

100% RENEWABLE ENERGY IN THE NWT

BY 2050

STARTING THE CONVERSATION

October, 2016



Alternatives North

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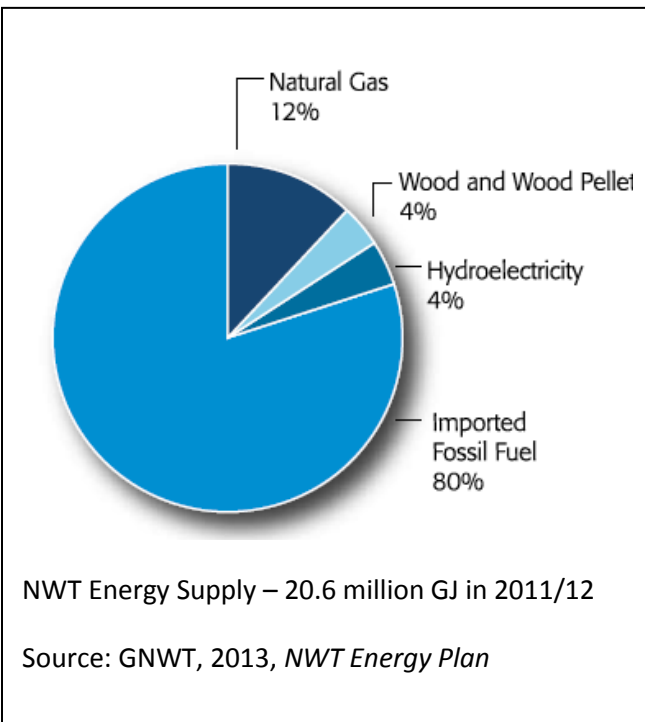
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EXECUTIVE SUMMARY

This report is based on the assumption that by 2050, there will be such a high carbon price on fossil fuels that they will no longer be economically competitive. Almost 200 countries, including Canada, signed the Paris agreement in December, 2015. Meeting the terms of that agreement requires switching to renewable energy by 2050 and the Canadian government has clearly indicated that it intends to use carbon pricing as one mechanism to encourage that switch. The NWT needs a vision for how the lights



will stay on, homes and buildings will be heated and people and goods will be transported, without fossil fuels.

In the NWT 8% of our energy comes from renewable sources. There are two separate small hydro electricity grids providing renewable electricity to the majority of the population, the last decade has seen the rapid deployment of a wood pellet heating infrastructure, a diamond mine has installed mega-watt scale wind turbines and 100kW+ grid-tied solar PV systems have been installed in Fort Simpson and Colville Lake.

These successes should be recognized and celebrated, and they should be used as examples to motivate a conversation on what comes next.

The NWT is a special place with unique challenges and opportunities. Renewable energy solutions must recognize that NWT winters are cold, dark and long, and that the vast distances between inhabited areas are not all connected by roads or electricity grids. This means that energy must be stored and transported so it is available when and where it is used. The good news is that a 100% renewable society in the NWT is possible using technologies that are commercially available right now.

This report is not about wishful thinking. It applies an engineering approach, establishing criteria and evaluating over 100 renewable energy options, covering all sectors of energy use. The criteria are:

0. Commercial availability,
1. Technical viability,
2. Costs,
3. Employment in the NWT,
4. Human health impacts,
5. Community self-sufficiency,
6. Other environmental impacts.

Commercial availability is listed as “Criteria zero” because this report does not evaluate technologies against the remaining criteria unless the entire supply chain is commercially available as of the time of writing. The remaining criteria are evaluated for each renewable energy option using a rating of “NEGATIVE”, “NEUTRAL” or “POSITIVE” in terms of how the technology compares to other renewable energy options (not how it compares with the current fossil fuelled system). It is obvious that a more quantified analysis of each option would be useful, and that different people will prioritise certain criteria over others. That level of analysis is beyond the scope of this report. The goal here is to show that a 100% renewable energy NWT is possible and encourage others to join a conversation about which of the many options should be pursued.

The year 2050 seems a long way in the future, but to achieve a 100% renewable energy system by then, work must start immediately. Over the next 34 years, much of the existing building and energy infrastructure will be replaced or rebuilt, presenting an opportunity to install renewable energy systems that will not end up stranding expensive assets. In other words, new infrastructure that is being built in the next few years will continue to function beyond 2050. If renewable energy systems are not installed, it will be more costly to replace stranded fossil fuel infrastructure before the end of its useful life.

In more populated parts of Canada, a 100% renewable energy system is being proposed that is based on electrifying heat and transportation. The supply of renewable electricity will be increased by pairing wind turbines and solar panels with large hydro reservoirs and short-term, grid stabilising battery storage. In the NWT, electrification of heat and local transport is an option, but the distances are so vast and population base so low that connecting all the inhabited areas with transmission lines to hydro storage reservoirs would be extremely costly. Biofuels present a more affordable option, providing up to 90% of the energy supply in the NWT because, like fossil fuels, they can be transported and stored for several years between fuel deliveries. The key biofuels will be wood, wood chips, wood pellets, compressed and liquid biogas and bio-jet fuel. Most of these bio-fuels could be sourced in the NWT, but imported bio-fuels might be more affordable.

Electricity plays a critical role in the North. When the power goes off, furnaces and boilers cannot run, water pipes start to freeze and the damage can become very expensive, very quickly. To ensure this does not happen, all communities are required (by the Public Utilities Board) to have a backup/redundant source of electricity – currently provided by diesel generators. In a 100% renewable energy NWT, in most cases, bio-fuel powered generators would provide back-up power and bio-fuel would become “the new diesel” – in the sense that if another renewable electricity source (wind, solar, hydro, or geothermal) was cheaper than “the avoided cost of biofuels”, then it would make economic sense to add it to the electricity mix, otherwise, bio-fuel powered generation could supply the entire community or mine.

The requirement that each community have a full set of back-up generators contributes significantly to the cost of electricity. There is an opportunity to reduce this cost if homes and building could be wired with “essential” and non-essential circuits. The essential circuits would be connected to a backup power

source, but non-essential circuits could be disconnected by the utility until the main generators could be repaired. Mines already use a similar system to keep production running without needing a full set of backup generators.

Numerous sources of renewable heat exist in the NWT. Any combination of wood, wood chips, wood pellets, ground source heat pumps, heat recovered from electricity generators and biogas would work and many of these could be sourced locally. Ground-based transportation could be electrified where affordable sources of renewable electricity are available or vehicles could be converted to compressed or liquid biogas.

Air transportation has the fewest options in terms of renewable energy. Bio-jet fuels are commercially available, but are currently used at a maximum of 50% blend with regular jet-fuel. For the industry to play its part, more research is needed to develop a renewable jet-fuel that can be used in existing aircraft engines.

A switch to local sources of renewable energy could provide a significant increase in NWT energy related employment. Currently, less than 10% of the NWT's energy supply currently comes from local sources but increased use of local hydro, solar, wind and, particularly, local biomass could increase that to 70%.

The key trend in terms of local human health is also the potential to switch to more local wood-based sources of energy. In the past, wood burning with old combustion technologies has produced local particulate pollution problems, but that can be addressed with high efficiency wood stoves, pellet appliances as well as pollution controls on larger facilities.

The following 100% renewable energy NWT scenario goes into more detail on a regional and sector by sector basis. It is just one of many possibilities. Other options will emerge as research continues and more people join the conversation.

A 100% RENEWABLE ENERGY NWT SCENARIO

The renewable energy supply chains that were evaluated the most positively in each sector result in the following 100% Renewable Energy scenario. This is only one of many possibilities. More emphasis on some criteria than others would produce different outcomes. For example, this report puts emphasis on self sufficiency and local employment thereby favouring local renewable energy sources like wood chips and locally produced wood pellets. Putting a higher emphasis on cost might shift the balance towards potentially cheaper, imported bio-fuels. More detailed research, including the costing of options and quantification of employment benefits and local environmental impacts, is required.

LONG DISTANCE TRANSPORT

AIR

In a 100% renewable energy NWT, all aircraft will be powered by bio-jet fuel. Smaller aircraft will replace their avgas spark plug engines with bio-jet fuel compatible “diesel” engines. The bio-jet fuel will be certified for low temperature operation and storage systems will be designed to keep the fuel stable over long storage periods

HIGHWAY

In a 100% renewable energy NWT, cars and light trucks will travel long distances using either battery power or compressed biogas. Larger transport trucks will use liquid biogas. Rapid charging stations connected to the north and south slave hydro grids, supplemented with solar panels will be built along highways 1,2,3 and 5 allowing batteries to be quickly re-charged on their way to the Alberta border, where they will be able to connect with an Alberta network of charging stations.

BARGE

In a 100% renewable energy NWT, barge traffic will be powered by compressed biogas. Tugs with electric drives will be supplemented by solar.

ELECTRICITY, LOCAL TRANSPORT & HEAT

In a 100% renewable energy NWT, homes and buildings will all be super-insulated, air tight and will take advantage of passive solar. Modestly sized homes will be so efficient that they would be heated with a single pellet or wood stove. Larger homes and buildings will be heated with wood pellet/chip boilers, clusters of buildings will use district heating systems recovering heat from bio-fuelled or geothermal power plants, supplemented with boilers burning locally harvested wood chips.

In a 100% renewable energy NWT, local transport will be provided by either electric vehicles charging from the local renewable electricity source or vehicles converted to run on compressed biogas.

COMMUNITIES ON THE NORTH SLAVE POWER GRID

In a 100% renewable energy NWT, the communities on the North Slave power grid will get most of their electricity from upgraded Snare and Bluefish hydro systems. The hydro system will have expanded storage capacity to help mitigate the impacts of low water years as well as power electric vehicles. Backup and additional power would be available from a wood chip powered combined heat and power (CHP) plant.

The Con Mine will be a seasonal heat storage system, storing solar, excess hydro and waste heat energy from the CHP plant in the water of the flooded mine during the summer. In the winter, heat pumps will draw the heat back from the mine and be combined with heat from the CHP plant to heat homes and buildings through a district heating system.

