Potential for Wind Energy in Nunavut Communities

Prepared for

Qulliq Energy Corporation

by

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Foreword

The authors have worked diligently to provide Qulliq Energy Corporation (QEC) with sound, objective information and their best professional advice. One aspect of the work was found to be more challenging than anticipated, that of getting cost quotations and detailed technical information. The high level and broad nature of this study, and the limited time available, meant that there were no specific projects for which to get hard quotations, based on detailed specifications, from suppliers. Nonetheless, the authors feel that they have provided a credible product which QEC can use for further and serious consideration of wind energy development in Nunavut. It has been a challenging but interesting and meaningful project, and we are grateful to QEC for selecting us to do this important study.

Acknowledgements

There was a lot of detailed information required to complete this project, and without cooperation from QEC and many government agencies as well as manufacturers and suppliers it would not have been possible. In particular we would like to recognize the efforts of Taufik Haroon, Manager - Energy Management of QEC who dug far and wide through his organization to find and supply the information we requested of him. The representatives of government agencies, equipment manufacturers and suppliers and of service suppliers that were of assistance are too numerous to list, but their contributions were no less valuable. We are grateful to all of you!

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1.0 Executive Summary

There is enough wind data available from Environment Canada weather balloon stations and from community airports to confirm that there is a significant wind resource in many Nunavut communities. In more than half of the communities the annual average wind resource at 25 meters above ground level is above 7 meters per second, equivalent to about 25 kilometers per hour.

There are two manufacturers that make wind turbines capable of operating at temperatures as low as -40°C. One is Enercon (based in Germany) that makes large turbines, 2.3 MW and up. There are four Enercon 2.3 MW turbines installed at the Diavik Diamond mine in Northwest Territories and one Enercon 3.0 MW turbine installed at the Raglan mine in northern Nunavik. The other is Northern Power Systems (based in USA) that makes a 100 kW wind turbine suitable for smaller villages. There are a number of Northern Power Systems 100 kW turbines scattered in villages throughout Alaska.

Battery based systems that store electrical energy, and supply energy and capacity back to the power grid, are available from several manufacturers or suppliers. These systems range in capacity from 250 kW to over 10 MW and can store from 200 kWh to over 10 MWh of energy. Several battery technologies are available and have differing attributes for differing applications. More global practical experience will be necessary to know how much wind energy can be integrated into a diesel generator based grid before battery based or other grid stabilization mechanisms are required.

The high level estimated capital costs (-50% / +100%) of potential wind energy projects were developed from details but using a format from which project costs could be estimated for all Nunavut communities. These costs were then combined with community specific wind and development site information to calculate the economics of wind generation in all communities using the RETScreen modeling data. The list of ten most economic communities for wind development was then reduced to a list of five using a combination of professional judgment and other factors.

After further refining the capital costs, detailed modelling using HOMER was carried out for the top five communities. The projected return on equity (ROE) for wind projects in four of these five communities all met or exceeded the 8% ROE that the authors believe to be appropriate for QEC in today's markets, and one was lower. The results show that there is justification for QEC moving forward to the next phases of one or two potential wind energy projects.

In the author's view Iqaluit is the best location for a first project involving large turbines. Capital costs could range from about $35.2 million to $68.6 million depending on project size, and the ROE could be 14.5% or more. The levelized cost of energy (LCOE) from wind (without storage) may be as low as $0.15/kWh and the hybrid system LCOE may be as low as $0.297/kWh. In the authors' view the best location for a first project using small wind turbines is Sanikiluaq. Capital costs could range from about $4.2 to $10.5 million depending on project size. The LCOE of wind energy (without storage) may be as low as $0.23/kWh, but the hybrid system LCOE would be a bit higher than with diesel generation alone.

The next steps for either potential project are to install a meteorological mast to accurately measure the wind resource and to initiate a prefeasibility study to further examine the projects.

2.0 Introduction

Qulliq Energy Corporation (QEC) and the Government of Nunavut are committed to promoting alternatives to diesel electric energy generation. They believe that wind energy technology may represent one technology that could enhance and diversify the existing electricity infrastructure in Nunavut.

To assist in assessing the potential QEC issued a Request for Proposal (#201592) for a study regarding potential wind energy in Nunavut. The objective of the study is to provide QEC with a list of communities in which wind turbine generators can be installed and integrated with the diesel plant based power systems. The intent of the wind energy integration is to shut down at least one generator in the diesel plants where more than one would normally be operating and otherwise to reduce fuel consumption and other variable costs.

Among other details contained in the Scope of Work as provided in the RFP, the study is to analyze and refine the wind resource in all 25 Nunavut communities; review previous reports; to determine which communities have the potential for economic wind generation; provide a short list of communities; and recommend next steps that QEC could pursue with respect to wind energy development. The study was also to discuss wind turbine technology available to Nunavut, the battery storage technologies; and any other recommendations considered to be of value to the study and to QEC.

This report has been prepared on the basis that QEC would be developing the potential wind projects, so financial parameters relevant to a regulated electric utility were used. For QEC the authors used a debt – equity ratio of 60:40, an interest rate of 4%, and a return on equity 8% (5.6% cost of capital for new projects). The supply projects that are eventually developed may be structured differently than envisioned by the authors. Where modelling indicated that there was surplus wind energy it was not assigned any value. In practice it would be appropriate to examine the possibility of selling this energy as a substitute for heating oil, thus generating some additional revenue and further improving the ROE and decreasing greenhouse gas emissions.

The cost estimating in this report assumes that developers would have a reasonable familiarity with wind projects (in addition to exercising sound project management and strict cost control). If this is not the case then initial projects involving each of the larger and smaller turbines referenced in this report could experience some added costs due to the “learning curve”. However, subsequent projects built by a previously inexperienced developer would likely experience somewhat lower costs.

3.0 Wind Resource Assessment Methodology

To estimate the wind energy potential in a community, wind speed measurements are required. The wind data used for the wind analysis was extracted from Environment Canada's (EC) climate data, which is available online at their website (www.climate.weatheroffice.ec.gc.ca). According to EC there is a climate (weather) station at all the airports in the Nunavut communities. The data from these stations contain hourly measurements of wind speed and direction, temperature, pressure, humidity, and other parameters. The wind measurements at these stations are made at 10 m above ground level (AGL) which is the standard height for airport weather measurements in Canada.

For each community we extracted the last four years of measurements to calculate an annual average speed for the RETScreen model. We also used the wind measurements to create a one-year time series of wind speed for the HOMER Energy model.

The wind speed measured at 10 m AGL needs to be projected to higher levels to estimate the mean wind speed for wind turbines with taller towers. The wind turbines used for this analysis are at a 25 m height (North Wind 100) and at a 57 m height (Enercon E70).

Turbulent air flow over rough surfaces tends to generate a vertical profile of horizontal winds that are fairly well predictable. The wind speed profile near the ground is dependent on neutral well mixed air conditions and the roughness of the ground surface. This vertical profile can be defined by the natural log law equation (see Stull, 2000):

$$\boldsymbol{u_2 = u_1 \frac{\ln(z_2/z_o)}{\ln(z_1/z_o)}}$$

Where u_1 is the known wind speed at z_1 (typically at 10 m AGL), and is projected to u_2 at the height z_2. The surface roughness is defined by z_o which as a rule of thumb is 1/10 the height of the grass, brush, or ground undulations surrounding the site where the measurements are made. This equation is considered most accurate up to approximately 100 m above the surface. The surface roughness z_o can be categorised by the type and size of vegetation as well as the hilliness of the ground itself.

At most of the climate stations we used a surface roughness of z_o = 0.005 m, which is typical of level fields around the airports. Using this surface roughness value and the equation above we can calculate the wind speed at heights up to 100 m above the surface station.

In most communities that are flat, the above assumption will suffice for estimating the wind speed within several kilometers of the community. In hilly terrain we rely more on the upper air measurements from nearby weather balloon stations to estimate the wind speed at the height of the hill of interest. There six weather balloon stations in Nunavut and those are Hall Beach, Iqaluit, Baker Lake, Coral Harbour, Resolute, and Cambridge Bay. The wind speed profiles shown in Figure 1 are from a ten-year (2006-2015) span of measurements.

The wind speeds that have been estimated for each community are listed in the RETScreen results in Table 3. RETScreen Modeling - Summary Table of 25 communities. The potential wind development sites for which the wind speeds in the 25 individual communities were estimated were selected by a review of the 1:50,000 topographic maps, with respect to airport location, road locations, the highest available elevation for a wind project (to maximize the available wind speed), and professional judgment.

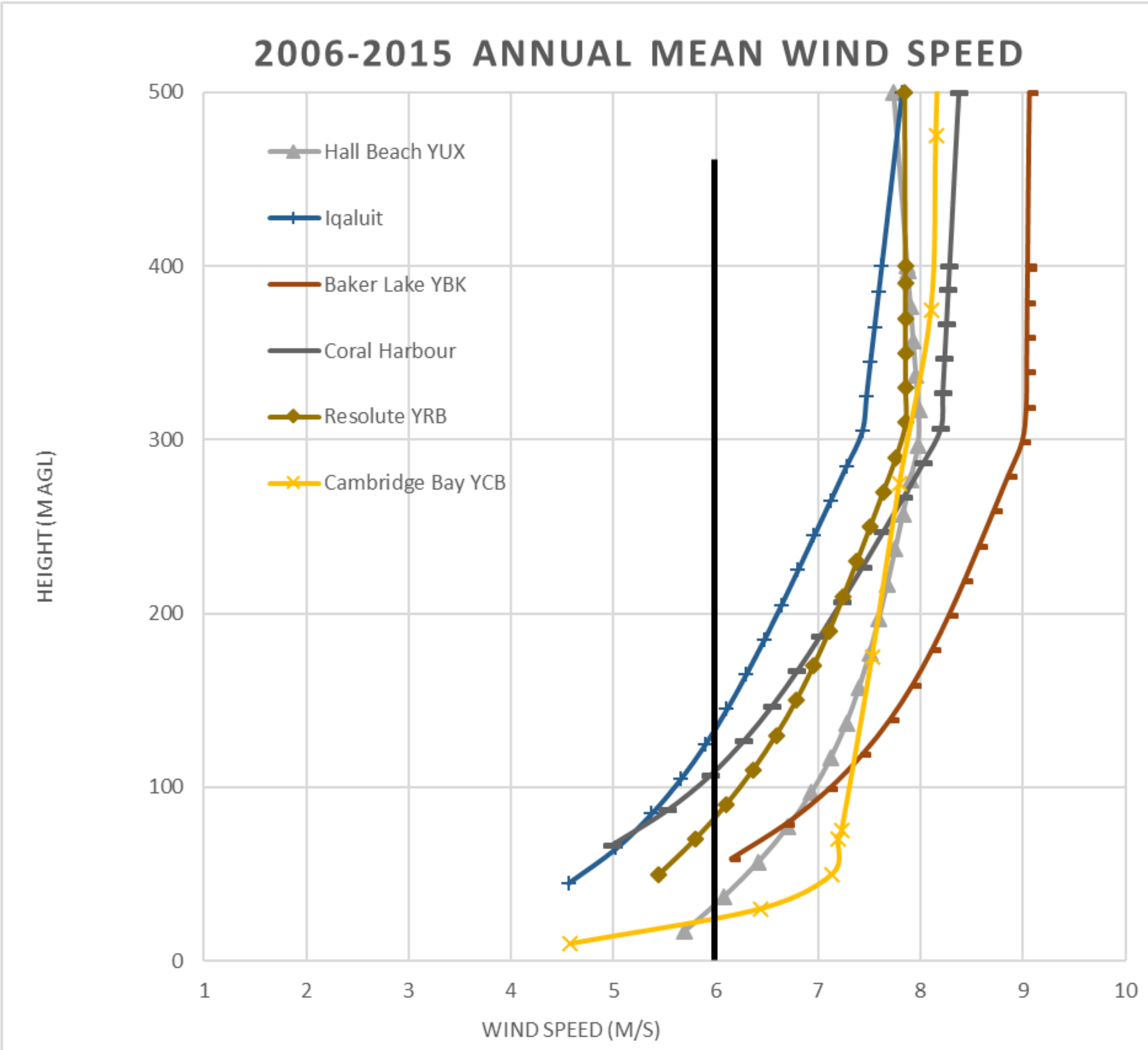

Figure 1: vertical profiles of horizontal wind speeds for the six Nunavut upper air stations.

4.0 Environmental Constraints

4.1 Environmental factors

In this study the authors have not considered environment factors such as flora, fauna, land, and water. In the site selection process the proposed turbine locations have been kept at least 500 m away from homes. The information available from Department of Environment was not considered to be helpful in site selection. In subsequent study phases of individual projects (pre-feasibility and feasibility) it will be necessary to undertake environmental assessments. This will include evaluation of risks to flora, fauna, land, and water.

In this desk-top study site specific geotechnical issues could not be evaluated. The proposed turbine locations were kept close to existing roads and where rock or gravel appear to be present. Permafrost was assumed to be everywhere in estimating foundation costs.

4.2 Airport related constraints

Conversations were held with various individuals at Transport Canada and NAV CANADA in regards to air regulations and how they would impact wind energy development in Nunavut. According to both Transport Canada and NAV CANADA, obstructions within a 4 km radius are limited to 45 m maximum height above airport elevations. There is no leeway on height, regardless of lighting and marking, within the 4 km radius. NAV CANADA informed the authors that this 4 km restriction is not always a circular area and that this depends on terrain surrounding the airport. Outside of 4 km radius it becomes a matter of how obstructions such as wind turbines would affect airplane approaches to the airport.

This 4 km radius and 45 m obstacle limitation stems from Transport Canada's TP312 airdrome standards for airport themselves without approaches. NAV CANADA through their own TP308 expands on Transport Canada's TP312 to make approaches to the airstrip workable. This means that wind turbines would most likely not be permitted if they would be in the approach paths to the airport. NAV CANADA tries to minimize raising approaches as raising them can make the approaches unflyable. However, NAV CANADA did say that at some airports it might be possible to raise the approaches provided that they are not at their upper limits already. When selecting the wind development sites the authors have avoided the straight lines of flight to and from the runways in all communities. This does not necessarily mean that the sites are out of the way of the approaches.

It is expected that there will be requirements for obstruction lighting for the wind turbines and possibly painting. To get a clear understanding of the suitability of each site the project proponent will need to submit Aeronautical Clearance Obstruction Form to Transport Canada and Land Use Submission Form to NAV CANADA. Approvals from both Transport Canada and NAV CANADA will be required.

It is not uncommon for remote airports to have navigational aids (NAVAIDS) which impose additional restrictions upon wind energy developments. NAV CANADA informed us that all but one of the airports in Nunavut have NAVAIDS such as VORs, NDBs, or RADARs. In regards to wind turbines, VORs need a minimum of 15 km of clear distance while NDBs are less restrictive. RADARs are the most restrictive and they have an 80 km restriction radius for wind turbines. As wind turbines may affect NAVAIDS, all possible wind energy developments and each individual wind turbine would need to be submitted for a full review by NAV CANADA. Some turbines may be allowed depending on their locations and heights.

According to NAV CANADA, older VORs are not very flexible and for them wind turbines will create interference. If a case where a community airport has an older VOR, wind turbines would need to be outside 15 km radius from the VOR. Newer VORs have greater tolerances and will not be disrupted with a small number of turbines placed within the 15 km radius. At the present time it is not clear how many wind turbines new VORs could handle without interference. Also, it is not clear which communities have newer VORs. Out of top five shortlisted communities, Arviat and Sanikiluaq have NDBs only. Table 1 lists the navigational aids in Nunavut communities.

