PROVISION OF TECHNICAL AND ECONOMIC STUDIES FOR A 100% RENEWABLE PENETRATION SCENARIO FOR BROCHET, LAC BROCHET, AND TADOULE LAKE

Final REPORT FOR AKI ENERGY

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CONTENT

1 EXECUTIVE SUMMARY

In Manitoba's Remote Communities of Barren Lands First Nation (Brochet), Northlands Denesuline First Nation (Lac Brochet) and Sayisi Dene First Nation (Tadoule Lake), diesel fuel currently represents the primary energy source for heat and electricity. This dependency upon diesel fuel has resulted in negative impacts on the local environment from oil spills, pollution, and indoor air quality issues, and consequentially, contributes toward human and environmental health and safety issues along with associated environmental remediation and health care costs.

Diesel fuel is shipped to these communities via a winter road system (posing challenges in and of itself). Due to transportation factors, fuel then arrives in these communities at a high cost, which has a negative impact upon heating and electricity pricing, impeding economic development and food security within Northern communities.

The current 60 Amp residential connection limit within the communities' results in a number of electricity usage restrictions. These factors hinder conveniences within the community homes due to the fact that electric heating load is prohibited by Manitoba Hydro. Comfort within community homes is also hindered as a result of Heat Recovery Ventilation (HRV) units being usually turned off in order to avoid higher energy costs. The bypassing of HRV units leads to high home humidity levels and subsequent mold formation. As such, Band Chief and Council and local members of affected communities have expressed a strong desire to explore alternative energy options that reduce and/or eliminate diesel fuel use and reduce electricity costs to avoid energy poverty amongst the Band Members. It is possible to provide 100 Amp residential service with a biomassed fueled organic rankine cycle generator. Loads can be managed with aggressive DSM and demand response control of the blowers at the sewage lagoon and control of any electric hot water tanks not on biomass or geothermal heating loops.

Clean and renewable energy from wind, solar, and batteries has been proven economic and reliable in other remote Northern communities in Alaska and the North West Territories. As one such example in Kotzebue Alaska, wind turbines and batteries are supplying approximately one-third of the town's annual electrical energy, displacing nearly 950,000 litres of diesel fuel per year. The remote community of Colville Lake in the North West Territories has recently installed a Solar PV, battery, and diesel-powered hybrid system that has significantly reduced the town's reliance on diesel fuel. Successful renewable implementations have reinforced the desire of Brochet, Lac Brochet, and Tadoule Lake to "get off oil" and employ similar proven renewable energy sources in each of their respective communities.

In response to the communities' desire to investigate alternative clean energy supply on behalf of their members, Indigenous and Northern Affairs Canada (INAC) has funded Aki Energy to develop a Community Energy Plan (CEP) for Brochet, Lac Brochet, and

Tadoule Lake by the spring of 2017. Shamattawa, the fourth remote community in Manitoba may also join this study at a later date. This CEP addresses both supply and Demand-Side Management (DSM) considerations for heat and electricity. In support of the CEP, Soft White 60 Corporation (SW60) has been engaged by Aki Energy to perform a pre-feasibility study of clean electricity supply alternatives that could be realized within the target remote communities over the next five years.

In performing its analyses, SW60 utilized HOMER Pro software to produce technically feasible electrical resource scenarios that are optimized for least value of the levelized cost of electricity (LCOE) and may be realized in the target remote communities. The study utilizes a 25-year planning horizon, taking into account hourly wind speeds and solar insolation levels, along with 15 minute existing fixed-speed diesel generator loading, and equipment data to represent battery, Organic Rankine Cycle (ORC) generation, and variable-speed diesels. The accuracy of the results of the HOMER Pro optimization process is related to the confidence level of the input of the technical and costing data. In this pre-feasibility analysis, in addition to data from manufacturer's equipment specifications and data embedded in the HOMER Pro generation data library, a portion of input data had to be estimated to represent specific generation and/or storage devices. SW60's HOMER Pro modelers have extensive experience in this area and surmise that the LCOE values presented in this report are equivalent to a Class 4 or Class D level, with accuracy estimated to be between -30% to +50%.

It is important to note that the wood supply for the ORC is available from two sources—local fire-killed trees which are still standing in forest burn areas near each community, and Forestry Management Units (FMUs) located along the shared winter road, and in the Lynn Lake area. Manitoba Sustainable Development's Forestry Branch and local university research reports indicate that there are abundant local wood resources of fire-burnt timber, providing at the present rate of electricity and heat consumption between 50 and 200 years of wood supply for 100% biomass heating and electrical generation near each community. If the feasibility study finds this source of biomass to be uncertain, then there are three Forestry Management Units (FMUs) that can be harvested—FMU 71, FMU 72, and the western portion of FMU 79 as shown in Figure 1 below. The sustainable Annual Allowable Cut (AAC) for these three FMUs exceeds the expected ORC fuel consumption for all three communities. The feasibility study will need to include a thorough survey of the available wood supplies, both from local fire-kill sources and from these FMUs. Although harvesting from these FMUs would require some use of diesel for equipment and transportation, it would be significantly less than the fuel required to transport the diesel currently brought into the three communities. These FMUs are clustered along the shared winter road and around Lynn Lake, while the diesel currently being consumed is usually transported from Alberta.

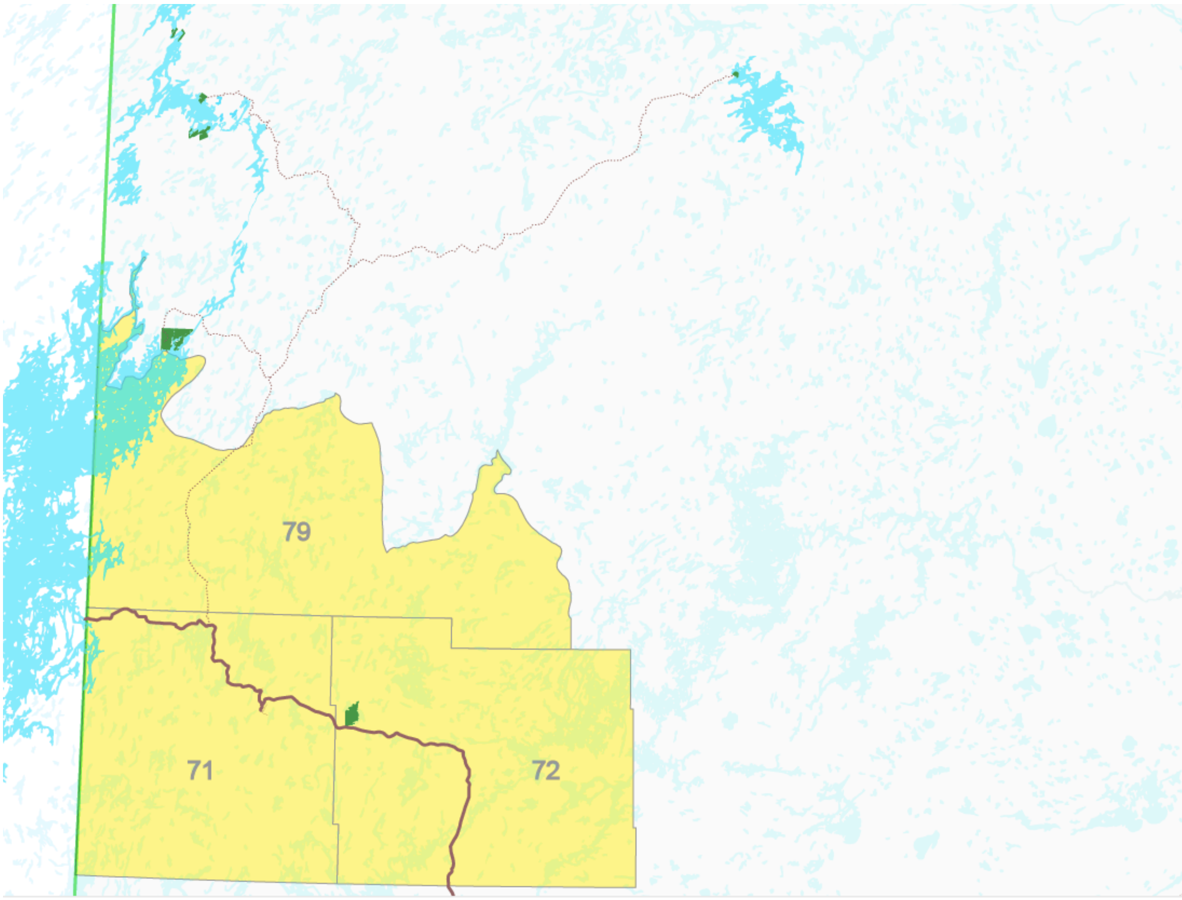

Figure 1: Map of FMU 71, FMU 72 and FMU 79

It has been determined that there is ample truck capacity and winter road season duration to supply all three communities with a full year's supply of wood at a sustainable, reasonable cost ($137/ tonne), which forms the basis for the wood cost data inputs in the aforementioned HOMER Pro analysis. It is envisioned that a significant reduction in diesel oil supply and transportation requirements will result within these communities once the ORCs are 100% operational.

As a corollary to the ORC being 100% operational, it is recommended that the existing Manitoba Hydro diesel units be maintained and left in place as back-ups with enough diesel fuel for one year of operation at 100% community loading. As the ORCs become 100% operational, the Manitoba Hydro diesels and associated tank farms may eventually be decommissioned. In all cases, the firm back-up electrical energy supply would then be transferred to additional ORC to provide an N-1 design within each community.

It is important to note that biomass-fueled ORC generation systems have proven reliable in numerous locations throughout Europe and North America, although none have yet been utilized in Northern, remote off-grid First Nations Communities in Canada. The current perception that ORC is more complex than diesel generators may be partially correct. However, it is envisaged that with adequate training of local personnel and appropriate maintenance contracts in place with reputable ORC equipment suppliers, the risk of failure of this technology may be effectively mitigated in the remote Northern First Nations Communities.

The study results indicate that the deployment of ORC, Solar PV, wind power and battery renewable electrical energy systems in all three communities could reduce the consumption of diesel fuel to nearly zero, which will result in almost a 100% reduction in greenhouse gas (GHG) emissions from electrical generation sources. HOMER Pro results show that a capital investment ranging from $17.4 million in Tadoule Lake and Brochet and $18.4 million in Lac Brochet for ORC, Solar PV, wind power and batteries for renewable electrical energy sources in these remote communities may achieve renewable electrical energy penetrations of 100%. These also achieve a lower LCOE of 59.2 ¢/kWh to 78.4 ¢/kWh than the "business as usual" case of the $1.13 to $1.19/kWh from fixed-speed diesel generators.

For a 100% renewable penetration of electrical generation technologies for Lac Brochet, Brochet and Tadoule Lake, the best economic resource selection is the combination of ORC, PV, wind power and battery. The LCOE varies from 59.2 ¢/kWh for Lac Brochet, 68.4 ¢/kWh at Brochet and 78.4 ¢/kWh at Tadoule Lake. The average annual operating costs vary from 29.3 ¢/kWh for Lac Brochet, 29.5 ¢/kWh at Brochet and 30.6 ¢/kWh at Tadoule Lake, which represents the lowest marginal operating costs of all cases evaluated by HOMER Pro. When using ORC, solar PV, wind power and batteries, the operating savings over fixed-speed diesel range from $50 million in Tadoule Lake to $82.5 million in Lac Brochet over a 25-year period. The best technical configuration would also be the one with the greatest diversity of proven renewable supply options, also represented by ORC, PV, wind power and battery. There is also ample waste heat from the ORC to heat the entire communities with 200% heat available in La Brochet, 140% in Brochet and 160% in Tadoule Lake. The excess waste heat available can be used for additional uses; including food security systems such as freezers and greenhouses, or additional economic development via hotels and laundromats.

The addition of batteries is always required to make intermittent solar PV and wind power options realizable for all communities. In all cases, the introduction of solar PV and wind hardly change the LCOE and the benefits of resource diversity are significant, and either some solar PV, wind, or both could be included, with a preference given to solar PV due to its ease of maintenance over the more complicated nature of wind power systems. Supplemental benefits include local job creation within the community energy sector in the areas of wood harvesting, transportation, and electricity and heat generation O&M, as well as further economic development through community-owned generation facilities and businesses.

There were cases studied where no cost of capital for the equipment and construction of the facility was included. However, this cost may be beyond the boundary acceptable for these community projects if INAC has a limit on its budgeted capital expenditures. Other factors such as diversity of supply, dispatchable resources, redundancy, operation and maintenance issues, ease of grid integration, environmental issues, DSM, demand response, available incentives, policy issues, local climate, and maturity of technology also need to be considered.

Based upon these preliminary results, it is recommended that a full feasibility study be pursued for the electrical energy and associated heating options for Brochet, Lac Brochet, and Tadoule Lake.

**NOTE: Due to the fact that simulations, economic analyses, price forecasts, and the types of information contained in this report represent material of a complex and predictive nature, and the recognition that a portion of the underlying data is based upon assumptions and inputs derived and provided from various independent sources, Soft White 60 Corporation cautions readers and users of this report alike to be aware that any real world deviation from the underlying assumptions and data contained in this report may result in differences in relation to the results obtained.*

2 INTRODUCTION

Aki Energy has contracted SW60 to perform a pre-feasibility study of renewable electricity supply alternatives that could be realized within the remote communities of Brochet, Lac Brochet, and Tadoule Lake over the next five years. In so doing, these renewable options will be compared against one other, traditional fixed-speed diesel generation, and new advanced variable-speed diesel generators.

