.

It is likely that only after there is a firm arrangement in place could a project developer commence detailed work including tendering for wind turbines. Wind turbines of the type considered in this report will take 6 months to deliver, and it may be wiser to assume that these could be late by 1 or 2 months. Allowing a total of 9 months for the tendering, selection, ordering, and delivery of the turbines, would bring the turbines to Tuktoyaktuk at the end of

2009. Foundation installation will be at its lowest cost when the ice road between Inuvik and Tuktoyaktuk is in, typically January to April (see later sections of this report). For the transportation of the wind turbines the major river crossings of the Dempster Highway must also be at near full capacity – ferry or ice road.

This timing would suggest that installation, construction, and commissioning would ideally take place in early 2010. A March – April timeframe as days lengthen and the weather moderates before any thaw, and before the ice road closure (see historical ice road opening and closure dates in the resource CD), may be the ideal time.

There may be ways to "hurry" a project along by commencing work sooner (and spending money which must then be available), but in the authors' view this will involve some risk and "hurrying" almost always results in additional costs. It is best that the project be done in a carefully timed and considered manner so as to minimize costs and risks.

2.4 NTPC PPA terms

Shortly after the award of this study, NTPC issued an RFP for wind generation. This RFP provides the terms and conditions that a project proponent will have to accept and meet in the provision of wind power. NTPC was contacted with some questions and they responded that they would provide answers to our questions and those of other interested parties in a timely manner to all parties. In our review of the RFP we did not note anything in the interconnection requirements that would pose a problem for the turbines being considered.

The points in that RFP may have implications for this project on which requests were made to NTPC for clarification, are listed below.

- The specified penetration level limit for Tuktoyaktuk is listed as 250 kW. It is hoped that NTPC would be prepared to offer some flexibility on increasing this level slightly to enhance the economics of the project;
- If a medium penetration project is economic and dump energy becomes available, it is not clear that the wind plant owner could transport electrical energy to be sold as thermal energy to clients on NTPC's wires at no cost. This should be pursued, depending on the configuration of the project; and
- The RFP (Section 3.1) states "The point of connection for wind generation will be at NTPC's existing power plant or substation. Maps showing the location of NTPC's diesel power plants and substations for any community can be provided upon request." If this requirement is retained, it will mean that either the wind plant must be near the generating point or substation, within the community, or the developer would need to install lines to connect the wind plant into the diesel plant. It is anticipated that NTPC would be agreeable to allow the wind plant to be connected to the existing distribution infrastructure. This needs to be confirmed.

NTPC's interconnection document "Distributed Resource Technical Interconnection Guideline" was also reviewed. All the wind turbines considered appear to be able to conform to the power quality and reliability requirements of the utility.

The primary points of concern are related to connection and operating transients that might affect system frequency stability or voltage flicker. The final configuration of the wind project would need to be confirmed but a medium penetration system is unlikely to affect the frequency stability of the system, given the existing surplus capacity of the diesel. Also the reactive power flows can be attenuated by a number of ways to mitigate and flicker events that may occur.

2.5 Human resources capacity and training needs

Project champion or manager: There are a significant number of administrative issues that need to be carried forward from securing financing, to liaising with manufactures, to assisting in project tendering and design, to project construction and commissioning, and to project operations. To date this effort has been shared by the GNWT and TDC. A project champion or a project manager (possibly a business partner) could facilitate this process for the initial "hub" project as well as coordinating the development of future "spoke" projects. Funding for this position could be made available through the IRAP program for small and medium sized enterprises[4].

Maintenance Technicians: It has been repeatedly emphasized that operations and maintenance are key to successful wind-diesel projects in the North. Having qualified, accessible, and trained human resources that are readily available will minimize downtime thus increasing project profitability and prolong the life of the wind turbines and other equipment.

Based on discussions with potential suppliers, training local operations and maintenance technicians would be a preferred option. However, this would require a minimum number of turbines for such an investment to be worthwhile. Operations and maintenance estimates are in the order of 40-80 person-hours per turbine per year[5]. This means that it would require in the order of 20 wind turbines to be installed in the hub and spoke model to keep the equivalent of one technician employed full-time servicing them. In practice, of course, technicians would normally work in pairs. Manufacturers suggested people with mechanical and basic electrical experience could be trained. A likely practical approach would involve training diesel (or other mechanical) technicians normally employed in non-wind projects for part time work on wind projects including routine annual wind turbine maintenance as well as emergency short-term diagnostics and minor repairs.

Training would require approximately 2 weeks, one of which would be spent at the manufacturer's office and one with the manufacturer's technicians in the field servicing operating turbines. It would also be wise to have the manufacturer trained people involved in the installation work. This process is dependent on the size and scope of both the near-term and the longer-term project, and would require negotiation with the manufacturer at the time of project tender or tender award. In the case of a hub project in Tuktoyaktuk the training should be negotiated as part of the equipment sale and servicing contract. If not negotiated at the outset,

[4] http://irap-pari.nrc-cnrc.gc.ca/main_e.html
[5] Note: As a point of reference Entegrity wind estimates that turbines sold in grid-connected applications in southern Canada or the USA require approximately 20 person-hours/turbine/year.

the training could result in additional cost to the project. The earlier a supplier can be chosen the sooner details of the most effective training program can be designed.

It is best to train two or more technicians, although it is only possible to offer part-time employment to them, in the short term at least. However, they would ideally be involved in the construction phase of the project to increase their familiarity with the equipment and ensure they have an understanding of the location of key system components.

Operating staff: There will need to be a location where there is a computer monitoring the operations of the turbines in a project through a Supervisory Control and Data Acquisition (SCADA) system on a full time basis. All faults must be annunciated immediately, and ideally printed out in hard copy. The location will likely be an office where technically competent staff understands what the SCADA system is telling them. Ideally the office would be staffed around the clock seven days a week (for other reasons) and this would be an additional task. When spoke projects are installed they would be monitored from the same central location. Such operating staff would ensure that the turbines are operating properly, would reset them from the computer if they trip off-line on a fault, or call for maintenance technicians if the fault is such that a site visit is required. The operational people will also require training in the operation of the SCADA system software and in the basic operation and knowledge of the wind turbines. The manufacturer will need to be involved in this training, but this may not need to take place at the manufacturer's office.

2.6 Risks and opportunities for Tuktoyaktuk as a hub

There are a number of positive attributes that Tuktoyaktuk has as a site for a potential hub wind project. The community appears to be solidly in favour of a wind project, it is large enough to offer some economies of scale with respect to a wind project, it is home to people with technical skills based on its oil exploration background, it is central to a number of communities in the area, and it is reasonably accessible by ice road in winter, barge in summer, and by air year-round.

Tuktoyaktuk does have some challenges it will need to deal with as a hub wind project community. Foremost among them is the fact that its wind resource is a very modest 5.05 m/s (meters per second) at 30m above ground level (5.21 m/s at 40 meters). This will make the size of a wind project a compromise between achieving economies of scale and limiting the capital expenditures since the cost of wind generated power will be higher than diesel generated power at present fuel prices. Also a somewhat limiting factor is the seasonal accessibility by road rather than on a year-round basis, however its proximity to Inuvik is a mitigating factor. If it does become the hub for a number of spoke communities, there may be merit in maintaining some spare parts inventory in Inuvik rather than Tuktoyaktuk.

2.6 Potential spokes

The highest candidates for "spoke" communities include Sachs Harbour, Paulatuk, and Ulukhaktok. These communities are smaller than Tuktoyaktuk, but their wind resources are superior to that of Tuktoyaktuk. Beyond these obvious candidates, an organization based in

Tuktoyaktuk could also provide services to Aklavik, Old Crow (Yukon), and Nunavut communities.

There are likely further opportunities too. The Canadian Department of Defence maintains Distant Early Warning (DEW) line sites throughout the north, mining companies have exploration camps and mining operations, and so on. While the nature of wind projects in these other applications will be different than at Tuktoyaktuk, the principles are similar, and the necessary human resource skills the same.

3. FINANCIAL

3.1 Project capital and O&M costs

Each of the three turbines selected (as described in Section 4.2.1, Turbine manufacturers) was evaluated at four different capacity scenarios. The capital costs, for three of these scenarios, are summarized in Table 1. The capital cost for a project composed of four Entegrity EW15 turbines, 260 kW, was estimated at about $1.375 million or $5,288 per kW; the cost for three Distributed Energy NW100 turbines, 300 kW, at about $1.694 or $5,645 per kW; and the cost for four Wind Energy Solutions WES18 mk1 turbines, 320 kW, at about $2,221 million or $6,942 per kW. The complete analysis and the rationale for the capital costs are discussed in Appendix 9.

The annual O&M (Operation and Maintenance) costs are based on discussions with manufacturers who have generally estimated the O&M costs for locations that are highly accessible. O&M costs have been increased in consideration of increased travel time, and costs associated with maintaining turbines in relatively remote Tuktoyaktuk. O&M costs are an important point for negotiation during the turbine procurement phase. Annual tax costs were calculated using the government of Northwest Territories' estimate that the wind plant will be taxed at the rate of $5.15 per $1,000 of assessment.

It is assumed that the project will be financed with a combination of equity provided by the project owners, and debt offered by conventional lending institutions. The ratio of debt to equity and the interest rates for both debt and equity can vary depending on many factors and each combination results in a different capital recovery factor. A range of debt and equity ratios and interest rates are summarized in Table 2. For each combination of debt to equity ratio and interest rate, a blended interest rate is computed. The capital recovery factor is then computed by calculating the annual cost of borrowing $1, using the blended interest rate over a term of 20 years. For the analysis in this study, it has been assumed that the project would be financed at 70% debt and 30% equity and that debt is available at 6% and equity is available at 14%. This results in a capital recovery factor of 0.105, as indicated in Table 2.

The annual capital cost repayment is calculated by multiplying the capital cost, taken from Table 1, by the capital recovery factor. This provides for the repayment of capital over the project life of 20 years.

The total of the annual costs are presented in Table 3 below. As can be seen the overall annual costs tend to follow the capital costs of the projects as the recovery of the capital is the single largest component of these annual costs. Complete details of cost calculations leading to the cost of energy on a $ per kWh basis for all project configurations can be found in Appendix 10.