Table 1. Navigational Aids in the Nunavut Communities[1]

Community	**Type of NAVAIDS**
Arctic Bay (Ikpiarjuk)	No NAVAIDS
Arviat	NDB only
Baker Lake	VOR & NDB
Cambridge Bay	VOR & NDB
Cape Dorset	NDB only
Chesterfield Inlet	NDB only
Clyde River	NDB only
Coral Harbour	VOR & NDB
Gjoa Haven	NDB only
Grise Fiord	NDB only
Hall Beach	VOR and NDB
Igloolik	NDB only
Iqaluit	VOR, NDB & RADAR
Kimmirut	NDB only
Kugaaruk (fmr. Pelly Bay)	NDB only
Kugluktuk	NDB only
Pangnirtung	NDB only
Pond Inlet	NDB only
Qikiqtarjuaq (fmr. Broughton Island)	NDB only
Rankin Inlet	VOR & NDB
Repulse Bay	NDB only
Resolute Bay	VOR & NDB
Sanikiluaq	NDB only
Taloyoak	NDB only
Whale Cove	NDB only

We have inquired into the 60 m tower at Iqaluit and the wind turbine at Rankin Inlet, and NAV CANADA informed the authors that wind turbines cause interference but towers do not. As for Rankin Inlet, NAV CANADA said that it might have a newer VOR, or that the single 66 kW wind turbine created an unnoticeable interference.

[1] Short listed communities are highlighted.

Iqaluit airport has a RADAR and as a result NAV CANADA might not allow wind turbines within 80 km of the radar site. We were told that Transport Canada requires new NAVAIDS to have tolerances built into them and as a result newer RADARs would allow a small number of wind turbines within the 80 km radius. According to Enercon, in Germany no turbines are allowed within 15 km of the radar sites.

As Iqaluit presents the greatest single opportunity to reduce diesel consumption for power generation in the territory, we have submitted an Aeronautical Clearance Obstruction Form to Transport Canada and a Land Use Submission Form to NAV CANADA. Responses to these should provide a clear idea of the restrictions that would be imposed on the wind project in that area. The site that was chosen by the team as the most ideal from wind resource perspective is being assessed by Transport Canada and NAV CANADA in accordance with zoning regulations, effect on the approaches, and marking requirements. The timeline for submission review by NAV CANADA is approximately 12-14 weeks, however for Iqaluit they have placed it in the rush file. As of the date of this report no responses have been received from either Transport Canada or NAV CANADA.

5.0 Wind Turbine Technologies

5.1 Large wind turbines

Large wind turbines that are commonly used by developers of large on-shore wind farms are available from a number of manufacturers. These turbines typically range in size from about 1.5 MW up to about 4 MW, but larger ones are in development and will soon be produced on a serial basis.

Perhaps the most significant improvement over the past five years or so has been the development of lighter and stronger blades that allow their length to be increased and the energy production in more moderate wind speed regimes to be increased. This increased energy capture has been driving down the cost of producing electricity from wind.

Other trends evident over the past decade include the move to variable speed operation and direct drives. Variable speed operation reduces some of the stresses on the turbines and allows a slightly higher efficiency in energy capture. This has been made possible with cost effective solid state technology to convert fluctuating frequency AC power to DC power and back to a steady frequency AC power. Direct drive systems eliminate the need for gearboxes and at least one major bearing, thereby reducing mechanical energy losses and increasing the reliability of the turbine.

Several large turbine manufacturers were researched on line and/or contacted, including Enercon, Nordex, Senvion (formerly Repower), and Siemens. While a number of turbine manufacturers have cold climate and blade heating options, the authors found that only Enercon makes a turbine that is designed so that it can operate in temperatures down to -40°C, albeit at a reduced capacity between -30°C and -40°C. For all other manufacturers the operating temperature was limited to -30°C. In some cases the turbine, if running as the temperature dropped below -30°C, was allowed to continue to run but would not restart until the temperature was above that threshold.

Table 2. Comparison of anti/de-icing systems and cold climate capabilities of wind turbines

Manufacturers	**Northern Power**	**Enercon**	**Nordex**	**Senvion**	**Siemens**
Turbine model	NW100 Arctic (100 kW)	E70E4 (2.3 MW)	N117/3000 (3.0 MW)	3.2M114CCV (3.2 MW)	SWT-2.3-101 (2.3 MW)
Anti/de-icing capabilities	hydrophobic polymer coating	Anti-icing: hot air blown from the start of the blade to the edge	Anti-icing system heats tip of the blades	Anti-icing and de-icing (only on new models)	De-icing system (electric resistance heating)
Cold temperature operation	-40 degrees Celsius	-40 degrees Celsius (2.3 MW and larger models)	-30 degrees Celsius	-30 degrees Celsius	-25 degrees Celsius

Enercon was probably the first manufacturer to commit to direct drive for their commercial wind turbines. They have a reputation of being the most reliable wind turbine on the market. Four Enercon E70 2.3 MW wind turbines that operate to -40°C and have blade heating to overcome the effects of frost and icing, have been running at the Diavik Diamond mine in Northwest Territories since 2012. In 2014 a similarly equipped Enercon E82 3.0 MW wind turbine was installed at the Raglan mine near the tip of the Ungava Peninsula in northern Quebec.

In the author’s opinion Enercon should be the manufacturer of choice for large wind turbines in Nunavut. The technologies incorporated into their turbines and their experience in very cold Canadian climates makes them stand out from the other manufacturers. The Enercon E70 2.3 MW turbine was selected for modelling in this report.

Brochures on wind turbine technologies will be made available to QEC via Dropbox.

5.2 Small wind turbines

The authors refer to wind turbines of a size suitable to smaller communities as small wind turbines. These are turbines that can range from 50 kW to several hundred kW in capacity. They do not include the “household” scale turbines that are more typically referred to as “small” wind turbines in other contexts. The authors are quite familiar with the turbines in this size range. With respect to the technologies used in these small turbines, they generally try to follow the trends of the larger turbines but because of a very limited market and sales volumes they cannot be quite as sophisticated.

The only available wind turbine that is designed to operate in temperatures down to -40°C is the Norther Power Systems’ North Wind 100. This is a 100 kW turbine with direct drive, and while it does not (yet at least) have a blade heating system the Arctic version comes with a black ice-phobic blade coating to mitigate the impacts of frost and icing. Experience in a severe rime icing environment in Yukon has shown that the black ice-phobic coating improves energy production by promoting a more rapid de-icing following ice accumulation.

Like the much larger Enercon wind turbines, the North Wind 100 was developed at the outset as a direct drive turbine. And like the large utility wind turbines its rotor diameter has increased from the original 19 m over time and is now available with a rotor diameter of up to 24.4 m.

Northern Power Systems has been focused on developing wind turbine technologies for remote communities. More recent developments that are either available now or will be in the near future include a “ballasted” foundation that does not require concrete. A metal foundation “container” is simply filled with locally available rock or sand. A second valuable development is a crane-less installation mechanism. This is a hydraulic mechanism that will raise a turbine on a 25 m tower into place so that a crane is not required. Getting a crane to and from a remote community can be very expensive. Once purchased this mechanism can be used for installing any number of turbines. Look for this mechanism to be available for the taller tower options in future.

In the authors’ view Northern Power Systems’ North Wind 100 should be the turbine of choice for Nunavut.

Brochures on Northern Power Systems wind turbine technology will be provided to QEC via Dropbox.

6.0 Energy Storage Technologies

6.1 General

The energy storage market is continuing to grow as more electrical utilities are embracing the technology across the globe. There are an increasing number of energy storage manufacturers as well as battery chemistry agnostic solution integrators. As a result, the cost of energy storage is continuing to drop and it is expected this will continue for the foreseeable future as market saturation has not been reached and as markets continue to expand with decreasing costs.

The authors held conversations with a few energy storage providers and have concentrated their efforts on companies that can provide fully packaged solutions and that have a diversity in battery chemistries that they can work with. They must also have been able to provide all-inclusive budget cost estimates. The firms that met these conditions were Saskatchewan Research Council, EOS, Younicos, Sentinel Solar-Aquion Energy. The level of costing detail provided varied from supplier to supplier.

In general it appears that lithium-ion batteries (there are several lithium-ion chemistries in use) are the preferred technology for smaller systems. For larger systems there are also other technologies that become attractive, and the authors feel that it would not be appropriate to single out one battery technology that is preferable to others for the larger systems. It goes without saying that conventional lead-acid batteries are not contenders in this application.

Some energy storage system providers (e.g. Younicos) have indicated that their systems can provide grid frequency and voltage stabilization functions, but it is not certain that all can perform this function.

Brochures on various battery energy storage systems will be provided to QEC via Dropbox.

6.2 Saskatchewan Research Council

The Saskatchewan Research Council (SRC) provides diverse energy services, one of which is providing fully packaged energy storage solutions. While working on remediation of the Gunnar, Saskatchewan abandoned uranium mine powered by diesel generation, SRC developed their Hybrid Energy Container (HERC) Power System to maximize the fuel savings. SRC was responsible developing the Cowessess First Nation's utility scale wind-energy storage project. The HERC Power System comes with a battery bank, invertors, controls, and a small diesel generator all packaged into a shipping container. SRC's designed the HERC Power System to be modular, rugged and easily transportable. Note that SRC is battery chemistry agnostic and can provide batteries with other chemistries other than lithium-ion, but as lithium-ion technology performs better in cold climates the authors requested budget cost estimates based lithium-ion batteries.

SRC has provided us with an estimate for a small, fully commissioned HERC Power System. This 250 kW 250 kWh energy storage system includes the following: lithium-ion batteries with integrated protection, inverters, AC and DC circuit breakers, grid transformers, and an insulated modular container that is rated for operation down to -40°C ambient temperatures. Budget pricing included transportation to site, construction, and commissioning.

SRC prefers to work with Saft batteries when packaging a lithium-ion battery system solution for their clients. Saft batteries were chosen by Northwest Territories Power Corporation for their Colville Lake solar-diesel-battery project. Realistic life cycle of the battery is 12 years (based on the Cowessess system). It is difficult to forecast what the replacement cost will be 12 years from now but it is expected to be significantly lower. End of life for batteries is defined as the threshold when the effective usable energy storage has decreased to below 80% of its original rated capacity. SRC estimates that the cost of new battery, removal of old battery, re-installation and testing would cost about $75,000 above the battery replacement purchase cost for a small system.

SRC is also a potential supplier for larger capacity battery systems more suitable for use in power systems using the Enercon E70 2.3 MW wind turbine.

6.3 EOS Energy Storage

EOS is a New York based manufacturer of zinc hybrid cathode batteries, which are aqueous electrolyte-based batteries. This is a product new to the market. Their primary use is energy storage. These batteries have a long life cycle and are competitively priced. EOS offers Aurora 1000/4000 energy solution that has a charging capacity of 1 MW and an energy storage capability of 4 MWh. It is housed in a 40 ft. container, which would need to be winterized for use in Nunavut. This system would need to be packaged with Schneider Electric's 1 MW inverter that is available in a winterized 20 ft. container.

EOS has its technology deployed with big utilities in the US such as Con Edison and GDF Suez, and are expecting to carry out numerous megawatt scale projects this year. EOS' Aurora 1000/4000 energy system will be installed at San Ramon Technology Centre owned by Pacific Gas and Electric Company (PG&E). This project was funded by California Energy Commission. Recently PG&E awarded a 10 MW, 40 MWh project to a developer using the EOS energy system. The EOS Aurora DC battery system costs $160 per kWh of storage capacity[2].

6.4 Younicos

Younicos is German energy storage and energy management company based in Berlin. The company is experienced in integrating the components involved in battery energy storage systems and in providing engineering, installation, integration, and operational services related to energy storage. Younicos is battery chemistry agnostic and works with lithium-ion, vanadium redox, and advanced lead-acid batteries among others. In 2014 Younicos acquired Xtreme Power located in Austin, Texas. Through the acquisition of Xtreme Power, Younicos gained the advanced inverter technology that Xtreme had developed as well as their advanced lead-acid batteries. Younicos relies on proven battery technology and its own advanced inverters to produce plug-and-play energy storage systems.

Xtreme Power inverters are now found in the Younicos Y-Cube, which is a fully integrated, containerized energy storage solution which, according to Younicos, is plug-and-play, thus reducing the challenges of installation and integration. The Y-Cube is designed with two enclosures, two 250 kVA Y-Converters are housed in one enclosure and batteries are housed in the other. These enclosures are usually stacked on

[2] http://www.businesswire.com/news/home/20151203005885/en/Convergent-Energy-Power-Announces-10-MW-40

top of each other to reduce space requirements. Younicos has integrated controls into the design of power conversion system that allows the Y-Converter to communicate directly with the batteries. According to Younicos, this gives their energy storage system unrivalled response time and performance. The Y-Cube is a fully packaged modular energy storage solution. For example, in six Y-Cube enclosures Younicos can provide 4 MWh of LGChem lithium-ion battery storage, 1 MW of Y-Converter inverter capacity, Younicos control hardware and software, the necessary integration hardware, and all HVAC and fire suppression equipment. A system with 11 MWh of nameplate energy storage, with 5 MW of inverter capacity, and with other necessary components, would come in 13 Y-Cube enclosures. Younicos has cold climate versions of the energy storage solutions that are rated for ambient temperatures down to -55°C.

Younicos has two battery test centres, one in Berlin, Germany and the other in Austin, Texas. The test centre in Texas deals with lithium-ion, advanced lead acid batteries, and inverters. At these test centres Younicos can carry out simulations, testing protocol, modelling on how to increase wind penetration, etc. Younicos will bring prospective buyers to one of their test centres to showcase how their systems would work.

By taking over Xtreme Power, Younicos also gained Xtreme's portfolio of projects in Hawaii and the one in Kodiak, Alaska. In 2015, Younicos raised $50 million to finance growth, one of their main investors was First Solar. Spread across twenty projects globally, Younicos has installed just shy of 100 MW of capacity along with the related energy storage. Their biggest project to date has been repowering a 36 MW capacity plus energy storage plant for Duke Energy Renewables in Texas. This project will involve replacing lead-acid energy storage batteries with Younicos' lithium-ion batteries. This project is expected to come on line by end of first quarter of this year. Recently, Younicos has completed a standalone 5 MW capacity plus energy storage facility in Schwerin, Germany. Younicos is also providing software for a 10 MW capacity plus energy storage project in Leighton Buzzard, UK.

Through their business development office in New Brunswick, Younicos has experience working in Canada and in remote areas. They are currently working with First Nations communities in New Brunswick and Northern Ontario.

6.5 Sentinel Solar – Aquion Energy

Aquion Energy is a Pennsylvania based manufacturer of saltwater batteries that are clean, safe and sustainable. Aquion has developed Aqueous Hybrid Ion batteries that rely on non-toxic and abundant materials. These saltwater batteries are intended for long-duration applications and are capable of high performance at low cost. According to Aquion, their saltwater batteries have a long lifecycle, require minimal maintenance, and can handle an incredible amount of abuse. One of Aquion's competitors confirmed that the chemistry that Aquion uses is very hard to damage.

Sentinel Solar is an Ontario based provider of complete solar solutions and are also a distributor for Aquion Energy. Sentinel has developed the Sentinel Bolt plug-and-play, modular, containerized energy storage system. The Sentinel Bolt systems use Aquion saltwater batteries, bidirectional inverters and they come prewired to reduce the amount of work at the installation site.

Solvest, a turn-key installer of off-grid solar-battery systems, has said that the Sentinel/Aquion plug-and-play system is very robust, requires very little maintenance, and is cost competitive with lithium-ion based battery systems. Aquion batteries are heavier than their lithium-ion counterparts. According to Solvest Aquion and Eos are some of the best battery energy storage options on the market for the purpose of reducing the operation of diesel generators.

6.6 PREP Global

For the off-grid communities reliant on diesel generation PREP offers their BluVert system that combines a Variable Speed Generator (VSG) along with BluVert's patent pending Energy Management System (EMS) to maximize the fuel savings. The EMS is the enabling technology that allows the VSG operation, as well as the control, the ride-through, and the short term backup for the entire power plant. The EMS can also offer optimized economic dispatch of fixed speed generators. Lastly, the BluVert system allows for easier integration of renewable generation by providing fill-in power. PREP can provide VSGs in sizes from 350 kW to 1 MW and larger for inclusion to existing power plants. To date PREP has carried out testing on a scaled down system at their facility that demonstrated the power quality and control algorithms. PREP is looking to deploy their first commercial system.