COMMUNITIES ON THE SOUTH SLAVE POWER GRID

In a 100% renewable energy NWT, the communities on the South Slave power grid will get their electricity from the Taltson hydro system. An expanded Taltson system with upgraded power lines will meet all local transport and most heating needs with electricity. Each community will have a Rankine cycle CHP plant heating a group of buildings with a district heating system and providing power backup in case of an outage on the main transmission lines.

Ground source heat pumps will take advantage of the softer ground and higher thermal gradients in the South Slave region to reduce heating costs. Some people will heat with local wood or wood pellets.

COMMUNITIES IN THE THERMAL ZONE

In a 100% renewable energy NWT, communities currently in the thermal zone will get their power from a variety of renewable sources. Depending on what is available, small hydro, geothermal or wind will provide the majority of the power. All the communities will have biomass powered CHP plants to run a district heat system, provide “top up” power when other sources are insufficient, as well as backup power. Solar panels will supplement power production. The biomass CHP plant will be either a wood chip/pellet boiler with a Rankine cycle engine¹ attached or a wood pellet gasifier connected to a modified “diesel” generator.

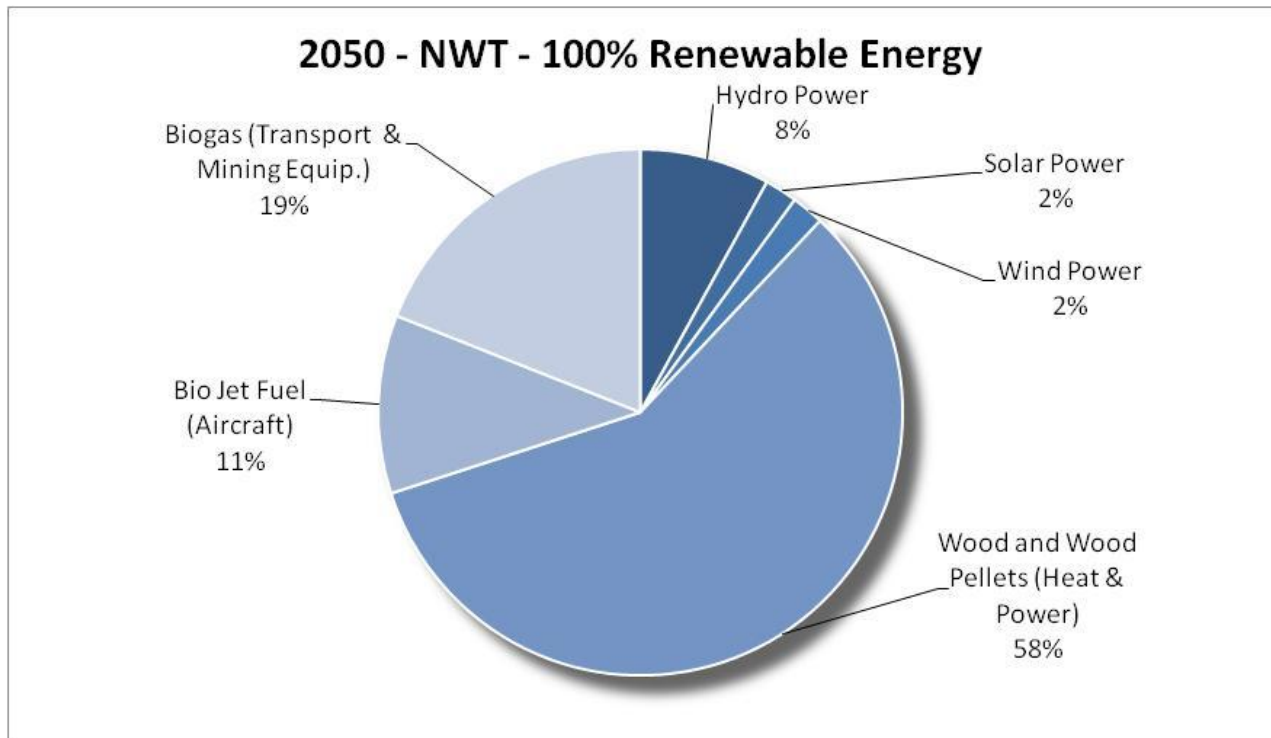
Local vehicles will be powered by rechargeable batteries. Vehicles used for longer journeys will use compressed biogas if recharging stations are not available along the highway.

¹ A Rankine Cycle engine is similar to a steam turbine, except that it operates using a closed loop using a fluid that gasifies at a lower temperature than water/steam. Steam systems operate at high pressures and the potential for explosions mean they are highly regulated and the required steam engineers are expensive. Rankine engines do not operate at high pressure, and do not require steam engineers, but are also less efficient.

MINES

In a 100% renewable energy NWT, some new mines will get their electricity from a hydro line from the Taltson hydro grid. Older mines and those too far from hydro resources will use wood pellet powered CHP plants for both heat and power. Mobile mine ore handling equipment will run either on swappable battery packs or compressed biogas.

2050 NWT ENERGY SUPPLY – PIE CHART



The above pie chart shows one of many possible renewable energy combinations in the year 2050. It assumes:

- a doubling of hydroelectricity,
- wind and solar power provide 50% of remaining non-hydro power,
- replacement of jet-fuel & avgas with bio jet fuel,
- replacement of diesel for transportation with biogas,
- wood, wood chips and wood pellets provide heat and the remainder of electricity.

INTRODUCTION

During the Paris climate negotiations in December 2015, nearly 200 countries agreed to keep global warming below 2⁰C and to work towards a 1.5⁰C limit¹. An analysis of climate modelling scenarios by the International Panel on Climate Change (IPCC) shows that to keep global temperature rise below 1.5⁰C by the end of this century, the world must be running on 100% clean energy by mid-century.² Canada has committed “to an ambitious global agreement that is anchored in science and leads the world towards a low-carbon, climate resilient economy”.³

Northerners⁴ have been sounding the alarm about climate change for decades, recognizing that the north has been warming faster than other regions.⁵ Northern governments have also spoken for years about the need to transition to renewable energy and increase efficiency.⁶

In the NWT, there have been successes: there are two separate small hydro electricity grids providing renewable electricity to the majority of the population. The City of Yellowknife has one of the most energy efficient building codes in the world. The last decade has seen the rapid deployment of a wood pellet heating infrastructure. A diamond mine has installed mega-watt scale wind turbines. 100kW+ grid-tied solar PV systems have been installed in Fort Simpson and Colville Lake and solar panels are appearing on homes and businesses.

These successes should be recognized and celebrated, and they should be used as motivating examples to begin a conversation on greater success. In the rest of Canada, a vision is developing of a 100% renewable energy society based on a shift in heating and transportation towards electricity and a shift towards renewable electricity generation from wind and solar systems.^{7 8}

The NWT is a special place with unique challenges and opportunities. Renewable energy solutions must recognize that NWT winters are cold, dark and long, and that the vast distances between inhabited areas are not all connected by roads or electricity grids. The NWT has renewable energy success stories and there are many opportunities for more. But these challenges and opportunities will not be addressed by simply waiting to adopt technologies and policies that are developed in the rest of Canada.

Through this project Alternatives North and its partners want northerners to envisage/imagine a 100% renewable energy society in the NWT. That aspiration begins with this technical overview of current renewable energy use and an evaluation of options. The World Wildlife Fund has initiated a similar conversation in Nunavut and it is hoped that what we learn will have application throughout the Canadian North⁹.

GOALS

These are the project goals set by the partners:

- Develop and document a vision for a 100% renewable energy society in the NWT that is achievable by 2050.
- Describe a process that allows new ideas and options to be evaluated.
- Evaluate options for a 100% renewable future for the NWT, based on a broad set of values, including social, economic, environmental and cultural criteria.
- Stimulate discussion among the public, key players and politicians.

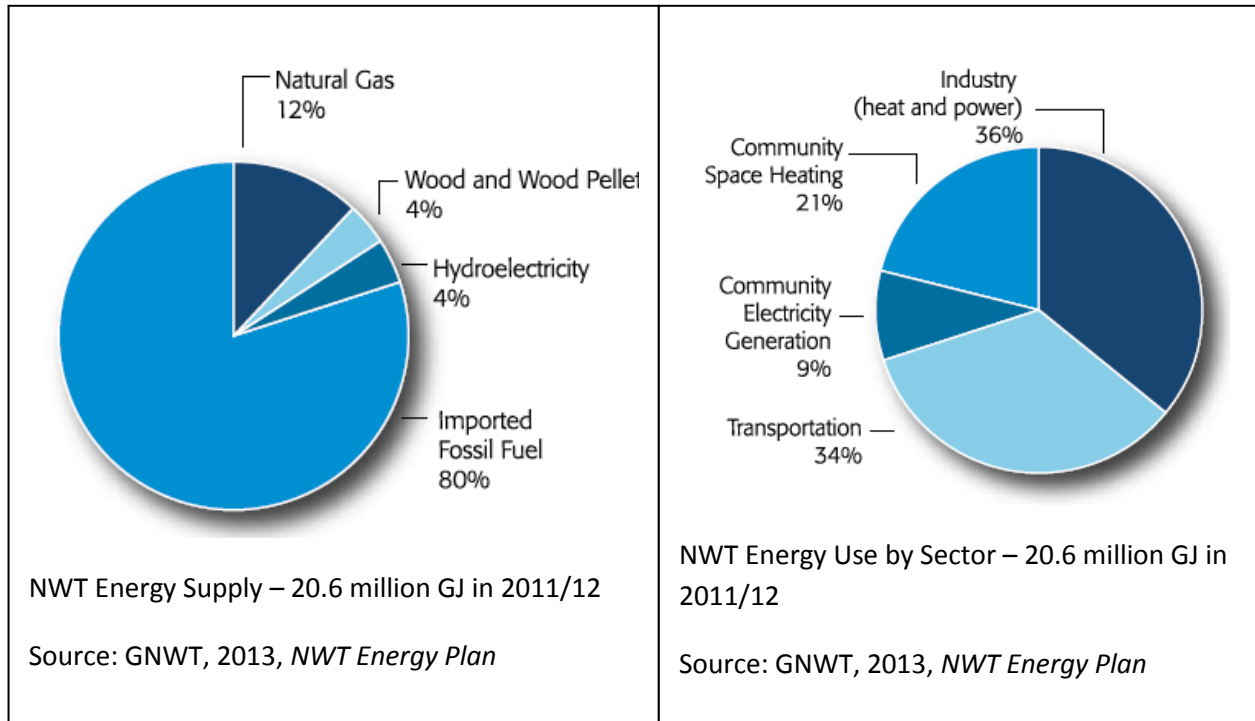
ASSUMPTIONS & LIMITATIONS

Addressing the energy use of all sectors of a society within the confines of a small project budget requires some constraints and assumptions on the scope of the study. Therefore this study:

- Assumes that 100% renewable energy is required in all sectors by 2050,
- Looks at the overall energy mix and the breakdown of energy sources by percentages only – the study will not attempt to model total energy flows,
- Focuses on energy use and the resulting greenhouse gas production within the boundaries of the NWT – it does not include “upstream” emissions such as those from fossil or renewable fuel production, and it does not include human or animal food as an energy source,
- Assumes that NWT society stays proportionally the same as it is now:
 - The population may grow or shrink, but the proportional distribution of population between smaller and larger communities will stay the same,
 - The economy may grow or shrink, but the same percentage of economic activity and energy demand will come from government administration, mining, etc.,
 - Efforts will continue to promote conservation and energy efficiency in all sectors, which will reduce overall demand for energy, but will not change the proportion of energy needed for heating versus electricity versus transportation, etc.

CURRENT ENERGY MIX

The following charts are based on data from 2011. A “2015 NWT Energy Profile” will be included in the next version of this report.



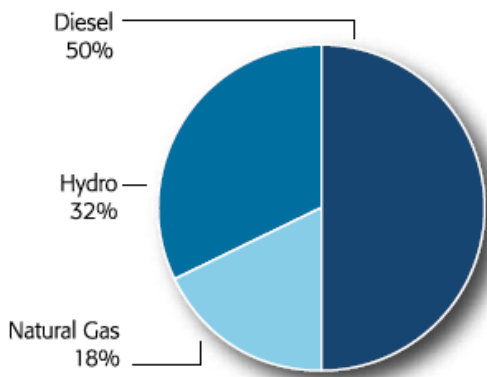
This study covers all energy demands and supplies the NWT society needs to function (except food).

The 2013 GNWT Energy Plan says the NWT uses about 20,000 Terajoules of energy in a typical year. Of that only 8% is considered renewable energy from a combination of hydro-electricity, wood and wood pellets. The remainder is imported in the form of fossil fuels such as gasoline, diesel, liquid natural gas (LNG) and jet-fuel.

Energy use can roughly be divided evenly into three sectors; Transportation, Industry and Communities. In communities, energy use can be split into thirds again; one third goes to electricity and two thirds to space heating. One quarter of the energy used in transportation is used in aircraft; the remaining three quarters is used by vehicles.

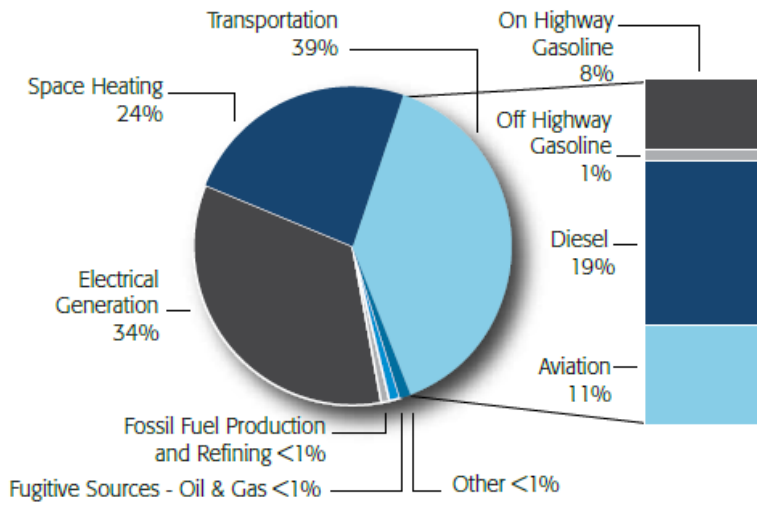
Roughly one third of electricity production comes from renewable hydro-electric facilities, with the remaining power coming from diesel (half) and natural gas (one sixth) powered generators.

The final chart in this section shows that the NWT’s greenhouse gas emissions are directly related to the burning of fossil fuels for energy. (Other jurisdictions would also have emissions from agriculture and changing land-uses).



NWT Electricity Generation, Incl. industrial – 720 GWh in 2010

Source: GNWT, 2013, *NWT Energy Plan*



NWT Greenhouse Gas Emissions – 1,300 kT in 2011/12

Source: GNWT, 2013, *NWT Energy Plan*

ENERGY DEMAND OVER TIME

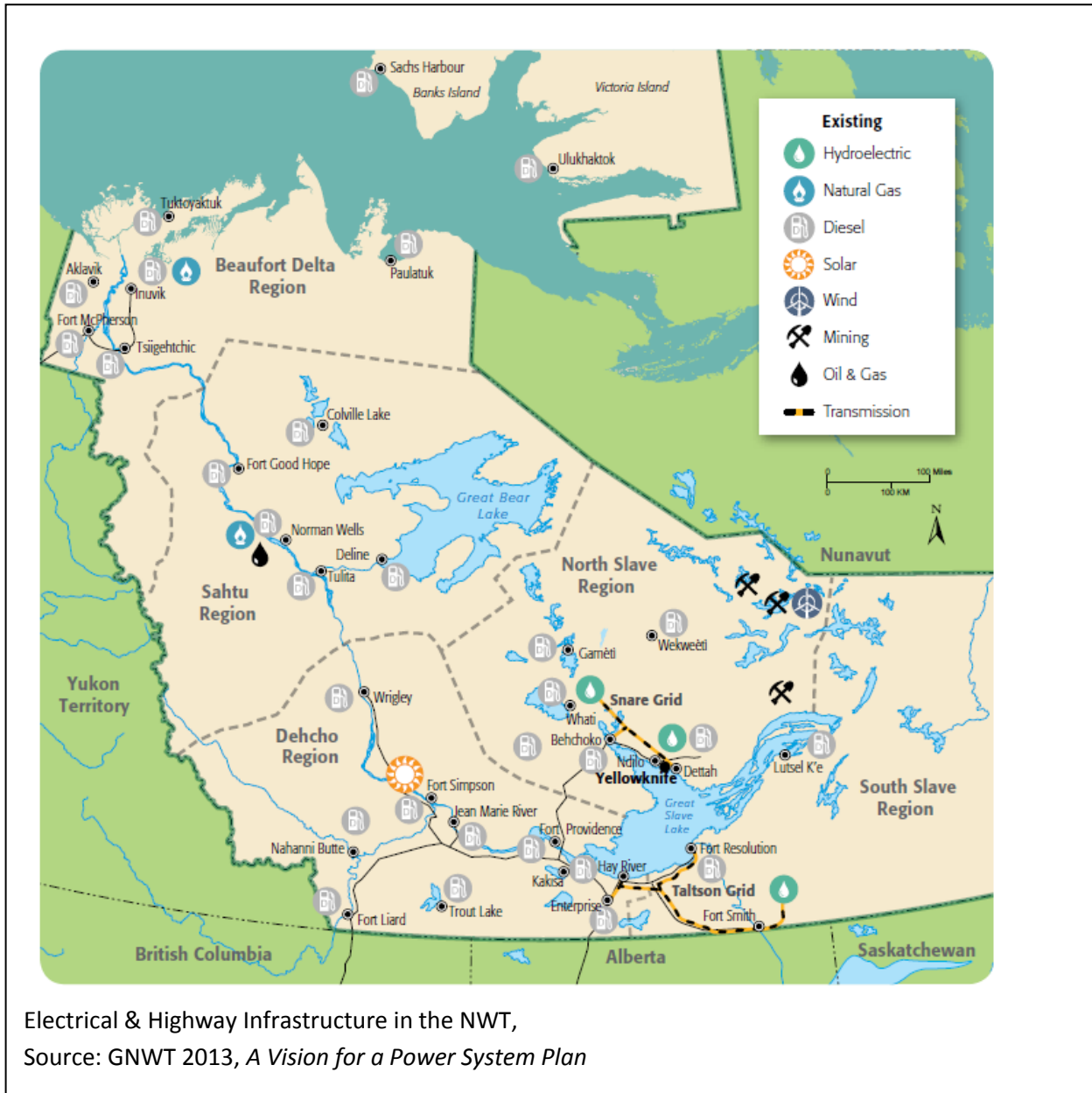
In all parts of the world, the demand for energy can be broken down into immediate, daily and seasonal cycles. The rhythms of human activity may be different in the NWT than in other parts of the world, which means that the energy demands may also be different. For example, an airplane needs a large amount of energy over just a few minutes to take off (same all around the world), electricity demand in the NWT is usually highest just after work when people are cooking (in hotter places, air conditioning creates a larger demand during the middle of the day) and demand for heating oil is highest during the coldest months of winter (the NWT is one of the coldest places in the world).

The following table breaks down NWT energy service demands and describes how they vary over short-term, daily and seasonal cycles.