Once the capital cost of each project configuration and O&M costs have been developed these become inputs into the simulation of the project, along with the wind turbine power curves, wind data and electrical load data.

Turbine Supplier	Entegrity Wind Systems			Distributed Energy Systems			Wind Energy Solutions		
Turbine designation	EW15			NW100			WES18 mk1		
Tower Height (m)	37 meters			37 meters			40 meters		
	Single turbine	**Med. Pen. Min. Load**	**Med. Pen. Avg. Load**	**Single turbine**	**Med. Pen. Min. Load**	**Med. Pen. Avg. Load**	**Single turbine**	**Med. Pen. Min. Load**	**Med. Pen. Avg. Load**
Rated Capacity (kW)	**65**	**250**	**500**	**100**	**250**	**500**	**80**	**250**	**500**
Number of Turbines	**1**	**4**	**8**	**1**	**3**	**5**	**1**	**4**	**6**
Installed Capacity (kW)	65	260	520	100	300	500	80	320	480
Cost category									
Project Design & Mgmt									
project design	$10,000	$30,000	$30,000	$10,000	$30,000	$30,000	$10,000	$30,000	$30,000
environmental assessment	$10,000	$15,000	$15,000	$10,000	$15,000	$15,000	$10,000	$15,000	$15,000
project management	$10,000	$15,000	$15,000	$10,000	$15,000	$15,000	$10,000	$15,000	$15,000
Site Preparation									
road upgrading / construction	$20,000	$25,000	$35,000	$20,000	$25,000	$35,000	$20,000	$25,000	$35,000
powerline	$30,000	$40,000	$50,000	$30,000	$40,000	$50,000	$30,000	$40,000	$50,000
Wind Equipment Purchase									
wind turbines	$156,200	$624,800	$1,249,600	$275,500	$826,500	$1,252,500	$349,830	$1,399,320	$2,098,980
shipping	$25,000	$40,000	$80,000	$35,000	$50,000	$80,000	$25,000	$40,000	$80,000
transformers	$7,000	$20,000	$40,000	$10,000	$20,000	$40,000	$8,000	$20,000	$40,000
wind plant master control	$2,000	$10,000	$15,000	$2,000	$10,000	$15,000	$2,000	$10,000	$15,000
Installation									
foundations	$50,000	$180,000	$320,000	$60,000	$162,000	$240,000	$60,000	$192,000	$288,000
Ginpole	$10,000	$10,000	$10,000				$10,000	$10,000	$10,000
equipment rental	$10,000	$15,000	$20,000	$50,000	$65,000	$75,000	$10,000	$15,000	$20,000
control buildings		$20,000	$20,000		$20,000	$20,000		$20,000	$20,000
utility interconnection	$20,000	$30,000	$40,000	$20,000	$30,000	$40,000	$20,000	$30,000	$40,000
Commissioning	$15,000	$15,000	$25,000	$25,000	$30,000	$40,000	$15,000	$15,000	$25,000
labour - assembly & supervision	$10,000	$25,000	$50,000	$15,000	$30,000	$45,000	$10,000	$25,000	$50,000
travel and accommodation	$10,000	$25,000	$35,000	$20,000	$30,000	$40,000	$10,000	$25,000	$35,000
Diesel Plant Modifications									
high speed comm. & controller		$20,000	$20,000		$20,000	$20,000		$20,000	$20,000
SCADA		$30,000	$30,000		$30,000	$30,000		$30,000	$30,000
dump load		$20,000			$20,000			$20,000	
plant modifications			$20,000			$20,000			$20,000
wind diesel integration		$10,000	$40,000		$10,000	$40,000		$10,000	$40,000
Other									
dump heaters and controls BL			$50,000			$50,000			$50,000
initial spare parts	$5,000	$10,000	$10,000	$10,000	$20,000	$20,000	$10,000	$20,000	$20,000
SUBTOTAL CONSTRUCTION	**$400,200**	**$1,229,800**	**$2,219,600**	**$602,500**	**$1,498,500**	**$2,212,500**	**$609,830**	**$2,026,320**	**$3,046,980**
Contingency	$50,000	$100,000	$200,000	$75,000	$150,000	$200,000	$75,000	$150,000	$200,000
TOTAL CONSTRUCTION	**$450,200**	**$1,329,800**	**$2,419,600**	**$677,500**	**$1,648,500**	**$2,412,500**	**$684,830**	**$2,176,320**	**$3,246,980**
Owners Costs									
manage project organization	$10,000	$20,000	$35,000	$10,000	$20,000	$35,000	$10,000	$20,000	$35,000
negotiate agreements	$15,000	$25,000	$40,000	$15,000	$25,000	$40,000	$15,000	$25,000	$40,000
TOTAL OWNERS' COSTS	**$25,000**	**$45,000**	**$75,000**	**$25,000**	**$45,000**	**$75,000**	**$25,000**	**$45,000**	**$75,000**
TOTAL PROJECT COST	**$475,200**	**$1,374,800**	**$2,494,600**	**$702,500**	**$1,693,500**	**$2,487,500**	**$709,830**	**$2,221,320**	**$3,321,980**
Installed cost per kW	**$7,311**	**$5,288**	**$4,797**	**$7,025**	**$5,645**	**$4,975**	**$8,873**	**$6,942**	**$6,921**

Table 1: Capital cost estimates for three turbine types and three capacity scenarios

The analyses have been carried out with as much new information as could be obtained within the time and budget constraints of this project. These analyses have enabled the most attractive configurations to be identified and have identified wind turbine technologies that are likely to offer the most economic alternatives. It has enabled some conclusions that have reasonably good confidence, including wind energy generation estimates, diesel fuel displacement estimates, and the selection of the most economic project size.

Debt	5.00%	6.00%	7.00%	8.00%
	Debt/Equity = 70%/30%			
Equity	**Blended Interest Rate**			
10%	6.50%	7.20%	7.90%	8.60%
12%	7.10%	7.80%	8.50%	9.20%
14%	7.70%	8.40%	9.10%	9.80%
16%	8.30%	9.00%	9.70%	10.40%
	Capital Recovery Factor			
10%	0.091	0.096	0.101	0.106
12%	0.095	0.100	0.106	0.111
14%	0.100	**0.105**	0.110	0.116
16%	0.104	0.110	0.115	0.121
	Debt/Equity = 60%/40%			
	Blended Interest Rate			
10%	7.0%	7.6%	8.2%	8.8%
12%	7.8%	8.4%	9.0%	9.6%
14%	8.6%	9.2%	9.8%	10.4%
16%	9.4%	10.0%	10.6%	11.2%
Project life is assumed to be 20 years in all cases				
	Capital Recovery Factor			
10%	0.094	0.099	0.103	0.108
12%	0.100	0.105	0.110	0.114
14%	0.106	0.111	0.116	0.121
16%	0.113	0.117	0.122	0.127

Table 2: Capital Recovery Factors

Turbine Supplier	**Entegrity Wind Systems**			**Northern Power Systems**			**Wind Energy Solutions**		
Turbine designation	EW15			NW100			WES18 mk1		
Tower Height (m)	37 meters			37 meters			40 meters		
	Single turbine	**Med. Pen. Min. Load**	**Med. Pen. Avg. Load**	**Single turbine**	**Med. Pen. Min. Load**	**Med. Pen. Avg. Load**	**Single turbine**	**Med. Pen. Min. Load**	**Med. Pen. Avg. Load**
Rated Capacity (kW)	**65**	**250**	**500**	**100**	**250**	**500**	**80**	**250**	**500**
Number of Turbines	**1**	**4**	**8**	**1**	**3**	**5**	**1**	**4**	**6**
Installed Capacity (kW)	65	260	520	100	300	500	80	320	480
TOTAL PROJECT COST	$475,200	$1,374,800	$2,494,600	$702,500	$1,693,500	$2,487,500	$709,830	$2,221,320	$3,321,980
Project Life	20	20	20	20	20	20	20	20	20
Financing Costs (Capital Recovery Factor)	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105
Annual Capital Cost	$49,850	$144,220	$261,690	$73,694	$177,653	$260,945	$74,463	$233,022	$348,484
Annual O&M Costs	$10,000	$25,000	$45,000	$10,000	$20,000	$30,000	$10,000	$25,000	$35,000
Taxes & leases	$2,447	$7,080	$12,847	$3,618	$8,722	$12,811	$3,355	$10,239	$15,307
Total Annual costs	**$62,297**	**$176,300**	**$319,537**	**$87,312**	**$206,374**	**$303,756**	**$88,119**	**$269,462**	**$400,593**

Table 3: Annual costs for three project scenarios and the three turbines types

However, the information is still somewhat limited on several parameters and these areas of uncertainty need to be further considered. In particular estimates of installed costs have been made estimated with a number of assumptions that merit further refinement. These include the following.

- Project management costs

The cost estimates assume that the project is carried out with limited project management expenditure. Caution is required to ensure this project is not over-administered during the design, construction, or operations phases as small projects cannot afford any unnecessary overhead costs.

- Turbine Costs and Technology

Turbine costs were based on budgetary estimates, for a potential project, from the wind turbine suppliers. It is probable, once there is confidence that a project is approved and the exact number of turbines required and the project schedule is finalized, that suppliers will be prepared to 'sharpen their pencils'.

The technology also introduces some uncertainty. The NW100-21 for instance produces the lowest cost power of the three wind turbines considered in this study, but there have been no field test results to confirm the turbine performance with the larger 21 meter rotor. There has been ample operational experience with the 19 meter design, and some with the 20 meter design, but the 21 meter design, which is the key to the improved economics, has limited operating experience to date. The EW15 has also not been tested on the 37 meter tower offered for this project.

- Shipping costs

Once the turbine is selected, the shipping costs need to be more closely considered. The analyses assumed shipping from Toronto which may be incorrect. The analyses also assigned a premium for the tubular towers for the NW100 and WES18 mk1 turbines. It is possible these premiums are incorrect or that additional measures may be required (say for barging the tower sections) that can affect sipping costs significantly.

- Site preparation costs

These costs also need to be more closely evaluated, when the site selection process is completed.