6.7 Shipstone Corporation

Shipstone is an Alberta based developer of energy storage solutions. Shipstone has developed a system that offers high power ramp rate storage and is specifically designed and built to bring renewable power into diesel micro-grids at high penetration levels. The Shipstone system claims to offer perfect stability at 100% renewable penetration levels, and will even improve the diesel system stability by providing high surge power headroom. In 2013, Sustainable Technology Development Canada funded Shipstone to demonstrate its capacity to store, manage, and integrate renewable power. The company has a system installed in the T'Sou-ke First Nation community on the Vancouver Island, BC where it is providing smoothing capability for a solar-diesel system. Shipstone combines their technology with Lithium-Ion batteries found in the Nissan LEAF electric automobile to provide 15 minutes of energy storage capability which allows the diesel generators to shut down when wind energy (or other intermittent renewable power supply) is abundant. Shipstone's approach to energy storage is to use the smallest amount possible and still provide smooth transfer between renewable energy supplies and the diesel generation. The Shipstone system is scalable from 20 kW to several megawatts.

7.0 Cost Estimating

7.1 General

There are very few successful wind energy projects in Canada's north. Consequently there is virtually no history of cost experiences to use as a base or a benchmark with which to "truth" cost estimates that are developed. Nonetheless, the authors have diligently pursued cost estimates that are as realistic as possible in the circumstances. While a Class D estimate (-50% to +100%) is a reasonable expectation for this level of study, the intent was to try to do better than that.

The only two isolated wind projects in the north are at the Diavik Diamond mine (NWT) and the Raglan mine (Nunavik). Both of these projects are at locations where there is substantial technical and project management experience, and a substantial amount of construction equipment. While the authors are aware of these projects and possess such information as is publicly available, they are different enough that the high level summary data available could only be used as a rough guide.

Without allocating more time and cost than was available for this study, and without much more project specific information, hard quotations could not be obtained. Also, some suppliers, despite signed Non-Disclosure Agreements (NDAs) with the authors, were concerned about the release of proprietary information and provided only limited costing and technical information.

All cost estimates are provided in Canadian dollars (February 2016). Where costs or prices were provided to the authors in $US, a conversion rate of $1 CDN = $0.70 US was used. It should be noted that quite a lot of the equipment that would be used in wind projects is manufactured outside of Canada and fluctuations in the value of the Canadian dollar relative to other currencies make price forecasting challenging. It may be that the Canadian dollar reached its lowest values during the time in which this report was prepared. If that proves to be the case, costs for imported equipment at some future time could be lower than the estimates provided in this report, and project economics would become more robust.

7.2 Wind turbines

Large wind turbine cost estimating had to be based on less reliable techniques than budget quotes from the preferred supplier, Enercon. While all study team members signed NDAs with Enercon ultimately the desired financial (and technical) information was not released because QEC did not have a signed NDA with Enercon.

The cost estimates provided by the authors for the Enercon E70 2.3 MW cold climate wind turbine (with blade heating) was developed using 2012 budget information for an Enercon E82 2.0 MW wind turbine that is in the public domain, general wind turbine costing information that is available publicly on the web, and the personal experience of the authors. The estimate developed for the E70 2.3 MW cold climate wind turbine is $4.2 million including transformer, blade heating, transport to Montreal, on-site crane costs, installation, and commissioning.

Cost estimating for the much smaller Norther Power Systems' North Wind 100 was based on budget pricing by the manufacturer. Northern Power's remote installation kit consisting of a turbine with a 25 m mono pole tower, foundation to be filled with local ballast (i.e. no concrete is required), a hydraulic tower raising system (avoids the need for a crane), transport to a port (e.g. Montreal), and commissioning was $US440,000 ($CDN628,571). Subsequent turbines are $US410,000 ($CDN585,714) as the hydraulic tower raising mechanism costing $US30,000 ($CDN42,857) is a unit that can be used for raising as many turbines as necessary. Depending on numbers purchased, the cost per turbine could drop as much as $US50,000 (approximately $CDN70,000). Because of the uncertainty about the numbers of turbines in any project that QEC might wish to undertake, the authors only included a 10% discount for purchases of two or more turbines. Northern Power is actively considering an hydraulic lifting system for taller towers, and as taller towers would be desirable for wind energy production and could result in some additional costs, no further possible discounts were applied.

7.3 Energy storage

Costs for energy storage systems were based on budget pricing information from a number of different suppliers. As described in Section 6 there are a variety of battery technologies available, and there are also variations in battery system charging and supply capacities relative to the energy storage capacity from supplier to supplier. Battery technology is evolving quite rapidly and we expect costs to continue to track downward steadily. In addition to the information obtained from the suppliers contacted, some reports on battery technology available on the web were also consulted.

For these reasons the authors decided to provide generic package costs for small and large systems based on all the information received from all of the suppliers. For a battery system to support a small community using the North Wind 100 wind turbine, the authors chose a typical module having a capacity of 250 kW along with a battery energy storage capacity of 200 kWh. The all-in installed cost for such a system was estimated to be $1 million. Estimated operating and maintenance costs for such a system is $10,000 per year. Battery replacement would be required after about 12 years of use (when the battery capacity drops below 80% of its original value.

For larger communities using the Enercon E70 2.3 MW wind turbine, a typical module having a capacity of 1 MW along with a battery energy storage capacity of 1 MWh. For such a system the authors estimated the all-in installed cost to be $2.5 million. Operating and maintenance costs for this system was estimated to be $40,000 per year. Battery replacement, if necessary, will depend on the technology involved, but no more than about every 12 years (lithium-ion technology).

In addition to energy storage to increase wind energy displacement of diesel generation, battery energy storage systems were also added to projects to provide grid frequency and voltage stability where the displacement of diesel generation by wind energy exceeded 12% on an annual basis. The authors are not aware of a documented body of knowledge that would assist in determining exactly when such stabilization mechanisms become necessary, and have tried to err on the side of caution. Should battery energy storage systems are found not to be required until higher levels of diesel displacement, the economics of projects will improve. This will be especially true for smaller projects that use the North Wind 100 turbine as the battery energy storage system represents a high percentage of the capital costs for these projects.

7.4 Crane services

For the installation of small North Wind 100 turbines, it was assumed that the hydraulic tower lifting system would be used to that no crane would be required for the installation. However, some heavy equipment would still be required for the assembly of the turbines. As well, the containers in which the North Wind 100 are transported are 40 foot containers, and from what the authors could ascertain, these could not be handled by standard NEAS and NSSI ocean transport companies' equipment. Thus the rental for four months of a 70 ton rough terrain crane ($100,000) was included in the costs for projects using the North Wind 100.

If QEC is to actively pursue a project involving North Wind 100 wind turbines, then the next phase of work (a prefeasibility study) should look into the trade-offs between the remote installation option and a conventional crane (somewhat larger than the 70 ton unit considered in this report) installation option so that a taller tower option might be used. Towers up to a hub height of 37 meters are available for crane installation.

For the much larger Enercon E70 wind turbine a large crane would be required. Based on the limited technical information available, but knowing that the Enercon rotor and stator can be lifted into the nacelle separately, a 450 all-terrain ton crane was budgeted. Crane supply companies in eastern Canada were contacted. Detailed information was supplied by two firms and indicative pricing was obtained from another by telephone. It was assumed that a project involving the larger turbine would be installed over the course of one season following a year (or more) of preparation. The crane was assumed to be rented for a 4 month period which was intended to include return transport to the project site from a port in or near Montreal.

Monthly rental rates quoted ranged from $100,000 per month for a 450 ton crane up to $145,000 per month for a 600 ton crane. In addition, there were costs to bring the cranes to and from Montreal, which varied between different suppliers based on the crane location or base. The most expensive quoted was for the 450 ton crane and to be conservative that figure was used. Monthly rental rates were based on 176 hours per month (minimum cost); additional operating hours were assumed to be nil since four months of rental were included. The four-month cost for the 450 ton crane rental FOB Montreal amounted to $520,000.

In addition to the large crane, a smaller helper crane is required. Based on comments from the crane suppliers, a 90 ton rough-terrain crane was budgeted. This crane might be useful in unloading the equipment from the ocean vessels/barges at the project community. As with the large crane it too was assumed to be rented for a 4 month period. The charge-out rate for this crane was quoted at $30,000 per month but the cost of getting it to and from Montreal was very modest. The four-month cost was estimated to be $124,000.

If a project involving Enercon E70 turbines is contemplated, a prefeasibility study could examine the cost effectiveness of the purchase of a helper size crane that could then be left on site and used for other projects in Nunavut. For example the installation of North Wind 100 turbines.

7.5 Transportation services

Ocean transport was considered in two different ways. First was transport using the established carriers NEAS and NSSI. The published freight rates (per ton) for 2015 were used at face value as the cost for shipping. The shipping rates for 2016 had not yet been published, but diesel fuel prices have dropped over the past year and no high volume discounts were assumed to apply, so the authors considered this to be a reasonable first estimate of shipping cost.

Freight rates to Iqaluit were rounded to $300 per ton and freight rates to communities on the western Hudson Bay coast were rounded to $375 per ton. Return haul (of cranes to Montreal) was estimated to cost $250 per ton from either location. Using these unit freight cost figures and the shipping weights of the equipment to be transported (whether wind turbines, cranes or other supplies), the shipping costs were calculated.

The second approach to costing the transport cost was to obtain a budget price for a dedicated ocean vessel to bring all the project equipment and supplies direct to the project site. The one estimate obtained resulted in overall transport costs about the same as in the first approach so the authors stayed with the figures from the first approach.

7.6 Roads and power lines

A potentially significant cost centre for any wind project are the roads and power lines between the project site and the diesel plant substation where the wind energy is integrated into the local grid.

Road distances were estimated once the wind resource assessment identified suitable development sites, as close to the community as reasonably possible. Road costs were difficult to establish with certainty, canvassing local communities and agencies resulted in costs estimates ranging from $100,000 per kilometer to $1,000,000 per kilometer. Ultimately the authors had to use their judgment and decided that new roads for projects using the North Wind 100 turbine were to be costed at $250,000 per kilometer.

Projects using the large Enercon E70 wind turbine had new roads costed at $500,000 per kilometer and road upgrades costed at $250,000 per kilometer. The large crane required to install these turbines would likely require a more substantial road than required for the lighter equipment used for the smaller turbine.

Regardless of the turbine size, in every project using more than one turbine, had road distances added for each additional turbine to account for the separation between.

Power line cost estimates were based on input from QEC. The authors determined that a budget cost of $250,000 per kilometer for the assumed three-phase 25kV overhead power line would be reasonable. For all projects (regardless of turbine size) one kilometer of underground collector power line at $400,000 per kilometer was included in the cost estimates. Additional underground collector distance was included in the costs for each turbine in projects where more than one was used to account for the separation between turbines.

The underground collector is typically used in the vicinity of wind farms for safety reasons where cranes may be operating. They are also often used from the tops of hills or ridges where the turbines are installed down to the base of the hill or ridge as power lines in these locations may be more susceptible to high turbulent winds and icing. Icing together with turbulent winds may result in phase to phase conductor faults and thus outages. Sometimes underground lines are also used where degradation of view are a concern. A distance of one kilometer was included in every project but if shorter distance is sufficient there would be a small cost reduction to the project.

7.7 Other costs

There are a number of other construction cost items that the authors had to estimate in order to get the construction costs. These include the following (the figures in brackets are first the costs for projects involving the larger Enercon E70 wind turbine and second for the smaller Northern Power Systems' North Wind 100 wind turbine respectively):

1. Wind resource assessment ($200,000 and $150,000);
2. Prefeasibility study cost estimate ($200,000 and $100,000);
3. Feasibility study cost ($1 million and [$250,000 + $20,000 per additional turbine]);
4. Utility interconnection (electrical) ($1 million and [$250,000 plus $20 per additional turbine);
5. Geotechnical and foundation design ([$750,000 + $75,000 per turbine] and [$10,000 +$10,000 per turbine]);
6. Foundations ($1.5 million per turbine and $50,000 per turbine);
7. Local equipment rental ($250,000 per turbine and $10,000 per turbine);
8. Site building ($100,000 and $100,000);
9. Turbine assembly and supervision ($100,000 per turbine and [$100,000 + $50,000 per turbine]);
10. Several others as outlined in Attachments 1, 2, and 3.

To the construction cost a 10% contingency was added – only 10% because the authors tried to err on the high side in cost estimating in the first instance. Then estimates of owners' costs (staff training, owner's project management and engineering (including frequency and voltage stability), and a Snowcat or equivalent for winter maintenance activities) were added to arrive at the total project costs.

Operating and maintenance costs for the wind turbines and for the battery integration systems (where applicable) were estimated and included in cost listing so that they were available for the RETScreen and HOMER modelling.

7.8 Cost summaries

The large cost components described in the sections above and all other smaller cost components were compiled into Excel summary spreadsheets. Spreadsheets were developed for three broad categories of wind projects.

One spreadsheet was developed for Iqaluit which would use the larger Enercon E70 2.3 MW turbine. The columns of the spreadsheet detail the costs for projects of 2, 3, 4, or 5+ turbines. Iqaluit being the largest community has the highest electrical load and multiple large turbines could be installed there. A copy of this spreadsheet is presented in Attachment 1.

A second spreadsheet was developed for a regional cluster of three communities each of which could be considered to have the potential of using one large Enercon E70 turbine (potentially two in the case of Rankin Inlet). For the purposes of sharing fixed costs as much as possible, the authors assumed that the three larger communities on the western Hudson Bay coast area would be constructed at the same time (in the same year). However, each of these three communities had differing road and power line requirements so one spreadsheet was prepared for each of them, but based on shared transport and crane costs. Copies of these three spreadsheets are presented in Attachment 2.

The third spreadsheet was developed for projects using the North Wind 100 turbine. The spreadsheet outlines the costs for projects using 1, 2, 3, 6, and 10 turbines. There was also a column which allowed the number of turbines, the road distance, and the power line distance to be entered as variables. A copy of this spreadsheet is presented in Attachment 3.

8.0 Assessments of all Nunavut Communities

8.1 Development of electrical load profiles

The authors were not able to get from QEC hourly electrical load data for all Nunavut communities, and the data that was available was not in a format that could be read by the modelling software used. Thus the hourly load data available from an off-grid community in the Yukon used as a base and was scaled up or down to provide a reasonable match with the electrical demand and energy actually experienced in the communities being modeled. While suitable for the high level of work undertaken in this study, it would be highly desirable to use actual community load data for subsequent work on potential projects.

8.2 RETScreen analyses

RETScreen is an excel-based clean energy project analysis software tool that helps decision makers quickly determine the technical and financial viability of potential renewable energy, energy efficiency, and cogeneration projects. The RETScreen Wind Energy Project Model is used world-wide to evaluate the energy production, life-cycle costs and greenhouse gas emissions reduction for central-grid, isolated-grid, and off-grid wind energy projects ranging in size from large scale multi-turbine wind farms to small scale single-turbine wind-diesel hybrid systems.

The energy model uses a custom power curve and a Weibull wind speed probability distribution function to calculate the energy curve of the turbine. Energy production is then adjusted for pressure and temperature effects, as well as for various losses (array, airfoil, availability).

The financial model considers the capital cost of the power system, operations and maintenance costs, theoretical export rate (avoided cost of diesel fuel), inflation, project life, debt ratio and debt interest rate.

The results of the energy and financial models are economic metrics describing the financial viability of the project: pre-tax Internal Rate of Return (IRR) – equity, pre-tax IRR – assets, simple payback and equity payback. The pre-tax IRR on assets (%) represents the true interest yield provided by the project assets over its life before income tax. It is calculated using the pre-tax yearly cash flows and is also referred to as the return on assets (ROA) which is similar to the cost of capital for regulated utilities. It is calculated by finding the discount rate that causes the net present value of the assets to be equal to zero.

The simple payback represents the length of time that it takes for a proposed project to recoup its own initial cost, out of the income or savings it generates. A negative payback period would be an indication that the annual costs incurred are higher than the annual savings generated. The equity payback represents the length of time that it takes for a project to recoup its equity investment (as opposed to debt) out of the cash flows generated by the project. The equity payback considers project cash flows from its inception as well as the leverage (level of debt) of the project, which makes it a better time indicator of the project merits than the simple payback.