In addition to the Executive Summary and Introduction, this report is organized into four primary sections. Section 3 – DESCRIPTION OF GENERATION OPTIONS IN THE REMOTE COMMUNITIES describes the following electrical generation technologies: biomass (wood chip)-fueled ORC generation, solar PV, wind power, fixed-speed (traditional) diesel generation, variable-speed (advanced) diesel generation, and batteries. Section 4 – HOMER CASE STUDIES describes the HOMER Pro software tool that optimizes the amount and mix of generation technologies proposed as the best solution based upon the least value of the levelized cost of electricity (LCOE). Section 5 – ANALYSIS OF SIMULATION RUNS describes the various combinations of renewable technologies selected by SW60 to be analyzed by the HOMER Pro software tool and the resulting HOMER Pro selection of technologies and LCOE results. Section 6 – Action Items and next Steps discusses follow-on activities pertinent to this study. The final and aptly named Section 7 – CONCLUSIONS AND RECOMMENDATIONS discusses the conclusions and recommendations based upon the HOMER Pro results and SW60's analysis.

The LCOE values presented in this report are estimated to be at a Class 4 or Class D level with accuracy estimated to range from -30% to +50%. This level is typical for a pre-feasibility study that has an incomplete definition of the final characteristics of the project. It is important to note that an appropriate amount of contingency should to be applied to the capital and operating costs in order to achieve this level of accuracy. Normally a 25% contingency on capital costs and a 50% contingency on operating costs are used in a prefeasibility study. These contingencies (higher capital and operating costs) have not been applied in this prefeasibility study because the recommended full feasibility study would provide a better LCOE accuracy.

This report on electricity supply options is one of four reports related to methods to reduce diesel fuel consumption on the remote communities. The other three reports relate to heat supply options, DSM on electricity consumption, and DSM on heating systems. Aki Energy will collate all four reports and produce a comprehensive Master Report, based on these four components.

3 DESCRIPTION OF GENERATION OPTIONS IN THE REMOTE COMMUNITIES

3.1 Organic Rankine Cycle (ORC) for High Temperature Biomass in Remote Communities

The use of biomass Combined Heat and Power (CHP) is a strong contender for Manitoba's remote communities, as a sustainable supply of biomass may be found within relatively close proximity, along with a viable back-up supply option for wood delivered via winter roads.

The biomass (wood chips) can be used productively, supplying 16% of its energy as electricity and over 50% of its energy as heat for small-scale systems at about 1.0 MW or less. The application of biomass is well established for providing heat-only, using combustion systems over a wide range of scales; however, generating CHP at small-scale is relatively rare in Canada, while small-scale biomass CHP systems are common in Europe where electrical power is more expensive in comparison to North America. This is shown on a world map of ORC units in Figure 2 below where each site on the map is available for interactive investigation via the following link: http://orc-world-map.org/. Note that there are biomass ORCs in operation in northern BC and Alberta as well as in the Nordic countries of Europe. Biomass ORC started in commercial operation in Europe in the late 1990's and have been expanding worldwide ever since, with over 150 biomass ORC installations worldwide as of August 2016.

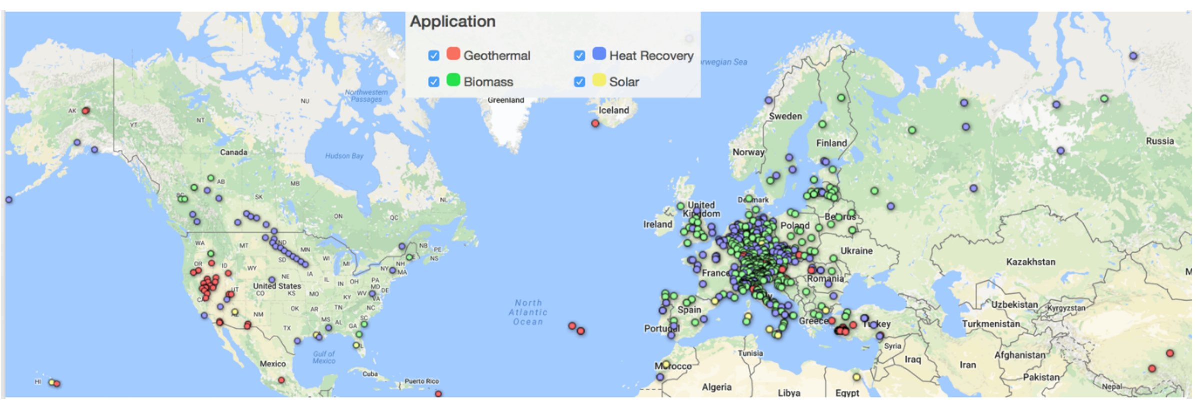

Figure 2: Map of ORC Units in the World as of 08/16/2016

ORC is well-suited for applications within Manitoba's remote communities, allowing heat to be delivered at district heating temperatures of 90°C. The ORC system is coupled to a high temperature biomass combustor that produces a flue gas temperature between 750°C and 1,000°C (see Figure 1.0). Like a steam-based system, the relatively high temperature heat is used to vaporize a working fluid that then turns a turbine, driving a generator to produce electricity.

An organic fluid is used as the working fluid in an ORC. The lower working fluid pressures eliminate the need for a 24/7 operator to be in attendance. The efficiency of ORC units depends upon the temperature output of the combustor. At the highest end, 1,000°C flue gas temperatures will provide an efficiency of 16.3%. Depending upon operation set-up and the moisture content of the wood chips, more than 50% of the energy in the wood chips can provide heat (hot water) at 90°C, which can be injected into a district energy system, achieving a CHP efficiency of at least 65%.

The system is typically sized to match the community electric power loads while supplying heat in excess of the community's total heating needs. ORC systems often have a high availability of 97%, and generator can load follow well down to 10% of its rating while still providing heat for the district energy system. ORC systems require trained personnel to be on hand at major overhauls and it may be possible for local Band members to be trained to fill these roles. Otherwise, there may be additional expenses to obtain qualified service (if not available locally). To ensure speedier repairs, it is recommended that key replacement components and an appropriate inventory of spare parts be kept on-site.

ORC System Energy Diagram

Figure 1 below shows an overall energy balance diagram for an ORC system. The efficiency of the cycle is only part of the energy balance and is included in the diagram. An ORC system is an indirect fired system, meaning that a standalone combustion system generates a hot flue gas by combining air with biomass inside a combustion chamber. The generated hot flue gas transfers most of its heat to a thermal oil using air-to-liquid and air-to-vapor heat exchangers. Inside these heat exchangers circulates a thermal oil within a closed loop piping arrangement. This thermal oil powers the turbine after it has vaporized. There are a few issues that can be overlooked when looking at the energy balance:

1) Higher Heat Value (HHV) versus Lover Heating Value (LLV): The biomass fuel HHV energy content is used in North America. In Europe, they remove the latent heat energy content of the water formed during combustion from the HHV and quote energy efficiency based on LHV. LHV leads to higher efficiencies. In Figure 3 we assume that the energy balance is based on HHV as it would be incorrect to make such a diagram based on LLV and not write so in the diagram.
2) System efficiency versus cycle efficiency: The proper approach is to have the energy balance based on the overall system efficiency using the HHV based on bone dry wood; however, cycle efficiency is often shown. Cycle efficiency only starts after the energy has been transferred to the heat exchangers.
3) Theoretical or real system: A theoretical cycle will always have a higher system efficiency than an actual system that is built. When building a real system, there are constraints that reduces the theoretical efficiency like limiting the

rotational speed of the turbine, maximum temperature a commercially available steel can withstand, and limiting combustion temperatures to prevent thermal NOx from forming.

4) The moisture content of the wood will affect how much water vapour is contained in the flue stack and slightly change overall system performance.
5) There will be small variations between summer and winter performance.

The energy balance in Figure 3 is as follows:

1) The HHV of the wood per bone dry ton is converted to a hot gas and this is the 100% energy mark. In the diagram the amount of excess air introduced controls the flue gas temperature to 950°C which is on the high end for small-scale biomass combustors.
2) 1.2% of the heat is lost through the furnace combustor walls to the air in the room that the system is located in.
3) 2.0% of the hot flue gas is extracted to control the grate temperature of the combustor. The grate is where the fuel ultimately rests upon to combust when not air born in the combustor. This 2% all goes to add energy to the hot water and is not lost; however, it is unavailable to make electricity and thus slightly lowers the electrical efficiency of the ORC system.
4) 3.1% of the energy taken from the thermal oil is reintroduced in the flue gas.

The energy in the flue gas located inside the furnace: 100% – 1.2% – 2.0% + 3.1% = 99.9%

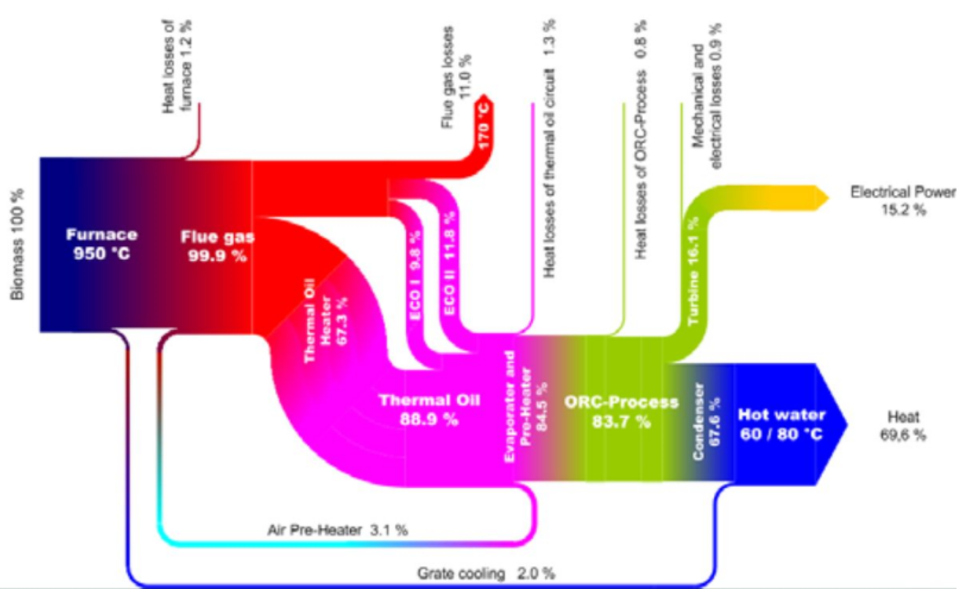

Figure 3: Example for the energy flow diagram for a typical ORC system

Here the diagram shows the overall energy efficiency and we assume it is based on HHV. The ORC performance can be changed to produce less power and higher temperature heat as a tradeoff. We also assume that a relatively high combustor system is used with the convection heat exchanger located at the back end of the combustor.

1) Of the 99.9% of the energy in the flue gas, 67.3% is transferred to the thermal oil via the thermal oil heat exchanger, 9.8% via the first economizer heat exchanger, and 11.8% via the second economizer heat exchanger.
2) The flue gas has now been cooled down but not enough to condense the water vapour in the flue gas. 11% of the energy in the flue gas escapes though the chimney and is released to the air. This value goes up if the wood has more moisture.

The energy available to make electricity contained in the thermal oil: 99.9% – 11% = 88.9%

3) 3.1% of the thermal oil energy is sent back to the flue gas to preheat the combustion air (see point 4 above)
4) 1.3% of heat in the thermal oil is lost to the air that surrounds the piping system
5) 0.8% of heat in the thermal oil is lost to the air when making electricity with the ORC

The energy available to make electricity contained in the thermal oil: 88.9% - 1.3% - 3.1% - 0.8% = 83.7%

6) Now the cycle efficiency of the ORC is 18.1% (not shown) and is able to convert the 83.7% of energy in the oil to yield 15.2% electricity and 67.6% heat contained in hot water
7) During this process 0.9% of heat and power is lost

The energy balance: 87.7% - 0.9% => yields 15.2% electricity and 67.6% hot water

8) Finally, 2.0% of heat is added to the hot water from the furnace to cool the grate (see point 3) so 69.6% of net heat is generated

The energy balance for the heat: 67.6% + 2.0% = 69.6%

3.2 Solar Photovoltaic (PV) Systems in Remote Communities

A photovoltaic (PV) system generates electricity by means of photovoltaic effect using semi-conductors. PV panels operate without any moving parts, are silent, and have no environmental emissions after they have been manufactured. Furthermore, no operator is required to operate PV systems.

A typical PV system is composed of rows of solar panels that convert sunlight directly into DC electricity at approximately 20% efficiency. Additionally, PV systems also require inverters to convert the DC current to AC current, as well as racking for mounting the panels, cabling, combiner boxes, disconnect switches to bring the PV power to a common location, and for grid connected systems, a step-up transformer to convert the PV system voltage to a utility compatible voltage (see Figure 4).

A two-axis solar tracking system can be used to improve the system's overall energy capture by about 25% to 30% over fixed tilt systems. Although tracking systems today can make economic sense in certain applications, they also add complexity of moving parts to a PV system. It is recommended to use fixed tilt systems in Manitoba's remote communities, as availability of land space is not an issue, and as such, simply adding more PV panels is instead, preferred. The use of tracking should only be considered if it would be beneficial to produce more power at times close to sunrise and sunset.

PV systems have developed from being a high-cost niche market application 20 years ago into a competitively-priced mature technology used for mainstream electricity generation today. Installed prices in southern Manitoba for commercial scale PV systems are approximately $2.50/Wdc, while installations in Manitoba's remote communities are estimated at approximately $7.50/Wdc due to remote transportation, logistics, and installation factors. PV panels alone (without additional hardware, engineering, and installation costs) are currently available for less than $1.00/Wdc.

PV systems are relatively insensitive to deployment scale when compared to other forms of generation. In Manitoba's remote communities, there is substantial room to reduce the present cost of solar PV once installers have gained more experience in remote communities. Moreover, there are opportunities to train First Nations people to install PV racks and panels while maximizing the use of local materials to anchor the racks.

Off-grid systems often include an integrated BESS to smooth out daily variations due to clouds or other shading and to move daytime energy to night-time use. They may also be necessary to permit safe and stable grid interconnection to an existing micro-grid consisting of fixed speed diesel generators.

An area of concern in small micro-grid applications such as Manitoba's remote communities relates to the fact that there is substantially more solar energy available in summer, reducing the ability to meet community loads with solar PV in winter months. Moreover, PV generation is subject to large fluctuations due to passing clouds, increasing the possibility of voltage sags and frequency fluctuations. As such, PV needs to be properly integrated into each community, with detailed planning of the complete generation and grid system.