- Foundation costs

Foundation cost estimates may also vary significantly. For instance the NW100 may be available on a self erecting tower by the time a project is initiated. Also the specific details for adapting the tubular towers to adfreeze piles may be more or less costly than estimated.

- Utility interconnection

These costs also need to be more closely evaluated when the site selection process is complete.

- Control systems

The control system requirements also need to be more closely assessed once the project configuration has been finalized.

- Operation and maintenance costs

Operation and maintenance is another area of uncertainty. The manufacturers have as yet acquired only limited experience for small numbers of their turbines in small communities with difficult access. All are optimistic they can support the technology economically but this is an area which will need to be more closely explored.

3.2 Project revenues

3.2.1 Sale of electricity

For a wind project to be economic the annual revenue generated by a wind plant must be sufficient to pay all capital and operating costs associated with the installation and operation of the wind plant. The primary source of revenue is derived from the sale of electricity that is sold to the local utility. The amount of electricity generated is dependent upon the extent of the wind resource as well as the number, efficiency, and reliability of the wind turbines installed.

Although the sale of electricity to displace diesel fuel used to generate electricity is the primary source of revenue, secondary sources of revenue are available for higher penetration projects. At increasing penetration levels, wind generated electricity cannot be absorbed by the system and so it becomes surplus or ‘dump’ energy that must be rejected. For Arctic communities this surplus energy can be used for thermal purposes although some investment in heaters, etc. is required to realize these benefits. Also in high penetration systems, where diesels can be turned off, there are revenues available as a result of diesel plant life extension. However, for practical purposes, current technology is likely to limit revenue to electricity sales, and that has been assumed in this analysis. An important factor in the decision making on practical project size and configuration is that the calculated cost of wind energy, based on our assumptions and analyses, is more expensive than diesel power generation. More aggressive wind deployment scenarios are considered for reference purposes.

3.2.2 Carbon Credits

An additional source of revenues for the project is the sale of carbon credits. There is currently neither a Federal market for carbon credits, nor clarity on how this market will evolve in the coming years. Alberta has developed a $15 per tonne CO_2 fund for large emitters who exceed provincial intensity targets which clean power retailers can access. British Columbia, on the other hand has implemented a carbon tax that will reach $30/tonne by the year 2012. If either the Federal or Territorial governments adopt either measure, additional revenues may be available to a wind-diesel project in Tuktoyaktuk. Diesel fuel generates about 3 kg of CO_2 per litre or in the order of 0.8 kg CO_2 per kWh. Table 4 shows that approximately 100,000 litres of diesel fuel would be displaced by the suggested medium penetration, minimum load wind projects. This is equivalent to about 300 tonnes CO_2 per year. At $15/tonne this is equivalent to $4,500 annually, and at $30 per tonne $9,000 annually.

A carbon credit or trading system is relatively complex and involves tracking and verifying carbon reductions as well as finding potential buyers, both of which can absorb potential revenues. One of the key aspects of a carbon credit system is that it often only applies to projects that are built after the system is in place, which may mean that a Tuktoyaktuk project would not benefit from such a system. Voluntary markets exist, a list of participants can be found at www.carboncatalog.org/providers/canada for Canada. The average price for these offsets is in the order of $20/tonne, although it should be noted that there will be transaction as well as verification costs that could cost $5/tonne or more.

A federal or territorial carbon tax would increase the cost of diesel fuel, thereby increasing the value of displaced fuel. This system would be much simpler for a wind-diesel project to take advantage of, but would require flexibility in the original PPA to allow for such increments in avoided cost of diesel to be collected by the wind power project.

In the near term, the most likely source of additional revenues from carbon credits would be through the voluntary offset market.

3.2.3 Other revenues

As discussed in Section 2.1, CanWEA has lobbied the federal government for an appropriate support program for wind projects in the north which they called ReCWIP. If implemented as the proposed ReCWIP program or as an ecoENERGY program, it would provide a capital subsidy of $900 per kW installed and a 10 year production incentive of $0.10 per kWh. Such a program could supply $270,000 in up front capital subsidies and up to about $39,000 per year in incentive payments for the first 10 years of operation. These are very significant to a potential project.

Table 4 indicates that the most economic project appears to be one composed of 3 NW100 wind turbines. This table also indicates that about 35,000 kWh of power will be surplus in the winter. If this power could be sold for space heat it would worth about $0.10 per kWh and provide revenue of about $3,500 per year. The total amount of annual surplus wind energy is about 76,000 kWh, and if it all could be sold for $0.10 per kWh it could provide revenues of $7,600 per year. However, there is also likely to be some cost associated with these sales so net revenues would remain to be determined.

Other possible revenue sources could come from R&D and training contracting opportunities with colleges, manufacturers, utilities, and national organizations. The authors suggest that these possible sources should not be counted on to begin with, but if a project proceeds these opportunities should be pursued as supplemental revenue sources.

3.3 Project return vs. risks

The project economics are summarized in Table 4, in which the cost of energy estimates, for each of the turbine configurations, is presented.

In this table, the annual wind generation absorbed into the system and the annual costs, incurred with each configuration, are summarized. The simple cost of energy is then computed adding the annual financing costs, calculated by multiplying the capital cost by an assumed capital recovery factor (or fixed charge rate), to the annual operating costs arising from taxation and operating and maintenance costs. Note that there is a deduction of 10% from the theoretical energy absorbed to allow for periods of turbine non-availability and power losses.

The ‘Simple Cost of Energy’ for each configuration is shown in the bottom line of Table 4. For all three turbines, it is shown that there is a significant improvement (reduction) in the cost of energy by installing more than one turbine and currently no substantial economic benefit to be gained by installing higher penetration levels than those indicated in the ‘medium penetration minimum load’ configuration (other than perhaps a fifth EW15 turbine). This indicates that the most economic installation, assuming no thermal energy can be sold and that no revenue can be obtained from diesel life extension, is to install multiple wind turbines with capacity roughly equivalent to minimum system load.

It appears based on the results shown in Table 4 that the most economic configuration is to install about four EW 15s (it may be that 5 would be equally good), three NW 100-21s, or four WES18 mk1 turbines. In relative terms, the Distributed Energy Systems’, NW100-21 appears to offer the most economic alternative for Tuktoyaktuk. These represent a reasonable number of turbines for some economies of scale and from a practical operations and maintenance perspective. The simple cost of energy, for this scale of project is $0.49 per kWh, significantly higher than the assumed avoided cost of diesel at approximately $0.30 per kWh. This would support the conclusion that wind penetration beyond the 250 kW limit indicated by NTPC, other than to achieve a practical size of project, is not attractive under the assumptions used in this report.

Turbine Supplier	**Entegrity Wind Systems**			**Northern Power Systems**			**Wind Energy Solutions**		
Turbine designation	EW15			NW100			WES18 mk1		
Tower Height (m)	37 meters			37 meters			40 meters		
	Single turbine	**Med. Pen. Min. Load**	**Med. Pen. Avg. Load**	**Single turbine**	**Med. Pen. Min. Load**	**Med. Pen. Avg. Load**	**Single turbine**	**Med. Pen. Min. Load**	**Med. Pen. Avg. Load**
Rated Capacity (kW)	**65**	**250**	**500**	**100**	**250**	**500**	**80**	**250**	**500**
Number of Turbines	**1**	**4**	**8**	**1**	**3**	**5**	**1**	**4**	**6**
Installed Capacity (kW)	65	260	520	100	300	500	80	320	480
TOTAL PROJECT COST	$475,200	$1,374,800	$2,494,600	$702,500	$1,693,500	$2,487,500	$709,830	$2,221,320	$3,321,980
Wind Generation (MWh)	100	399	799	181	542	903	132	526	790
Wind Absorbed (MWh) (100% Availability)	95	355	638	171	465	718	126	452	645
Wind Absorbed (MWh) (90% Availability)	86	319	574	154	419	646	113	407	580
Wind Dumped (MWh)	5	45	161	9	76	185	6	74	145
Wind Dumped Winter (MWh)	0	19	90	1	35	101	1	37	80
Fuel Consumption ('000 litres)	1258	1194	1121	1240	1167	1101	1252	1199	1128
Total Fuel Saved (litres)	23795	87538	160824	42419	114708	180991	31211	111597	162251
Fuel Saved / turbine (litres)	23795	21885	20103	42419	38236	36198	31211	27899	27042
Project Life (yeaars)	20	20	20	20	20	20	20	20	20
Total Project Cost	$475,200	$1,374,800	$2,494,600	$702,500	$1,693,500	$2,487,500	$709,830	$2,221,320	$3,321,980
Annual Capital Cost	$49,850	$144,220	$261,690	$73,694	$177,653	$260,945	$74,463	$233,022	$348,484
Annual O&M Costs	$10,000	$25,000	$45,000	$10,000	$20,000	$30,000	$10,000	$25,000	$35,000
Taxes & leases	$2,447	$7,080	$12,847	$3,618	$8,722	$12,811	$3,656	$11,440	$17,108
Total Annual costs	$62,297	$176,300	$319,537	$87,312	$206,374	$303,756	$88,119	$269,462	$400,593
Wind Absorbed (MWh)	86	319	574	154	419	646	113	407	580
Financing Costs (Capital Recovery Factor)	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105
Simple Cost of Energy ($ per kWh)	**$0.726**	**$0.552**	**$0.557**	**$0.567**	**$0.493**	**$0.470**	**$0.780**	**$0.662**	**$0.690**

Table 4: Summary of project economics

This analysis is most useful for comparative purposes and it does provide a fair analysis of the various alternatives available, and it allows the most economic configurations to be identified.

Table 4 takes the annual energy absorbed, from the simulation summary (Table 7 page 43), and discounts it by 10% to reflect a projected turbine availability of 90%. This provides an indication of the energy that is displaced by each configuration of wind. There is no revenue credited to the surplus energy that is available at increasing penetration levels or to the potential cost savings from diesel life extension since it is felt this is not a practical revenue source at this time.

3.4 Funding to support feasibility and capital costs

The most economic project configurations with each of the three turbines, as identified in Table 4, are further evaluated in Table 5. The objective is to estimate how significant an initial investment from a third party would be required to enable the projects to be viable economically. It is assumed that an initial, non-repayable, capital investment would be found to defray a portion of the initial capital costs. This would reduce the financing costs of the project over the operating life and allow the project to function on an economically sustainable basis.