The pre-tax IRR on equity (%) represents the true interest yield provided by the project equity over its life before income tax. It is calculated using the pre-tax yearly cash flows and the project life. It is also referred to as the return on equity (ROE) or return on investment (ROI) or the time-adjusted rate of return. It is calculated by finding the discount rate that causes the NPV of the equity to be equal to zero. This was the financial metric chosen to rank the 25 projects.

The main limitations of the model are that the stand-alone wind energy projects requiring energy storage currently cannot be evaluated. Additionally, the model addresses primarily low penetration technologies (maximum of 30%). In order to accurately evaluate high penetration projects for the top five communities, Hybrid Optimization of Multiple Energy Resources (HOMER) was utilized.

Comparisons of the RETScreen model predictions against results of an hourly simulation program and against monitored data shows that the accuracy of the RETScreen Wind Energy Project Model is excellent in regards to the preparation of pre-feasibility studies.

8.3 Top 10 communities

The ten communities with the best conditions for a wind power project as evaluated by RETScreen are:

1 Iqaluit
2 Rankin Inlet
3 Baker Lake
4 Arviat
5 Cambridge Bay

6 Resolute Bay
7 Sanikiluaq
8 Gjoa Haven
9 Cape Dorset
10 Hall Beach

Table 3 on the following page displays the details of the RETScreen modeling inputs and results. The 25 communities are presented by rank based on pre-tax internal rate of return (IRR) on equity (%).

Table 3. RETScreen Modeling - Summary Table of 25 communities

		Wind	Summary					Initial Costs			Financial Viability			
Rank	Community	Annual Wind Speed (m/s)	Number of turbines	Capacity (kW)	Capacity factor	Electricity exported to grid MWh	Penetration (limited to 30% Max)	Export rate ($/MWh) (based on 2016 forecasted fuel cost)	Road length (km)	Power line Length (km)	Power system cost ($)	Pre-tax IRR - equity (%)	Pre-tax IRR - assets (%)	Simple Payback (years)	Equity Payback (years)
1	Iqaluit*	7.4	2	4600	32%	12,814	22%	341.75	3	5	24,754,500	25.1%	10.2%	7.9	4.2
2	Rankin Inlet	7.2	14	1400	39%	4,736	27%	299.95	0.5	2	14,676,995	14.4%	4.5%	11.8	7.4
3	Baker Lake	7.4	7	700	40%	2,455	28%	323.65	1	2	8,590,131	13.7%	4.1%	12.1	7.8
4	Arviat	7.1	8	800	38%	2,653	30%	299.02	0.5	1	9,066,826	12.1%	3.2%	13.1	8.7
5	Cambridge Bay	6.2	13	1300	27%	3,015	27%	343.82	0.5	4	14,337,800	11.2%	2.6%	13.7	9.3
6	Resolute Bay	7.3	4	400	40%	1,392	27%	312.31	2	2	6,197,547	7.8%	0.4%	16.1	12.3
7	Sanikiluaq	7.3	3	300	41%	1,008	28%	337.08	1	1.5	4,895,852	7.7%	0.4%	16.2	12.4
8	Gjoa Haven	5.9	5	500	28%	1,237	23%	364.80	0.5	1	6,399,242	7.4%	0.2%	16.5	12.7
9	Cape Dorset	6.3	6	600	31%	1,624	26%	304.29	1	2	7,700,937	5.3%	-1.3%	18.4	15.4
10	Hall Beach	6.2	2	200	41%	710	21%	303.86	0.5	0.5	3,594,157	3.5%	-2.5%	20.2	18.2
11	Coral Harbour	5.8	4	400	27%	944	27%	352.08	0.5	2.5	5,922,547	2.7%	-3.1%	21.0	19.6
12	Pond Inlet	7.3	4	400	40%	1,390	23%	302.28	3	7	7,847,547	2.5%	-3.2%	21.2	20.0
13	Igloolik	5.4	8	800	23%	1,637	25%	313.67	0.5	1	9,066,826	1.8%	-3.7%	21.9	21.2
14	Taloyoak	5.8	4	400	27%	960	25%	391.93	3	5	7,297,547	1.4%	-4.0%	22.4	22.0
15	Kugluktuk	5.2	8	800	21%	1,506	26%	331.24	0.5	0.5	8,929,326	1.4%	-4.0%	22.4	22.0
16	Repulse Bay	6.1	4	400	30%	1,036	27%	329.50	1	5	6,747,547	0.8%	-4.5%	23.1	23.4
17	Chesterfield Inlet	7.2	1	100	39%	342	16%	386.45	0.5	1	2,842,463	0.2%	-5.0%	23.8	24.6
18	Pangnirtung	8.0	4	400	44%	1,533	24%	289.33	10	10	10,597,547	-0.9%	-5.6%	26.9	> project
19	Kugaaruk (fmr. Pelly Bay)	7.2	2	200	39%	685	24%	357.61	4	4	5,519,157	-0.9%	-5.8%	25.1	> project
20	Arctic Bay (Ikpiarjuk)	7.2	2	200	39%	686	22%	299.97	1	4	4,694,157	-1.7%	-6.4%	26.0	> project
21	Clyde River	5.9	4	400	28%	980	26%	290.19	1.5	2.5	6,197,547	-2.1%	-6.7%	26.4	> project
22	Whale Cove	7.6	1	100	42%	366	19%	341.10	0.5	2	3,117,463	-3.2%	-7.6%	27.8	> project
23	Qikiqtarjuaq (fmr. Broughton Island)	7.6	2	200	42%	727	26%	299.94	1	7	5,519,157	-3.9%	-8.1%	28.6	> project
24	Grise Fiord	7.8	1	100	44%	328	27%	334.67	8	10	7,379,963	negative	negative	64.1	> project
25	Kimmirut	7.0	1	100	36%	319	16%	303.15	6	6	5,729,963	negative	negative	68.0	> project

*Enercon, WS measured at 57 m

Variables common among all projects

Losses (20% total):

Array losses	5%
Airfoil losses	5%
Miscellaneous losses	5%
Availability	95%
Wind Shear Exponent	0.14

Financial Parameters:

Inflation rate	2 %
Project life	25 years
Debt ratio	60%
Debt interest rate	4%
Debt term	25 years

Wind Turbine Specifications:

	NPS NW100C-24	**Enercon E70 E4**
Power capacity per turbine	100 kW	2300 kW
Hub height	25 m	57 m
Rotor diameter per turbine	25 m	71 m
Swept area per turbine	471 m^2	3959 m^2
Energy curve data	Custom, see Figure 6 & Figure 7	
Shape factor	2.1	

8.4 Top 5 communities

8.4.1 Inuit regional development corporations

After completing RETScreen modeling the three Inuit regional development corporations were contacted. The authors spoke to Sheldon Nimchuk, Director Project Development & Partnerships at Qikiqtaaluk Corporation (QC) and Derrick Webster, Director of Corporate Services at Sakku Investments Corporation. Despite multiple attempts, the authors were unable to contact Kitikmeot Corporation. Thus it is not known if Kitikmeot Corporation is interested in wind energy and in participating in wind energy project(s) with QEC.

Mr. Nimchuk was very encouraged to learn that QEC was evaluating wind energy in the communities. He indicated that QC is very keen on renewable energy and mentioned a couple of initiatives that are underway, including a study on a small hydro project in Pangnirtung and a potential solar photovoltaic array which would be part of a hotel development in Iqaluit. QC also expressed an interest in research and development level renewable energy projects. QC is creating a new division which would be focused on capacity building in the communities they represent, for the purpose of economic development. Mr. Nimchuk said that QC sees renewable energy development as part of economic development. QC harbors ambitions of becoming an independent power producer and is willing to partner on economic wind energy projects with QEC.

According to Mr. Webster, Sakku is very interested in being involved in energy and renewable energy projects. As a business entity they are mandated to make a profit and are interested in being involved in projects that are profitable. They have the appetite for owning projects and have the financial capacity to be involved provided that the projects make economic sense. Sakku expressed interest an in reviewing the findings of this study and if the business cases makes sense, Sakku would be interested in discussions with QEC.

8.4.2 Selection process

To arrive at the top 5 communities, the authors considered the top 10 communities with respect to RETScreen economics as described in Section 8.3 and added judgment factors.

Cambridge Bay was not selected for three reasons, first that it is a community in transition with respect to its electrical load. QEC on-line business documents indicate that the Canadian High Arctic Research Station (CHARS) may lead to electrical load increases of up to 70%. This would bring it into the category where a large turbine could be considered. Second is that there is also some question about the projected wind speed accuracy, specifically that it might in fact be a bit lower thus weakening the economics. And third is that it far enough away from other communities that a large turbine installed here could not be "clustered" with other communities to spread and reduce the fixed costs.

Resolute Bay was not selected for two reasons, first being that access to the identified wind turbine installation site is uncertain – it could be costlier than estimated. The second reason is that Resolute Bay is distant from major service hubs, and technical support for a first-of-its-kind project in Nunavut would be important.

For these reasons Sanikiluaq was considered a better candidate for an early development project involving North Wind 100 turbines than either Cambridge Bay or Resolute Bay.

8.4.3 Grid voltage and frequency stability

In providing power service to customers, electric power utilities are mandated to maintain voltage and frequency fluctuations to within specified standards (among many other standards). The authors are aware that sometimes isolated power systems have had to incorporate battery storage systems in order to maintain voltage and frequency stability with increasing levels of wind energy displacement of diesel generation. For example Kodiak Electric Association (KEA) (Kodiak City, Alaska) installed such a battery system in order to increase wind energy contribution beyond a 10% share of the power supply towards 15% to 20%. Their power system has about 80% of its energy supplied by hydro with the remainder being diesel prior to wind energy installation.

There is not a satisfactory body of knowledge that would enable the authors to determine whether all-diesel power systems would encounter the same frequency and voltage fluctuations as KEA's hydro based system. However, to be conservative the authors have determined that it would be appropriate to add battery storage systems to potential wind energy projects whenever the wind displacement of diesel generation exceeded 12%. This is at a much lower level of diesel displacement than desirable or cost effective for maximizing wind energy utilization (based on HOMER modelling).

When QEC is advancing studies for the advancement of one or more wind projects in prefeasibility or feasibility studies, the issue of voltage and frequency stability of the diesel generator based power system(s) will need to be investigated. There may also be other grid stabilization mechanisms that would be more cost effective than battery energy storage systems.

8.4.4 HOMER modelling

The Hybrid Optimization of Multiple Energy Resources (HOMER) software was chosen to study the top five communities described in the selection process:

1. Iqaluit
2. Rankin Inlet
3. Baker Lake
4. Arviat
5. Sanikiluaq

HOMER is a power system analysis and optimization model that was developed by the National Renewable Energy Laboratory of the US Government and is distributed and supported by HOMER Energy (http://www.homerenergy.com). HOMER simplifies the evaluation of design options for off-grid power systems for remote, stand-alone and distributed generation applications.

There are three main tasks that can be performed by HOMER: simulation, optimization and sensitivity analysis. In the simulation process, HOMER simulates the operation of a system by making energy balance calculations for each of the 8,760 hours in a year. For each hour, HOMER compares the electric demand in the hour to the energy that the system can supply in that hour, and calculates the flows of energy to and from each component of the system. For systems that include batteries or fuel-powered generators, HOMER also decides for each hour how to operate the generators and whether to charge or discharge the batteries (if this component is considered).

HOMER performs these energy balance calculations for each user-defined system configuration. From these energy balances, the feasibility of a configuration will be determined (i.e., whether it can meet the electric demand under user specified conditions), and estimates the cost of installing and operating the system over the lifetime of the project. The system cost calculations account for costs such as capital, replacement, operation and maintenance, fuel, and interest.

Optimization: After simulating all of the possible system configurations, HOMER displays a list of configurations, sorted by net present cost (NPC) that can be used to compare system design options. Sensitivity Analysis: An optimization process is conducted for each sensitivity variable specified. For example, if wind capacity is identified as a sensitivity variable, HOMER will simulate all system configurations for the range of sizes that were specified.

The annual savings are estimated by subtracting the annualized costs for each supply method from each other, giving the overall saving or loss for each year. The annual savings are then cumulatively summed to provide the cash flow for the duration of the project.

8.4.5 HOMER Model set up and Simulation

For each community, unique data was used to set up and simulate a wind/diesel/battery hybrid power project. The required data included: electric load, generator and diesel fuel specifications, wind resource & temperature, wind turbine generator properties and battery specifications. The schematic displayed in Figure 2 presents an example of the simulated system architecture.

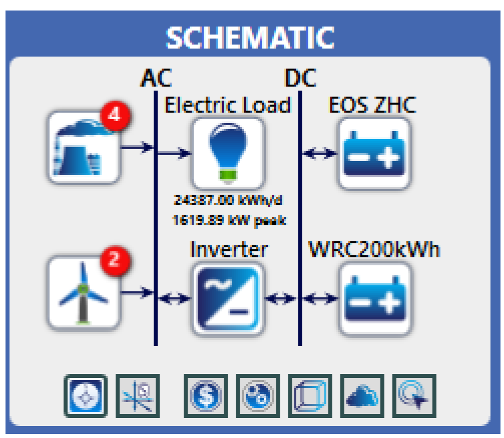

Figure 2. Example of Schematic – Baker Lake

Electric Load

A typical annual demand profile for remote northern communities was synthesized using data from a diesel based community in the Yukon. This hourly data was scaled to each community based on the unique annual average kWh per day provided by QEC. Figure 3 and Figure 4 provide an example of the synthesized and scaled demand profiles respectively.

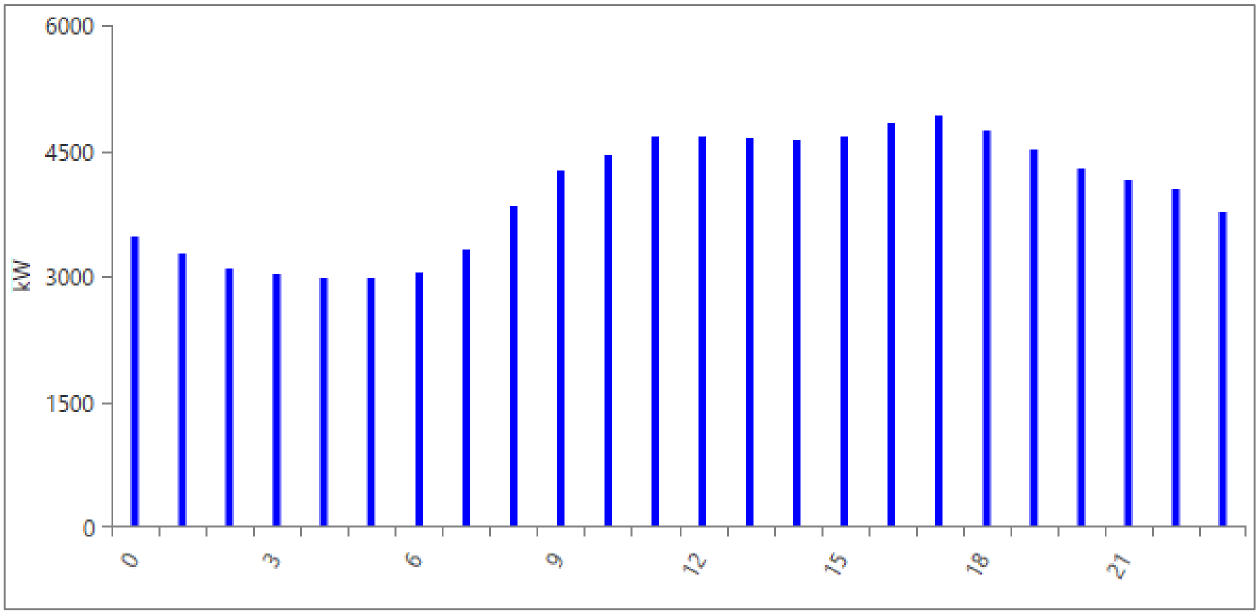

Figure 3. Daily demand profile example – Iqaluit

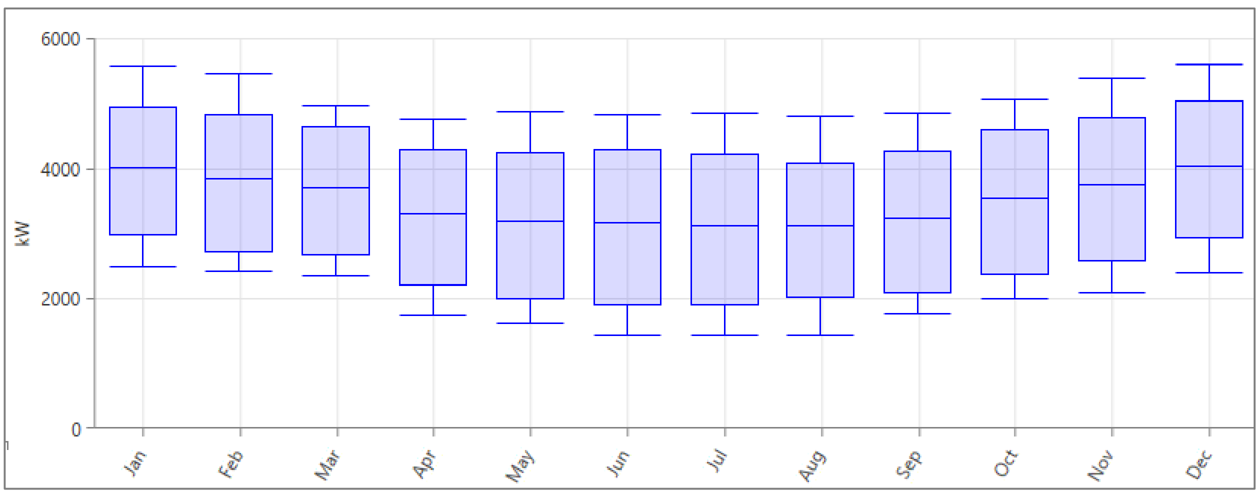

Figure 4. Seasonal demand profile example – Iqaluit

To ensure that the synthesized and scaled demand reflected the true system, comparisons between real data and HOMER estimated data were made. These comparisons are shown in Table 4.