Of particular concern in Manitoba's remote communities is ensuring that other generation technologies that may be used there can accommodate the intermittent nature of PV electrical energy, especially relating to the fact that no Solar PV generation is available at night. As such, installing only PV with batteries in these communities is not a wise choice. The amount of batteries and costs required to do so would be prohibitive, and the design would have significant GHG's embedded into the manufacturing of such large quantities of batteries. Therefore, an integrated approach to renewables that minimizes the amount of kWh of batteries is also required.

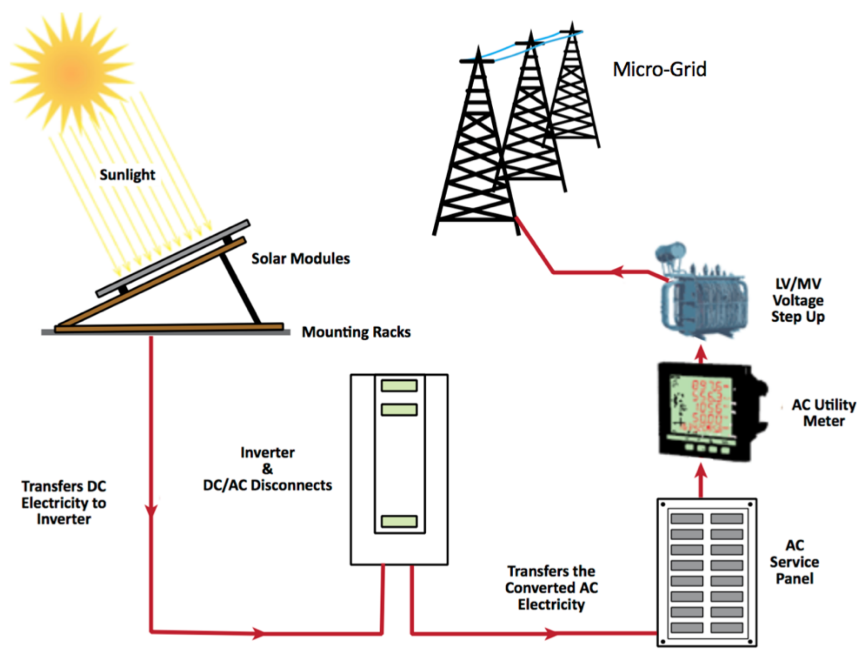

Figure 4: Overview of Solar PV Power Plant Courtesy of International Finance Corporation

3.3 Wind Power in Remote Communities

In many jurisdictions across North America, wind power is the lowest cost resource, often yielding electric power for no more than a few cents per kWh. However, this requires access to a good wind resource with relatively high capacity factors, large scale deployments (>100 MW), a large utility that can address wind intermittent generation within its grid, an absence of ice and cold weather impacts upon turbines, and access to skilled labor for operation and maintenance.

For Manitoba's remote comminutes, most of these conditions are not applicable or available. Wind resource information is poor in these remote communities and needs to be verified by monitoring as suggested in Marc Arbez's report to the Community Energy Plan "Development of a Wind-Energy Resource Assessment Strategy for Manitoba's Off-Grid First Nations". Wind generation can provide substantial benefits to remote communities, allowing generating power when Solar PV cannot. Wind Power in the areas of the three remote communities is stronger in winter when the energy is needed the most. Wind Power capacity above a 20% of the dispatchable generation level is likely to require storage to manage wind ramping due to wind gusts and for stabilizing the micro-grid. However, in order to be effective, it is critical to evaluate wind power from a remote community point of view, and not from a large utility point of view, as power costs have the potential to exceed $1.00 per kWh in these locations. With proper data gathering and analysis, there is substantial room to adapt this technology to remote communities.

Unlike biomass, solar, and diesel generation which are located in or near the community, wind power generation requires reviewing the wind resource location and its impact on how long a transmission line may be required. In this study, simulations are performed with HOMER Pro using simulated meteorological data that is not specific to Brochet and Lac Brochet while using measured wind data at Tadoule Lake. As such, Northlands may have a better wind resource on one of its nearby hills, requiring a 10 km transmission line. As these hills all surround lakes, it may be possible to use pumped storage and eliminate the need for batteries. It is important to note that such approaches require detailed assessments that are beyond the scope of this study. Moreover, wind turbines for remote communities are still underdeveloped and lack examples of demonstrated long-term proven sites.

While Nordic developed wind turbines are rugged, typically smaller than large utility scale wind turbines, require no large crane, and are relatively low efficiency, however, they may be capable of withstanding the harsh winter conditions within the remote communities. In this study, wind turbines that can withstand the icing that can occur in these remote communities were selected for analysis.

Since annual average wind speeds are generally lower in Northern Manitoba compared to acceptable industry standards, wind power will likely have a low capacity factor, unless turbines can be placed in locations that have micro climate conditions leading to a better wind resources. As described previously, such placements are beyond the scope of this particular study.

3.4 Batteries in Remote Communities

Utility-scale battery storage is undergoing a predictable price decrease. As lithium-ion battery costs (uninstalled) decrease to $150/kWh, down from $500 and even

$1,000/kWh just a few years ago, and with battery cycle life improvements and energy density increases (along with corresponding battery pack size decreases), these developments will in the near future permit high density modular battery trailers to be deployed in Southern Manitoba at approximately $200/kWh. The current cost for large scale installation in Southern Manitoba is estimated to be $1000/kWh and current installed costs of lithium-ion batteries in the remote communities are estimated to be $2500/kWh. Additionally, the issue of cold weather and its impact upon batteries is not a technical challenge and has been addressed, with overheating in summer remaining more of an issue. Finally, remote communities will not be impeded due to their location other than in terms of transportation costs and access to trained personnel. While the need for batteries can vary significantly, many kWh of batteries is still required to support 1 kW of load if the system is not designed properly.

Battery storage can be used in remote communities to:

- Support the micro-grid to address short temporal variations. The storage capacity in such cases is relatively small compared to the load.
- Power short time intervals to address periods when no power is available during forced and planned outages for base load generators such as biomass and diesel.
- Provide large storage capacity to address relatively long periods of intermittent generation from a few hours to a few days. For this scenario, other solutions that can be considered include:
  - Biomass CHP systems
  - Variable speed diesel engines
  - Pumped water storage

3.5 Fixed and Variable Speed Diesels in Remote Communities

Although there is an inherent goal to eliminate diesel fuel use in remote communities, diesel use may still be required for limited conditions and for some time. In remote communities, power systems must have at least an N-1 factor of redundancy (loss of one largest generator and still meet system load). It is difficult for wind power and Solar PV to provide base load power, let alone provide system redundancy.

Additionally, the high cost of replacing diesel engines may be mitigated by installing portable and containerized diesel gensets, similar to those used in winter camps. As the renewable energy systems are installed, portable gensets may be sized more appropriately. The important lesson in this case is to consider diesel engines as part of the planning process for renewables. Of critical importance is a departure from "business as usual" and viewing the diesel engine as only providing power when renewable energy systems are unable to address current loads. The antiquated notion of having diesel engines serving as the preferred dispatchable power source needs to be updated and effectively eliminated within remote communities.

Fixed-speed diesel generators do not integrate well with renewable energy. These diesels cannot operate at low partial loads (below 30% of rating), and may require solar PV and wind power to be run back (spill available power by effectively turning off the Solar PV panels or the wind turbines), even when it can be produced at no additional cost. A better approach that favours renewables involves decoupling engine speed from electrical frequency. That is, by adopting a variable-speed drive, the engine operates at the most advantageous operating speed at any given load. By being able to operate at low load (10% of rating), variable-speed diesels do not waste fuel when partially loaded, and achieve considerable fuel savings over fixed-speed diesel generators.

The outcome of this synergy is reduced emissions. Additionally, variable-speed diesels operate at lower speeds when compared to fixed-speed diesels so that wear and tear is reduced, incomplete combustion at low load is avoided, and periods between overhauls is extended, resulting in reduced maintenance costs.

4 HOMER CASE STUDIES

4.1 Modelling Approach

This study is focused upon evaluating options for generating electricity that serves the existing loads in each of the three communities under review. The typical approach to evaluating electrical power options is to seek out the least-cost system configuration, from among reasonably available technical options that could be realized within five years, due to the fact that at current loading levels, some existing diesels will need to be replaced within this timeframe.

This approach therefore excludes small hydro, which typically takes between 7 and 10 years from concept development through to in-service date. While connection to Manitoba Hydro's grid is also an option, due to high costs ($300 to $500+ million) it is considered out of scope for this study.

Thus, it has been determined that the technical options to be evaluated in this study include:

- Solar PV
  - Note that the Northlands Denesuline First Nation in Lac Brochet will be installing a 280 kW Solar PV system that has already been designed and fully funded for installation in 2017/2018. This has been modelled as a 300 kW Solar PV system in the HOMER Pro cases that are analysed in section 5.
- Wind turbines
- Li-Ion batteries
- ORC power generation
- Variable-speed diesel generation

Fixed-speed Diesel generation has also been included in this analysis, in order to provide a benchmark cost against the results of the other configurations that were evaluated.

SW60 used HOMER Pro v.3.8.6 to construct its study models. All technical options were incorporated into each of the three communities, with the goal of determining which combinations and sizes of each option were technically feasible and then calculating their associate economics within each community.

HOMER Pro utilizes a levelized costing methodology to determine the rank order of proposed system configurations. This is essentially a Net Present Cost (NPC) evaluation of all capital, fuel, variable and fixed O&M, and a final negative cost for the salvage value of the investment. This represents the typical approach to determining the best option for addressing the objective, which results in the least-cost option to serve the electricity load. The metric HOMER Pro derives is called the LCOE (Levelized Cost of Electricity), which represents the discounted present value of all costs, divided by the discounted volume of energy generated. It should be noted that an approach to exclude capital costs and treat them as sunk costs (usually a policy decision) is an alternate method for determining the best option of new energy sources. In this case, electrical generation technologies with low operating costs are favoured over others that have higher operating costs such as fuel purchases.

INAC has also requested that SW60 provide an evaluation that does not include capital and capital replacement costs, but only annual fuel and O&M costs. In the current Manitoba Hydro diesel electric generation system, as mandated by the Manitoba Public Utilities Board (PUB) only these costs are currently borne by the local community. Since HOMER Pro attempts to seek out the least-cost system configuration, when capital and replacement costs are cancelled, HOMER Pro will attempt to maximize the capacity of all generation resources having low or zero variable costs. This mayl result in a significantly different system configuration than HOMER Pro proposes under a full capital costing evaluation.

Accordingly, SW60 has done the electric resource option evaluation both ways, with related discussion following the sub-sections where each approach is presented below.

4.2 Global Parameters for the Model

HOMER Pro seeks to optimize the system configuration by simulating all possible combinations to determine which of these are the feasible cases to meet current load and a stipulated reserve requirement (20% in these cases). The reserve requirement is a safety margin that ensures that there is sufficient power generation capability online to address load spikes. However, instead of utilizing a larger reserve margin in the remote communities, it may be possible to use load shifting when the peak hits a critical level to automatically trip off all the electric hot water tanks (of which there are over 100, each rated at least 4.5 kW each). Options such as this should be studied further in the future proposed feasibility study, and have not been modelled in this high-level pre-feasibility analysis.

In order to facilitate the speed of processing for many possible combinations of generation components and their sizes, HOMER Pro performs simulations on a single year basis, assuming no annual changes in weather or load profiles. To take into consideration the time value of costs, HOMER Pro extrapolates annual simulated results for as many years as programmed within the model, and discounts these costs back to the present value.

HOMER Pro assumes that all costs are unchanged in real terms, although it is possible to perform a multi-year run to reflect time-changing effects such as real cost escalation, equipment deterioration, and load growth. However, optimization is not possible in a multi-year run, so the system configuration must first be determined in an annual run and equipment sizes must be locked-down by the modeler.

The following are the primary global parameters that HOMER Pro uses in the context of how it performs its simulations:

- Discount rate used
    - 5.88% real (8% nominal cost of capital, less 2% inflation: (1+8%)/(1+2%)-1)).
    - This is the same discount rate used by Manitoba Hydro and recommended by the Treasury Board of Canada.
    - Since the general intent of the economic evaluation of various technology configurations in this report was to rank-order and thus compare the options, changing the discount rate would not change the rank-order of the options and thus only a single discount rate was used.
- Reserve Margin
    - 20% reserve is ensured to be available in the current time-step (one hour was used).
    - HOMER Pro can accommodate time steps as low as one minute. One hour time steps are adequate for a pre-feasibility study.
    - This is about twice the reserve margin used in highly interconnected grids and offers the additional safety needed for a small grid to meet sudden load changes.
- Wood Resource cost
    - Costs for wood, transport, and chipping were provided by INAC, which were derived from University of Manitoba research, Manitoba Sustainable Development - Forestry Branch, MIT, and local wood harvesting and transportation company consultations. An average cost at the community was taken between the range of high and lower estimates, with an average cost of $137.37/tonne used in HOMER Pro.
- Diesel fuel cost for Variable-Speed Generators
    - Manitoba Hydro produces a Diesel fuel price forecast that would be used for projecting fuel costs for each of their isolated generation facilities in the three communities. These costs are given in 2015 CAD dollars, and are then inflated to 2017 CAD dollars using the Manitoba CPI figures provided by Manitoba Hydro within the forecast document.
    - The latest forecast is dated July 2016, and forms the basis for the price used in the HOMER model for each location.

- Note that this latest diesel fuel forecast is 30% lower than the Manitoba Hydro's 2014 diesel fuel price forecast, which needs to be kept in mind when comparing the study's results to those of prior studies completed in 2014.
- Additional costs of 2.3 cents per litre to account for a GHG tax of $10.00/tonne of GHG and future remediation costs of 30 cents per litre have been added to the 2016 diesel forecast price derived by Manitoba Hydro.
- This results in fuel costs at Lac Brochet: $1.2441 per litre; Brochet: $1.1331 per litre; Tadoule Lake: $1.2701 per litre

4.3 Community Load Data

SW60 developed a separate model for each community to reflect their unique electricity load patterns, and in the case of Lac Brochet, to incorporate the expected divergence from historical patterns owing to the construction of the new health centre, aerated sewage lagoon, biomass district heating pumps and geothermal district heating pumps that will soon be there.