The analysis indicates that a non-repayable capital investment of about $770,000 would be required to make the project self sustaining for either the EW15 or the NW100 turbines.

Turbine Supplier		**Entegrity Wind Systems**	**Northern Power Systems**	**Wind Energy Solutions**
Turbine designation		EWS15/50	NW100	WES18 mk1
Tower Height (m)		37 meters	37 meters	40 meters
	Zero Wind	**Med. Pen. Min. Load**	**Med. Pen. Min. Load**	**Med. Pen. Min. Load**
Rated Capacity (kW)		**250**	**250**	**250**
Number of Turbines		**4**	**3**	**4**
Installed Capacity (kW)		260	300	320
TOTAL PROJECT COST		$1,374,800	$1,693,500	$2,221,320
Wind Generation (MWh)		399	542	526
Wind Absorbed (MWh) (100% Availability)		355	465	452
Wind Absorbed (MWh) (90% Availability)		319	419	407
Wind Dumped (MWh)		45	76	74
Wind Dumped Winter (MWh)		19	35	37
Fuel Consumption ('000 litres)	1282	1,194	1,167	1,199
Total Fuel Saved (litres)		87,538	114,708	111,597
Fuel Saved / turbine		21,885	38,236	27,899
Project Life		20	20	20
Total Project Cost		$1,374,800	$1,693,500	$2,221,320
Annual Capital Cost		$144,220	$177,653	$233,022
Annual O&M Costs		$25,000	$20,000	$25,000
Taxes & leases		$7,080	$8,722	$11,440
Total Annual costs		$176,300	$206,374	$269,462
Wind Absorbed (MWh)		319	419	407
Simple Cost of Energy		**$0.552**	**$0.493**	**$0.662**
Target Cost of Energy ($/kWh)		$0.30	$0.30	$0.30
Annual Revenue with 'Target COE'		$95,788	$125,645	$122,081
Annual operating costs		$32,080	$28,722	$36,440
Debt Service revenue		$63,708	$96,923	$85,641
Capital cost serviced by Debt Service Revenue		$606,745	$923,079	$815,630
Capital subsidy required to achieve 'Target COE'		**$768,055**	**$770,421**	**$1,405,690**

Table 5: Capital subsidies required for economic viability for wind projects

Renewable energy projects such as wind power are capital intensive, and while there are no long-term fuel costs, there are significant opportunity costs in tying up capital in a project that will need to operate for many years to repay that capital. Attracting capital funding assistance can therefore minimize this risk. There are numerous potential sources for funding support, some of which are listed in this section, in addition to potential support from companies who are interested in working in the region, notably oil, gas, and mineral exploration companies. These companies may be looking for opportunities to assist in local community development projects.

Important points to emphasize in any applications for funding assistance are:

- Greenhouse gas benefits;
- Diversification of local economies;
- Use of a local renewable resource;
- Development of regional capacity in a new industry to the North; and
- Additional funding is being sought to complement GNWT's support to make the project a viable "hub".

Potential government funding assistance programs are listed below.

3.4.1 National Research Council (NRC) – Industrial Research Assistance Program (IRAP)

The NRC Industrial Research Assistance Program (NRC-IRAP) provides a range of both technical and business oriented advisory services along with potential financial support to growth-oriented Canadian small and medium-sized enterprises (SMEs). The program is delivered by an extensive integrated network of 260 professionals in 100 communities across the country. Working directly with these clients, NRC-IRAP supports innovative research and development, and commercialization of new products and services.

NRC-IRAP views SMEs as the strategic backbone of the Canadian economy and is committed to working with them to realize their full potential and to turn knowledge and innovation into strategic opportunities, jobs, and prosperity for all Canadians.

The following is taken from an email discussion between Tim Weis of the Pembina Institute and Craig d'Entremont of NRC, the latter being the author of the text:

"As we discussed, if we could identify a suitable proponent, i.e.: an SME (Small Medium Enterprise) in the NWT, to work with, we might put together a project proposal aimed at IRAP seeking funding to undertake a Technical/Business Feasibility Study for the establishment of a wind farm in the western Arctic.

…IRAP places its emphasis on technology development/adaptation/integration etc. Our approach here might be to undertake a feasibility study.

As I mentioned to you yesterday IRAP could fund up to 50% of the salaried costs (contractor labour costs) associated with such a project up to a certain approved maximum. There can be no more than 75% government funding."

The program contact for the North is:
Barbara Nyland
Innovation & Network Advisor, IRAP West
7th Floor, Room W-742, 9107-116 St.
Edmonton, AB, T6G 2V4
Ph: (780) 495-8257
Email : barbara.nyland@nrc.gc.ca
http://irap-pari.nrc-cnrc.gc.ca/main_e.html

3.4.2 Indian and Northern Affairs Canada – ecoENERGY for Aboriginal and Northern Communities

INAC will support energy efficiency and renewable energy projects, with active Aboriginal and northern community involvement, which lead to concrete, quantifiable, and verifiable greenhouse gas (GHG) and criteria air contaminants (CAC) emissions reductions.

Large Energy Projects are designated as projects which: have substantial GHG emissions reductions of above 4,000 tonnes over the project life cycle; are well developed and have passed through all or part of the feasibility and early planning stages; and, represent complex endeavours that require a range of partnerships and arrangements to implement.

The maximum life cycle considered for GHG and CAC calculations for both small and large projects will be 20 years. Contributions are up to a maximum of $250,000 per project. More information on large projects can be found at: www.ainc-inac.gc.ca/clc/prg/eco/lpfc_e.html.

The program contact for Remote Communities is:
Daniel Van Vliet
Manager, Off-Grid Communities Initiative
Renewable Resources & Environment Directorate
Indian and Northern Affairs Canada
10 Wellington St., Room 613
Gatineau, QC, K1A 0H4
Ph: (819) 953-8107
Email : vanvlietd@ainc-inac.gc.ca
http://www.ainc-inac.gc.ca/clc/

3.4.3 Indian and Northern Affairs Canada NWT Region – Targeted Investment Program (TIP)

INAC is investing in the north, northerners, their communities, and businesses through an economic development program known as Strategic Investments in Northern Economic Development (SINED). This program is tailored to the needs of each territory and, in the NWT, the Targeted Investment Program (TIP) has been established under SINED.

TIP focuses primarily on investments designed to build knowledge in key economic sectors, enhance economic infrastructure, develop capacity, and promote diversification. Investments made under TIP are guided by multi-year investment plans in each territory.

In the NWT, five strategic investment areas have been identified to address economic development priorities:

1. Geoscience Data Collection - increase geological resources knowledge base;
2. Growing the NWT Tourism Industry –diversify an underdeveloped industry;
3. Access to Capital for Small Business – increase participation in the economy;
4. Transportation and Energy Infrastructure – support economic infrastructure and industrial initiatives; and
5. Enhancing Local Capacity to Seize Economic Opportunities – increase northern business capacity and support economic diversification activities.

Approximately $22.8 million is available in the NWT over three years to March 31, 2009. These funds will be allocated based on projects aligned with the Investment Plan. **All projects must be completed by March 31, 2009.**

Investment projects will occur either through targeted invitations or open calls for Expressions of Interest. These calls for projects under the Targeted Investment Plan (TIP) will be accepted in the areas of Tourism Infrastructure and Product Development; Enhancing Local Capacity to Seize Economic Opportunities; and Transportation and Energy Infrastructure Planning.

It is most likely that the proposed project in Tuktoyaktuk could be successful under the "Access to Capital for Small Business" or the "Enhancing Local Capacity to Seize Economic Opportunities" categories.

The program contact for TIP is:
Greg Landsberg
INAC, Northwest Territories Region
4920 – 52nd Street
P.O. Box 2760
Yellowknife NT X1A 2R1
Toll Free: 1 866 669 2620 or 867 669 2627
Fax: 867 669 2711
Email: landsbergg@inac.gc.ca
http://nwt-tno.inac-ainc.gc.ca/si-f_e.htm

4. TECHNICAL

4.1 Possible project sites

4.1.1 Project sites

Figure 4 on the following page shows a Google Earth image of the Tuktoyaktuk area, overlaid with the legally surveyed areas (which were extracted from the MACA GIS website) in colour. The purple surveyed areas are commissioner's land and the brown ones private land.

Figure 4 is overlain with a wind rose to show the wind energy by direction; average wind speeds are given at the end of each axis. One possible project site is identified as Area 1 in Figure 4. It has an area of about 6.5 hectares, but may not necessarily need to be this large. The diamond markers show possible locations for a series of wind turbines. In Area 1 the ground elevation is at least 4 m above sea level (ASL). The blue line is an existing three phase power line, and the red line is a possible new road location. Building roads is expensive since gravel is scarce in Tuktoyaktuk and may need to be trucked in some distance in winter. Area 1 is more attractive than the first site considered, marked as Area 2, because there are fewer horizontal space constraints caused by roads and shorelines. Also, Area 1 is within 200 m of power line while Area 1 extends to over 600 m away from existing power lines, which are also very expensive to build in Tuktoyaktuk.

4.1.2 Geotechnical information

According to NRCan[6] the Tuktoyaktuk area is a moraine deposit with till and associated gravel and sand deposited directly or with minor reworking by glacier ice, and generally modified by cryoturbation. In Tuktoyaktuk the moraine is a veneer that is generally less than 1 m thick and severely modified by thermokarst (land surface that forms as ice-rich permafrost melts).

There are a number of studies that find the soil make up in this region to be of granular nature with sand and silt. We are not aware of specific studies covering the areas that are being proposed as possible wind project sites although there appears to be gravel extraction nearby. Experience from site visits, and the installation of small anchors for a wind monitoring tower in Area 2, reveals that the soil is a mixture of silt and clay, with a consistency of soft mud. In late September (2007) the frozen layer was found to be about 1 m below the surface. Starting in 1990, the Geological Survey of Canada (GSC) established and monitored a set of instrumented sites, designed to monitor the active layer in the Mackenzie Valley and Delta to describe variability over time as well as space (see Figure 5). In the Tuktoyaktuk area the average active layer depth ranged from 60 to 110 cm below the surface, which is consistent with what was found when driving anchors for a wind monitoring tower.