Energy Service	Energy Source(s)	Short Term Demand Cycles	Daily Demand Cycles	Annual Demand Cycles
Electricity	Diesel Generators / Hydro / Wind / Solar	On-demand	Lower overnight, peaks in morning and at end of workday	Highest in winter ¹⁰
Air Transport	Jet Fuel / Av Gas 100LL	Highest at take-off	Higher in day-light hours	Highest Jan – March (winter road re-supply)
In-town transport	Gasoline/Diesel	High when accelerating	Higher in day-light hours	Higher in Winter ¹¹
Highway Transport	Gasoline / Diesel	High when accelerating	Higher in day-light hours	Year Round
Barged transport of Goods	Diesel	Steady	Day and Night	Only in Summer and Fall
Mine Ore Handling	Diesel	High when accelerating	Day and Night	Year Round
Space Heating	Heating Oil / Propane / Natural Gas / Wood	Steady – higher when colder	Lower during the day; higher at night	Highest in Winter; low in Summer
Hot Water and Industrial Process Heating	Heating Oil / Propane / Natural Gas / Wood	On-demand	Steady	Steady

Daily and seasonal cycles are natural rhythms and renewable energy sources also fluctuate with the rhythms of nature, but they do not necessarily match the rhythms of human activity. This will be discussed in more detail in the “overview of Renewable Energy Sources”. It is important to note that the only NWT energy service demand that matches solar power availability is barging of goods, which only occurs when waterways are ice-free. In hotter places, solar panels are well matched to demand, where the demand for electricity is highest on sunny summer days (due to air conditioning loads). Storing renewable energy for times when it is needed is one of the biggest challenges.

SUPPLY CHAINS & STORAGE



Another key factor that makes the NWT different from most of North America is that it is “remote”, meaning that it requires unique energy supply chains and storage solutions. There are few all season roads, and no connections to provincial natural gas pipelines or electricity grids. In southern Canada, higher population densities spread the cost of energy infrastructure over a larger number of people. This allows energy to be moved relatively cheaply from one place to another through transmission lines, pipelines, railways and highways. The cost of energy transportation infrastructure in the NWT combined with the low population base makes getting energy supplies to where they are needed more

challenging and expensive. The lack of transmission lines and pipelines also means that energy is moved as fuel shipped by truck and barge and stored for longer periods than in most of North America.

As solutions are developed for moving the rest of North America towards renewable energy, it is important to remember that these solutions may not be suited to the NWT's circumstances. For example, electrical storage has become a major topic of research, but the priorities for research are storage that lasts a few minutes (grid stabilization) or up to a few hours (electric vehicles). The NWT requires seasonal storage of energy that can meet energy demand through the winter months and for up to a year between fuel deliveries.

Another example of northern circumstances is the proposal that solar and wind energy and hydro reservoirs could complement each other if they are on the same power grid – hydro reservoirs can hold back water on sunny or windy days and generate power when the wind dies down or the sun sets. Even if the NWT had a good solar resource and windy regions (it does) and hydro reservoirs (it does), if there is no transmission line between the two, the proposal will not work.

EVALUATION CRITERIA

This study proposes a set of evaluation criteria for proposed renewable energy options for the NWT. Each option will be evaluated in consideration of the complete supply chain from energy source/NWT border to final point of use. New options could be evaluated using the same criteria.

The year 2050 seems a long way in the future, but the transformation to a 100% renewable energy system must start immediately. Over the next 34 years, much of the existing building and energy infrastructure will be replaced or rebuilt, presenting an opportunity to install renewable energy systems that will not end up stranding expensive assets. In other words, new infrastructure that is being built in the next few years will continue to function beyond 2050. If renewable energy systems are not installed, it will be more costly to replace stranded fossil fuel infrastructure before the end of its useful life.

Renewable energy technologies are continuously evolving and it is difficult to predict which options currently under development will actually become commercially available. For decades hydrogen fuel cells, fusion reactors, Stirling engines and second generation ethanol production facilities have all been “just a few years away.” The transition to renewable infrastructure needs to start immediately and therefore needs to be based on technology that is commercially available right now.

Decades of hard work and ingenuity have been needed to adapt commercially available fossil fuel powered systems to work in the NWT. High travel costs, limited local technical capacity, intermittent communications (for remote monitoring), and extremely cold temperatures are a few of the challenges. Commercially available renewable energy technologies will face the same challenges. For these reasons, the first criterion for inclusion in this report is that the renewable energy system be commercially available.

The remaining criteria listed will help evaluate which energy systems are most appropriate for implementation in the NWT. Each energy system will be rated as “**NEGATIVE**”, “**NEUTRAL**” or “**POSITIVE**” in terms of how it compares to other renewable energy options (not how it compares with the current system).

Evaluation Criteria	Key Questions
0 Commercial Availability	Is the complete renewable energy supply chain commercially available? If not, the energy system is disqualified from in depth consideration.

Evaluation Criteria	Key Questions
1 Technical Viability	<p><u>Technological Maturity</u></p> <ul style="list-style-type: none"> • For how many years has the energy system been commercially available? • How many systems have been installed world-wide? <p><u>Northern / Remote Experience</u></p> <ul style="list-style-type: none"> • For how many years has the technology been used in the North? • How many systems have been installed in the North? • If not yet in use in the North, is it being developed at a scale that will work in the NWT? <p><u>Synchronised to rhythms of Northern energy demand</u></p> <ul style="list-style-type: none"> • Is the energy source available when it is most needed? <p><u>Ease of Transport</u></p> <ul style="list-style-type: none"> • If being imported, how easy is it to transport on NWT highways, winter roads and barges? What is the energy density during transport? <p><u>Storable</u></p> <ul style="list-style-type: none"> • If imported, is the energy source easy to store in NWT conditions? What is the energy density during storage? <p><u>Climate Change Resilient</u></p> <ul style="list-style-type: none"> • Will the energy system be able to adapt to a warming climate?
2 Costs	<ul style="list-style-type: none"> • Are costs more or less expensive than the other 100% renewable energy options? • Are costs expected to decrease? • Are transportation costs higher or lower than other renewable energy options? • Are storage costs higher or lower than other renewable energy options?
3 Employment in the NWT	<ul style="list-style-type: none"> • Will the system create or reduce employment in the NWT – compared to other renewable energy options? Will the change be permanent?
4 Human Health Impacts	<ul style="list-style-type: none"> • Will the system create public health benefits or impacts relative to other renewable energy options?
5 Community Self Sufficiency	<ul style="list-style-type: none"> • Will the system reduce the use of imported fuels? Will more money stay in the NWT? Compared with other renewable energy options.
6 Other Environmental Impacts	<ul style="list-style-type: none"> • Will the system create environmental impacts or benefits other than eliminating greenhouse gas emissions? Compared with other renewable energy options.

OVERVIEW OF RENEWABLE ENERGY SOURCES

Any future renewable energy system will need to be a combination of energy supply chains – gathering energy from a variety of renewable sources and making it available at the times and places that energy services are needed.

Potential local renewable energy sources in the NWT include:

- Solar energy
- Wind energy
- Hydro-electricity
- Geothermal heat – Steam and Low Temperature
- Ground Source Heat Pumps
- Air Source Heat Pumps
- Water Source Heat Pumps
- Biomass from local forests (cord wood, saw-mill waste, wood chips, pellets, etc.)
- Biogas from local sources such as land-fills, sewage and organic waste

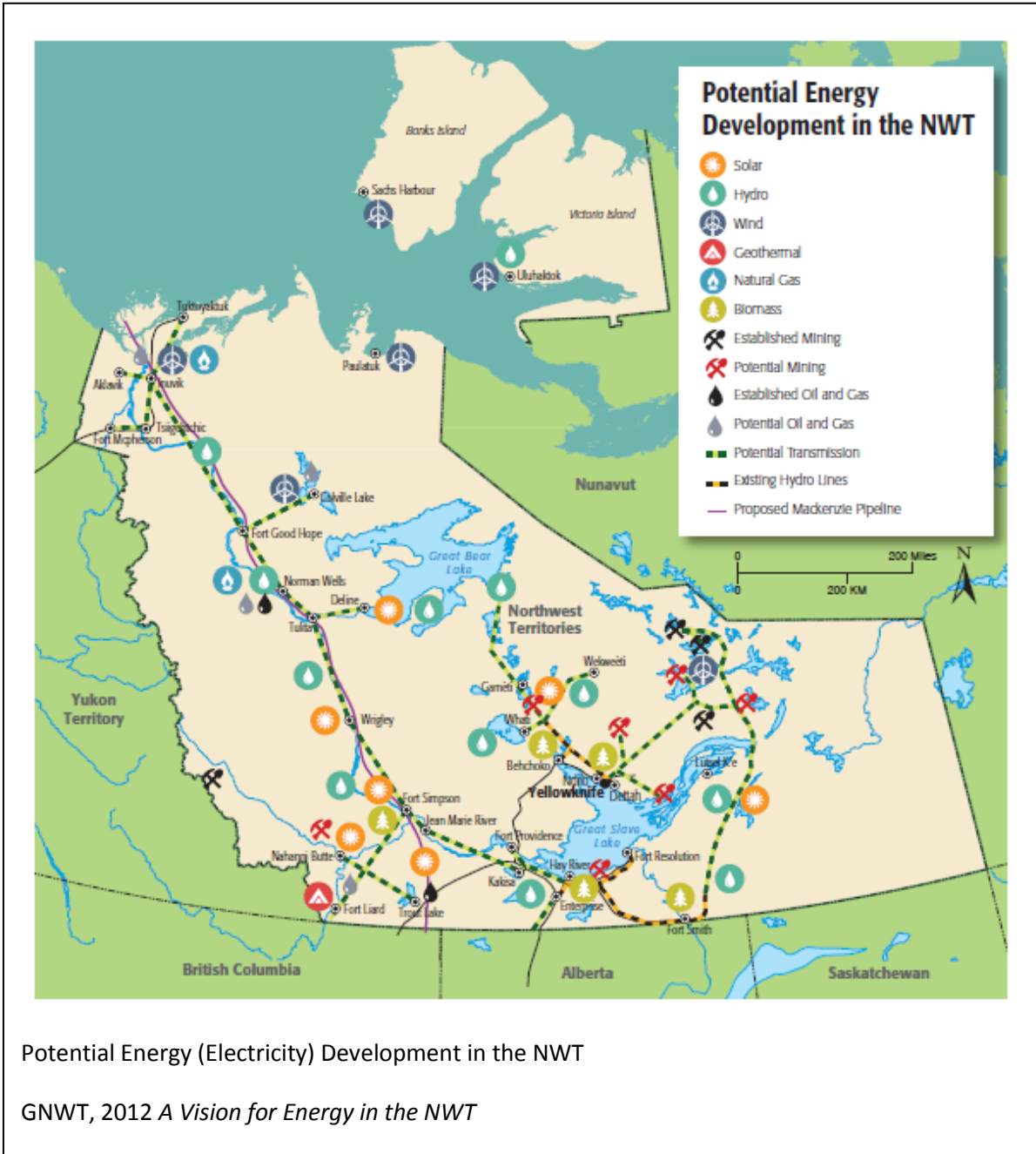
Potential imported renewable energy sources include:

- Renewable electricity from transmission grids in Saskatchewan or Alberta – assuming that these Provinces switch to 100% renewable electricity.
- Wood pellets
- Bio-jet fuel
- Bio-diesel
- Ethanol
- Compressed Bio-gas
- Liquefied Bio-gas

Potential renewable energy source considered not commercially available and therefore not evaluated:

- Imported or locally generated hydrogen
- Small nuclear (not really renewable either)

The following map shows one vision for how the electricity system of the NWT could develop over the next few decades. It shows an ambitious network of long transmission lines, but also shows that there is potential for wind, solar, small hydro, geothermal and biomass based electricity production.



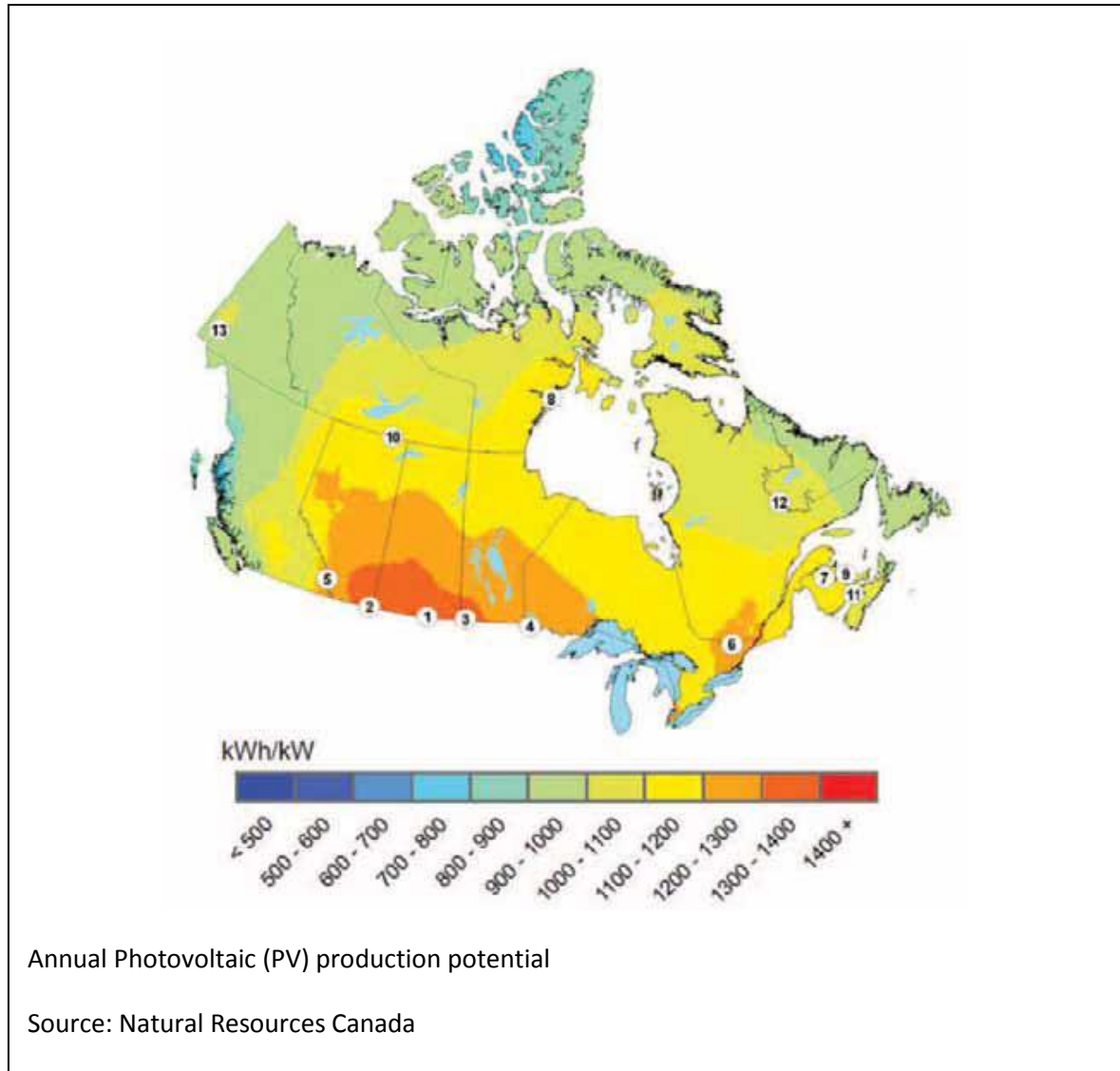
RENEWABLE ENERGY VARIABILITY OVER TIME

The variation of energy demand over time was discussed in the previous section. In an ideal renewable energy system, energy demands would correspond with the availability of renewable energy sources. The following table shows how some sources vary a lot over time, while others have built-in storage capacity that allows them to be used whenever they are needed.

Energy Source	Short Term Variability	Daily Variability	Annual Variability
Solar	Highly variable when partly cloudy	Higher in day-light hours, zero when dark	Much less in Winter
Wind	Highly variable in gusty winds	Depends on location	Depends on location
Snare Hydro	On demand	On demand	Lower in winter Lower in droughts
Taltson Hydro	On demand	On demand	On demand
Geothermal heat	On demand	On demand	On demand
Ground Source Heat Pumps	On demand	On demand	On demand
Air Source Heat Pumps	On demand	Lower at night	Lower in winter
Water Source Heat Pumps	On demand	On demand	Lower in winter
Biomass from local forests	On demand	On demand	On demand
Biogas from local sources	On demand	On demand	On demand
Imported power from AB & SK	On demand	On demand	On demand
Imported Wood Pellets	On demand	On demand	On demand
Imported bio-jet fuel	On demand	On demand	On demand
Imported Bio-diesel	On demand	On demand	On demand

Energy Source	Short Term Variability	Daily Variability	Annual Variability
Imported Ethanol	On demand	On demand	On demand
Imported Compressed Biogas	On demand	On demand	On demand
Imported Liquefied Biogas	On demand	On demand	On demand

SOLAR RESOURCES IN THE NWT



The Solar resource in the southern part of the NWT is comparable to Ottawa and all inhabited areas, including Sachs Harbour have a greater solar resource than Berlin, Germany. As of 2014, Germany had installed more Solar PV than any other country. ¹².

WIND RESOURCES IN THE NWT



Wind Speeds across the North

Source: GNWT 2012, NWT *Energy Charrette Participant Guidebook*

The wind resource in the NWT is higher in coastal areas (off-shore in Great Slave Lake and Great Bear Lake as well as along the Beaufort Sea Coast), in areas with higher elevations and near Diavik Diamond Mine. The winds along in the coastal areas are stronger when there is open water (summer and fall) while the winds at higher elevations are stronger in the winter. ¹³

HYDRO-ELECTRIC RESOURCES IN THE NWT



North Slave (Snare) and South Slave (Taltson) Electrical Grids

Source: GNWT 2013, *A Vision for a Power System Plan*

NORTH SLAVE

The North Slave grid is powered by the Snare and Bluefish hydro facilities. The Snare generating station is the larger of the two and is connected to Yellowknife by a 240 km transmission line. The available power ranges from 35 MW in August to 25MW over the winter, depending on how high the water is in the reservoirs. The system has limited storage capacity and while 25% of the available energy is spilled during high water times, reserves can be quickly depleted during low water years.¹⁴

SOUTH SLAVE

The South Slave grid is powered by the Taltson hydro station and includes 465 kilometers of transmission lines. The average load on the system ranges between 8 and 12 MW, which is less than the available capacity at all times. It is estimated that 50% of the available energy is currently not used.¹⁵