Community annual loads were derived by averaging the hourly loads reported by Manitoba Hydro for the period between January 01, 2013 and December 31, 2016. Where anomalies were identified in individual annual datasets, they were averaged out.

The following figures show the adjusted load data for the four years. The hourly loads are on the Y-axis in kW, and the X-axis represents the hour number beginning in the first hour of Jan. 01, 2013. In this data set the load is flat in Lac Brochet and decreasing in Brochet and Tadoule Lake. Load growth appears non-existent and warrants more investigation. It is thought that some electric heaters are used as the winter peak load correlates well to the heating degree days (more load on cold days). This should not be the case with oil heat, if the homes were heated with oil alone. In the case that biomass or geothermal heat is realized in these communities, then it is likely that the electric heaters will disappear and the winter peak load could be reduced.

There is more rationale to assume zero load growth in the remote communities. Two recent DSM Reports on these communities, one from Alex Fleming of Demand Side Energy Consultants and another from Gio Robson of Prairie House Performance suggests that 20 to 25% load reductions are possible. The electric hot water tanks in these communities represent a substantial portion of the electric load. If a full biomass district heating or ORC district heating is realized in these communities then the electric hot water tanks can be replaced with district energy sourced hot water tanks. The existing fuel oil furnaces will also be replaced with district heating. It should be noted that during the recent DSM audit, that 100% of the sampled houses had electric dryers and these would all be replaced with heat pump dryers or biomass water loop dryers when the district heating system is in place. This together with DSM measures could likely ensure zero load growth for many years (25 years in SW60 assumption).

The renewable energy systems that would be employed in the remote communities would be part of a smart grid which is an operational scenario involving smart meters, smart controllers and communications, energy storage, renewable energy resources, energy efficiency and smart appliances. This would allow the control of the production and distribution of more reliable electricity with more resilience and fewer voltage and current spikes and less harmonics.

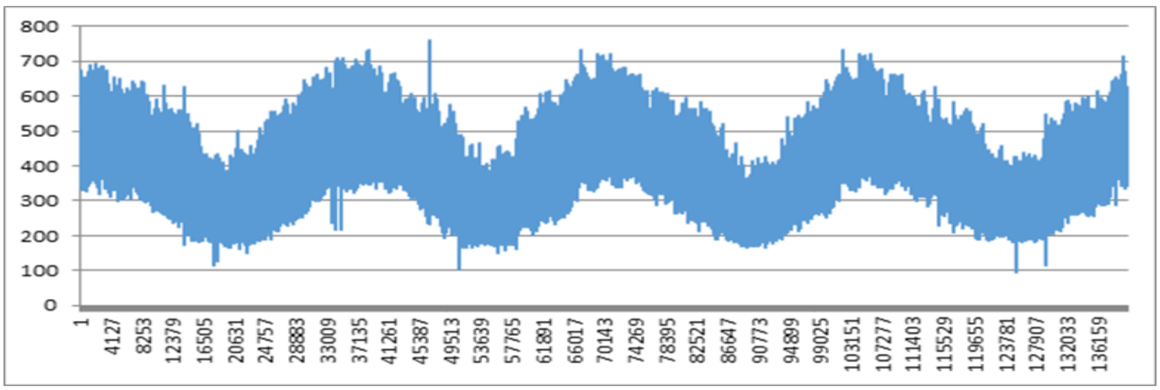

Figure 5: Lac Brochet Historical Hourly Load (2013-16)

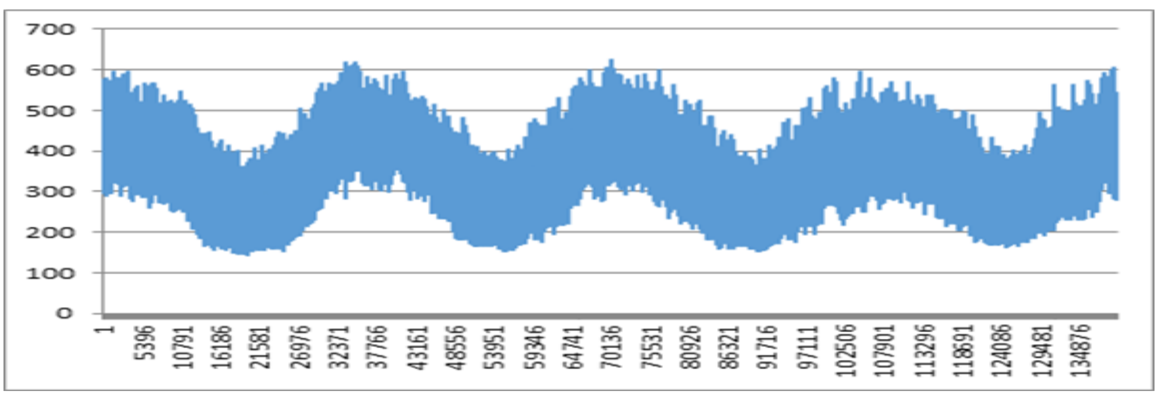

Figure 6: Brochet Historical Hourly Load (2013-16)

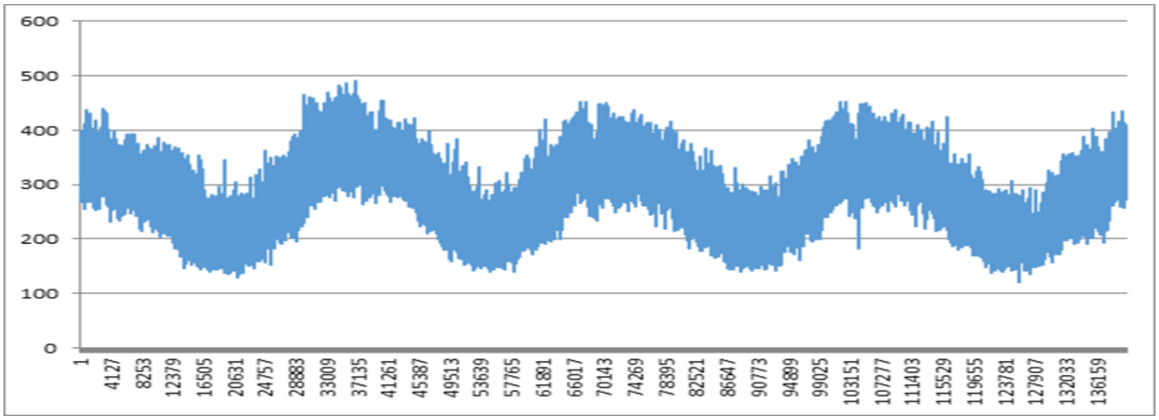

Figure 7: Tadoule Lake Historical Hourly Load (2013-16)

HOMER Pro processes the four years of data for each community, and establishes a typical year's load profile. The following figure displays the results for Lac Brochet, as an example.

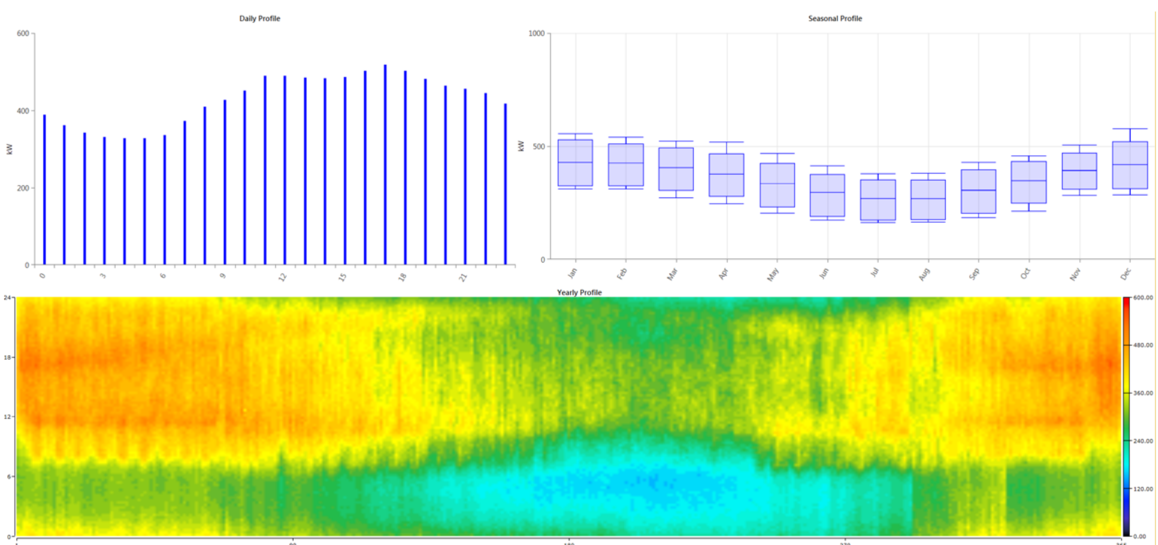

Figure 8: Lac Brochet Load Profile

The top-left component in Figure is the average hourly load during a given day for Lac Brochet. The load is on the Y-axis in kW, and the X-axis represents the hour during the day. The boxplot on the top right is the monthly range of loads, with the months on the X-axis.

The bottom of Figure 8 is a heat map which displays both the hourly and seasonal patterns in one place. Each day's specific hourly load is represented by one thin vertical strip moving across the X-axis, and the seasonal pattern can be discerned by the changes in colour. The colour legend is on the right, with blue being low load, and growing to red with higher loads. The load profiles for the other communities are similar, except for having lower loads on the X-axis, as evidenced in the earlier historical load figures.

4.4 Weather Data

Weather data for each community was drawn from two different web sources on the Government of Canada web sites. Wind speeds are found on Environment Canada's Homogenized Surface Wind Speed Data page, and monthly average solar data was taken from NRCan's Photovoltaic and Solar Resource Maps page. Wind speed data collected at a 10m height was available for The Pas, and this was assumed appropriate for Lac Brochet and Brochet and it was elevated to a 50 m hub height in HOMER Pro. Tadoule Lake wind speed data was collected and cleansed by Marc Arbez (Wind Power Consultant) at a 20m height, and this was used and elevated to a 50 m hub height in HOMER Pro. Marc Arbez also submitted his wind "Development of a Wind-Energy Resource Assessment Strategy for Manitoba's Off-Grid First Nations Report" as part of the overall Community Energy Plan for the Manitoba Remote Communities.

The weather data used by HOMER Pro includes the wind speed (m/sec) at the assigned hub height above ground (50 m in our case) and for solar, Global Horizontal Incidence (GHI) at ground level. When the wind data is collected at a different height, HOMER will apply a conversion procedure to bring the input numbers to the target height.

GHI is a measure of all direct and indirect light that is available to a horizontal surface that the location, and is measured in kW/m^2 per day. The following Figures for Tadoule Lake illustrate the weather data that is similar for the other two communities.

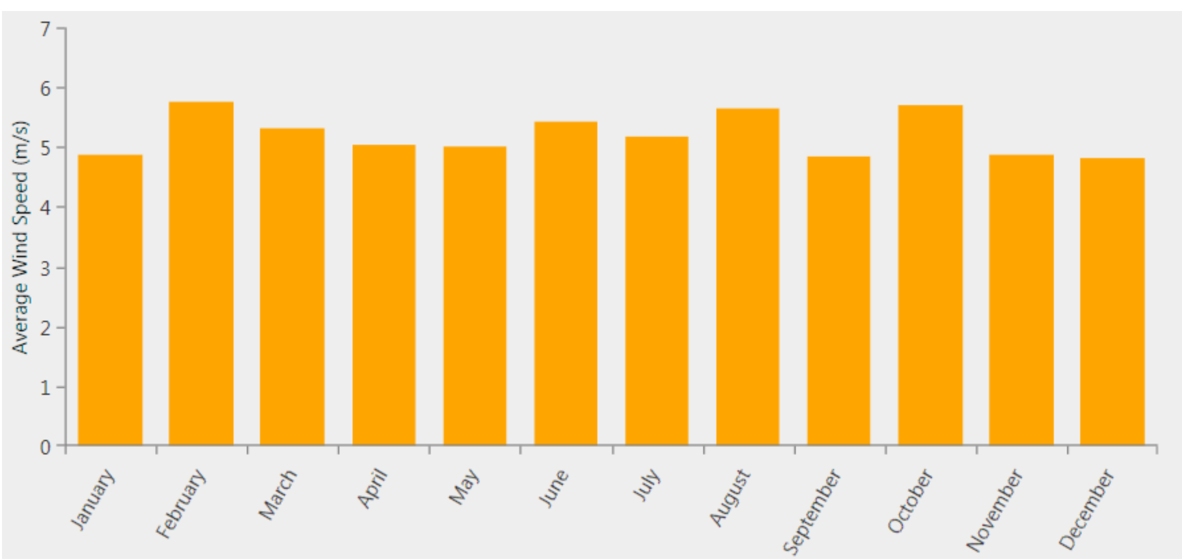

Figure 9: Tadoule Lake Wind Data at 50 m Height

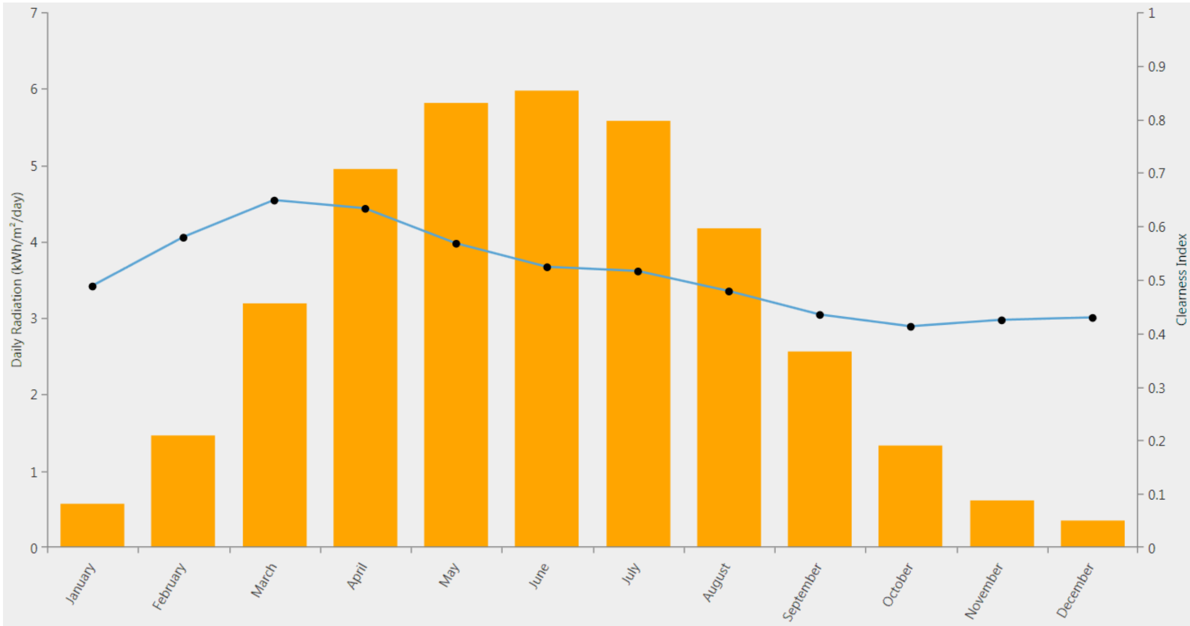

Figure 10: Tadoule Lake GHI Data

4.5 Indicative Electricity Generation Components Selected

To provide the needed power generation, the following equipment were selected:

- Solar PV
  - Canadian Solar manufacturer, model All-Black CS6K-290MS
  - Nominal rating: 290 W per panel
  - Tilt-angle set at 50°
- Wind turbine
  - Northern Power Systems manufacturer, model NPS100C-21
  - Nominal rating: 100 kW each
  - A 50 m tilt-up tower was assumed available from another manufacturer
- ORC generator
  - HOMER Pro-supplied generic biogas generator was used to model the ORC
  - The biogas generator model was modified to reflect capacity and efficiencies of Turboden 600 kW or 280 kW units as used in the studies.

- Variable-speed Diesel generator
    - Innovus manufacturer, model VSG600
    - Nominal rating: 590 kW
- Battery
    - Tesla manufacturer, model Powerpack 2
    - Nominal rating: 210 kWh
    - Expected life increased to 20 years to reflect newer similar alternatives from other manufacturers

All but the ORC generator was already in HOMER Pro's database of equipment, and all technical and performance specifications therein were unmodified except the Tesla Powerpack 2 cycle life was set to 20 years. Installed costs, maintenance scheduling, and costing for all components were estimated by SW60.

4.6 Selected Configurations Evaluated

The following cases were evaluated in order to allow HOMER Pro to determine the optimal balance of sizes that minimize the LCOE for each case:

1. ORC, solar PV, battery
2. ORC, Variable-Speed Diesel Generator (VSDG)
3. ORC, PV, wind turbine, battery
4. VSDG, PV, wind, battery
5. ORC, wind, battery
6. ORC, VSDG, PV, battery
7. ORC only
8. VSDG only
9. Typical Fixed-speed Diesel Generator (FSG) only – for reference

Some components may be automatically sized for optimally minimizing LCOE by HOMER Pro, whereas others have a fixed size relating to the manufacturer or standard usage. The components that have pre-determined sizes include the ORC units (standard sizes determined from Turboden manufacturer's catalogue) and the diesel generators (determined by Innovus Power the manufacturer for VSG, along with typical sizes for standard FSG units). The PV field is assumed to be infinitely sizeable, in sub-1 kW increments, and the selected wind turbines are in 100 kW increments, with the number of wind turbines selected by HOMER Pro. Batteries are utilized in increments of 210 kWh modules.

When optimizing, HOMER Pro selects the capacity for each of PV, wind, and batteries to suit the load and reserve required in the current time step. The ranging on these sizes is restricted to be within a range set by the modeler. In this way, one can allow technologies such PV to be automatically sized by HOMER Pro during a run, but constrained to be less than 2,000 kW, as one such example.

An important metric for any generation technology is its capacity factor. The capacity factor of a generation technology is the ratio of an actual electrical energy output of a generating device over a specified period of time to the maximum possible electrical energy output over the same amount of time. In this report, HOMER Pro is calculating annual average capacity factors, which can if desired also be calculated weekly, monthly, etc. A high annual capacity factor (> 50%) is desirable as it means the generating asset is very well used instead of sitting idle much of the time.

The term capex refers to the installed cost of the generation asset. It typically includes the equipment cost (generator and balance of plant), labour for installation, grid connection, land, security and project management. The term opex refers to the cost of the operation and maintenance cost of the generating asset. It includes fixed and variable costs. Fixed costs typically include insurance, taxes and legal fees. Variable costs typically include fuel costs, labour costs and consumables like oil filters etc.

5 ANALYSIS OF SIMULATION RUNS

Initially, the various cases were run with full estimated capital costs included in the calculation of the LCOE. A summary of results is presented below, split into three segments to fit standard page width.

Analysis and discussion begins with Lac Brochet.

5.1 Lac Brochet

		Lac Brochet											
		1. ORC, Solar PV, Battery				2. ORC, Variable Speed Diesel Gen				3. ORC, Solar PV, Wind, Battery			
All costs in 2017 CAD		Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor
Organic Rankine Cycle		1,200	4,373.1	91.74%	41.6%	880	4,691.5	98.44%	60.9%	1,200	4,308.4	90.38%	41.0%
Variable Speed Diesel		0	0.0	0.00%		590	74.5	1.56%	1.4%	0	0.0	0.00%	
Solar PV		300	393.8	8.26%	15.0%	0	0.0	0.00%		250	328.2	6.88%	15.0%
Wind Turbine		0	0.0	0.00%		0	0.0	0.00%		100	130.2	2.73%	14.9%
Batteries	kWh	420				0				420			
Fixed Speed Diesel		0	0	0.00%		0	0	0.00%		0	0	0.00%	
Total	MWh		4,766.9	100.00%			4,766.0	100.00%			4,766.7	100.00%	
Total Capex	$, million	$ 18.0				$ 14.0				$ 18.4			
Annual Opex	$, million	$ 1.4				$ 1.6				$ 1.4			
LCOE	$/kWh	$ 0.589				$ 0.554				$ 0.592			
Annual Avg Operating Cost	$/kWh	$ 0.296				$ 0.327				$ 0.293			
Fuel and Heat													
Wood for ORC	tonnes/yr	2,965				3,193				2,921			
Diesel	L/yr	0				19,230				0			
Total Thermal Available from ORC	MWh/yr	17,006				18,245				16,755			
Heat Equivalent in Heating Fuel Oil	L/yr	1,586,093				1,701,566				1,562,621			
Actual Heating Fuel Oil used	L/yr	756,758				756,758				756,758			
Value of F.O. Saved (using lesser of above)	$/yr	$ 941,483				$ 941,483				$ 941,483			
Relevent Figures													
Wood Cost	per tonne	$ 137				$ 137				$ 137			
Diesel Cost	per Litre	$ 1.244				$ 1.244				$ 1.244			
Annual Peak Load	kW	867				867				867			
Annual Load Served	MWh/yr	4,765.6				4,765.6				4,765.6			

Lac Brochet

All costs in 2017 CAD

		4. VSG, Solar PV, Wind, Battery				5. ORC, Wind, Battery				6. ORC, VSG, Solar PV, Battery			
		Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor
Organic Rankine Cycle		0	0.0	0.00%		1,200	4,512.9	94.55%	42.9%	600	4,181.0	87.61%	79.5%
Variable Speed Diesel		1180	4,182.7	87.67%	40.5%	0	0.0	0.00%		590	197.5	4.14%	3.8%
Solar PV		250	328.2	6.88%	15.0%	0	0.0	0.00%		300	393.8	8.25%	15.0%
Wind Turbine		200	260.4	5.46%	14.9%	200	260.4	5.45%	14.9%	0	0.0	0.00%	
Batteries	kWh	630				630				630			
Fixed Speed Diesel		0	0	0.00%		0	0	0.00%		0	0	0.00%	
Total	MWh		4,771.2	100.00%			4,773.3	100.00%			4,772.2	100.00%	

		4. VSG, Solar PV, Wind, Battery	5. ORC, Wind, Battery	6. ORC, VSG, Solar PV, Battery
Total Capex	$, million	$ 12.1	$ 17.6	$ 14.7
Annual Opex	$, million	$ 2.8	$ 1.4	$ 1.5
LCOE	$/kWh	$ 0.778	$ 0.574	$ 0.552
Annual Avg Operating Cost	$/kWh	$ 0.582	$ 0.288	$ 0.312

Fuel and Heat		4. VSG, Solar PV, Wind, Battery	5. ORC, Wind, Battery	6. ORC, VSG, Solar PV, Battery
Wood for ORC	tonnes/yr	0	3,051	2,823
Diesel	L/yr	1,060,193	0	51,066
Total Thermal Available from ORC	MWh/yr	0	17,550	16,259
Heat Equivalent in Heating Fuel Oil	L/yr	0	1,636,807	1,516,416
Actual Heating Fuel Oil used	L/yr	756,758	756,758	756,758
Value of F.O. Saved (using lesser of above)	$/yr	$ 0	$ 941,483	$ 941,483

Relevent Figures		4. VSG, Solar PV, Wind, Battery	5. ORC, Wind, Battery	6. ORC, VSG, Solar PV, Battery
Wood Cost	per tonne	$ 137	$ 137	$ 137
Diesel Cost	per Litre	$ 1.244	$ 1.244	$ 1.244
Annual Peak Load	kW	867	867	867
Annual Load Served	MWh/yr	4,765.6	4,765.6	4,765.6

Lac Brochet

All costs in 2017 CAD		7. ORC only				8. VSG only				9. FSG only			
		Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor
Organic Rankine Cycle		1,480	4,766.0	100.00%	36.8%	0	0.0	0.00%		0	0.0	0.00%	
Variable Speed Diesel		0	0.0	0.00%		1770	4,766.1	100.00%	30.7%	0	0.0	0.00%	
Solar PV		0	0.0	0.00%		0	0.0	0.00%		0	0.0	0.00%	
Wind Turbine		0	0.0	0.00%		0	0.0	0.00%		0	0.0	0.00%	
Batteries	kWh	0				0				0			
Fixed Speed Diesel		0	0	0.00%		0	0	0.00%		1600	4,765.6	100.00%	34.0%
Total	MWh		4,766.0	100.00%			4,766.1	100.00%			4,765.6	100.00%	
Total Capex	$, million	$ 17.8				$ 10.2				$ 8.8			
Annual Opex	$, million	$ 1.5				$ 3.4				$ 4.7			
LCOE	$/kWh	$ 0.604				$ 0.879				$ 1.133			
Annual Avg Operating Cost	$/kWh	$ 0.315				$ 0.714				$ 0.990			
Fuel and Heat													
Wood for ORC	tonnes/yr	3,246				0				0			
Diesel	L/yr	0				1,213,204				1,400,106			
Total Thermal Available from ORC	MWh/yr	18,534				0				0			
Heat Equivalent in Heating Fuel Oil	L/yr	1,728,597				0				0			
Actual Heating Fuel Oil used	L/yr	756,758				756,758				756,758			
Value of F.O. Saved (using lesser of above)	$/yr	$ 941,483				$ 0				$ 0			
Relevent Figures													
Wood Cost	per tonne	$ 137				$ 137				$ 137			
Diesel Cost	per Litre	$ 1.244				$ 1.244				$ 1.244			
Annual Peak Load	kW	867				867				867			
Annual Load Served	MWh/yr	4,765.6				4,765.6				4,765.6			

General Observations

In Case 1, ORC, PV, and batteries are selected as the basis for configuring a system that will meet the Lac Brochet load. HOMER Pro suggests that in this mix, the majority of the energy (92%) should be provided by ORC, as this leads to the least-cost production of electricity, with solar PV providing just 8% of the energy. This reflects the high capital cost of solar PV relative to the amount of energy collected, the costs of the requisite battery capacity, and the difference in the capacity factor of the two technologies.

Although there is relatively little PV capacity in this configuration, which is typically of limited contribution during winter when load is highest, the battery capacity is contributing by providing needed backup reserves when one of the two ORC generators is down for scheduled or unscheduled outages during the peak load season. This is shown by the significant drawdowns in the batteries’ state of charge in the figure below.

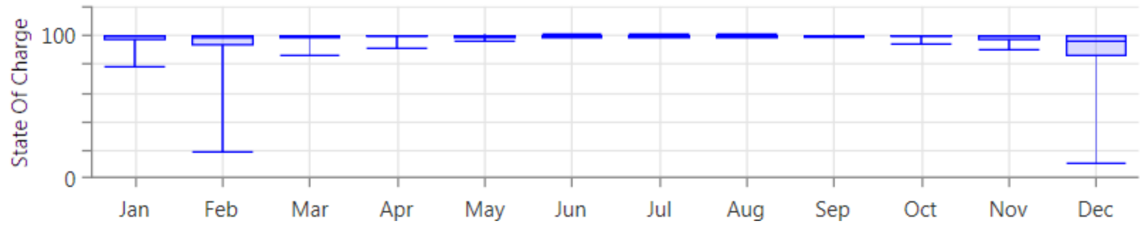

Figure 11: Lac Brochet - Case 1 - Battery state of charge

In Case 2 (ORC and VSG), nearly all of the energy is provided by the ORC generators (1@600 kW and 1@280 kW). Although generally we used a standard 600 kW ORC size, in this case two ORC sizes were selected (600 and 280 kW) to avoid skewing the LCOE economic comparisons overtly with too much overcapacity in one technology relative to the other. The minimum size of VSG modeled is 590 kW and having two 600 kW ORCs and one 590 kW VSG would be an investment in overcapacity. Consequently, VSG is the only available backup for either ORC unit, as there is no other power source available in this configuration.