[6] NRCan Earth Science Sector: http://apps1.gdr.nrcan.gc.ca/mirage/show_image_e.php

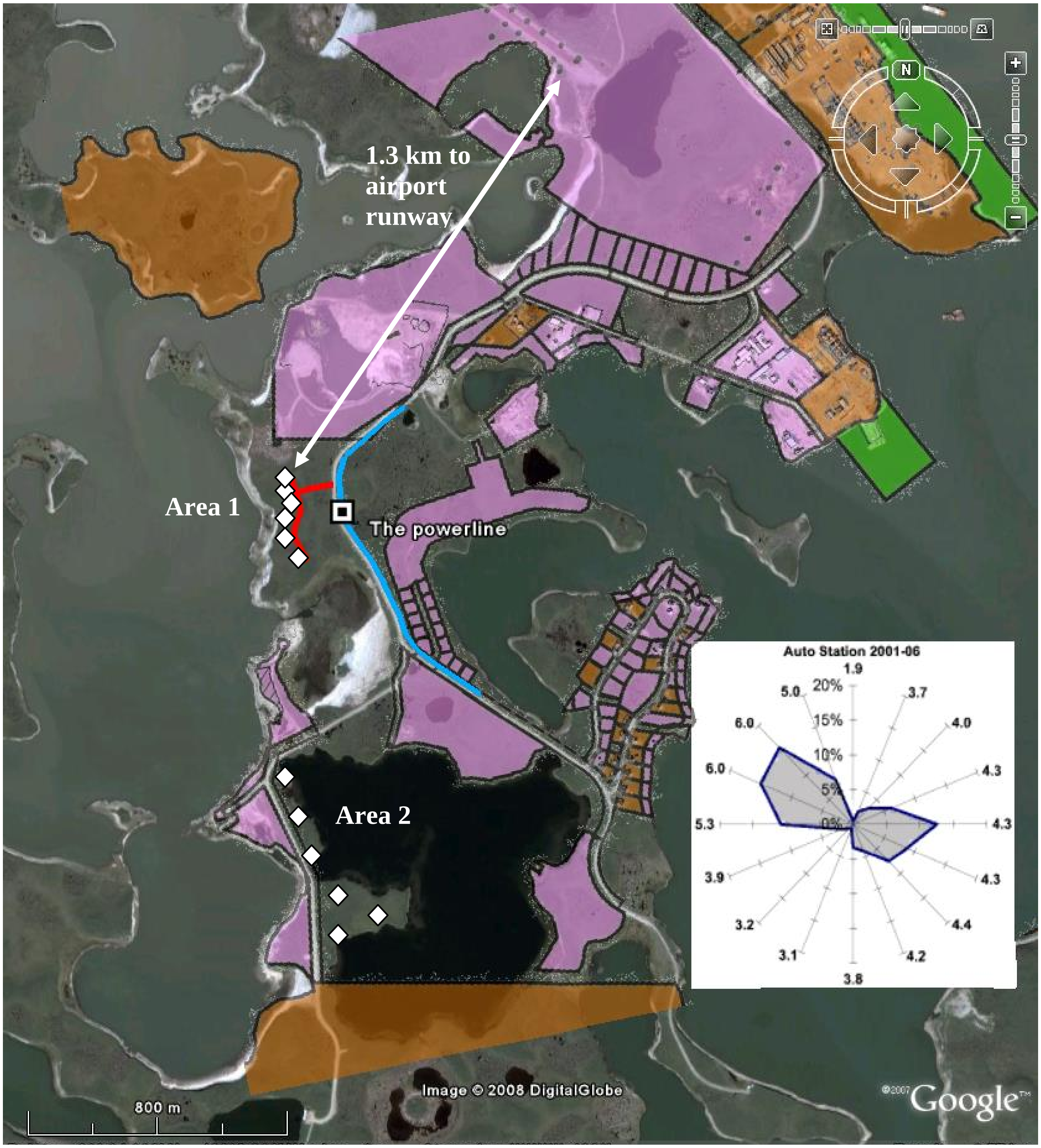

Figure 4: Tuktoyaktuk area showing: part of the airport runway and two possible wind project sites labeled Area 1 and Area 2; Commissioner's land in purple, private land in brown; and a wind rose showing wind energy distribution by direction.

Biggar and Kong (2001) carried out pile load tests at several Short Range Radar sites and included Tuktoyaktuk in their study. The article is presented in Appendix 11. Their Tuktoyaktuk study location was the DEW line site, on top of a small rounded hill bordering

Tuktoyaktuk Harbour, which has an average geodetic elevation of 14 m ASL. The general stratigraphy encountered during the pile drilling consisted of a granular fill overlying a layer of native granular overburden on top of a thick layer of ice extending from a depth of approximately 3.5 m to in excess of 15 m, where the drilling was terminated. There were no visible soil particles within the ice samples.

From the information reviewed there does not appear to be bedrock near the surface. It is also likely that massive ice will be encountered a few metres from the surface everywhere in the Tuktoyaktuk area.

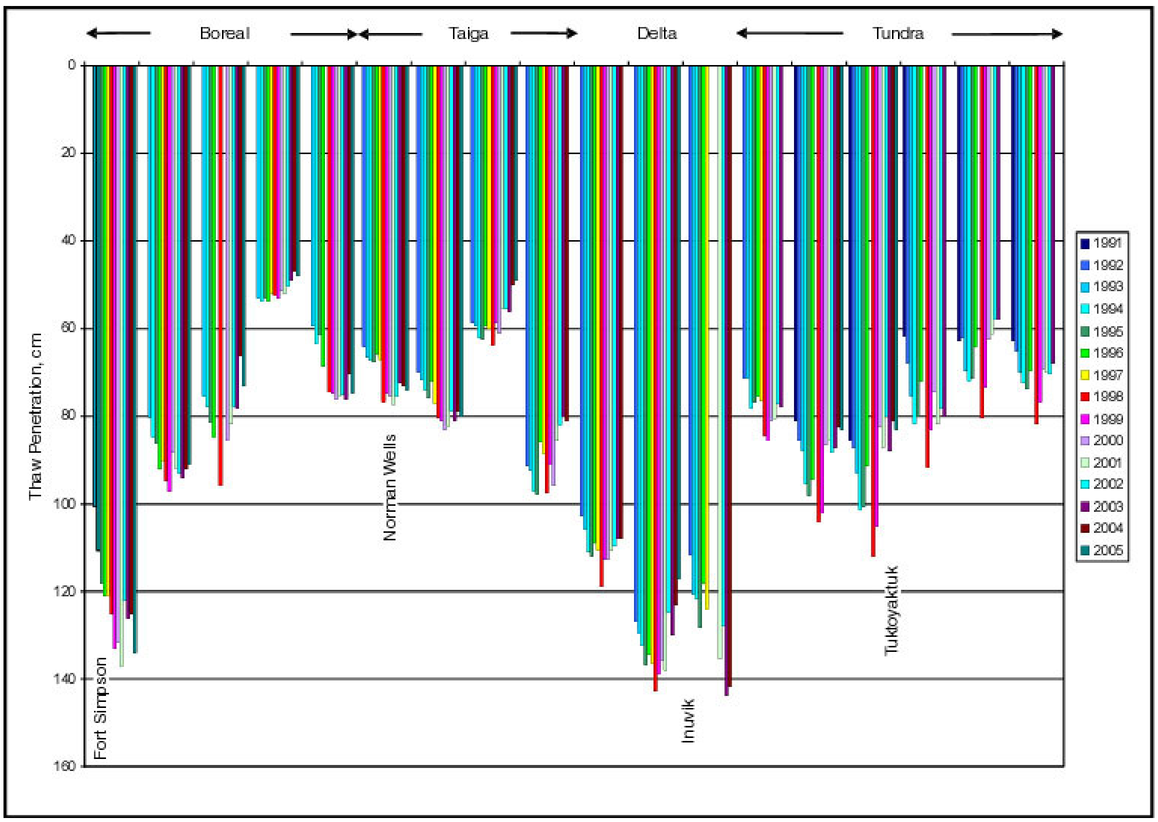

Figure 5: Thaw layer in permafrost for four locations including Tuktoyaktuk. The chart shows year to year variation of maximum thaw penetration (active layer) at selected sites, measured from an initial ground surface at time of maximum thaw. Source: http://gsc.nrcan.gc.ca/ permafrost/mapping_e.php

4.2 Evaluation of wind turbine options

4.2.1 Turbine manufacturers

A number of wind turbine manufacturers were identified as having products in the 50 to 100 kW capacity range potentially suitable for the north. These included Atlantic Orient Canada, Bergey Windpower, Distributed Energy Systems (formerly Northern Power Systems), Enercon, Entegrity Wind Systems, Energie PGE, and Wind Energy Solutions. In addition there are those who feel that refurbished used wind turbines from the era when all commercial wind turbines were relatively small, should be a serious consideration. The authors of this report considered it important that, as far as possible, turbines that could operate in temperatures down to -40°C and with some proven track record, particularly in the north, should be their primary focus.

Examination of product information available on web sites and discussions with various manufacturers helped to narrow the field. For the purposes of this report the authors selected three for further consideration for a project in Tuktoyaktuk including the Entegrity Wind Systems EW15, Distributed Energy Systems' (formerly Northern Power Systems) NorthWind100 with a 21 meter rotor (which we refer to as NW100 or NW100-21), and the Wind Energy Solutions WES18 mk1 (often referred to as WES18). This is not to exclude any project proponent from considering any other turbine, just that the authors saw these three as probably being the front runners and meriting serious consideration. Readers and project proponents are encouraged to consider all available options.

The EW 15 has a 15 meter rotor, with three blades that operate, in free yaw mode, downwind of the tower. The turbine is nominally rated at 50 kW but has a peak output of 65 kW. It is offered on a 37 meter, free standing lattice tower. The tower can be supplied hinged for a winch-up installation without a crane. Entegrity has a number of turbines installed in Alaska, most notably at Kotzebue.