Table 4. Estimated versus True community load characteristics

Communities	Daily average (kWh/day)	Actual Peak (kW)	HOMER estimated peak (kW)	Actual average (kW)	HOMER estimated average (kW)
Iqaluit	158,374	9,707	10,519	6,599	6,599
Rankin Inlet	48,705	3,194	3,235	2,029	2,029
Baker Lake	24,387	1,868	1,620	1,016	1,016
Arviat	24,252	1,734	1,611	1,010	1,011
Sanikiluaq	9,930	685	660	414	414

Generator and fuel specifications

For each community, QEC provided data on the diesel engine lineup. From this information, each unique generator was modeled in HOMER. Table 5 displays the variables required to model each generator.

Table 5. Diesel generator model set up

Variable	Value
Diesel fuel price	$1.11/L
Minimum allowable loading on a continuous basis to avoid glazing and carbon buildup	40%
Remaining life	140,000 hours max – total run time to date
Fuel curve	Figure 5
Replacement Cost (Capital cost set to $0)	$2M/MW
O&M cost	$35/hour per 1 MW
Maintenance Schedule	Not considered
Schedule	Optimized operating mode, all week

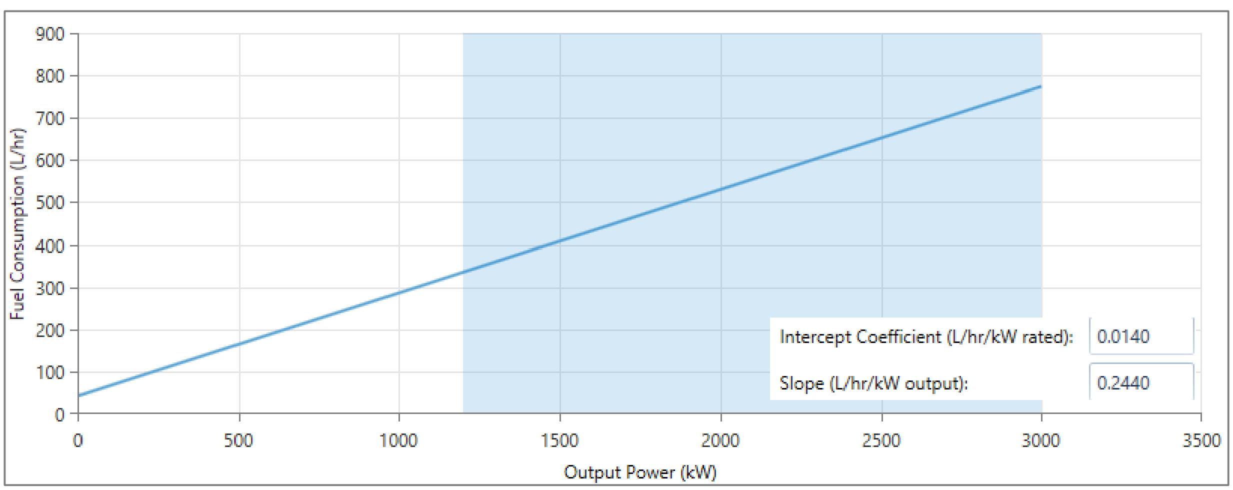

Figure 5. HOMER default fuel curve

Wind Turbine Generator (WTG)

Unlike the RETScreen model, the HOMER model considered two different types of wind turbines technologies, as discussed in sections 5.1 and 5.2. The HOMER modeling provides the cost of wind energy but provides that separately from the cost of the battery energy storage system if also included.

Table 6. WTG generator model set up

Variable	**Value**
Capital / Replacement Cost	Unique costs based on number of turbines, road and power length (See section 7)
O&M/y	$125 per year per kW
Lifetime (y)	25
Hub height (m)	57 (E70), 25 (NW100)
Consider ambient temperature effects?	Yes
Power Curve	See Figure 6 and Figure 7
Electrical bus	AC
Consider Maintenance Schedule?	No
Turbine Losses (%):	20% (to match RETScreen)
Availability	5%
Turbine Performance	4%
Environmental	4%
Wake effects	2.9%
Electrical	3%
Curtailment	3%
Other	0%

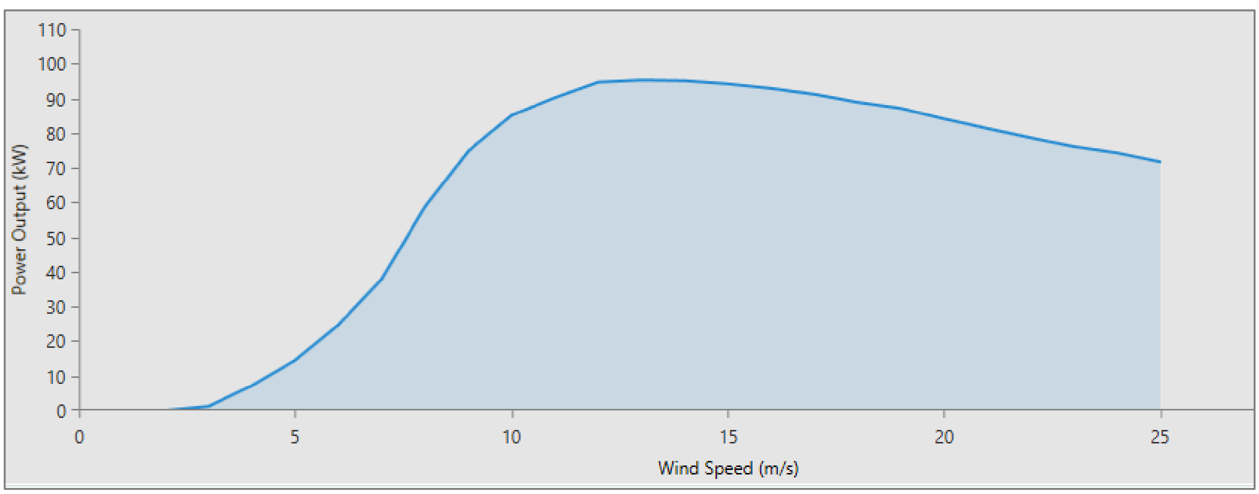

Figure 6. NW100 Power curve

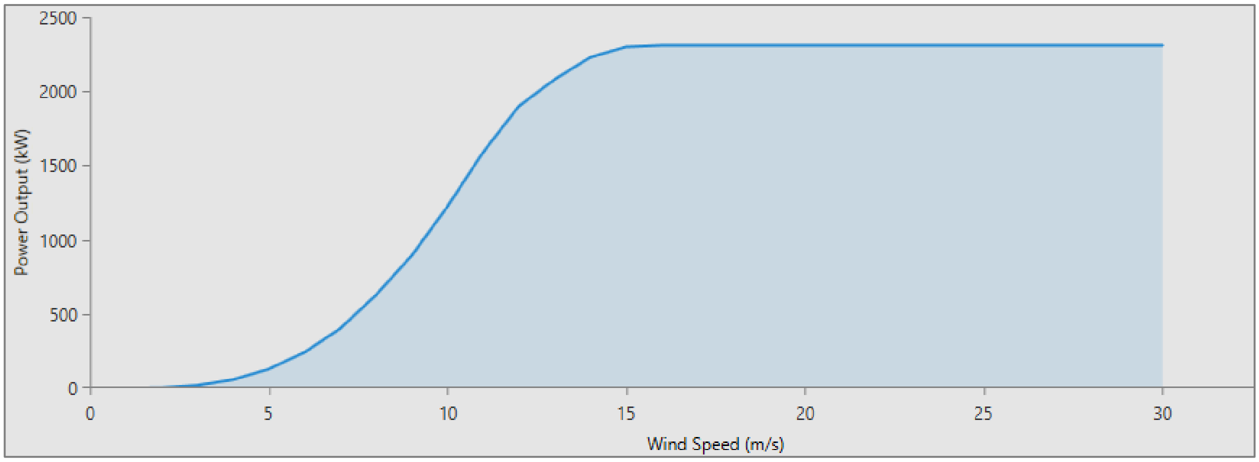

Figure 7. E70 Power curve

Energy Storage

Section 6 discusses energy storage technologies. Two types of generic batteries were modeled in HOMER: one based loosely on the Zinc Hybrid Cathode such as provided by EOS, and one based on Lithium-ion technology such as can be provided by the Saskatchewan Research Council. Table 7 displays the variables required to model each battery. Please note that in the HOMER model, the battery energy storage system is a component separate from the wind energy supply. While being part of the overall hybrid system energy cost it is not incorporated into the cost of wind energy even if these two components are installed and costed as one project.

Table 7. Battery - model set up

Variable	**EOS Zinc Hybrid Cathode**	**SRC Li-ion**
Capital Cost (with contingency)	$2.75M per 1 MWh	$1.1M per 200kWh
Replacement Cost	$500/kWh of storage	
O&M	$40/kW/year	
Lifetime (y)	10 years	
Round trip efficiency	85%	

System Control

System controls such as dispatch strategy and generator control are vital to the analysis and are defined by the user. A dispatch strategy is a set of rules that govern the operation of the generators and the battery bank. HOMER can model two dispatch strategies, cycle charging and load following. The optimal strategy depends on many factors, including the sizes of the generators and battery bank, the price of fuel, the O&M cost of the generators, the amount of wind power in the system, and the characteristics of the wind resource.

Under the load following strategy, whenever a diesel generator is needed it produces only enough power to meet the demand. Load following tends to be optimal in systems with a lot of renewable power and was the strategy selected for this study.

Economics

The economic conditions of a project are vital to the financial feasibility. Although they may change with time, todays financial conditions were used for this study. The economic inputs in HOMER allow for the specification of the annual real interest rate, project lifetime, system fixed capital and O&M costs and a capacity shortage penalty. Specific inputs are listed in Table 8.

Table 8. Project Economics

Variable	Description
Discount Rate	4%
Expected Inflation Rate	2%
Project lifetime	25 years. The number of years over which the net present cost of the project should be calculated
System fixed capital and O&M costs	$0. The fixed costs that occurs regardless of the size or architecture of the system. These parameters would affect the total net present cost of each system, but would affect them all by the same amount. Therefore, they have no effect on the system rankings.
Capacity shortage penalty	$0. A penalty applied to the system for any capacity shortage.

Constraints

Constraints are conditions which systems must satisfy. HOMER discards systems that do not satisfy the specified constraints; therefore they do not appear in the optimization results or sensitivity results. The user-defined constraints are listed in Table 9.

One of the key constraints is allowing for operating reserve. Operating reserve is defined as surplus operating capacity that ensures reliable electricity supply even if the load suddenly increases or wind power output suddenly decreases. The required amount of operating reserve is defined using four inputs, two related to the variability of the electric load and two related to the variability of the wind resource. The total required operating reserve is the sum of the four values. In this simulation, a conservative approach was taken, whereby the power system is operated so as to keep the operating reserve equal to or greater than a minimum threshold. Any shortfall is recorded as a capacity shortage.

Table 9. Project Constraints

Variable	Description
Maximum annual capacity shortage	0: The maximum allowable value of the capacity shortage fraction, which is the total capacity shortage divided by the total annual electric load.
Operating Reserve as a percent of hourly load	10%: HOMER adds this percentage of the hourly average primary load (AC and DC separately) to the required operating reserve for each hour. A value of 10% means that the system must keep enough spare capacity operating to serve a sudden 10% increase in the load.
As a percent of wind power output	50%: HOMER adds this percentage of the wind turbine power output to the required operating reserve in each time step. The system must keep enough spare capacity operating to serve the load even if the wind turbine output suddenly decreases 50%.

8.4.6 HOMER Energy model short listed community simulations

The annual energy production from the selected wind turbine is calculated using a combination of HOMER model and Excel spreadsheet calculations. Applicable to this study, the energy model uses published wind turbine power curves, diesel plant production specifications, and one-year hourly time series measurements of both wind speed and community power load to model the energy output of various power generators.

The energy produced by the selected turbine is based on the published power curves less 20% to adjust for turbine availability and various losses. Also included the effect of temperature using monthly mean temperatures and altitude. In all cases the elevation at which the proposed wind turbines are installed was taken into account when determining the height restrictions within a 4 km radius of the local airports.

Iqaluit

For Iqaluit the average load is 6.6 MW and the annual energy consumption is 57.8 GWh per year. Enercon E70 with battery storage system steps of 1 MW of capacity and 1 MWh of energy storage (1 MW/1 MWh) were considered. The project site that is considered is northeast of Iqaluit where hills reach heights above 250 m ASL. This area is outside the airport airspace but is, at closest, 3 km from a VOR, which may be a concern for airplane navigation. If this becomes the case then the project may need to move further away, thus increasing powerline and road cost.

Result

The HOMER simulation for a 3 wind turbine project, with a 1 MW/1 MWh battery energy storage system for grid stability, indicates that 15.4 GWh of wind energy would be generated annually. This would displace 24.5% of the diesel generation. The ROI is 9.8% and the discounted payback is 12.0 years. The return on equity (ROE) after debt payments (60% debt at 4% interest) is 18.5%. This wind project would cost $35.2M. The levelized cost of energy (LCOE) from wind (excluding the battery energy storage system) would be $0.16 per kWh, and the LCOE for the hybrid system would be $0.305 per kWh.

The simulation for a 4 wind turbine project, suggested that a 3 MW/3 MWh battery energy storage system would be optimum for wind energy utilization (and also grid stability). The modelling indicates that 20.5 GWh of wind energy would be generated annually. This would displace 31.4% of the diesel generation. The ROI is 9.1% and the discounted payback is 13.4 years. The ROE after debt payments is 16.8%. This wind project would cost $48.9M. The LCOE of wind energy (again excluding the cost of the battery energy storage system) would also be $0.16 per kWh and the LCOE of the hybrid system would be $0.300 per kWh. This indicates that the incremental cost of energy from the additional wind turbine plus the increased battery capacity, is less than the cost of diesel generation.