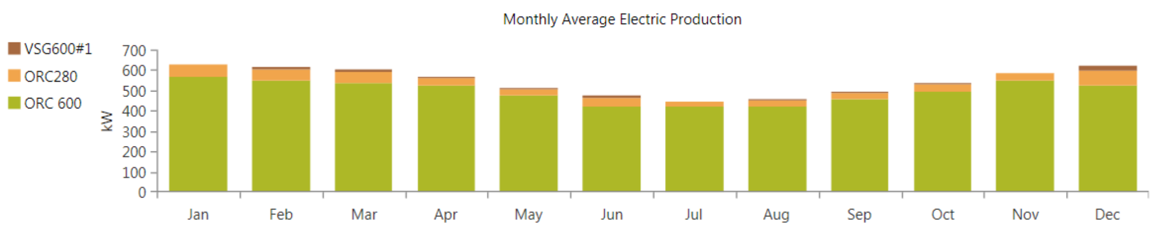

Figure 12: Lac Brochet - Case 2 - Minimal use of VSG, as backup

In Case 3 (ORC, PV, wind, battery) ORC is again the primary energy supplier, with the other renewables providing energy when weather permits and also when one ORC is down for maintenance. There is a significant battery capacity needed to store the intermittent energy from wind and solar to follow the community load when one ORC is down. This case has the lowest operating cost of the three so far, although only marginally better than Case 1, where more PV is provided and no wind turbines. That being the case, having both solar and wind resources available provides better diversity of supply, especially since wind power is available day and night, summer and winter.

In Case 4 (VSG, PV, wind, battery) the VSG is the primary energy supplier and the renewables are providing energy when one VSG is down for maintenance. There is a relatively large battery capacity needed to store the intermittent energy from wind and solar to follow the community load when one VSG is down. Annual average operating costs and overall levelized costs in this case are considerably higher than in all prior cases. Although VSG is less costly then ORC, the levelized cost is higher because of the relatively high fuel operating cost.

It can be noted that although VSG generates net GHGs and ORC does not, this VSG technology in diesel generation is 17.5% more efficient than FSG, and therefore produces less GHGs than the FSG discussed in Case 9.

In Case 5 (ORC, wind, battery) there is again a significant battery component to assist in meeting the load when one of the two 600 kW ORC units is down for maintenance. Since there is not much margin for this community's load with only 1,200 kW ORC capacity, any outage will require sufficient battery capacity to bridge the relatively low capability of the two 100 kW wind turbines. It might have been possible to have one less battery if wind power capacity was increased, but HOMER's optimization found otherwise.

In Case 6 (VSG, ORC, PV, battery), there is a mix of both diesel and ORC-renewable generation. ORC still dominates in the share of total energy supplied, indicating its relative operating cost advantage even though its initial capital cost is higher. Solar makes up 8% of production, with VSG used for backup and to assist solar PV for battery charging.

The next three cases are presented as reference for comparing the pure costs of each major non-intermittent technology, and are offered as "business-as-usual" options for supplying the communities.

In Case 7 the ORC-only configuration is the highest capital cost technology of the non-intermittent options by far. However, its levelized and average annual operating costs are the lowest within the set of all three fully dispatchable technologies.

In comparing the LCOE across the cases, which includes initial and replacement capital costs, the configurations with ORC have the lowest levelized costs when VSG is also part of the mix. The lowest average operating costs occur with ORC when intermittent power and batteries are present, however, the total capital cost is also highest.

In considering the ORC and intermittent systems, items including capex, LCOE, and operating costs are all approximately the same. On balance, it may be decided that a policy decision is the final determinant, especially if environmental and community acceptance are particular goals. The best technical configuration would also be the one with the greatest diversity of renewable supply, represented by Case 3 where both wind and solar power are present. Case 6 has diversity but it's not 100% renewable, and does not garner as much heating fuel oil credits as does Case 3, for example. The lowest marginal operating cost is with Case 3, while offering the most diverse energy source outside of use of diesel, and this makes it a primary contender for both the best policy and economic choice.

The Cases where ORC and VSG are present (2 and 6), have almost the same capex and opex, but case 6 provides for additional renewable options that allow for extra peak capacity and less reliance on ORC and its associated feedstocks. These two cases have the lowest LCOE by a small margin, but have somewhat higher operating costs than the cases where ORC is used instead of VSG. The comparative economics moderately favour biomass-fueled ORC over diesel VSG.

This commentary for Lac Brochet's tables of results is indicative of the general contents in the remaining two sets of tables, for Brochet and Tadoule Lake. There is enough in common between all three sites to be able to generalize the following points:

- Incorporating the cost of capital into the method for selecting an optimal system configuration tends to preclude much capacity in intermittent energy sources. This is a function of the significant capital cost relative to the requirement to provide electricity when it is needed.
- Solar PV can offer a good source of electricity, however, the further north the location, the greater the divergence between when it is needed (winter) and when it is most available (summer).
- In order to better enable solar PV and wind turbines to meet electricity demand, even on a daily basis, a significant further investment in battery capacity is inevitable to capture this intermittently supplied energy.
- Variable-speed diesel generation is quite cost-effective, especially compared to fixed-speed diesel generation.

ORC generation can offer the side benefit of significant amounts of waste heat from the combustors. HOMER Pro's economic evaluation of technical options does not include the value of this waste heat in potentially providing an offset in the consumption of diesel fuel for central heating. To help indicate the potential benefit in recoverable waste heat from the ORC combustor, the tables provide additional estimates for the value of displaced heating fuel oil if this waste heat is used for district heating within the communities. The waste heat from the ORC plant offers significant parallel benefits to the community by displacing the cost of fuel oil and reducing or eliminating its deleterious environmental impact and indoor air quality health impacts. **This aspect of implementing a biomass power plant to replace the reliance on diesel fuel should be considered a strong decision point in the final determination of power options.**

Where intermittent generation is present, a significant battery capacity must also be available, especially for solar. During the summer, there is a relatively large amount of solar energy available, but the electricity load is at its lowest and the excess solar energy cannot be stored very long. Wind power is somewhat less a contributor to this effect because it can charge the battery at any time during the day and across all seasons. This connection between cost per kW of intermittent power and the necessary battery capacity tends to make all intermittent sources more expensive from an initial capital outlay perspective than would be expected in other regions.

Incorporating VSG with ORC in the configuration provides the most complete capability to meet the risk of outages. To have both ORC and VSG means both technologies can be relied upon for base load and load following capabilities, and each is not reliant on the other. This may be an issue if there is any near-term concern in using ORC technology. However there remain several fixed-speed diesel generators in Manitoba Hydro's plant that may have their operating life extended for several more years, and accumulated experience with the ORC plant should lead to comfort with regard to its reliability and economic operation. Therefore, the ORC VSG combination need not be pursued as the ORC FSG would be occurring by default anyway.

5.2 Brochet

		Brochet											
		1. ORC, Solar PV, Battery				2. ORC, Variable Speed Diesel Gen				3. ORC, Solar PV, Wind, Battery			
All costs in 2017 CAD		Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor
Organic Rankine Cycle		1,200	3,186.0	90.41%	30.3%	600	3,415.8	96.93%	65.0%	1,200	3,055.8	86.72%	29.1%
Variable Speed Diesel		0	0.0	0.00%		590	108.2	3.07%	2.1%	0	0.0	0.00%	
Solar PV		250	337.8	9.59%	15.4%	0	0.0	0.00%		250	337.8	9.59%	15.4%
Wind Turbine		0	0.0	0.00%		0	0.0	0.00%		100	130.2	3.69%	14.9%
Batteries	kWh	210				0				210			
Fixed Speed Diesel		0	0	0.00%		0	0	0.00%		0	0	0.00%	
Total	MWh		3,523.8	100.00%			3,524.0	100.00%			3,523.8	100.00%	
Total Capex	$, million	$ 17.0				$ 10.6				$ 17.7			
Annual Opex	$, million	$ 1.1				$ 1.1				$ 1.0			
LCOE	$/kWh	$ 0.672				$ 0.550				$ 0.684			
Annual Avg Operating Cost	$/kWh	$ 0.298				$ 0.318				$ 0.295			
Fuel and Heat													
Wood for ORC	tonnes/yr	2,174				2,321				2,088			
Diesel	L/yr	0				27,837				0			
Total Thermal Available from ORC	MWh/yr	12,390				13,284				11,884			
Heat Equivalent in Heating Fuel Oil	L/yr	1,155,544				1,238,886				1,108,317			
Actual Heating Fuel Oil used	L/yr	765,925				765,925				765,925			
Value of F.O. Saved (using lesser of above)	$/yr	$ 949,747				$ 949,747				$ 949,747			
Relevent Figures													
Wood Cost	per tonne	$ 137				$ 137				$ 137			
Diesel Cost	per Litre	$ 1.240				$ 1.240				$ 1.240			
Annual Peak Load	kW	580				580				580			
Annual Load Served	MWh/yr	3,522.7				3,522.7				3,522.7			

Brochet

All costs in 2017 CAD		4. VSG, Solar PV, Wind, Battery				5. ORC, Wind, Battery				6. ORC, VSG, Solar PV, Battery			
		Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor
Organic Rankine Cycle		0	0.0	0.00%		1,200	3,393.8	96.31%	32.3%	600	3,096.2	87.86%	58.9%
Variable Speed Diesel		1180	3,055.9	86.72%	29.6%	0	0.0	0.00%		590	89.9	2.55%	1.7%
Solar PV		250	337.8	9.59%	15.4%	0	0.0	0.00%		250	337.8	9.59%	15.4%
Wind Turbine		100	130.2	3.69%	14.9%	100	130.2	3.69%	14.9%	0	0.0	0.00%	
Batteries	kWh	210				210				210			
Fixed Speed Diesel		0	0	0.00%		0	0	0.00%		0	0	0.00%	
Total	MWh		3,523.9	100.00%			3,523.9	100.00%			3,524.0	100.00%	
Total Capex	$, million	$ 10.1				$ 15.7				$ 13.2			
Annual Opex	$, million	$ 2.2				$ 1.0				$ 1.1			
LCOE	$/kWh	$ 0.858				$ 0.641				$ 0.603			
Annual Avg Operating Cost	$/kWh	$ 0.635				$ 0.297				$ 0.313			
Fuel and Heat													
Wood for ORC	tonnes/yr	0				2,310				2,112			
Diesel	L/yr	778,223				0				22,930			
Total Thermal Available from ORC	MWh/yr	0				13,198				12,041			
Heat Equivalent in Heating Fuel Oil	L/yr	0				1,230,898				1,122,971			
Actual Heating Fuel Oil used	L/yr	765,925				765,925				765,925			
Value of F.O. Saved (using lesser of above)	$/yr	$ 0				$ 949,747				$ 949,747			
Relevent Figures													
Wood Cost	per tonne	$ 137				$ 137				$ 137			
Diesel Cost	per Litre	$ 1.240				$ 1.240				$ 1.240			
Annual Peak Load	kW	580				580				580			
Annual Load Served	MWh/yr	3,522.7				3,522.7				3,522.7			

Brochet

All costs in 2017 CAD		7. ORC only				8. VSG only				9. FSG only			
		Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor
Organic Rankine Cycle		1,200	3,524.0	100.00%	33.5%	0	0.0	0.00%		0	0.0	0.00%	
Variable Speed Diesel		0	0.0	0.00%		1180	3,524.2	100.00%	34.1%	0	0.0	0.00%	
Solar PV		0	0.0	0.00%		0	0.0	0.00%		0	0.0	0.00%	
Wind Turbine		0	0.0	0.00%		0	0.0	0.00%		0	0.0	0.00%	
Batteries	kWh	0				0				0			
Fixed Speed Diesel		0	0	0.00%		0	0	0.00%		1200	3,523.9	100.00%	33.5%
Total	MWh		3,524.0	100.00%			3,524.2	100.00%			3,523.9	100.00%	
Total Capex	$, million	$ 14.4				$ 6.8				$ 6.6			
Annual Opex	$, million	$ 1.1				$ 2.3				$ 3.5			
LCOE	$/kWh	$ 0.616				$ 0.804				$ 1.130			
Annual Avg Operating Cost	$/kWh	$ 0.300				$ 0.655				$ 0.985			
Fuel and Heat													
Wood for ORC	tonnes/yr	2,397				0				0			
Diesel	L/yr	0				895,563				1,041,844			
Total Thermal Available from ORC	MWh/yr	13,704				0				0			
Heat Equivalent in Heating Fuel Oil	L/yr	1,278,127				0				0			
Actual Heating Fuel Oil used	L/yr	765,925				765,925				765,925			
Value of F.O. Saved (using lesser of above)	$/yr	$ 949,747				$ 0				$ 0			
Relevent Figures													
Wood Cost	per tonne	$ 137				$ 137				$ 137			
Diesel Cost	per Litre	$ 1.240				$ 1.240				$ 1.240			
Annual Peak Load	kW	580				580				580			
Annual Load Served	MWh/yr	3,522.7				3,522.7				3,522.7			

General Observations

In Case 1, ORC, PV, and batteries are selected as the basis for configuring a system that will meet the Brochet load. Similar to Lac Brochet, HOMER Pro suggests that in this mix, the majority of the energy (90%) should be provided by ORC, as this leads to the least-cost production of electricity, with solar PV providing 10% of the energy. This again reflects the high capital cost of solar PV relative to the amount of energy obtained, the costs of the requisite battery capacity, and the difference in the capacity factor of the two technologies. This particular mix of technologies is among the higher initial capital cost systems having intermittent capacity, yet does not have a significant advantage over the others in terms of operating costs.

In Case 2 (ORC and VSG) once again, the bulk of energy is provided by the ORC generator, with VSG accounting for only 3%. VSG is used when necessary as an adjunct to ORC when it is down for maintenance, as there is no other power source available in this configuration.