Distributed Energy Systems' NW100 is available with a 21 meter rotor (in addition to 19 and 20 meter rotors) with three blades that operate upwind of the tower. The turbine, rated at 100 kW, uses a direct drive generator. It is offered on a 37 meter tubular tower which, at present is not available with a winch-up or self erecting option. This unit therefore requires a 75 tonne or larger crane for installation. There are a number of NW100 units operating throughout Alaska.

The Wind Energy Solutions WES18 mk1 has an 18 meter rotor and two blades which operate upwind of the tower. The turbine is rated at 80 kW and uses a direct drive generator. It is offered on a 40 meter tower which is available with a self erecting option. There were a few WES18 units installed in northern Canada, under the original manufacturer, Lagerwey and their Canadian distribution partner or licensee, Dutch Industries, but they are all out of service now for various reasons.

Additional details on each of these three turbines are provided in the resource CD accompanying this report.

4.2.2 Turbine modifications and options

The three wind turbine models selected for analyses in this report are available with options that may be key to a successful project in Tuktoyaktuk. All are available with a low temperature option package to permit them to operate to -40°C.

Another important consideration was tower height. As the cost of power lines and roads makes it uneconomic for wind power projects to be located at optimum wind resource sites any distance from communities, the better wind resources have to be accessed by raising the turbine as high as possible. Both the EW15 and the NW100 have optional 37 meter towers which were selected for consideration. It is possible that the EW15 could be supplied with towers of about 43 meters (140 feet) or 49 meters (160 feet). The WES18 is available with a 40 meter tower.

Tower installation was also a consideration. The NW100 has, to date, only been supplied with a crane installed tower. While this may be possible in Tuktoyaktuk, it would be a problem in other small Beaufort Sea and Mackenzie Delta communities. However, Distributed Energy Systems have a conceptual self erecting tower design and would be willing to work with project proponents on the completion of this design. The WES18 40 meter tower is available with a self erecting option, and the EW15 is available with a hinged tower design that can be winched up with a gin pole. It is likely then that all three turbines could be installed in remote locations without the use of a crane.

As icing is a concern for some remote community locations, anti-icing measures were considered. None of the manufacturers have optional heating systems for their turbine blades to mitigate serious icing conditions; however, they all expressed a willingness to cooperate with proponents to help develop such systems. For less serious icing or frosting mitigation there are some options available for all turbines. First is the application of a black, low ice adhesion coating to the turbine blades (much like paint). This has been done on commercial wind turbines in Yukon, and on community scale wind turbines, including the NW100 and EW15, in Alaska. For up-wind turbines (WES18 and NW100) the wind instruments that help keep those up wind are available in heated versions (for example the NRG Ice Free 3™).

All manufacturers have warranty and service contracts available as options and these need to be examined and specified at the time of project tendering. Similarly the training of operating and maintenance staff is either a requirement of the manufacturer or available from them. Given that the staff operating and maintaining a potential project in Tuktoyaktuk are likely to be inexperienced with wind turbines, the authors see this as a very important option which must be arranged and specified at project tender.

Although it was not a consideration in this report, it is worth noting that Distributed Energy Systems has long been involved in wind-diesel integration systems, and thus have the potential to supply more than just the wind turbines for a project. Similarly Wind Energy Solutions indicate that they have wind-diesel integration equipment. To the author’s knowledge they do not have any operating wind-diesel systems in North America. Entegrity Wind Systems only make wind turbines.

4.2.3 Conceptual foundation designs

The design and installation of foundations in the permafrost of the north can be challenging and expensive. Where competent bedrock is at or near the surface foundations may be a bit more straightforward, but where there is no bedrock, and especially in ice rich silts foundations are challenging. In these situations adfreeze piles appear to be a practical solution.

The authors suggest that the objective of the wind turbine foundation design for a project in Tuktoyaktuk should be a design for a "worst case" situation so that it could also be used in all other remote communities with similar (or better) ground conditions. Whether such a design could reasonably be applied to bedrock conditions by substituting rock bolts for piles would remain to be determined. However, the more the designs can be standardized for the lowest common denominator the less re-engineering (and cost) will need to be repeated for each future community (spoke) project.

Dowland Contracting Ltd. of Inuvik (www.dowland.ca) is a company that is experienced in pile installation and construction in northern conditions (see the information on foundations provided on the resource CD accompanying this report), provided very helpful input to the authors. From the foundation design parameters provided by wind turbine manufacturers, it was thought that the EW15 (three legged lattice tower) would demand the highest requirement from a foundation. On that basis Dowland arranged for Philip Nolan of Structure All Consulting Engineers Ltd. of Yellowknife to prepare a conceptual foundation pile design. With this information Dowland Contracting was able to provide a budget estimate for the installation of pile foundations for wind turbines in Tuktoyaktuk in winter. Winter installation is easier and cheaper thanks to the winter road from Inuvik and solid ground working surface.

Experience in Alaska is that it that foundations are generally expensive. Kotzebue uses adfreeze piles for their Entegrity wind turbines (on 80 foot – 25 meter – towers). Other small coastal communities have had far more challenging conditions due to warm unstable permafrost in silt. The active layer of the permafrost can be up to 14 feet deep in some locations, and in at least one case thermo-siphons were installed to ensure that the permafrost remained frozen.

In the ice-rich silt permafrost of the Tuktoyaktuk region of the Mackenzie River delta it appears that piles will be required for the foundations of wind turbines. According to Petrie (2007) piles need to be drilled in from 1/3 to 2/3 of the wind turbine tower height. For a 40-m tower this would mean 13 to 27 m deep into the ground. Petrie describes the use of helix screw piles in Akula Heights where there was also no bedrock. They drove and screwed the helix piles into predrilled holes, and added thermo-siphons to ensure that the relatively warm (unstable) permafrost remained frozen. The resource CD includes copies of papers of interest by Brad Reeve of Kotzebue Electric Association and Brent Petrie of Alaska Village Electric Cooperative.

4.2.4 Equipment for O&M

Tuktoyaktuk is relatively isolated and anyone traveling there from "the south" may incur significant traveling expenses. Similarly transporting equipment to and from the community can take time and be costly. For these reasons the authors believe that it is important that local people be trained in the operation and maintenance of the equipment installed in a wind project. To avoid delays in dealing with operational and maintenance issues, and to minimize down time, it is advisable to provide the local staff with the necessary tools and instruments to service and diagnose problems in the installed projects. The range of tools, instruments, and equipment (general and turbine specific) will be more extensive than found in more populated areas where these are available nearby. In discussions with manufacturers leading up to a tender for wind turbines, a list of required maintenance tools and equipment (general and specific) should be obtained.

Similarly it is likely desirable to maintain a wider and higher inventory of spare parts than in other parts of the country.

4.3 Wind-diesel integration

NTPC's interconnection requirements and power quality and reliability requirements as it relates to a potential wind development project is covered in Section 2.4 of this report.

4.3.1 Wind-diesel equipment requirements

The equipment required to integrate wind energy into a diesel system varies by wind penetration level. The equipment requirements are outlined in Appendix 12. In low or medium low penetration configurations the equipment required for wind-diesel integration is a communications system, a dump load, and a dump load controller. This is modest and should not require significant capital investment.

4.3.2 Modeling of a project in Tuktoyaktuk

For a conventional utility connected wind project, where the output from a wind plant flows into an essentially infinite grid, the amount of wind capacity is usually not limited by utility constraints. However, in wind-diesel applications, such as in Tuktoyaktuk, where electricity is generated by relatively small diesels, the amount of wind capacity is restricted by both technical and economic constraints. Technical limits are reached when the amount of wind capacity is so high that it affects system frequency and voltage stability. However, at the current state of technology and at present costs, economic limits are more prominent since increased wind capacity, above a certain point, displaces less fuel on an incremental basis and economics deteriorate with larger wind capacity. Appendix 12 describes the basic configurations related to wind-diesel systems.

To evaluate the economic viability and technical impact of installing wind power into Tuktoyaktuk the operation of the system was simulated. Parameters of interest were evaluated over a one year period (the data used is found in the resource CD).

To determine the most economic wind plant layout a number of configurations were assessed using a computer simulation model. Homer, a computer model developed by NREL, the US National Renewable Energy Laboratory, assesses the technical and financial implication of different configurations of renewable energy technology in different applications.

To use Homer, detailed information must be compiled related to:

- Diesel plant information;
- Load data (hourly data for one year);
- Wind data (hourly data for one year); and

- Wind turbine data (performance, cost parameters; numbers of units to be evaluated).

Using the input data, the model analyzes the operation of the system, without wind and with each of the wind plant configurations. The output of the model can then be used to evaluate the results of each simulation. By adding different amounts of wind power, each with its own cost and performance parameters, the relative cost for each configuration can be computed.

Wind data was obtained, in one hour increments, from wind resource assessments carried out by Aurora Research Institute. As the modeling program Homer does not take into account air densities, the authors adjusted the wind speed the appropriate amount to simulate the increased energy production (based on a stall regulated wind turbine). The adjusted wind speeds were then used in the modeling program.

The power curves for the three candidate wind turbines, which were used in the analyses, are summarized in Table 6. The power curves for the WES18 and for the EW15 were taken from the Homer database since the power curves coincided with power curves from several other sources. The power curve for the NW100-21 was provided by the manufacturer but it was modified slightly, at low wind speeds, for this analysis. The submitted power curve is not based on field tests and the rotor efficiency, based on calculations using data provided by the manufacturer, is improbably high at low wind speeds. As a result the power curve has been modified at low wind speeds to reflect more typical rotor efficiencies.

Each wind turbine was evaluated in four different scenarios:

- Single turbine

  A single wind turbine is installed

- Medium Penetration - Minimum

  Wind capacity was limited to, nominally, minimum system load. This is the criteria for NTPC's current RFP in which they recommend 250 kW as the upper limit of permissible wind capacity for Tuktoyaktuk. The configurations evaluated had installed capacity varying from 260 kW to 320 kW.

- Medium Penetration - Average

  Wind capacity was sized to equal average system load. The configurations evaluated had installed capacity varying from 480 kW to 520 kW. This level of wind capacity is high enough that substantial amounts of wind energy cannot be absorbed into the electrical system.