The model revealed that 6 wind turbines and an optimal 4 MW/4 MWh battery energy storage system would provide the lowest LCOE for the hybrid system (which includes diesel energy) at $0.297 per kWh. The wind project would generate 30.8 GWh/year, the wind displacement of diesel generation would be 39.9%. With 6 wind turbines there would be about 10.8% excess wind energy. The capital cost for such a system would be $68.6M for the wind project. For this configuration the return on investment (ROI) would be 8.2% and the discounted payback 15.1 years. The return on equity would be 14.5%. The LCOE of wind energy from this project is $0.15 per kWh. Again the cost of energy from the additional wind turbines and battery capacity is less than the cost of diesel generation as shown by the decreased hybrid system LCOE.

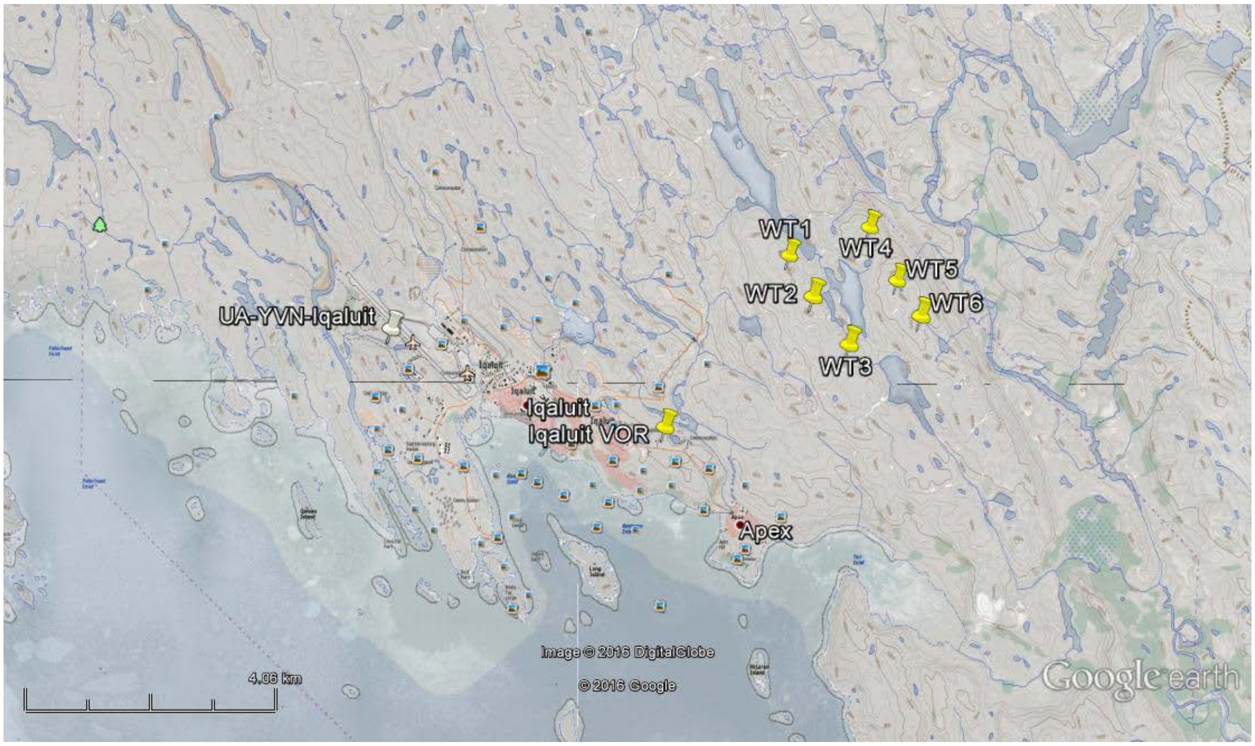

Figure 8. Potential Turbine Locations – Iqaluit

<u>Rankin Inlet</u>

Rankin Inlet consumes 17.8 GWh of energy annually, and its average load is 2,029 kW. Both the NW100 and the E70 turbines were included in the model simulations along with the battery energy storage options. The location for the NW100s is at the site of the original 65 kW wind turbine. This location is within 4 km of the airport but the turbines would fall under the 45-m ceiling set by the airport authorities. The E70, however, needs to be outside of the 4 km radius as it is a taller turbine. So the costs include about 7 km of powerline and road upgrade.

Results

The HOMER simulations for one E70 with a 1 MW/1 MWh battery energy storage system (for grid stability) indicated that it would generate 6.0 GWh/year. This generation would displace 32.2% of the diesel generation. This option would cost $20.1M, have a ROI of 7.1% and discounted payback of 17.6 years. The return on the equity would be 11.8%. The LCOE of wind energy (without the battery energy storage system) would be $0.19/kWh, and the LCOE of the hybrid system would be $0.302 per kWh.

The model simulations indicated that two Enercon E70s with a 1 MW/1 MWh battery storage system would produce the lowest hybrid system LCOE supply for Rankin Inlet at $0.283 per kWh. This system would generate 12.2 GWh/year, displace 48.6% of the diesel. This project would cost $28.1M, the ROI would be 7.8%, the discounted payback 16.1 years, and the return on equity would be 13.5%. The LCOE of wind energy is estimated to be $0.15 per kWh, not including the cost of the battery energy storage system. However, the incremental cost of energy from the additional wind turbine is less than the cost of diesel generation since the LCOE of the overall hybrid power system decreased.

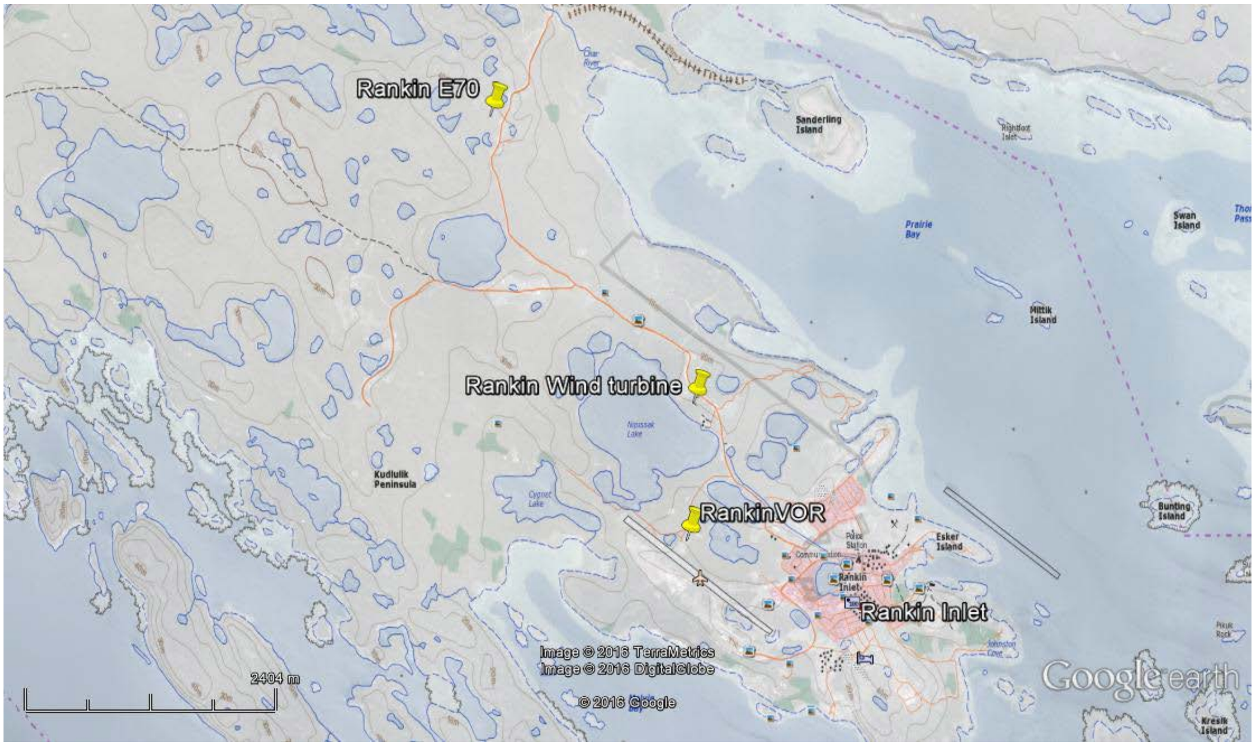

Figure 9. Potential Turbine Location – Rankin Inlet

The simulations using the NW100s were halted at 24 turbines (100 kW of capacity more than one Enercon E70 turbine), as it was felt that any project development site would become impractically crowded. This many turbines could also become problematic with the local VOR and other land use issues. The return on investment was 7.3% and the LCOE of wind energy $0.19/kWh.

The authors would like to remind the readers that the capital costs estimated for the potential project in Rankin Inlet using Enercon E70 turbines was based upon the fixed costs shared with Baker Lake and Arviat, i.e. all three communities would have Enercon E70 turbines installed at the same time. If a stand-alone two Enercon E70 turbine project were to be undertaken capital cost estimates would increase.

Baker Lake

Baker Lake consumes 8.9 GWh of energy annually, and its average load is 1,016.1 kW. Both the NW100 and the E70 turbines were included in the model along with battery energy storage system options. The proposed development site for the wind farms are at least 5 km away from the airport and so would have not height restrictions. The VOR, however, may pose a problem as the turbines may interfere with navigational aids. Using fewer turbines or moving the site to the east may solve this problem.

Results

The HOMER simulations indicate that the optimum configuration for lowest hybrid system LCOE at $0.307 per kWh was a project of 16 NW100s plus a 1 MW/1 MWh battery energy storage system. This project would generate 5.2 GWh/year and displace 51.2% of the diesel energy. The project would cost $20.2M. The ROI is 6.2% and discounted payback 20.4 years. The return on equity would be 9.5%. The LCOE of wind energy (not including the battery energy storage system) was estimated to be $0.21/kWh.

The authors also simulated a single E70 with a 1 MW/1 MWh battery energy storage system for comparison. Such a project would generate 5.8 GWh/year, wind displacement of diesel would be 47.8%. This configuration would cost $19.0M. This option would have a ROI of 5.6%, an ROE of 8.0%, and a discounted payback of 23.1 years. The LCOE of wind energy (without the battery energy storage system) is estimated to be $0.20 per kWh and the LCOE for the hybrid system $0.321 per kWh. Because the LCOE of the hybrid system is higher this indicates that the cost of wind energy from a single Enercon E70 turbine (2.3 MW) project is higher than the cost of wind energy from 16 NW100s (1.6MW total).

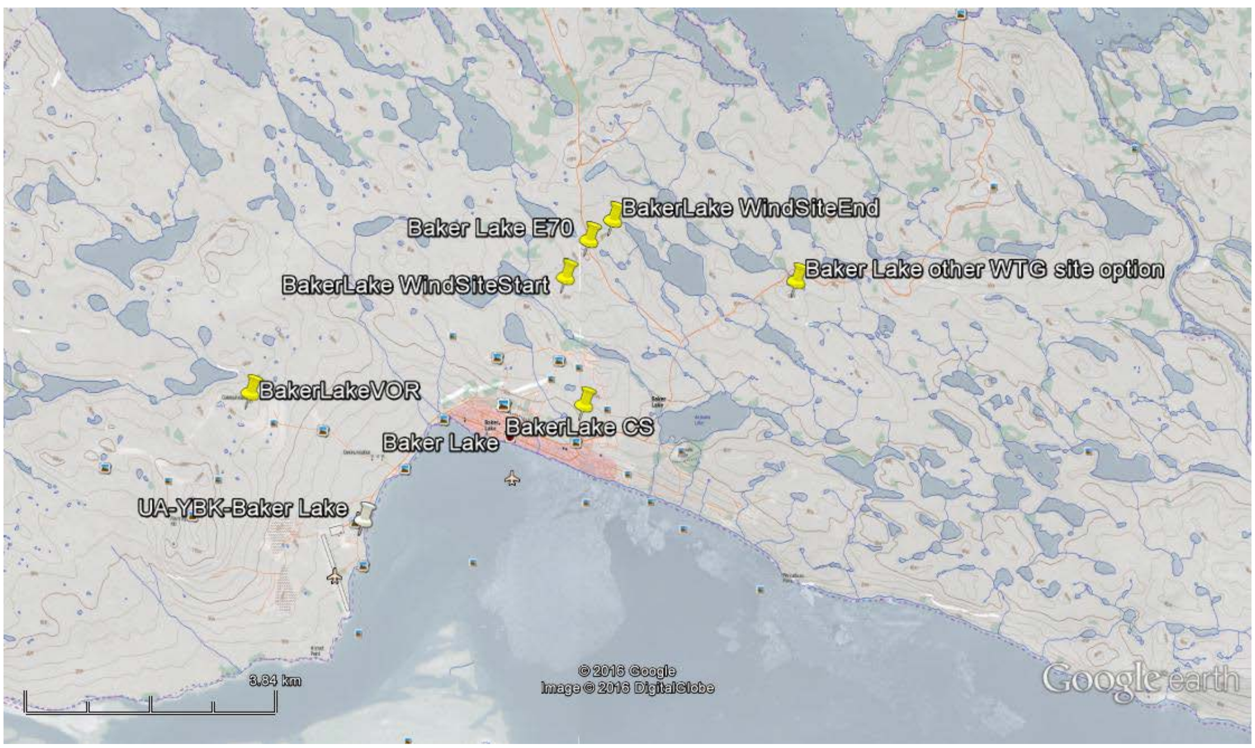

Figure 10. Potential Turbine Locations – Baker Lake

Arviat

Arviat consumes 8.85 GWh of energy annually, and its average load is 1,010 kW. Both the NW100 and the E70 were included in the model simulations along with the battery energy storage options. The NW100 turbines can be located closer to the community since they are on shorter towers and would be under the 45-m ceiling set by the airport authorities. The E70 needs to be outside the 4 km limit of the airport. Because these turbines are on the beach there would need to be a geotechnical assessment to see if these suggested locations are feasible. If the beach is not possible then there is a location 4 km west of Arviat and the airport, this location may also be suitable for the E70.

Result

The HOMER model suggests 18 NW100s with a 1 MW/1 MWh battery storage system provides the lowest hybrid system LCOE at $0.302 per kWh. This system would generate 5.8 GWh/year and displace 55.6% of the diesel generation. The project would cost $21.0M, the ROI would be 6.4%, and the discounted payback 18.8 years. The return on the equity would be 10.0%. The LCOE of wind energy (without the battery energy storage system) was projected to be $0.20 per kWh.

The HOMER simulation predicted that a single E70 with a 1 MW/1 MWh battery energy storage system would generate 5.9 GWh/year and displace 50.5% of the diesel. This option would cost $19.6M, have a ROI of 5.7%, a ROE of 8.3%, and have a discounted payback of 22.2 years. The LCOE of wind energy was $0.20 per kWh, and the LOCE of the hybrid system was projected to be $0.319 per kWh. Again the higher LCOE indicates that the cost of wind energy from an Enercon E70 wind turbine (2.3 MW) was higher than from 18 NW100s (1.8 MW).

Figure 11. Potential Turbine Location – Arviat

Sanikiluaq

The average load in Sanikiluaq is 414 kW and the annual energy consumption is 3.6 GWh. The NW100 turbines were considered for this project along with a 250 kW/200 kWh lithium-ion battery energy storage system (for grid stability and energy storage). The site is within the airport's 4 km air space but will be below the 45-m ceiling imposed on tall structures. The wind development site considered is 1 km southeast of Sanikiluaq.

Result

The HOMER model calculated that for a 2 NW100 turbine project, without a battery energy storage system for grid stability, would generate 0.66 GWh/year. The wind displacement of diesel energy would be 18.0%, higher than the 12% limit set by the authors for no grid stabilization, so such a system might not be stable, detailed technical work would be required. The capital cost was estimated to be $4.18M. The ROI would be 4.3% and discounted payback would exceed 25 years (simple payback 18.9 years). The ROE would be 4.75%. The LCOE of wind energy from this project was projected to be $0.36 per kWh and the LCOE of the hybrid system $0.344 per kWh. Thus diesel generation is less costly than wind energy generation with 2 NW100s.