In Case 3 (ORC, PV, wind, battery) ORC is again the primary energy supplier, with the other renewables providing energy when weather permits and also when one ORC is down for maintenance. In this case, solar provides slightly more energy than at Lac Brochet. Once again, this case has the lowest operating cost of the three thus far.

In Case 4 (VSG, PV, wind, battery) the VSG is the primary energy supplier and the renewables are again providing energy when conditions permit and when one VSG is down for maintenance. Similar to Lac Brochet, the LCOE and annual average operating costs are significantly higher in this case than in almost all other configurations with intermittent power.

In Case 5 (ORC, wind, battery) there is only a small battery component to assist in meeting the load when one of the two 600 kW ORC units is down for maintenance. Only 100 kW of wind have been recommended by HOMER Pro in this instance, and while the annual operating cost is among the lowest so far, the LCOE remains significantly higher than in Case 2 where less ORC capacity was modeled.

In Case 6 (VSG, ORC, PV, battery), there is a mix of both diesel and renewable generation. ORC still dominates in the share of total energy supplied, indicating its relative operating cost advantage, even though its initial capital cost is higher. The VSG is used to augment production, partially because HOMER Pro determined that it is more cost effective to limit the capital investment in ORC and make up the balance of capacity using renewables (primarily PV) and VSG.

The results of the next three reference cases essentially mirror the patterns observed for Lac Brochet.

Case 2 (ORC, VSG) has the best apparent economics for Brochet, given its second lowest capex, lowest LCOE, and on-par marginal operating cost. However, if a higher renewable penetration level is desired, along with a more diverse generation mix, Case 6 presents the next most attractive overall alternative. Again, as with the discussion of Lac Brochet, Government policy and community preferences may guide where the priorities lie. Case 3 has the lowest overall marginal operating cost, and a diversified renewable strategy offers the most flexibility in weather- and economic-related security of power supply. Weather-related security comes from no over-reliance on one element of the environment (sunny or windy days) and economic security comes from reducing exposure to the risk of oil cost increases. In this context, again the full mix of Case 3 offers potentially better future cost and environmental stability.

The final observations from Lac Brochet also generally apply here.

Another observation may be made for Brochet by comparing the LCOE for each case against that for Lac Brochet, in that they are all higher. This is generally the result of using the same fixed sizes of ORC and VSG for both Lac Brochet and Brochet analyses.

Lac Brochet has the largest load of the three. The minimum standard size for VSG units, as selected from the supplier with the variable-speed patent, is 590 kW nominal.

To avoid skewing the economic comparisons between cases, it was necessary to select a representative ORC size, and as such, 600 kW was used. For each community having a lower load than Lac Brochet, these sizes still represent what is available, and therefore must be selected within the model. Typically, this results in greater overcapacity for Brochet than for Lac Brochet, which increases the LCOE due to the fact that less energy is produced from the same capital investment. In this context, the marginal cost of operations is more representative of the actual economics of each case.

It may be possible to select ORC unit sizes more closely aligned to the community load, however, there are presently few options in VSG sizing.

5.3 Tadoule Lake

Tadoule Lake

All costs in 2017 CAD

		1. ORC, Solar PV, Battery				2. ORC, Variable Speed Diesel Gen				3. ORC, Solar PV, Wind, Battery			
		Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor
Organic Rankine Cycle		1,200	2,535.7	88.50%	24.1%	600	2,786.3	97.24%	53.0%	1,200	2,326.3	81.14%	22.1%
Variable Speed Diesel		0	0.0	0.00%		590	79.0	2.76%	1.5%	0	0.0	0.00%	
Solar PV		250	329.5	11.50%	15.0%	0	0.0	0.00%		250	329.5	11.49%	15.0%
Wind Turbine		0	0.0	0.00%		0	0.0	0.00%		100	211.1	7.36%	24.1%
Batteries	kWh	210				0				210			
Fixed Speed Diesel		0	0	0.00%		0	0	0.00%		0	0	0.00%	
Total	MWh		2,865.2	100.00%			2,865.3	100.00%			2,866.9	100.00%	

		1. ORC, Solar PV, Battery	2. ORC, Variable Speed Diesel Gen	3. ORC, Solar PV, Wind, Battery
Total Capex	$, million	$ 17.0	$ 10.6	$ 17.7
Annual Opex	$, million	$ 0.9	$ 1.0	$ 0.9
LCOE	$/kWh	$ 0.775	$ 0.618	$ 0.784
Annual Avg Operating Cost	$/kWh	$ 0.316	$ 0.332	$ 0.306
Fuel and Heat				
Wood for ORC	tonnes/yr	1,747	1,909	1,610
Diesel	L/yr	0	20,158	0
Total Thermal Available from ORC	MWh/yr	9,861	10,836	9,047
Heat Equivalent in Heating Fuel Oil	L/yr	919,680	1,010,581	843,750
Actual Heating Fuel Oil used	L/yr	525,150	525,150	525,150
Value of F.O. Saved (using lesser of above)	$/yr	$ 651,186	$ 651,186	$ 651,186
Relevent Figures				
Wood Cost	per tonne	$ 137	$ 137	$ 137
Diesel Cost	per Litre	$ 1.240	$ 1.240	$ 1.240
Annual Peak Load	kW	430	430	430
Annual Load Served	MWh/yr	2,865.4	2,865.4	2,865.4

Tadoule Lake

All costs in 2017 CAD		4. VSG, Solar PV, Wind, Battery				5. ORC, Wind, Battery				6. ORC, VSG, Solar PV, Battery			
		Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor
Organic Rankine Cycle		0	0.0	0.00%		1,200	2,654.1	92.63%	25.2%	600	2,465.5	86.05%	46.9%
Variable Speed Diesel		1180	1,939.3	66.82%	18.8%	0	0.0	0.00%		590	70.2	2.45%	1.4%
Solar PV		250	329.5	11.35%	15.0%	0	0.0	0.00%		250	329.5	11.50%	15.0%
Wind Turbine		300	633.3	21.82%	24.1%	100	211.1	7.37%	24.1%	0	0.0	0.00%	
Batteries	kWh	420				210				210			
Fixed Speed Diesel		0	0	0.00%		0	0	0.00%		0	0	0.00%	
Total	MWh		2,902.1	100.00%			2,865.2	100.00%			2,865.2	100.00%	

		4. VSG, Solar PV, Wind, Battery	5. ORC, Wind, Battery	6. ORC, VSG, Solar PV, Battery
Total Capex	$, million	$ 12.2	$ 15.7	$ 13.2
Annual Opex	$, million	$ 2.0	$ 0.9	$ 1.0
LCOE	$/kWh	$ 1.010	$ 0.729	$ 0.690
Annual Avg Operating Cost	$/kWh	$ 0.673	$ 0.307	$ 0.334

Fuel and Heat		4. VSG, Solar PV, Wind, Battery	5. ORC, Wind, Battery	6. ORC, VSG, Solar PV, Battery
Wood for ORC	tonnes/yr	0	1,824	1,698
Diesel	L/yr	498,953	0	17,957
Total Thermal Available from ORC	MWh/yr	0	10,321	9,588
Heat Equivalent in Heating Fuel Oil	L/yr	0	962,618	894,221
Actual Heating Fuel Oil used	L/yr	525,150	525,150	525,150
Value of F.O. Saved (using lesser of above)	$/yr	$ 0	$ 651,186	$ 651,186

Relevent Figures		4. VSG, Solar PV, Wind, Battery	5. ORC, Wind, Battery	6. ORC, VSG, Solar PV, Battery
Wood Cost	per tonne	$ 137	$ 137	$ 137
Diesel Cost	per Litre	$ 1.240	$ 1.240	$ 1.240
Annual Peak Load	kW	430	430	430
Annual Load Served	MWh/yr	2,865.4	2,865.4	2,865.4

Tadoule Lake

All costs in 2017 CAD		7. ORC only				8. VSG only				9. FSG only			
		Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor
Organic Rankine Cycle		1,200	2,865.3	100.00%	27.3%	0	0.0	0.00%		0	0.0	0.00%	
Variable Speed Diesel		0	0.0	0.00%		1180	2,865.3	100.00%	27.7%	0	0.0	0.00%	
Solar PV		0	0.0	0.00%		0	0.0	0.00%		0	0.0	0.00%	
Wind Turbine		0	0.0	0.00%		0	0.0	0.00%		0	0.0	0.00%	
Batteries	kWh	0				0				0			
Fixed Speed Diesel		0	0	0.00%		0	0	0.00%		1200	2,865.2	100.00%	27.3%
Total	MWh		2,865.3	100.00%			2,865.3	100.00%			2,865.2	100.00%	
Total Capex	$, million	$ 14.4				$ 6.8				$ 6.6			
Annual Opex	$, million	$ 0.9				$ 2.2				$ 2.9			
LCOE	$/kWh	$ 0.703				$ 0.946				$ 1.190			
Annual Avg Operating Cost	$/kWh	$ 0.314				$ 0.763				$ 1.011			
Fuel and Heat													
Wood for ORC	tonnes/yr	1,963				0				0			
Diesel	L/yr	0				730,677				845,392			
Total Thermal Available from ORC	MWh/yr	11,143				0				0			
Heat Equivalent in Heating Fuel Oil	L/yr	1,039,243				0				0			
Actual Heating Fuel Oil used	L/yr	525,150				525,150				525,150			
Value of F.O. Saved (using lesser of above)	$/yr	$ 651,186				$ 0				$ 0			
Relevent Figures													
Wood Cost	per tonne	$ 137				$ 137				$ 137			
Diesel Cost	per Litre	$ 1.240				$ 1.240				$ 1.240			
Annual Peak Load	kW	430				430				430			
Annual Load Served	MWh/yr	2,865.4				2,865.4				2,865.4			

General Observations

In Case 1, HOMER Pro again directs the majority of the energy (89%) to be provided by ORC (as this leads to the least-cost production of electricity), with solar PV providing 11% of the energy. As previously noted, this reflects the high capital cost of solar PV relative to the amount of energy obtained, the costs of the requisite battery capacity, and the difference in the capacity factor of the two technologies.

In Case 2 (ORC and VSG), nearly all of the energy is provided by the ORC generator. VSG is again used when necessary as an adjunct to ORC when it is down for maintenance, as there is no other power source available in this configuration.

In Case 3 (ORC, PV, wind, battery) ORC is again the primary energy supplier, with the other renewables providing energy when weather permits and also when one ORC is down for maintenance. Although this case has the lowest operating cost of the three so far, its LCOE is considerably higher than Case 2.

In Case 4 (VSG, PV, wind, battery) the VSG is the primary energy supplier, with the renewables providing energy when practical and when one VSG is down for maintenance. Due to better wind resource data at Tadoule Lake, and to compensate for the high cost of diesel fuel, considerably more wind is utilized in this case than at Lac Brochet and Brochet.

However, the LCOE and annual operating costs in this scenario are the highest among Cases 1-6 for this location.

In Case 5 (ORC, wind, battery), ORC dominates the energy supply, with only 100kW of wind being practical under this scenario. This case has the lowest operating cost by a small margin, and among the lowest LCOEs.

In Case 6 (VSG, ORC, PV, battery), there is a mix of both diesel and ORC-renewable generation, with VSD being used relatively little. ORC still dominates in the share of total energy supplied, again indicating its relative operating cost advantage, even though its initial capital cost is higher. Solar and VSG are used to augment production, partially because HOMER Pro determined that it is more cost effective to limit the capital investment in ORC and make up the balance of capacity using solar and VSG. Due to the reduced ORC capacity, the capital cost of this scenario is less than that in Case 5.

The results of the next three reference cases again essentially mirror the patterns observed for Lac Brochet (and Brochet).

As with Brochet, Tadoule Lake's Case 2 (ORC, VSG) has competitive economics, given a low capex, lowest LCOE, and reasonably low annual opex and marginal annual operating costs. As with Brochet, if a slightly higher renewable penetration level is desired, along with a more diverse generation mix, Case 6 presents the next most attractive economic alternative. For a 100% renewable penetration for Lac Brochet, Brochet and Tadoule Lake, this policy then directs the decision on resource selection to the more community and environmentally acceptable option, Case 3.

It is noted that the LCOE for Tadoule Lake is higher than the other two communities, the reason for which was discussed at length in the Brochet commentary, in relation to Lac Brochet.

In all instances, it is important to note that various factors will need to be considered in the ultimate decision regarding which option to pursue. These factors may include financial constraints such as initial capital expenditure costs and annual operating and maintenance costs, as well as other items including GHG emissions, economic development, and environmental impacts, as well as political and community considerations.

These items, along with additional data and analysis should be studied in the feasibility study phase of this initiative, as articulated in Section 6 – ACTION ITEMS AND NEXT STEPS – of this Report.

5.4 System Configuration and Operating Cost under no-Capex Assumption

SW60 was requested to evaluate the scenario where capital costs were not to be incorporated into the development of an optimal generation system, where HOMER Pro would size components based on a least-LCOE metric, but with capital costs being set to zero. That is, in this configuration, the generation asset is considered to be a sunk cost.

When capital costs are not part of the discounted present cost calculation, HOMER Pro will only incorporate fuel, operating, and maintenance costs. This leads to optimal system configurations where generation technology with the least overall operating cost will dominate, and thus, HOMER Pro will attempt to select very large PV and wind turbine capacities. There are physical limits (nearby suitable space requirements and distances to the grid) and financial limits on amounts available to cover the sunk costs. As such, SW60 estimated that likely maximums are 2,000 kW for a solar PV field, and 1,000 kW of wind power.

By forcing these capacities into the mix, HOMER Pro can then determine what the sizes will be for the remaining technologies, and an estimate can then be made for the annual operation costs for this system configuration.

The following table illustrates the effect on the system configuration and operating costs for each community. The "Total Capex" shown in the table is the actual cost of this system configuration given the maximum capacities for solar PV and the wind turbine resource.