- High Penetration - Peak

Wind capacity was sized to equal peak system load. The configurations evaluated had installed capacity varying from 780 kW to 800 kW. This level of wind capacity is high enough that significant amounts of wind energy cannot be absorbed into the electrical system. There is also enough wind generation to enable the diesel to be taken off line for periods of time.

	EW15	NW100-21	NW100-21	WES18 mk1
(m/s)	(Homer)	(Manufacturer)	(Modified)	(Homer)
0	0	0	0	0
1	0	0	0	0
2	0	0	0	0
3	0	2.2	0	0
4	0	5.2	1.50	2.9
5	1.8	10.1	7.00	6
6	7.8	17.3	17.30	11
7	15.9	27.3	27.30	17.7
8	24	42.1	46.10	27.3
9	32.4	58.1	58.1	39.2
10	41.3	70.4	70.4	51.4
11	48.1	80.7	80.7	63.8
12	53.8	88.7	88.7	74.2
13	58.9	94.2	94.2	79.9
14	62.1	97.6	97.6	82.2
15	64.1	99.6	99.6	82.9
16	64.5	101.3	101.3	83.3
17	65.1	102.3	102.3	83.3
18	64.4	102.6	102.6	83
19	63.9	102.5	102.5	83
20	63.6	102	102	
21	62.7	101.3	101.3	
22	61.8	100.3	100.3	
23	60.9	99.3	99.3	
24	60	98.3	98.3	
25	59.1	97.5	97.5	

Table 6: Power curves for candidate wind turbines

The system electrical load was synthesized using average and peak load data provided by NTPC. These values were scaled to provide hourly data using existing community load data from another Arctic community. The synthesized load data, shown in Figure 6, may vary slightly from the actual values that occur with the Tuktoyaktuk system but the seasonal and daily variations should be representative of the actual load. The average and peak loads from the synthesized data are within 5% of the reported values in Tuktoyaktuk.

Diesel fuel consumption was computed by identifying a proxy diesel plant that was felt to reasonably represent the fuel consumption characteristics of the existing diesel plant in Tuktoyaktuk.

According to information provided, the Tuktoyaktuk diesel plant had three diesels: 725 kW, 960 kW and 1400 kW, this latter unit has now been replaced with one we believe to be another 960 kW unit. Figure 7 plots the fuel consumption for 750 kW and 910 kW gensets (no fuel consumption curves were available for the 960 kW unit). The load distribution for Tuktoyaktuk is such that a single 910 kW diesel can meet all of the load variations without operating, for extended periods, at extremely low loads. For the purpose of this analysis, it was assumed that the diesel plant was powered at all times by a 910 kW 1800 rpm diesel. This is somewhat simplistic but it is not felt to affect the accuracy of the results.

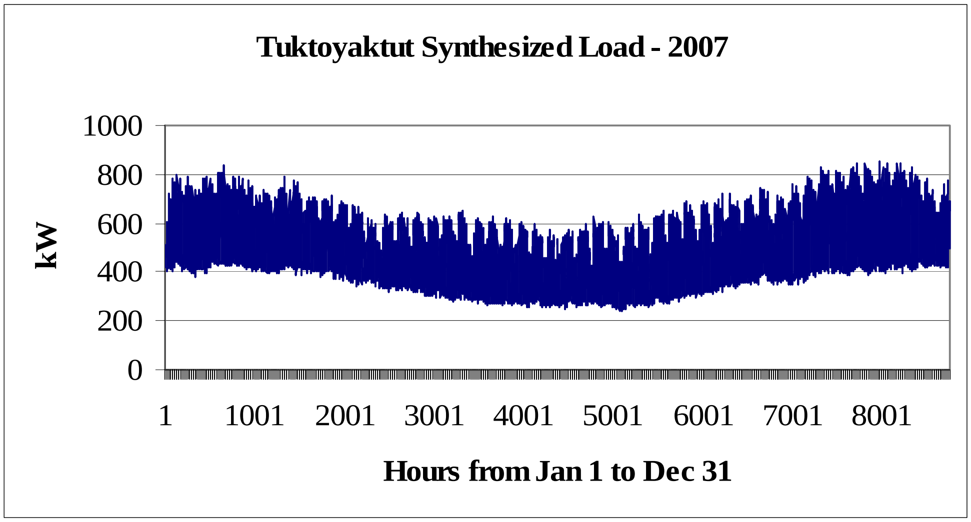

Figure 6: Annual synthesized Tuktoyaktuk load (January to December)

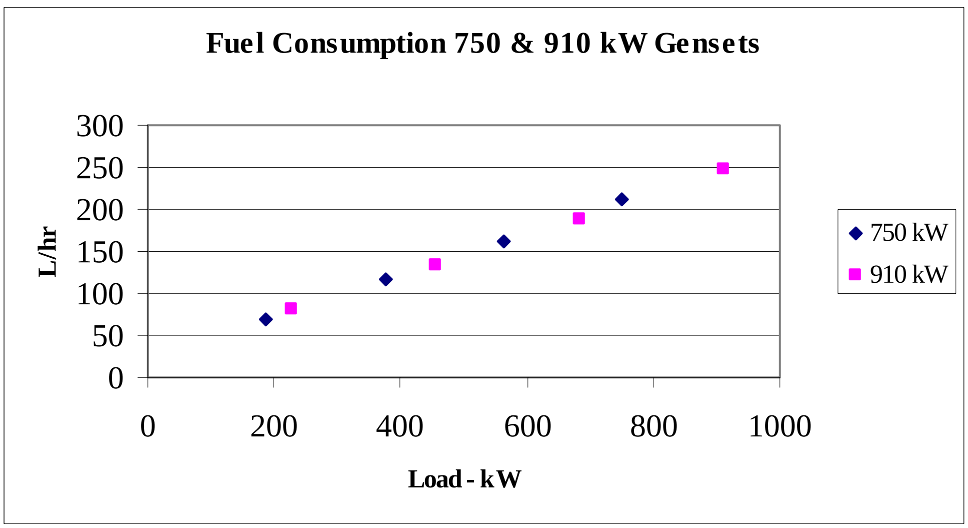

Figure 7: Diesel fuel consumption rates as a function of electrical load

The results of the Homer simulation for three scenarios with the three candidate turbines are summarized in Table 7. Appendix 13 provides the results for all four scenarios (with each of the three turbines) simulated. The salient points are as outlined below.

- Wind Generation increases proportionally to the number of turbines installed;

- Capacity Factor varies slightly from turbine to turbine, dependant upon the power curve. The NW100 has a slightly higher capacity factor, followed by the WES and EWS turbines. The variation in capacity factor is related almost solely to the power loading (expressed as rated capacity of the turbine divided by the swept area of the rotor) of the turbine design. Turbines optimized for low wind speed operation have relatively larger rotors;

Manufacturer		Entegrity Wind Systems			Northern Power Systems			Wind Energy Solutions		
Turbine designation		EWS15/50			NW100			WES18mk1		
Rated power		65 kW			100 kW			80 kW		
Tower Height		37 meters			37 meters			40 meters		
Rotor diameter		15 meters			21 meters			18 meters		
	No Wind	**Single turbine**	**Med. Pen. Min. Load**	**Med. Pen. Avg. Load**	**Single turbine**	**Med. Pen. Min. Load**	**Med. Pen. Avg. Load**	**Single turbine**	**Med. Pen. Min. Load**	**Med. Pen. Avg. Load**
Rated Capacity (kW)		65	250	500	100	250	500	80	250	500
Number of Turbines		1	4	8	1	3	5	1	4	6
Installed Capacity (kW)		65	260	520	100	300	500	80	320	480
Weights (kg)										
Rotor (kg)					614			900		
Nacelle (kg)		2420			5200			2100		
Tower (kg)		7045	est		5591			9400		
Total Shipping weight (tonnes)		11	44	87	13	39	66	14		
Min. Operating Range C		-40C			-40C			-40C		
Design Foundation Load - Fh	kN	71			156.1			149		
Design Foundation Load - Fv	kN	753 / -691	(single leg load)		-221.9			448.4		
Design Foundation Load - M	kNm	2843			2880			1136		
		Simulation results								
Total Load (MWh)	4429	4429	4429	4429	4429	4429	4429	4429	4429	4429
Wind Generation (MWh)		100	399	799	181	542	903	132	526	790
Capacity Factor %		17.5%	17.5%	17.5%	20.6%	20.6%	20.6%	18.8%	18.8%	18.8%
Wind Absorbed (MWh) (100% Availability)		95	355	638	171	465	718	126	452	645
Wind Dumped (MWh)		5	45	161	9	76	185	6	74	145
Wind Dumped Winter (MWh)		0	19	90	1	35	101	1	37	80
Hours with Diesels 'OFF'		0	0	168	0	0	192	0	6	156
Fuel Consumption ('000 litres)	1282	1258	1194	1121	1240	1167	1101	1252	1199	1128
Total Fuel Saved (litres)		23,795	87,538	160,824	42,419	114,708	180,991	31,211	111,597	162,251
% of Fuel Saved		1.9%	7.0%	13.5%	4.1%	9.3%	15.5%	3.0%	6.7%	12.8%
Fuel Saved / Turbine (litres)		23795	21885	20103	42419	38236	36198	31211	27899	27042

Table 7: Simulation summary

- Wind Absorbed increases in proportion to the number of wind turbines but increased wind capacity requires more of the wind energy to be dumped from the system in order to prevent the diesels from operating at low loads;

- Wind Dumped reflects the need to refuse wind energy from the system to ensure the diesels are not negatively impacted;

- Wind Dumped Winter computes the wind energy that is dumped during the winter months and which could be used a thermal energy if a heat sink was available economically;

- Hours with Diesels 'OFF' indicates the amount of time that the wind power is adequate to allow the diesels to be turned off. Operation in this mode permits increased diesel life to be extended;

- Fuel Consumption provides an indication of the amount of fuel that is consumed with each operating scenario;

- Total Fuel Saved indicates the amount of fuel saved by the configuration;

- % of Fuel Saved indicates the percentage of fuel saved by the configuration; and

- Fuel Saved / Turbine indicates the amount of fuel saved/turbine. This enables a quick evaluation on the incremental fuel savings per turbine.