The modelling of a project with 4 NW100 turbines plus a 250 kW/200 kWh battery energy storage system for grid stability showed that the wind project would generate 1.3 GWh/year. The wind displacement of diesel energy would be 33.7%. The capital cost was estimated to be $7.08M. The ROI was projected to be 4.5% and discounted payback exceeds 25 years (simple payback 22.0 years). The ROE would be 5.25%. The LCOE of wind energy from this project (without the wind energy storage system) was forecast to be $0.27 per kWh and the LCOE of the hybrid system $0.346 per kWh. The very slightly higher hybrid system LCOE indicates the incremental cost of the energy from the additional two wind turbines and the battery energy storage system together was very slightly higher than from the first two wind turbines without a battery.

A simulation of a project with 4 NW100 turbines but without a battery energy storage system was run for comparison and indicated that the ROE would be higher at 7.0% because of the lower capital cost. However, the authors do not believe that a 4 turbine system could operate without a battery energy storage system (or equivalent) to provide grid stability.

The simulation with 7 NW100s indicated that the project would generate 2.3 GWh/year and provide a diesel displacement of 52.2%. This project would need to include a 500 kW/ 400 kWh battery energy storage system to make it optimal. This project would cost $10.5M, the ROI would be 5.0% and the ROE would be 6.5%. The LCOE of wind energy would be $0.23 per kWh and the hybrid system LCOE would be $0.340 per kWh. However, the simulations also show that the discounted payback period would be in excess of 25 years, the project life indicating that the project is not economic at the estimated costs. The simple payback was projected to be 19.8 years. The slightly lower LCOE of the hybrid system indicates that the cost of the incremental wind energy from the further three wind turbines and the increased battery energy storage system was slightly less than from the other two project configurations.

Figure 12. Potential Turbine Location – Sanikiluaq

A summary of the HOMER modelling results of the top five communities is displayed in Table 10 on the following page.

Table 10. Summary Table – Top Five Communities

	Battery system (MW/MWh)	Capital cost ($ Million)	Annual Wind energy produced (GWh)	Diesel displaced (%)	LCOE hybrid system ($/kWh)	LCOE wind only ($/kWh)	Discounted payback (years)	ROI (%)	ROE (%)
Iqaluit 3 E70s	1/1	35.2	15.4	24.5	0.305	0.16	12.0	9.8	18.5
Iqaluit 4 E70s	3/3	48.9	20.5	31.4	0.300	0.16	13.4	9.1	16.8
Iqaluit 6 E70s	4 / 4	68.6	30.8	39.9	0.297	0.15	15.1	8.2	14.5
Rankin Inlet 1 E70	1/1	20.1	6.0	32.2	0.302	0.19	17.6	7.1	11.8
Rankin Inlet 2 E70s	1/1	28.1	12.2	48.6	0.283	0.15	16.1	7.8	13.5
Rankin Inlet 24 NW 100s	1/1	26.7	7.9	41.5	0.291	0.19	16.9	7.3	12.3
Baker Lake 16 NW 100s	1/1	20.2	5.2	51.2	0.307	0.21	20.4	6.2	9.5
Baker Lake 1 E70	1/1	19.0	5.8	47.8	0.321	0.19	23.1	5.6	8.0
Arviat 18 NW 100s	1/1	21.0	5.8	55.6	0.302	0.20	18.8	6.4	10.0
Arviat 1 E70	1/1	19.6	5.9	50.5	0.319	0.20	22.2	5.7	8.3
Sanikiluaq 2 NW100s	0/0	4.18	0.66	18	0.344	0.36	n/a (simple payback =18.9y)	4.3	4.75
Sanikiluaq 4 NW100s	250 kW / 200kWh	7.08	1.3	33.7	0.346	0.27	n/a (simple payback =20.0)	4.5	5.25
Sanikiluaq 7 NW100s	500 kW/ 400 kWh	10.5	2.3	52.2	0.340	0.23	n/a (simple payback =19.8y)	5.0	6.5

9.0 Conclusions

The key conclusions that flow from the study are as follows.

1. The wind resource data that was available was sufficiently reliable for reasonable accuracy wind speed predictions at potential wind turbine installation sites for most communities;
2. The wind resources in a number of communities are high enough to consider commercial wind energy development to displace diesel generation;
3. The RETScreen program used for screening all 25 Nunavut communities showed that in 8 communities an Internal Rate of Return on equity (Return on Equity or ROE) on potential wind projects was close to or exceeded 8%, an ROE that might be considered appropriate for QEC in today's markets;
4. The authors consider this to be a positive indication as all communities, other than Iqaluit, were initially modeled with the use of Northern Power Systems' North Wind 100 wind turbine. This turbine has a reputation for being expensive (even in USA) and given the low Canadian dollar relative to the US dollar is now even more expensive in Canada;
5. There are reliable small and large wind turbines suitable for Nunavut's climactic conditions available on the market. The small turbine is Northern Power's North Wind 100, a 100 kW wind turbine, and the large wind turbines are those produced by Enercon including the E70-E4, which is a 2.3 MW turbine, and larger models. These Northern Power and Enercon turbines are rated to operate down to -40°C (the Enercon capacity is reduced between -30°C and -40°C);
6. There are a variety of small and large battery storage systems available and the technology is rapidly evolving and the pricing is trending down over time. Some are capable of voltage and frequency stabilization.
7. The authors' short list of the top 5 communities to consider for wind energy development when modeled more comprehensively with HOMER showed attractive economics in all but one case, which was just below economic. In all cases the better development options (all with diesel displacement well in excess of 12%) required battery energy storage systems to either provide grid stability and in some cases to enhance diesel displacement. The battery energy storage systems allowed more wind turbines to be installed and enabled higher levels of diesel displacement than would otherwise have been the case.
8. While HOMER can competently model the displacement of diesel generation with wind energy, it cannot model grid stability. The authors are not convinced that grid frequency and voltage stability to within CSA standards would be achieved in cases of greater than 12% diesel displacement. For these cases (virtually all cases reported in this study) a battery energy storage system was included, however, further analysis and study of this issue is required. For the record it is noted that HOMER does not include the cost of owning and operating the battery energy storage systems in with the wind energy, it is modelled as a separate component. Thus in addition to considering the cost of wind energy (alone) the LCOE of the hybrid power system also needs to be considered.
9. All information indicates that QEC would be justified in moving forward with considering wind energy development using both large and small wind turbines in large and small communities

respectively. The following report section outlines the next steps that the authors consider to be justified and prudent;

10. In the authors' view Iqaluit is the most appropriate community on which to focus for a larger wind project using Enercon turbines (for example the E70 2.3 MW). Iqaluit has the most robust economics, more local technical and equipment resources than any other community, and a higher frequency of ocean transport than any other community. In order to minimize financial and technical risk, the 3 turbine project with a battery system for voltage and frequency stabilization would be a good first phase. Once experience is gained future expansion up to a total of 6 turbines, and possibly additional battery energy storage, would seem practical;
11. In the authors' view Sanikiluaq is the most appropriate community on which to focus for a smaller wind project using the North Wind 100 kW wind turbine. Sanikiluaq is relatively accessible and in slightly warmer waters (for ocean transport) than many other communities due to its more southerly location. A first phase with 4 or more wind turbines and a battery energy storage system (or other means) for voltage and frequency stabilization might be a conservative first phase. Once experience is gained with such a project an expansion with more turbines, and possibly additional battery energy storage, may be possible and practical. However, the economics of a project here at the costs estimated in this report would provide a lower ROE than would be appropriate for QEC. This means careful attention must be paid to the project design and costs, and / or a subsidy would be required.
12. For future developments it may be appropriate for QEC to consider the development of wind projects in 2 or 3 communities that are in relatively close proximity to each other at the same time so that high fixed costs (particularly for the large wind turbines) can be spread among them. For example Arviat, Rankin Inlet, and Baker Lake might all benefit from one (or two) large Enercon wind turbines rather than a large number of small ones.

10.0 Next Steps

From the authors' perspective the logical next steps are as follows.

1. QEC should study this report carefully to determine if it wishes to proceed with wind energy development. Assuming it does wish to proceed following are additional next steps;
2. Select which communities and with which wind turbine or turbines it wishes to proceed;
3. Establish wind monitoring stations in the summer of 2016;
4. Initiate one or more prefeasibility studies for the chosen projects. The authors believe that this can be done in parallel with the wind resource assessment, otherwise the time for a project development would be extended by at least a year;
5. The prefeasibility study would need to look at a number of issues identified in this report, including but by no means limited to:
    a. Airport related siting restrictions;
    b. Transportation options and logistics;
    c. Site environmental and geotechnical conditions;
    d. Investigation and measurement of potential grid frequency and voltage fluctuation issues, and the potential need for battery energy storage (or other) stabilization mechanisms; and
    e. Project cost estimates.
6. During this study the authors have contacted the regional Inuit development corporations that are responsible for the communities that were selected as the top 5 communities. The Sakku Investments Corporation of the Kivalliq Region and the Qikiqtaaluk Corporation of the Baffin region both showed interest in possible wind projects and the potential to partner with QEC on them. QEC might chose to discuss with the Sakku and Qikiqtaaluk corporations the potential projects in their regions prior or during the prefeasibility study phase;
7. Following prefeasibility studies, QEC could consider issuing a request for expressions of interest (EOI) for the project(s) that it plans to advance. Following in the steps of Manitoba Hydro and Northwest Territories Power Corp., the responses to the EOI could provide QEC with firm costs for the project(s). The EOI could be structured in a way that only full packaged solutions are accepted. For example, a developer could team up with a wind turbine vendor and an energy storage integrator to provide a turn-key proposal. This could allow QEC access to a diverse selection of wind turbines and battery energy storage systems. The EOI could be structured for companies to bid on providing QEC with the best project or the most attractive cost for a power purchase agreement in which QEC would buy power from the Independent Power Producer, or whatever features are most attractive to QEC.

11.0 Attachments

Attachment 1 Detailed cost summary Iqaluit

Attachment 2 Detailed cost summaries Arviat, Baker Lake, and Rankin Inlet

Attachment 3 Detailed cost summary projects using the North Wind 100 wind turbine

Attachment 1

Attachment 1
Cost summary Iqaluit

Nunavut Wind Project Capital Cost from Details - Iqaluit

Costs for Iqaluit Nunavut, E70-E4 57 m towers

Cost detail	Fixed costs	2 E70 2.3 MW, 57m steel tower	3 E70 2.3 MW, 57m steel tower	4 E70 2.3 MW, 57m steel tower	5+ E70 2.3 MW, 57m steel tower
Number of turbines					5
Project design and Management					
Wind resource assessment	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000
Prefeasibility cost	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000
Feasibility study including: environmental assessment & permitting, engineering	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000
Site Preparation					
new road construction ($500,000 per km) X 3.0km + (700m/T)	$ 1,500,000	$ 1,850,000	$ 2,200,000	$ 2,550,000	$ 2,900,000
road upgrade ($250,000 per km) X 4.0 km	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000
site & crane pad construction $20,000 per turbine		$ 40,000	$ 60,000	$ 80,000	$ 100,000
overhead powerline const. ($250,000 per km) X 8.0km	$ 2,000,000	$ 2,000,000	$ 2,000,000	$ 2,000,000	$ 2,000,000
underground 25kV collector ($400,000 per km) X 1km + (700m/T)	$ 400,000	$ 680,000	$ 960,000	$ 1,240,000	$ 1,520,000
Utility interconnection	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000
Wind Equipment Purchase					
wind turbines with towers (Enercon E70, 57m) $4,200,000 each including transport to Montreal, transformers, blade heating, on site crane costs, and on site installation and commissioning		$ 8,400,000	$ 12,600,000	$ 16,800,000	$ 21,000,000
transport to Iqaluit by ocean ($120,000 each)		$ 240,000	$ 360,000	$ 480,000	$ 600,000
Installation					
geotehnical & foundation design + ($75k/T)	$ 750,000	$ 900,000	$ 975,000	$ 1,050,000	$ 1,125,000
foundations $1,500k/T (steel & rock anchor footing)		$ 1,500,000	$ 3,000,000	$ 4,500,000	$ 7,500,000
local equipment rental $250k/T		$ 500,000	$ 750,000	$ 1,000,000	$ 1,250,000
crane mob and de-mob to port (large $120k + support $4k)	$ 124,000	$ 124,000	$ 124,000	$ 124,000	$ 124,000
crane demeurage costs (4 months) large $400k; small $120k	$ 520,000	$ 520,000	$ 520,000	$ 520,000	$ 520,000
crane transport costs	$ 166,000	$ 166,000	$ 166,000	$ 166,000	$ 166,000
crane - turbine installation in turbine cost, support within demurrage cost	$ -	$ -	$ -	$ -	$ -
site building	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000
wind integration (all-in installed costs for 1 MW & 1 MWh battery system)	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000
labour - assembly & supervision (above Enercon costs)		$ 200,000	$ 300,000	$ 400,000	$ 500,000
commissioning included in turbine cost				$ -	$ -
travel and accommodation + $25k/T	$ 100,000	$ 125,000	$ 150,000	$ 175,000	$ 200,000
Other					
initial spare parts	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000
Insurance		$ 300,000	$ 400,000	$ 500,000	$ 500,000
other overhead costs (contracts etc.)	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ 500,000
Subtotal construction	**$ 12,110,000**	**$ 24,095,000**	**$ 31,115,000**	**$ 38,135,000**	**$ 46,555,000**
Contingency 10%		$ 2,409,500	$ 3,111,500	$ 3,813,500	$ 4,655,500
TOTAL CONSTRUCTION	**$ 12,110,000**	**$ 26,504,500**	**$ 34,226,500**	**$ 41,948,500**	**$ 51,210,500**
Owners Costs					
staff training	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000
Owner's project management & engineering	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000
Snowcat or equivalent for maintenance	$ 300,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000
Subtotal owners costs	**$ 1,500,000**	**$ 1,500,000**	**$ 1,500,000**	**$ 1,500,000**	**$ 1,500,000**
TOTAL PROJECT COST	**$ 13,610,000**	**$ 28,004,500**	**$ 35,726,500**	**$ 43,448,500**	**$ 52,710,500**
Installed capacity kW		4,600	6,900	9,200	11,500
Installed cost per kW		**$ 6,088**	**$ 5,178**	**$ 4,723**	**$ 4,584**
Annual turbine O&M costs $125 per year per kW		$ 575,000	$ 862,500	$ 1,150,000	$ 1,437,500
Annual battery integration O&M $40 per kW per year			$ 40,000	$ 40,000	$ 40,000
Total annual costs		$ 575,000	$ 902,500	$ 1,190,000	$ 1,477,500