POTENTIAL HYDRO DEVELOPMENTS

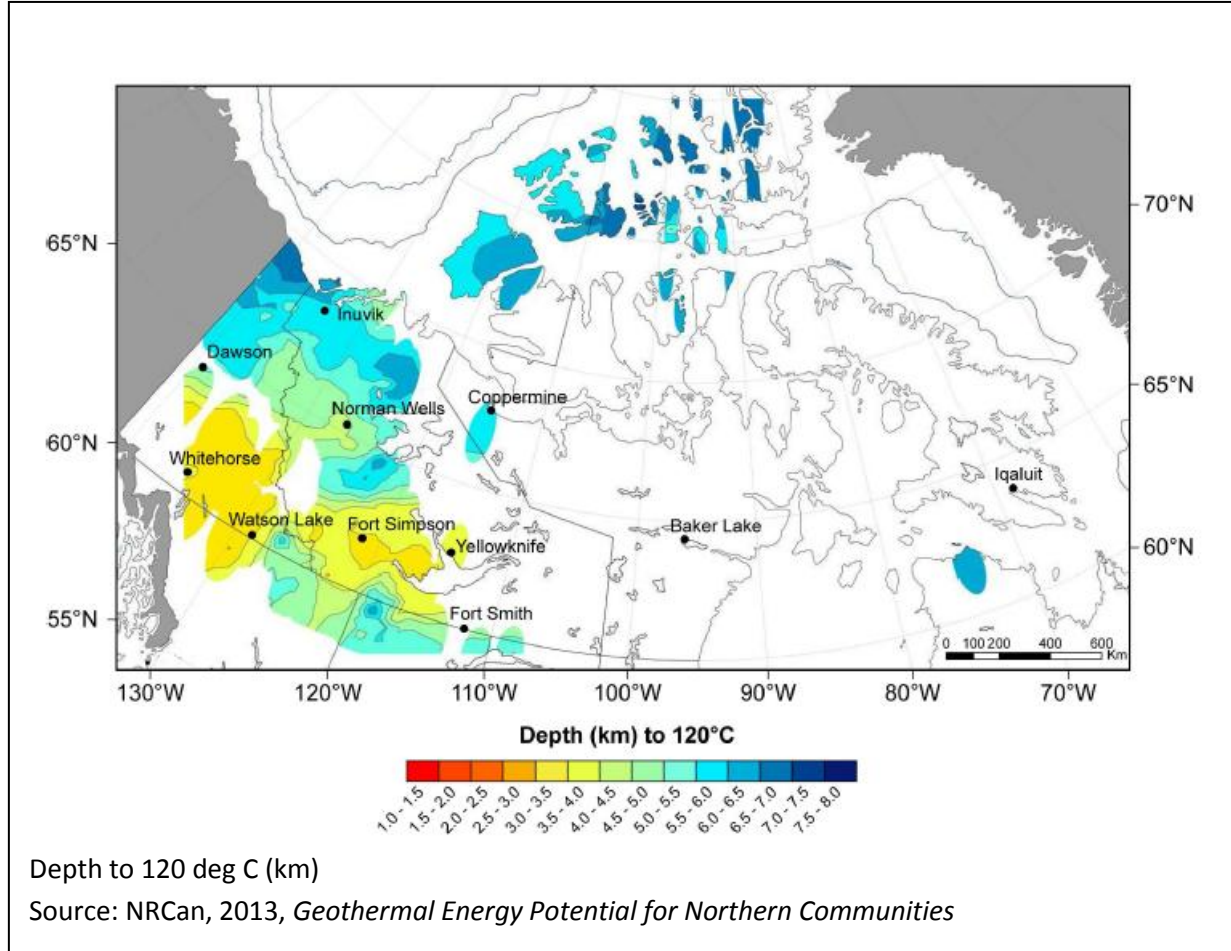
River	Developed (MW)	Undeveloped Potential (MW)
Bear River	0	568
La Martre River	0	27
Lockhart River	0	269
Mackenzie River	0	10,450
Snare River	30	33
Snowdrift River	0	1
Taltson River	18	172
Yellowknife River	7	0
TOTAL	55	11,520

Developed and undeveloped Hydro-electric resources in the NWT.

Source: GNWT, 2012, *NWT Energy Charrette Participant Guidebook*

The NWT has an impressive list of potential hydro developments – ranging from smaller, community-scale projects, up to huge projects that would theoretically export power to all of western North America. Evaluation of feasibility is more advanced for some projects than others.

GEOHERMAL RESOURCES IN THE NWT



Both the GNWT and the Federal Government have produced studies on the potential for geothermal power production the NWT. Highlights from the studies include:

- The highest potential is in sedimentary rocks around Fort Simpson. Signs of a resource are found as far south as Fort Liard, east towards Hay River and north towards Behchoko,
- Studies reviewed are all based on oil & gas wells – no direct evidence of temperatures exists as the cost of drilling a single test hole would be in the millions of dollars,
- There is no guarantee that there are reservoirs of hot water within economical reach of communities. Water reservoirs are more likely in sedimentary rocks than in Canadian Shield.
- Enhanced geothermal – where liquid is forced through hot rocks is theoretically possible.

A low temperature geothermal power generator is a system that requires a fluid/gas other than water/steam to drive a turbine. They typically operate at temperatures below 150 deg C.¹⁶ The lowest operating temperature system in North America is located at Chena Hot Springs in Alaska, which operates on temperatures as low as 75 deg C.¹⁷

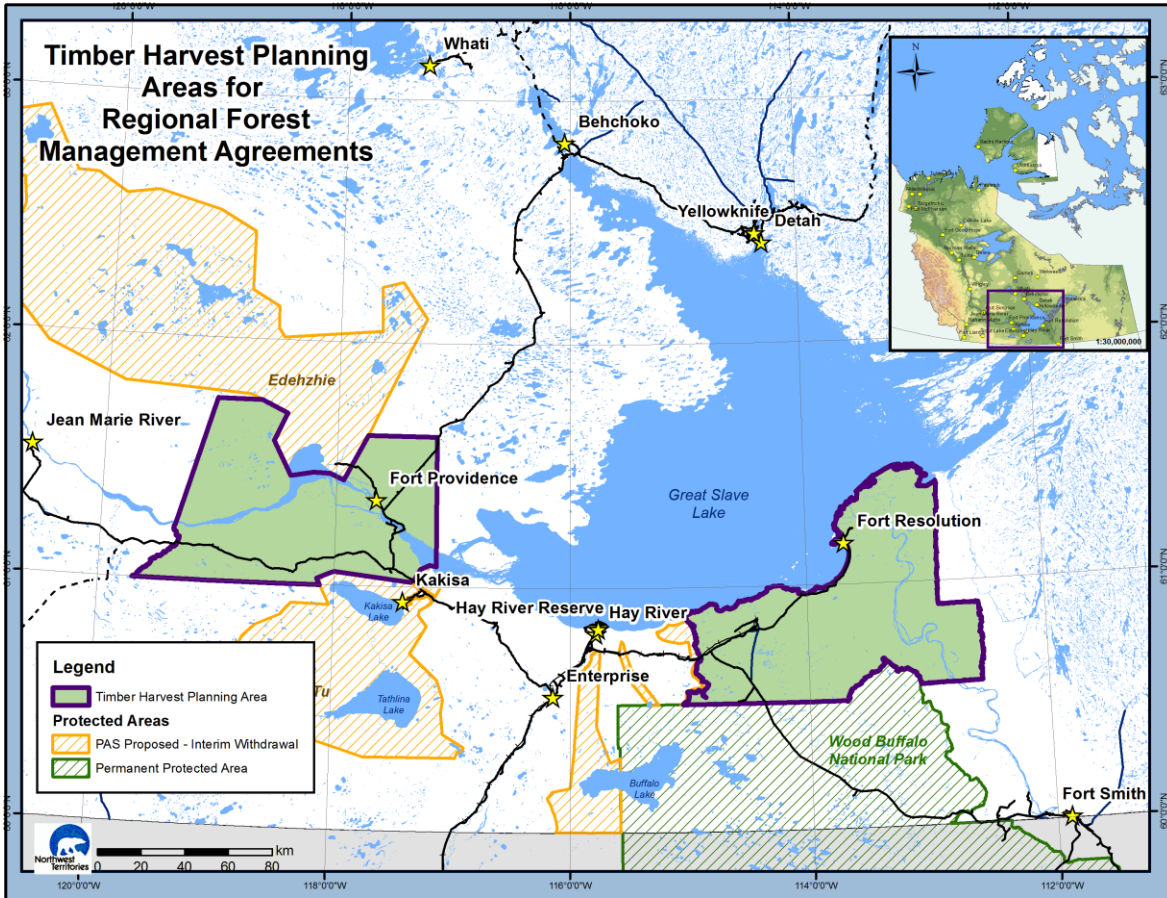
GROUND SOURCE HEAT RESOURCES IN THE NWT

Ground source heat is low temperature warmth found in the ground at relatively shallow depths. The resource is everywhere, but much cheaper to access in softer soils or if holes have already been drilled or dug. Because the temperatures are not warm enough to heat homes or buildings directly, a heat pump is used to “concentrate” the heat energy and produce water hot enough for heating. Heat pumps use electricity, but if the ground temperatures are high enough, they can produce up to 6 times more heat energy than the electrical energy need to run them.

Yellowknife’s Con Mine heat project is a good example where heat pumps could be used to raise the temperature of warm water that had been preheated in the depths of the abandoned mine (this project ran into financial difficulties before final technical studies were completed). Some people have tried drawing cooler water from expensive wells drilled into the bedrock in the Yellowknife area, but the heat pumps required so much electricity and electricity in Yellowknife is so expensive, that they were not economical.

Areas in the South Slave have access to less expensive hydro-electricity, higher thermal gradients and soft soils that are cheaper to excavate, so ground source heat makes the most economic sense in that region.

FORESTRY RESOURCES IN THE NWT



Source: <http://www.enr.gov.nt.ca/programs/forest-resources/forest-management-agreements>

Forest biomass is available throughout the NWT, except on the Beaufort Sea coast. The above map shows some area where timber harvesting agreements have been signed with the local Dene groups. These agreements were developed, in part, to supply a potential wood pellet manufacturing plant in the Hay River area.

EVALUATING RENEWABLE OPTIONS

The previous section has shown that there is no shortage of renewable energy sources in the NWT. The future renewable energy system needs to connect those sources to energy demand – through transportation and transmission networks that get the energy to where it is needed and through storage systems that make it available when it is needed.

The remainder of this report looks at possible renewable energy supply chains, starting with the energy service demand and working back to identify potential renewable energy sources (local or imported). Each energy supply chain option is evaluated based on the criteria and the “report card” is followed by commentary.

ELECTRICITY

There are lots of potential sources for generating renewable electricity in the NWT – both local and imported. Reliable electricity supply is critical in the North. Communities and mines depend on it to keep the furnaces and boilers running during the winter. If the power goes off and stays off for more than a couple of hours, water pipes start to freeze and the damage can become very expensive, very quickly. To ensure this does not happen, all communities are required (by the Public Utilities Board) to have a backup/redundant source of electricity – currently provided by diesel generators.

Backup diesel generators can run until the community runs out of diesel – there is no real time limit. More research is needed on how long backup electricity is required to run to meet the current regulations and what would be a practical limit that would ensure adequate reliability. For example, would battery or pumped storage systems that could run a community for a week in the winter be acceptable?