4.4 Other matters

4.4.1 Transportation logistics and costs

To get heavy equipment to Tuktoyaktuk there are two main transportation route options. One is road transportation all the way to Inuvik via the Alaska and Dempster Highways, and then by barge or winter ice road to Tuktoyaktuk depending on the season. One advantage is that this route can be used a significant portion of the year and is only unavailable during the freeze-up and break-up periods in fall and spring. During the summer (approximately mid-June to mid-September) barging freight from Inuvik to Tuktoyaktuk costs about $0.07 per pound, and the barges are of adequate capacity to move around a 200 ton capacity crane which, with counter weights, could weigh in the order of 100 tons, so barge capacity is not an issue. From approximately January through April there is a winter road of good capacity from Inuvik to Tuktoyaktuk. In February 2008 it official capacity was listed as 45,000 kg, but based on personal communications with the Inuvik office of GNWT's transportation department, loads of up to 62,000 kg can be taken over the ice road with special permits.

The second transportation option is road transport to Hay River NWT, and then barge down the Mackenzie River to Tuktoyaktuk. The barging season is about 3 months long, from mid-June (at the earliest) to about mid-September. This option is thus more time constrained.

The authors obtained a trucking quote of $21,000 for a 25 tonne load from Toronto to Hay River from Manitoulin Transport. A trucking quote from a year ago for an Entegrity EW15 to Hay River was $13,800 plus an additional $2,000 to Whitehorse, which probably means about $2,000 more from Whitehorse to Inuvik, total $17,800 to Inuvik. Trucking restrictions are not likely to be an issue except in spring when load restrictions are applied. It should also be noted that portions of the Dempster Highway between Yukon and NWT are subject to frequent blizzards and closures may occur for up to a week at a time. The incremental trucking cost from Hay River to Inuvik is about half the cost of barging.

Barge rates from Hay River to Tuktoyaktuk have been variously quoted at $400 per ton by Northern Transportation Company Limited (NTCL) www.ntcl.com, or $0.17 per pound ($340 per ton) by Horizons North Logistics (contact Willy Moore in Inuvik, 867-777-6000). The barge rate from Inuvik to Tuktoyaktuk was quoted by Horizons North at $0.07 per pound ($140 per ton). Container rates are available and may be advantageous, but additional charges can applied to high volume low weight freight, or freight that has an awkward shape that affects transport. Horizons North mentioned that if there was a wind project being installed in Tuktoyaktuk they would like an opportunity to discuss the transportation as a fixed price package.

Air transport into Tuktoyaktuk from Inuvik is available (about 30 minutes flying) but rates for this option were not obtained as air transport of heavy freight is usually too expensive to consider except in emergency situations.

At the time a project is confirmed and the transportation requirements known, competitive quotes for all of the transportation requirements can be obtained, and if possible, the transportation should be timed to minimize costs.

4.4.2 Research and development potential targets and participants

General research and development: There are inherent risks in using machines operating in a commercial application for research and development. These risks include: downtime and lost revenues when experiments are being setup using the equipment, limitations on the types of research that can be undertaken, and finally the potential for experiments to cause damage or significant changes to the equipment. These reasons may not only be a risk for the owner of the equipment, but also for any research facility, particularly Universities or colleges who operate on limited research budgets and with time constraints.

Suggested research topics include, anti-icing technology, blade extensions (for larger rotors), taller tower design, and energy storage. The Anti-Icing Materials International Laboratory (AMIL) is an engineering research laboratory associated with the University of Quebec at Chicoutimi that specializes in the study of de-icing methods to solve icing problems and minimize their inconveniences, and have a special research focus on wind turbines[7]. AMIL's wind energy field research efforts are currently focused on large-scale wind turbines located in Murdochville in the Gaspésie region of Quebec. A potential partnership could emerge for Tuktoyaktuk, whose environment is much colder and would offer a significantly different kind of ice accretion. Adding or designating a wind turbine to be a test machine would be the most appropriate way to facilitate this research. This turbine could be taken off-line to be instrumented or coated with anti-icing materials, during which time electricity generation revenues would be lost.

One of the advantages of anti-icing research is that it is unlikely to risk significant equipment damage, unlike blade extensions or even tower re-design. However, manufacturers expressed little interest in using a remote location for any short-term research and development work on blade re-design. It was made clear that fundamental re-engineering of a wind turbine such as changing blade length would happen at manufacturers' facilities, and then at an easily accessible grid-connected site before any remote applications. Research efforts focused on tower height increases or tower self-erection, notwithstanding the fact that a project in a location such as Tuktoyaktuk could benefit from advances made in any of these areas, may provide similar concerns.

Wind energy storage systems have been discussed for decades for wind-diesel systems. Ramea, Newfoundland, is home to a hydrogen storage research project, while other technologies have been tested at AWTS/WEICan. Tuktoyaktuk offers no obvious advantage over either of these two sites for future storage research.

[7] http://www.uqac.uquebec.ca/amil/amil/amil.htm?URL=amil/windturbine/index.htm

Wind Energy Institute of Canada (WEICan): Beginning in 1981, the Atlantic Wind Test Site (AWTS), located on the Northwest tip of Prince Edward Island has been Canada's only active research and development facility for wind energy. AWTS was transformed into the Wind Energy Institute of Canada (WEICan) in 2005, with the mandate of supporting the development of wind power generation in Canada. It is to focus on four key areas of work: testing and certification, research and innovation, industry training and public education, and technical consultation and assistance. Both AWTS and WEICan have been active in research and development of wind-diesel control systems. Tuktoyaktuk Development Corporation envisions that a project in that community could play a role as a cold weather facility for specific research and development needs on behalf of WEICan.

An extreme cold weather environment is the most attractive and unique quality that a project in Tuktoyaktuk may offer to WEICan. Tuktoyaktuk could serve as a certification facility for low temperature operations, down to -40°C. This would involve a dedicated tower foundation and base that could house different manufacturers' wind turbines for a period of up to 12 months. Turbines sizes could be in the 30-300 kW range. WEICan could be involved with creating and certifying a cold-weather standard for this class of turbine. Construction constraints (foundation and installation) for turbines larger than these would limit the attractiveness of Tuktoyaktuk as a certification location for these machines. It should be noted that to date WEICan has been largely dependent on funding from Natural Resources Canada (NRCan) to conduct its work. The 2008 budget did not include additional resources for WEICan, and there have been recent indications that NRCan support funding for the facility is declining.

Aurora Research Institute (ARI): For the past 5 years, ARI has been the lead organization in the Northwest Territories organizing and collecting wind data and conducting wind energy pre-feasibility studies. Continuing these efforts throughout the Northwest Territories will facilitate the development of future spoke communities. It has been suggested that ARI could also serve as a training facility for wind turbine operations and maintenance technicians broadly for the North. It was estimated that in Canada there are approximately 60 sites where wind-diesel projects could be installed over the next decade. Assuming many of these may be developed as hub and spoke models, there may be on the order of 20 technicians that require training. In many cases two or more technicians will be trained, and re-training will also be required. However, training is specific to both the turbine and the control system that is implemented so that a facility in Tuktoyaktuk may not be universally appropriate for training. Manufacturers typically suggest one-week on-site training requirements in addition to training at the factory. Therefore, there is likely a need for somewhere on the order of 20-50 person-weeks of training over the next 10 years that may be appropriate for a facility such as Tuktoyaktuk. Much of this depends on how quickly the market for wind-diesel systems in Canada grows and in large part is likely to be strongly dependent on the scope of Federal, or Territorial / Provincial support programs. In this context ARI would need to evaluate if a dedicated course or facility was a worthwhile investment.

Canadian Wind Energy Association CanWEA: CanWEA is a trade organization for the wind energy industry in Canada and is not active in research and development, but leads the policy change efforts to encourage and facilitate wind energy in Canada for both large and small scale systems. CanWEA has actively pursued a remote community wind incentive (ReCWIP), which to date has not been adopted by the Federal government. CanWEA's likely future role is to continue a push for Federal incentives as well as to provide an opportunity for Canadian wind-diesel project proponents to network. To date CanWEA has not played a role in any of the territories directly. To date the Northern caucus has focused on remote issues at a federal level, but could be approached to work specifically in the NWT. In particular to engage in policy discussions to lay the ground work for a hub and spoke model project that could be replicated elsewhere in Canada.

4.4.3 Equipment purchase for future project benefits

Through the course of planning for project construction, installation, commissioning and operations, a long term perspective should, in the authors' view, be taken. The designs of the various project components, the equipment used in the installation of project components, as well as the tools and the instruments used in commissioning and maintenance should be considered for purchase (new or used) for the future benefit of this and potential spoke projects rather than just rented or contracted. Any such designs and equipment that can be acquired by the project will reduce future O&M costs as well as reducing the costs of future projects. The same could be said for any operational equipment that may be considered – for example a supervisory control and data acquisition system (SCADA) system that could also handle spoke projects.

LIST OF APPENDICES

RESOURCE CD LISTING

Wind Turbine Information

- Distributed Energy NW100
- Entegrity EW15
- Wind Energy Solutions WES18 mk1

Dowland Contracting Ltd. pile foundation information

Environmental Assessment Best Practice Guide for Wildlife at Risk in Canada

Foundation Design for Wind Turbines in Warming Permafrost Brent Petrie 2007

Hamlet of Tuktoyaktuk Zoning Bylaw 258

Kotzebue Electric Association Wind Projects Brad Reeve 2002

Kotzebue Electric Association Operational Experiences Brad Reeve 2004

NTCL barging rates Hay River rates 2007

NTPC Wind RFP-1

NWT Interconnection Guidelines – as approved in PUB Decision 13-2007

NWT Winter Road Mackenzie Delta – Inuvik area

Overview of the Medium Penetration Wind Diesel System in Selawik Alaska Steve Drouihet 2004

Recommended protocols for monitoring impacts of wind turbines on birds

Transport Canada Aerodrome Standards and Recommended Practices 312E

Tuktoyaktuk Community Plan

Tuktoyaktuk wind speed at 30m temperature and electrical load data

Wind Turbines and Birds A Guidance Document for Environmental Assessment