All costs in 2017 CAD

Lac Brochet

		3. ORC, Solar PV, Wind, Battery				4. VSG, Solar PV, Wind, Battery			
		Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor
Organic Rankine Cycle		1,200	2,557.3	39.44%	24.3%	0	0.0	0.00%	
Variable Speed Diesel		0	0.0	0.00%		1180	2,434.6	38.27%	23.6%
Solar PV		2000	2,625.3	40.49%	15.0%	2000	2,625.3	41.27%	15.0%
Wind Turbine		1000	1,301.8	20.08%	14.9%	1000	1,301.8	20.46%	14.9%
Batteries	kWh	210				630			
Fixed Speed Diesel		0	0	0.00%		0	0	0.00%	
Total Produced	MWh		6,484.4	100.00%			6,361.6	100.00%	
Excess Energy	MWh		1,719.8				1,592.6		
Net Load Served	MWh		4,764.6				4,769.1		

Brochet

		3. ORC, Solar PV, Wind, Battery				4. VSG, Solar PV, Wind, Battery			
		Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor
Organic Rankine Cycle		1,200	1,700.5	29.81%	16.2%	0	0.0	0.00%	
Variable Speed Diesel		0	0.0	0.00%		1180	1,591.5	28.44%	15.4%
Solar PV		2000	2,702.8	47.38%	15.4%	2000	2,702.8	48.30%	15.4%
Wind Turbine		1000	1,301.8	22.82%	14.9%	1000	1,301.8	23.26%	14.9%
Batteries	kWh	210				420			
Fixed Speed Diesel		0	0	0.00%		0	0	0.00%	
Total Produced	MWh		5,705.0	100.00%			5,596.1	100.00%	
Excess Energy	MWh		2,161.2				2,071.4		
Net Load Served	MWh		3,543.8				3,524.6		

Tadoule Lake

		3. ORC, Solar PV, Wind, Battery				4. VSG, Solar PV, Wind, Battery			
		Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor	Capacity kW	Production MWh/year	Percent of Total kWh	Capacity Factor
Organic Rankine Cycle		1,200	1,193.6	20.09%	11.4%	0	0.0	0.00%	
Variable Speed Diesel		0	0.0	0.00%		1180	905.8	16.02%	8.8%
Solar PV		2000	2,636.0	44.37%	15.0%	2000	2,636.0	46.63%	15.0%
Wind Turbine		1000	2,111.0	35.53%	24.1%	1000	2,111.0	37.34%	24.1%
Batteries	kWh	210				420			
Fixed Speed Diesel		0	0	0.00%		0	0	0.00%	
Total Produced	MWh		5,940.6	100.00%			5,652.8	100.00%	
Excess Energy	MWh		3,138.7				2,749.3		
Net Load Served	MWh		2,801.9				2,903.5		

		Lac Brochet 3. ORC, Solar PV, Wind, Battery	Lac Brochet 4. VSG, Solar PV, Wind, Battery	Brochet 3. ORC, Solar PV, Wind, Battery	Brochet 4. VSG, Solar PV, Wind, Battery	Tadoule Lake 3. ORC, Solar PV, Wind, Battery	Tadoule Lake 4. VSG, Solar PV, Wind, Battery
Total Capex	$, million	$ 38.2	$ 31.7	$ 38.1	$ 31.1	$ 38.2	$ 31.1
Annual Opex	$, million	$ 1.6	$ 2.5	$ 1.3	$ 1.9	$ 1.2	$ 1.6
LCOE	$/kWh	$ 0.957	$ 1.029	$ 1.217	$ 1.235	$ 1.466	$ 1.400
Annual Avg Operating Cost	$/kWh	$ 0.247	$ 0.386	$ 0.235	$ 0.348	$ 0.210	$ 0.284
Fuel and Heat							
Wood for ORC	tonnes/yr	1,767	0	1,198	0	864	0
Diesel	L/yr	0	619,731	0	407,640	0	234,494
Total Thermal Available from ORC	MWh/yr	9,945	0	6,613	0	4,642	0
Heat Equivalent in Heating Fuel Oil	L/yr	927,527	0	616,747	0	432,928	0
Actual F.O. used	L/yr	756,758	756,758	765,925	765,925	525,150	525,150
Value of F.O. Saved (using lesser of above)	$/yr	$ 941,483	$ 0	$ 764,767	$ 0	$ 536,830	$ 0
Relevent Figures							
Wood Cost	per tonne	$ 137	$ 137	$ 137	$ 137	$ 137	$ 137
Diesel Cost	per Litre	$ 1.244	$ 1.244	$ 1.240	$ 1.240	$ 1.240	$ 1.240
Annual Peak Load	kW	867	867	580	580	430	430
Annual Load Served	MWh/yr	4,765.6	4,765.6	3,522.7	3,522.7	2,865.4	2,865.4

In interpreting the results from these cases, it should be understood that no cost of capital for the equipment and construction of the facility was used by HOMER to size the PV and wind turbines in this analysis. HOMER Pro would allow even more of these renewables, but they were capped for practical reasons. The amount of Solar PV was capped at 2,000 kW and the wind power was capped at 1,000 kW in these cases due to local space and distance concerns.

The capital cost associated with these renewables may be beyond the boundary acceptable for these community projects if INAC has a limit on its budgeted capital expenditures. In this context, SW60 does not recommend solely sizing the system based on an optimization on annual operating costs. Other factors such as diversity of supply, dispatchable resources, redundancy, operation and maintenance issues, ease of grid integration, environmental issues, DSM, demand response, available incentives, policy issues, local climate, and maturity of technology also need to be considered.

6 ACTION ITEMS AND NEXT STEPS

Moving forward, it is recommended that INAC proceed with conducting a comprehensive technical and economic feasibility study for the preferred option in each of the communities, including:

- Definition of evaluation criteria and selection of the preferred solution(s) for feasibility evaluation purposes
- Technical feasibility evaluation
- Economic feasibility evaluation
- Risk identification, mitigation, and management
- Sustainability analysis
- Community and stakeholder consultations
- Environmental Impact Assessment
- Socio-economic Impact Assessment
- Source(s) of funding
- Financial structure
- Ownership
- Stakeholder responsibilities (Band, Manitoba Hydro, etc.)
- Support, O&M, and training and capacity building requirements
- Gauging of capabilities and interest from contractors
- Outline of next steps including detailed design, procurement, and construction

7 CONCLUSIONS AND RECOMMENDATIONS

- For a 100% renewable penetration of electrical generation technologies for Lac Brochet, Brochet and Tadoule Lake, the best economic resource selection is Case 3 of ORC, PV, wind power and battery. This is also likely a better community and environmentally acceptable option. The LCOE varies from 59.2 ¢/kWh for Lac Brochet, 68.4 ¢/kWh at Brochet and 78.4 ¢/kWh at Tadoule Lake. The average annual operating costs vary from 29.3 ¢/kWh for Lac Brochet, 29.5 ¢/kWh at Brochet and 30.6 ¢/kWh at Tadoule Lake, which represents the lowest marginal operating costs of all cases evaluated by HOMER Pro. The best technical configuration would also be the one with the greatest diversity of proven renewable supply options, also represented by Case 3 where ORC, wind and solar power are present. There is also ample waste heat from the ORC to heat the entire communities with 200% heat available in La Brochet, 140% in Brochet and 160% in Tadoule Lake. The excess waste heat available can be used for additional uses; including food security systems such as freezers and greenhouses, or additional economic development via hotels and laundromats. **This aspect of implementing a biomass power plant to replace the reliance on diesel fuel should be considered a strong decision point in the final determination of power options.**
- Manitoba Sustainable Development's Forestry Branch and local university research reports indicate that there are abundant local wood resources of fire-burnt timber, providing at the present rate of electricity and heat consumption between 50 and 200 years of wood supply for 100% biomass heating and electrical generation near each community.
- If upon further investigation, the fire-burnt source of biomass appears uncertain, then there are three Forestry Management Units (FMUs) that can be harvested: FMU 71, FMU 72, and the western portion of FMU 79. The sustainable Annual Allowable Cut (AAC) for these three FMUs exceeds the expected ORC fuel consumption for all three communities. Thus, the recommended feasibility study will need to include a thorough survey of the available wood supplies, both from local fire-kill sources and from these FMUs.
- It has been determined that there is ample truck capacity and winter road season duration from FMU 71, 72 and 79 to supply all three communities with a full year's supply of chipped (at site) wood at a sustainable and reasonable cost of $137 per tonne.
- A significant reduction in diesel oil supply and transportation requirements will result within these communities once the ORCs are 100% operational.
- It is recommended that the existing Manitoba Hydro diesel units be maintained and left in place as back-ups with enough diesel fuel for one year of operation at 100% community loading. As the ORCs are 100% operational, the Manitoba Hydro diesels and associated tank farms may eventually be decommissioned. In all cases,

the firm backup electrical energy supply would then be transferred to the additional ORC to provide an N-1 design within each community.

- It is recommended to supply high–level training to local personnel so the ORC can be maintained with a local labour force and to also secure appropriate maintenance contracts with reputable ORC equipment suppliers to offset the risk of failure of this technology in the remote Northern First Nations Communities.
- Community benefits include local job creation within the community energy sector in the areas of wood harvesting, transportation, electricity O&M and district heating system O&M, as well as further economic development through community-owned generation facilities and businesses. There are opportunities to train Band Members to install Solar PV racks and panels and use local materials to anchor the racks.
- It is recommended that key replacement components for ORC, Solar PV, Wind Power, and Batteries be kept on-site to ensure speedier repairs.
- The addition of a Battery Energy Storage System (BESS) is always required to make variable Solar PV and wind power options realizable for all remote communities.
- It is recommended to use fixed tilt Solar PV systems in Manitoba's remote communities, as availability of land space is not an issue, and as such, simply adding more PV panels is instead, preferred. The use of tracking should only be considered if it would be beneficial to produce more power at times close to sunrise and sunset. Although tracking systems today can make economic sense in certain applications, they also add complexity of moving parts to a PV system.
- There is substantially more solar energy available in summer, reducing the ability to meet community loads with solar PV in winter months. PV generation is also subject to large fluctuations due to passing clouds, increasing the possibility of voltage sags and frequency fluctuations. As such, both Solar PV and wind power need to be properly integrated into each community, with detailed planning and high-level grid interconnection studies required for the complete generation and grid system.
- Wind resource information is poor in the remote communities and needs to be verified by monitoring as recommended in Marc Arbez's report to the Community Energy Plan "Development of a Wind-Energy Resource Assessment Strategy for Manitoba's Off-Grid First Nations".
- Wind generation can provide substantial benefits to remote communities, allowing generating power when Solar PV cannot (at night). However, in order to be effective, it is critical to evaluate wind power from a remote community point of view, and not from a large utility point of view, as diesel power costs have the potential to be near or exceed $1.00 per kWh in these locations. With proper analysis, there is substantial room to adapt this technology to remote

communities.

- Wind turbines for remote communities are still underdeveloped and lack examples of demonstrated long-term proven sites and thus currently there would there be more risk of underachieving expected energy production in Manitoba's Remote Communities.
- Even with batteries, it is difficult for wind power and Solar PV to provide base load power, let alone provide system redundancy.
- The high cost that has recently been reported to replace diesel engines may be mitigated by installing portable and containerized diesel gensets, similar to those used in winter camps. As the renewable energy systems are installed, portable gensets may be sized more appropriately (smaller units used) to provide better load following at lower system loading.
- Fixed-speed diesel generators (FSG) do not integrate well with renewable energy as these diesels cannot operate at low partial loads (below 30% of rating), and may require Solar PV and wind power to be curtailed. Variable speed diesel generators (VSG) are able to operate at low load (10% of rating) and are more efficient than FSG when partially loaded, resulting in VSG achieving considerable fuel savings (up to 35%) over fixed-speed diesel generators.
- Demand response options such as load shedding electric hot water tanks during peak load times to reduce system peaks are recommended to be studied further in the proposed feasibility study.
- There is information that the load growth in these communities can be flat for 25 years due to DSM measures and potential for a biomass district heating system to replace electric hot water tanks. The electric generation facilities would then not need upsizing for 25 years.
- It is possible to provide 100 Amp residential service with a biomassed fueled organic rankine cycle generator. Loads can be managed with aggressive DSM and demand response control of the blowers at the sewage lagoon and control of any electric hot water tanks not on biomass or geothermal heating loops.
- It is recommended that in the feasibility study that a detailed emission study be undertaken of the ORC, VSG and FSG.
- The connection between the high cost per kW installed of intermittent power in the remote communities and the necessary battery capacity tends to make all intermittent sources more expensive from an initial capital outlay perspective than would be expected in other regions where the installed cost is less.
- In the cases where HOMER Pro excluded the capital costs, large amounts of renewables (wind power and Solar PV) are selected due to their low operating costs. An approach to exclude capital costs and treat them as sunk costs (usually a policy decision) is an alternate method for determining the best option of new

electrical energy sources. Other policy decisions can be made about the rates needed to recover the operating costs such that the residential rate is the same as now (7.92 ¢/kWh) and commercial and government rates make up the difference, which would be much less than the rates paid today if renewables are used.

- In this case, electrical generation technologies with low operating costs are favoured over others that have higher operating costs such as fuel purchases. However, their capital cost may be beyond the boundary acceptable for these community projects if INAC has a limit on its budgeted capital expenditures. In this context, SW60 does not recommend solely sizing the system based on an optimization on annual operating costs. Other factors such as diversity of supply, dispatchable resources, redundancy, operation and maintenance issues, ease of grid integration, environment al issues, DSM, demand response, available incentives, policy issues, local climate, and maturity of technology also need to be considered.
- The renewable energy systems that would be employed in the remote communities is recommended to a smart grid which is an operational scenario involving smart meters, smart controllers and communications, energy storage, renewable energy resources, energy efficiency and smart appliances. This would allow the control of the production and distribution of more reliable electricity with more resilience and fewer voltage and current spikes and less harmonics.
- This pre-feasibility study shows that renewable electricity sources have good potential to be realizable in the remote communities and thus it is recommended that a full feasibility study be pursued for the electrical energy and associated heating options for Brochet, Lac Brochet, and Tadoule Lake.