Assuming that the backup needs to have similar performance to diesel generators, either a backup hydro source, a geothermal plant, or biofuels (wood chips, pellets, biodiesel, ethanol or biogas) would be needed to maintain the required level of redundancy. Wood pellets are probably the easiest bio-fuel to handle and store, but biogas (locally sourced, compressed or liquefied) could be run in existing diesel generators, particularly in those already modified to run on local or liquid natural gas. Where available, locally sourced wood chips, running combined heat and power (CHP) steam turbines or Rankine Cycle² engines, would provide the most local benefits as long as the best pollution controls were used.

As developing a second, fully redundant hydro system would be very expensive and geothermal resources have yet to be physically proven, biofuel powered generators would be the best back-up option. Once a bio-fueled power plant and supply chain is established, adding more capacity would be relatively easy. In these cases, biofuels would become the new diesel – in the sense that if another renewable energy source was cheaper than “the avoided cost of biofuels”, then it would make economic sense to add it to the electricity mix, otherwise, it would make economic sense to run the whole system on biofuels. For example, if the cost local wood chips was lower than the cost of wind energy, it would not make financial sense to put up a wind turbine alongside the wood chip powered generator, but if wind power was cheaper than wood chips, it would make financial sense to build a hybrid system, with wind turbines providing cheaper power when it was windy with the wood chip fired generator being used for back-up.

Community-wide utility scale power generators and distributors are also facing a challenge from small scale power generation. As small scale renewable power production (for example, solar and small

² A Rankine Cycle engine is similar to a steam turbine, except that it operates using a closed loop using a fluid that gasifies at a lower temperature than water/steam. Steam systems operate at high pressures and the potential for explosions mean they are highly regulated and the required steam engineers are expensive. Rankine engines do not operate at high pressure, and do not require steam engineers, but are also less efficient.

biomass based on combined heat and power units) becomes more competitive, the demand for power from the public utility will decrease. Decreased demand means that the fixed costs will be spread over reduced electricity sales, pushing the cost of power higher and encouraging more customers to start generating their own power. The role of a utility may shift to providing a reliable back-up to and temporary storage for privately produced power through its distribution network. As society adapts to this new reality, it will be necessary to ensure the utility remains financially viable while making the best use of renewable energy resources.

ELECTRICITY - NORTH SLAVE GRID

The Snare and Bluefish hydro systems provide a local renewable energy source that meets 95% of current needs of the North Slave grid, except during low water years – as has been recently experienced. Regulations require that, a 105% backup system be maintained in Yellowknife in case the Snare system becomes unavailable. The only locally available renewable energy sources that could provide the required 105% back-up capacity to the Snare Hydro line and produce renewable electricity to make up for shortfalls during low water years is locally harvested wood biomass or perhaps biogas generated from organic waste and captured from the landfill.

EVALUATION OF OPTIONS – TABLE - NORTH SLAVE ELECTRICITY

Option (Full Supply Chain)	Technical Viability	Handle New Demand?	Cost	Human Health	NWT Employment	Community Self- Sufficiency	Other Env. Impacts
Solar PV	NEGATIVE	NEUTRAL	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Wind	NEGATIVE	NEUTRAL	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	NEUTRAL
New Hydro-Electric Generator	POSITIVE	POSITIVE	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Hydro-Electric - Storage	POSITIVE	POSITIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Transmission line to Taltson, SK or AB grid	POSITIVE	POSITIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Geothermal Power (Steam)	NEGATIVE	POSITIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Geothermal Power (Low Temp)	NEGATIVE	POSITIVE	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Local wood chips / pellets	POSITIVE	POSITIVE	NEUTRAL	NEGATIVE	POSITIVE	POSITIVE	NEGATIVE
Imported wood pellets - steam / Rankine engine	POSITIVE	POSITIVE	NEUTRAL	NEUTRAL	NEGATIVE	NEGATIVE	NEUTRAL

Option (Full Supply Chain)	Technical Viability	Handle New Demand?	Cost	Human Health	NWT Employment	Community Self- Sufficiency	Other Env. Impacts
Imported wood pellets - gasification	POSITIVE	POSITIVE	NEUTRAL	NEUTRAL	NEGATIVE	NEGATIVE	NEUTRAL
Local Biogas	NEUTRAL	NEUTRAL	NEUTRAL	NEGATIVE	POSITIVE	POSITIVE	POSITIVE
Imported Compressed Biogas	NEGATIVE	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE
Imported Liquid Biogas	POSITIVE	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE
Imported Bio-diesel B100	NEUTRAL	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL
Imported Ethanol ED95	NEGATIVE	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL

EVALUATION OF OPTIONS – NORTH SLAVE ELECTRICITY – DISCUSSION

According to a recent review by Manitoba Hydro, The North Slave Hydro-electric system does not get enough precipitation to meet current demands of 195 GWh per year in ~10% of the years. In the remaining 90% of the years, there is more energy available than is needed. Diesel generators are used to meet the 10% shortfall, with the highest requirement in 2015 of 69 GWh. Diesel generators are also used to meet the requirement to have a 105% back-up (33 MW)¹⁸ in case the Snare transmission line is broken or during maintenance. In that role, they produced an average of 7.2 GWh per year since 2011.

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The Manitoba Hydro study shows that adding 80 GWh in additional loads would make use of available hydro in higher water years, but that, over time, one third of that additional electricity would need to come from the backup diesel generators. Electric cars, other forms of local electric transport, domestic hot water heating, electric space heating or ground source heat pumps drawing heat from Con Mine could make use of the excess hydro electricity, but for the system to be 100% renewable, an alternative to diesel fired generators would be needed.²⁰

NTPC does have a “load-shedding” agreement with the Giant Mine project that allows it to cut-off power to Giant Mine if NTPC needs extra power. This agreement reduces the requirement for backup capacity. It should be possible to further reduce the requirement for back-up if these types of agreements were expanded. With modern communications, it should be possible to automatically shut off non-essential power demand when the system is running in backup mode. For example, in a residence, the water circulation pump, furnace or boiler, and a couple of lighting circuits & plugs could be wired into a “back-up” circuit, while electric hot water heaters, cooking stoves, electric vehicles and other non-essential circuits could be wired so they could be shut off with a signal from the power plant. This would significantly reduce the cost of maintaining back-up capacity, but would require discussions with the public to see if they were willing to accept that type of change in service in exchange for lower power costs.

Software modelling shows that installing 70 MW of solar PV would generate roughly 70GWh²¹ of renewable electricity – the same amount that was generated by diesel due to low water levels in 2015. At 15W per square foot, this would require roughly 110 acres of solar panels or at 5kW per rooftop, 14,000 roof-top systems. Local environmental impacts would be reduced if the panels could be located on land that had already been cleared of trees – such as the area around the Con Mine. In low-water years, the solar electricity would allow the Snare reservoir to re-fill during the summer, which could eliminate the need to run the diesel generators. However, it would result in more spillage of water during normal and high water years. Solar could be used to power new loads but solar power availability is lowest in winter when most new loads would be at their peak. For these reasons, solar is not suitable to provide backup capacity.

A study by NTPC showed that installing 30 MW of Wind power would also generate roughly 70 GWh²² of renewable electricity with similar effects on water spillage as would be experienced adding solar. Ten 3 MW turbines would provide this capacity requiring land to be cleared for each base and an access road to be built. It is estimated that wind turbines kill one bird per year. At high elevations, wind may be stronger in the winter, which is better matched to new loads than solar. Wind also does not meet the minimum requirements to be considered adequate backup capacity.

Adding hydro generation capacity, such as up to 13 MW at Lac La Martre or 20 MW on the Snare system would reduce or eliminate the need to run diesels during low water years. As with the wind and solar options, this would result in significant over-capacity in normal and high water years. Some new loads could be powered by this new capacity – especially if these new systems included significant amounts of storage. Since those hydro options are on the same Snare hydro line, and interruptions on the Snare line are often the cause for power outages in Yellowknife, they would not eliminate the need for a back-up system in Yellowknife.

Adding seasonal hydro storage (increasing capacity to hold water in a reservoir, without adding more generators) could eliminate reliance on diesel during low water years – if enough storage could be added to the Snare system. The recent study by Manitoba Hydro estimates that 30 GWh of storage is possible on the Snare system at Ghost Lake,²³ but even that would not be enough to replace the low flow that occurred in 2015. If more storage could be created, extra hydro power could be generated in high water years to power new loads. Again, adding storage on the Snare system would use the same transmission line and would not eliminate the need for a back-up system in Yellowknife. More research is needed to determine if potential for more storage exists.

Pumped storage (where water is pumped into a reservoir at a higher elevation, when there is excess electricity available) could also be used to provide extra capacity in low water years. If the pumped storage was connected to Yellowknife on a different power line, it could assist with providing back-up power, if there was a problem on the Snare line, but it would eventually run out of water and therefore might not be an adequate back-up source. It would also be more expensive than adding storage to the current system because additional pumps/generators would be needed. If large enough, however, pumped storage could be used to supply new loads as well. More research would be required to identify a suitable location for pumped storage.

The GNWT has researched the possibility of building power lines from the Taltson hydro power facility near Fort Smith to the Snare hydro system and connecting the Taltson system to the Saskatchewan or Alberta provincial grids. The transmission line around Great Slave Lake was found to be too expensive, but this was in comparison to the current fossil fuel based system. When compared to other renewable energy options, a transmission line could be an economically competitive option. The Taltson hydro system has excess power and there is the potential to expand the system. The expanded system would require some local flooding in the Taltson watershed but would offer enough power to make up for low water years on the North Slave grid, and power additional loads such as electric vehicles, domestic hot water, ground source heat pumps at the Con Mine in Yellowknife plus new nearby mines. Depending on

where the transmission line connected to the Snare system, it could also eliminate the requirement for back-up diesel generators in Yellowknife.