Attachment 2

Attachment 2
Cost summary Arviat

Nunavut Wind Project Capital Cost from Details - 3 H Bay Communities - Arviat				
Costs for 3 H Bay communities Nunavut, E70-E4 57 m towers - Arviat				
Cost detail	**Fixed costs**	**1 E70 2.3 MW, 57m steel tower**	**2 E70 2.3 MW, 57m steel tower**	
Project design and Management				
Wind resource assessment	$ 200,000	$ 200,000	$ 200,000	
Prefeasibility cost	$ 200,000	$ 200,000	$ 200,000	
Feasibility study including: environmental assessment & permitting, engineering	$ 1,000,000	$ 1,000,000	$ 1,000,000	
Site Preparation				
new road construction ($500,000 per km) X 4.0km + (700 m/T)	$ 2,000,000	$ 2,000,000	$ 2,350,000	
road upgrade ($250,000 per km) X 0.0km	$ -	$ -	$ -	
site & crane pad construction $20,000 per turbine		$ 20,000	$ 40,000	
overhead powerline const. ($250,000 per km) X 4.0km	$ 1,000,000	$ 1,000,000	$ 1,000,000	
underground 25kV collector ($400,000 per km) X 1km + (700m/T)	$ 400,000	$ 400,000	$ 680,000	
Utility interconnection	$ 1,000,000	$ 1,000,000	$ 1,000,000	
Wind Equipment Purchase				
wind turbines with towers (Enercon E70, 57m) $4,200,000 each including transport to Montreal, transformers, blade heating, on site crane costs, and on site installation and commissioning		$ 4,200,000	$ 8,400,000	
transport to HBay by ocean ($150,000 each)		$ 150,000	$ 300,000	
Installation				
geotehnical & foundation design + ($75k/T)	$ 750,000	$ 825,000	$ 900,000	
foundations $1,500k/T (steel & rock anchor footing)		$ 1,500,000	$ 3,000,000	
local equipment rental $250k/T		$ 250,000	$ 500,000	
Cranes demurrage costs per community 1/3 each	$ 215,000	$ 215,000	$ 215,000	
Cranes transport costs per community 1/3 each	$ 100,000	$ 100,000	$ 100,000	
crane - turbine installation in turbine cost, support within demurrage cost	$ -		$ -	
site building	$ 100,000	$ 100,000	$ 100,000	
wind integration 0.5 MW & 500 kWh battery (all-in cost) X2 for 2T	$ 1,250,000	$ 1,250,000	$ 2,500,000	
labour - assembly & supervision (above Enercon costs)		$ 150,000	$ 200,000	
commissioning included in turbine cost				
travel and accommodation + $25k/T	$ 100,000	$ 100,000	$ 125,000	
Other				
initial spare parts	$ 50,000	$ 50,000	$ 50,000	
Insurance		$ 200,000	$ 300,000	
other overhead costs (contracts etc.)	$ 500,000	$ 500,000	$ 500,000	
Subtotal construction	**$ 8,865,000**	**$ 15,410,000**	**$ 23,660,000**	
Contingency 10%		$ 1,541,000	$ 2,366,000	
TOTAL CONSTRUCTION	**$ 8,865,000**	**$ 16,951,000**	**$ 26,026,000**	
Owners Costs				
staff training	$ 200,000	$ 200,000	$ 200,000	
Owner's project management & engineering, shared		$ 750,000	$ 1,000,000	
Snowcat or equivalent for maintenance	$ 300,000	$ 300,000	$ 300,000	
Subtotal owners costs	**$ 500,000**	**$ 1,250,000**	**$ 1,500,000**	
TOTAL PROJECT COST	**$ 9,365,000**	**$ 18,201,000**	**$ 27,526,000**	
Installed capacity kW		2,300	4,600	
Installed cost per kW		**$ 7,913**	**$ 5,984**	
Annual wind turbine O&M costs $125 per year per kW		$ 287,500	$ 575,000	
Annual battery system O&M costs $40 per kW per year		$20,000	$40,000	
Total annual costs		$ 307,500	$ 615,000	

Attachment 2
Cost summary Baker Lake

Nunavut Wind Project Capital Cost from Details - 3 H Bay Communities - Baker Lake				
Costs for 3 H Bay communities Nunavut, E70-E4 57 m towers - Baker Lake				
Cost detail	**Fixed costs**	**1 E70 2.3 MW, 57m steel tower**	**2 E70 2.3 MW, 57m steel tower**	
Project design and Management				
Wind resource assessment	$ 200,000	$ 200,000	$ 200,000	
Prefeasibility cost	$ 200,000	$ 200,000	$ 200,000	
Feasibility study including: environmental assessment & permitting, engineering	$ 1,000,000	$ 1,000,000	$ 1,000,000	
Site Preparation				
new road construction ($500,000 per km) X 0km + (700 m/T)	$ -	$ -	$ 350,000	
road upgrade ($250,000 per km) X6.0km	$ 1,500,000	$ 1,500,000	$ 1,500,000	
site & crane pad construction $20,000 per turbine		$ 20,000	$ 40,000	
overhead powerline const. ($250,000 per km) X 4.0km	$ 1,000,000	$ 1,000,000	$ 1,000,000	
underground 25kV collector ($400,000 per km) X 1km + (700m/T)	$ 400,000	$ 400,000	$ 680,000	
Utility interconnection	$ 1,000,000	$ 1,000,000	$ 1,000,000	
Wind Equipment Purchase				
wind turbines with towers (Enercon E70, 57m) $4,200,000 each including transport to Montreal, transformers, blade heating, on site crane costs, and on site installation and commissioning		$ 4,200,000	$ 8,400,000	
transport to HBay by ocean ($150,000 each)		$ 150,000	$ 300,000	
Installation				
geotehnical & foundation design + ($75k/T)	$ 750,000	$ 825,000	$ 900,000	
foundations $1,500k/T (steel & rock anchor footing)		$ 1,500,000	$ 3,000,000	
local equipment rental $250k/T		$ 250,000	$ 500,000	
Cranes demurrage costs per community 1/3 each	$ 215,000	$ 215,000	$ 215,000	
Cranes transport costs per community 1/3 each	$ 100,000	$ 100,000	$ 100,000	
crane - turbine installation in turbine cost, support within demurrage cost	$ -		$ -	
site building	$ 100,000	$ 100,000	$ 100,000	
wind integration 0.5 MW & 500 kWh battery (all-in cost) X2 for 2T	$ 1,250,000	$ 1,250,000	$ 2,500,000	
labour - assembly & supervision (above Enercon costs)		$ 150,000	$ 200,000	
commissioning included in turbine cost				
travel and accommodation + $25k/T	$ 100,000	$ 100,000	$ 125,000	
Other				
initial spare parts	$ 50,000	$ 50,000	$ 50,000	
Insurance		$ 200,000	$ 300,000	
other overhead costs (contracts etc.)	$ 500,000	$ 500,000	$ 500,000	
Subtotal construction	**$ 8,365,000**	**$ 14,910,000**	**$ 23,160,000**	
Contingency 10%		$ 1,491,000	$ 2,316,000	
TOTAL CONSTRUCTION	**$ 8,365,000**	**$ 16,401,000**	**$ 25,476,000**	
Owners Costs				
staff training	$ 200,000	$ 200,000	$ 200,000	
Owner's project management & engineering, shared		$ 750,000	$ 1,000,000	
Snowcat or equivalent for maintenance	$ 300,000	$ 300,000	$ 300,000	
Subtotal owners costs	**$ 500,000**	**$ 1,250,000**	**$ 1,500,000**	
TOTAL PROJECT COST	**$ 8,865,000**	**$ 17,651,000**	**$ 26,976,000**	
Installed capacity kW		2,300	4,600	
Installed cost per kW		**$ 7,674**	**$ 5,864**	
Annual wind turbine O&M costs $125 per year per kW		$ 287,500	$ 575,000	
Annual battery system O&M costs $40 per kW per year		$20,000	$40,000	
Total annual costs		$ 307,500	$ 615,000	

Attachment 3
Cost summary Rankin Inlet

Nunavut Wind Project Capital Cost from Details - 3 H Bay Communities - Rankin Inlet				
Costs for 3 H Bay communities Nunavut, E70-E4 57 m towers - Rankin Inlet				
Cost detail	**Fixed costs**	**1 E70 2.3 MW, 57m steel tower**	**2 E70 2.3 MW, 57m steel tower**	
Project design and Management				
Wind resource assessment	$ 200,000	$ 200,000	$ 200,000	
Prefeasibility cost	$ 200,000	$ 200,000	$ 200,000	
Feasibility study including: environmental assessment & permitting, engineering	$ 1,000,000	$ 1,000,000	$ 1,000,000	
Site Preparation				
new road construction ($500,000 per km) X 0.0km + (700 m/T)	$ -	$ -	$ 350,000	
road upgrade ($250,000 per km) X 7.0km	$ 1,750,000	$ 1,750,000	$ 1,750,000	
site & crane pad construction $20,000 per turbine		$ 20,000	$ 40,000	
overhead powerline const. ($250,000 per km) X 7.0km	$ 1,750,000	$ 1,750,000	$ 1,750,000	
underground 25kV collector ($400,000 per km) X 1km + (700m/T)	$ 400,000	$ 400,000	$ 680,000	
Utility interconnection	$ 1,000,000	$ 1,000,000	$ 1,000,000	
Wind Equipment Purchase				
wind turbines with towers (Enercon E70, 57m) $4,200,000 each including transport to Montreal, transformers, blade heating, on site crane costs, and on site installation and commissioning		$ 4,200,000	$ 8,400,000	
transport to HBay by ocean ($150,000 each)		$ 150,000	$ 300,000	
Installation				
geotehnical & foundation design + ($75k/T)	$ 750,000	$ 825,000	$ 900,000	
foundations $1,500k/T (steel & rock anchor footing)		$ 1,500,000	$ 3,000,000	
local equipment rental $250k/T		$ 250,000	$ 500,000	
Cranes demurrage costs per community 1/3 each	$ 215,000	$ 215,000	$ 215,000	
Cranes transport costs per community 1/3 each	$ 100,000	$ 100,000	$ 100,000	
crane - turbine installation in turbine cost, support within demurrage cost	$ -		$ -	
site building	$ 100,000	$ 100,000	$ 100,000	
wind integration 0.5 MW & 500 kWh battery (all-in cost) X2 for 2T	$ 1,250,000	$ 1,250,000	$ 2,500,000	
labour - assembly & supervision (above Enercon costs)		$ 150,000	$ 200,000	
commissioning included in turbine cost				
travel and accommodation + $25k/T	$ 100,000	$ 100,000	$ 125,000	
Other				
initial spare parts	$ 50,000	$ 50,000	$ 50,000	
Insurance		$ 200,000	$ 300,000	
other overhead costs (contracts etc.)	$ 500,000	$ 500,000	$ 500,000	
Subtotal construction	**$ 9,365,000**	**$ 15,910,000**	**$ 24,160,000**	
Contingency 10%		$ 1,591,000	$ 2,416,000	
TOTAL CONSTRUCTION	**$ 9,365,000**	**$ 17,501,000**	**$ 26,576,000**	
Owners Costs				
staff training	$ 200,000	$ 200,000	$ 200,000	
Owner's project management & engineering, shared		$ 750,000	$ 1,000,000	
Snowcat or equivalent for maintenance	$ 300,000	$ 300,000	$ 300,000	
Subtotal owners costs	**$ 500,000**	**$ 1,250,000**	**$ 1,500,000**	
TOTAL PROJECT COST	**$ 9,865,000**	**$ 18,751,000**	**$ 28,076,000**	
Installed capacity kW		2,300	4,600	
Installed cost per kW		**$ 8,153**	**$ 6,103**	
Annual wind turbine O&M costs $125 per year per kW		$ 287,500	$ 575,000	
Annual battery system O&M costs $40 per kW per year		$20,000	$40,000	
Total annual costs		$ 307,500	$ 615,000	

Attachment 3

Attachment 3
Cost summary projects with North Wind 100 wind turbine

Nunavut Wind Project Capital Cost from Details

Costs for Nunavut, NW 100 with 25 m hydraulic tilt towers & ballast foundation

Cost detail	Fixed costs	1 NW 100	2 NW 100	3 NW 100	6 NW 100	10 NW 100	Other number
Number of turbines		1	2	3	6	10	1
km of new road		3	3	3	3	3	3
km of new powerline		5	5	5	5	5	5
Project design and Management							
Wind resource assessment	$ 150,000	$ 150,000	$ 150,000	$ 150,000	$ 150,000	$ 150,000	$ 150,000
Prefeasibility cost	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000
Feasibility study including: environmental assessment & permitting, engineering	$ 250,000	$ 250,000	$ 270,000	$ 290,000	$ 350,000	$ 430,000	$ 250,000
Site Preparation							
road construction $250,000 per km	$ 250,000	$ 750,000	$ 750,000	$ 750,000	$ 750,000	$ 750,000	$ 750,000
road construction per additional turbine $25,000	$ 25,000	$ -	$ 25,000	$ 50,000	$ 125,000	$ 225,000	$ -
site & crane pad construction $0 per turbine							
overhead powerline const, $250,000 per km	$ 250,000	$ 1,250,000	$ 1,250,000	$ 1,250,000	$ 1,250,000	$ 1,250,000	$ 1,250,000
underground 25kV collector $40,000 per turbine	$ 40,000	$ 40,000	$ 80,000	$ 120,000	$ 240,000	$ 400,000	$ 40,000
Utility interconnection plus $20,000 per additional turbine	$ 250,000	$ 250,000	$ 270,000	$ 290,000	$ 350,000	$ 430,000	$ 250,000
Wind Equipment Purchase							
wind turbines with towers (NW100 25m hydraulic tilt ballasted foundation) $585,714 each including transport to port, and commissioning; $527,143 multiple		$ 585,714	$ 1,054,286	$ 1,581,429	$ 3,162,858	$ 5,271,430	$ 527,143
Hydraulic tilting equipment	$ 42,857	$ 42,857	$ 42,857	$ 42,857	$ 42,857	$ 42,857	$ 42,857
Marine transport							
Wind turbine transport $22,125 ea more than one		$ 25,125	$ 44,250	$ 66,375	$ 132,750	$ 221,250	$ 22,125
Helper crane return transport	$ 18,750	$ 18,750	$ 18,750	$ 18,750	$ 18,750	$ 18,750	$ 18,750
Installation							
geotehnical & foundation design + $10k per turbine	$ 10,000	$ 20,000	$ 30,000	$ 40,000	$ 70,000	$ 110,000	$ 20,000
foundations rock fill $50,000 / turbine		$ 50,000	$ 100,000	$ 150,000	$ 300,000	$ 500,000	$ 50,000
local equipment rental plus $10,000 per turbine	$10,000	$ 20,000	$ 30,000	$ 40,000	$ 70,000	$ 110,000	$ 20,000
crane monthly costs (4 months)	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000
crane site work - monthly rental includes 167 hours/mo		$ -		$ -		$ -	
site building	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000
wind integration 250kW & 200 kWh battery systems all-in, if required	$ 1,000,000	$ -		$ -		$ -	
labour - assembly & supervision incl crane operator + $50k/turbine	$ 100,000	$ 150,000	$ 200,000	$ 250,000	$ 400,000	$ 600,000	$ 150,000
commissioning included in turbine cost	$ -	$ -		$ -		$ -	
travel and accommodation + $15k/T	$ 25,000	$ 40,000	$ 55,000	$ 70,000	$ 115,000	$ 175,000	$ 40,000
Other							
initial spare parts	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000
Insurance $90,000 + $10,000 per turbine	$ 90,000	$ 100,000	$ 110,000	$ 120,000	$ 150,000	$ 190,000	$ 100,000
other overhead costs (contracts etc.)	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000
Subtotal construction	**$ 2,871,607**	**$ 4,102,446**	**$ 4,840,143**	**$ 5,639,411**	**$ 8,037,215**	**$ 11,234,287**	**$ 4,040,875**
Contingency 10%		$ 410,245	$ 484,014	$ 563,941	$ 803,722	$ 1,123,429	$ 404,088
TOTAL CONSTRUCTION	**$ 2,871,607**	**$ 4,512,691**	**$ 5,324,157**	**$ 6,203,352**	**$ 8,840,937**	**$ 12,357,716**	**$ 4,444,963**
Owners Costs							
staff training	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000
Owner's project management & engoineering (+$10,000 per turbine)	$ 200,000	$ 220,000	$ 240,000	$ 260,000	$ 320,000	$ 400,000	$ 220,000
Equipment for maintenance	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000
Subtotal owners costs	**$ 325,000**	**$ 345,000**	**$ 365,000**	**$ 385,000**	**$ 445,000**	**$ 525,000**	**$ 345,000**
TOTAL PROJECT COST	**$ 3,196,607**	**$ 4,857,691**	**$ 5,689,157**	**$ 6,588,352**	**$ 9,285,937**	**$ 12,882,716**	**$ 4,789,963**
Installed capacity kW		100	200	300	600	1,000	100
Installed cost per kW		**$ 48,577**	**$ 28,446**	**$ 21,961**	**$ 15,477**	**$ 12,883**	**$ 47,900**
Annual O&M costs $125 per year per kW		$ 12,500	$ 25,000	$ 37,500	$ 75,000	$ 125,000	$ 12,500
Annual O&M for battery system $40 per kW per year	$ 10,000						
Total annual costs		$ 12,500	$ 25,000	$ 37,500	$ 75,000	$ 125,000	$ 12,500