Power imported from Saskatchewan or Alberta is not a 100% renewable power source as both provinces generate electricity with coal fired generators. These will be phased out as the rest of Canada switches over to renewable energy, but this report focuses on renewable energy sources that are commercially available at the time of writing.

If a transmission line were run around the west end of Great Slave Lake, it would pass over one of the areas identified as having a high potential to generate geothermal power.

If one drills deep enough into the earth, the rocks become hot enough to produce steam, which can be used to generate electricity. A 2013 study by Natural Resources Canada²⁴ estimated that 150 deg C water could be found at a depth of 5km in the Yellowknife area. The structure of Canadian Shield rock makes it unlikely that a reservoir of hot water could be found. The same study estimated that Enhanced Geothermal (EGS) techniques could be used to inject water into the hot rocks at a depth of 6km and produce 250kW of electricity at a cost of \$0.20 to \$1.00/ kWh in Yellowknife. The sedimentary rocks between Behchoko and Fort Providence are estimated to be hotter and have a greater chance of containing water reservoirs. The North Slave grid does extend into the northern tip of this region, where power production costs are estimated at \$0.10/kWh at a depth of 6km. However, the power-line from Behchoko connects to the Snare hydro line, so running geothermal power through this line would not meet the requirement for back-up. These cost and resource estimates are very preliminary, based on a few relatively shallow wells. More research is needed before this option could be considered “commercially available” in the same sense as other renewable options such as wind, solar, biofuels or hydro.

Low temperature geothermal heat using ground temperatures less than 150 deg C can generate electricity using Rankine cycle engines. As mentioned above, the Canadian Shield rocks around Yellowknife are not ideal, but the sedimentary rocks between Behchoko and Fort Providence show more potential with power production costs estimated to be \$0.40 - \$0.60 /kWh at depths of 3-3.5 km. The low working temperatures result in relatively low efficiencies in producing electricity, so the process would result in large amounts of warm water. As mentioned above, these estimates are preliminary and more research would be needed to consider this option as “commercially available” as other options.

Geothermal power generation involves deep drilling and so there is potential for contamination of groundwater, depending on the local geology. As it is a steady source of power, it would be very suitable to powering new electric loads.

The requirement for 33 MW of backup capacity for the Snare Hydro line could be met using locally sourced wood chips and a steam boiler and turbine. A 33 MW back-up plant could also provide power during low water years and an even larger plant would allow new power loads to be added. Using steam to generate electricity is a mature technology, as is producing steam by burning wood chips²⁵.

The heat remaining after power production could be used to heat homes and buildings. Steam technology is highly regulated. Requirements to have certified power engineers on-site at all times add to the cost of steam powered systems. There is a large forest resource along the highway from Fort Providence to Yellowknife, and harvesting this wood for power production would produce more local jobs than other renewable energy options. Burning wood produces more local air emissions than other renewable energy sources, but these can be controlled with appropriate emission technology, such as modern boiler controls, and exhaust scrubbers cyclones.

Commercially available²⁶ Rankine cycle engines could generate electricity from local wood using hot water instead of steam, but their lower electricity production efficiency would require a much larger boiler to produce the required 33 MW of back-up power.

As mentioned above, a biomass boiler and steam turbine or a Rankine engine could meet all requirements to bring the Snare system up to 100% renewable energy. The same boiler could be fired with wood pellets if local wood chips were not available. Locally produced wood chips are typically cheaper, but they are not as “energy dense” as liquid fuels or wood pellets. This means that it would require more trucks to supply the same amount of energy in the form of wood chips. A general rule of thumb is that wood chips should be sourced from within a 100km radius to be economically competitive, but there is no technical reason why chips could not be transported from further away. Wood pellets are made of compressed saw dust and are more energy dense than wood chips, but it still takes roughly double the number of transport trucks to move the same amount of energy in wood pellet form as in liquid form. Wood pellets would not have the same local benefits for local employment, as wood chips, unless they were produced in the NWT.

People have been generating power using gasified wood for many years, but the systems have never been very reliable because the wood gases contain tars and gum up internal combustion engines, requiring frequent cleaning and maintenance. There are gasifiers under development that produce cleaner wood gases, but more research is needed to find one that is commercially available. One promising option, available in Germany, is to gasify wood pellets, which are much cleaner than cord wood or wood chips²⁷. The German units are available as 180kW combined heat and power units so they could be installed at larger buildings, providing renewable heat and back-up power capabilities at the same time. Around 160 of these units would be needed to fill the full back-up requirement.

Biogas could be produced by capturing it from local landfills and/or anaerobic digestion of local organic waste (instead of composting). It would be possible to store the biogas and use it as a fuel for the existing back-up diesel generators at the Jackfish power plant. The City of Yellowknife is introducing a curbside organic waste collection program. The current landfill is due to be closed and could be capped to capture the methane. The City is also planning a new sewage treatment facility that could generate biogas. Capturing and generating local biogas would create local employment and would generate additional environmental benefits in that gases captured from the landfill would reduce local methane emissions and the solids produced by the bio-digester could be used as a soil amendment (similar to compost). More research is needed to determine the scale of the local resource.

Biogas could be imported in either compressed or liquid form. The recent installation of a Liquid Natural Gas (LNG) terminal at the power plant in Inuvik shows these technologies work in the NWT. There are already proposals to import LNG to run the Jackfish power plant. It would be relatively simple to replace fossil natural gas with biogas. Local air quality would improve as methane burns more cleanly than other biofuels. Biogas could also be used to power new loads, but it would often be more efficient to use biogas directly at the point of use (for example in biogas powered vehicles or water heaters). Currently, there are very few natural gas liquefaction plants within a reasonable distance of Yellowknife and more research is needed to determine if any of them have a biogas supplier.

The NWT Power Corporation commissioned a study on liquid biofuels in 2007²⁸. It found that NTPC's current generators can only use fuel blended to include up to 30% biofuel with regular diesel (B30). Some new diesel engines can run on 100% biodiesel (B100), so, as the generators age and are replaced, the transition to B100 generators would not be that much more expensive. There are significant problems with cold temperature flow of biodiesel and with long term stability which could be improved by designing heated storage tanks and protecting the fuel from oxidation (perhaps with nitrogen blankets). As Yellowknife is on an all-weather highway, problems with long-term storage could be dealt with by re-supplying fuel more often. B100 burns cleaner than regular diesel. Biodiesel can be made from waste vegetable oil, various plant based oils, and even algae. The net-environmental impact of various feedstocks varies significantly. For example palm-oil based biodiesel has been accused of contributing to deforestation in some countries, while bio-diesel from waste-oil sources is considered to have little local environmental impact.

The NTPC study also looked at ethanol, but not in as much detail as biodiesel. Ethanol can be used in both spark-ignition engines and modified diesel engines. Although not mentioned in the NTPC report, a formulation known as ED95 is used in Sweden and several other countries to power modified diesel buses²⁹. ED95 is considered a 100% renewable energy source because even "pure" ethanol contains 5% water. E85 ethanol (15% gasoline) exhibits starting problems at temperatures below 0 deg C, but this is less of an issue with ED95 and should not be an issue for stationary generators inside heated power plants. As with biodiesel, the environmental impact of ethanol depends on the feedstock from which it is sourced. More research is needed to determine if ED95 is available in Canada and what modifications would be needed to allow it to be run in the existing diesel generators in Yellowknife.

ELECTRICITY – SOUTH SLAVE GRID

EVALUATION OF OPTIONS – SOUTH SLAVE ELECTRICITY – TABLE

Option (Full Supply Chain)	Technical Viability	Handle New Demand?	Cost	Human Health	NWT Employment	Community Self-Sufficiency	Other Environmental Impacts
Solar PV	NEGATIVE	NEUTRAL	NEGATIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE
Wind	NEGATIVE	NEUTRAL	NEGATIVE	NEUTRAL	POSITIVE	POSITIVE	NEUTRAL
New Hydro-Electric Generator	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Hydro-Electric - Storage	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Transmission line to SK or AB grid	POSITIVE	POSITIVE	NEGATIVE	NEUTRAL	POSITIVE	NEUTRAL	NEGATIVE
Geothermal Power (Steam)	NEGATIVE	POSITIVE	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Geothermal Power (Low Temp)	NEGATIVE	POSITIVE	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Local wood chips / pellets	POSITIVE	POSITIVE	NEGATIVE	NEGATIVE	POSITIVE	POSITIVE	NEGATIVE

Option (Full Supply Chain)	Technical Viability	Handle New Demand?	Cost	Human Health	NWT Employment	Community Self-Sufficiency	Other Environmental Impacts
Imported Wood pellets - steam / Rankin engine	POSITIVE	POSITIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE	NEUTRAL
Imported Wood pellets - gasification	POSITIVE	POSITIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE	NEUTRAL
Local Biogas	NEUTRAL	NEUTRAL	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Imported Compressed Biogas	NEGATIVE	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE
Imported Liquid Biogas	POSITIVE	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE
Imported Bio-diesel B100	NEUTRAL	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL
Imported Ethanol ED95	NEGATIVE	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL

EVALUATION OF OPTIONS – SOUTH SLAVE ELECTRICITY – DISCUSSION

The 8-12 MW of power demand in the South Slave region is supplied from the Taltson Hydro system. Approximately 50% of its available energy is not used, meaning that, even in low water years, there is capacity in excess of demand. The Taltson system follows the same PUB requirements for back-up in case the transmission lines go down, so there are backup diesel generators in Fort Smith, Hay River and Fort Resolution. To produce 100% renewable electricity a replacement would be needed for those back-up diesels.

All the options discussed for the North Slave grid could be used in the South Slave with the following considerations:

- Solar & wind would not increase the amount of renewable electricity (which is already at 100%) until all the existing hydro capacity is used,
- Geothermal power generation is estimated as having some potential in the extreme west end of the current South Slave grid,
- Wood chips or pellets burned in steam or Rankine engines could provide back-up to replace the diesels,
- The back-up diesel generators could be modified to burn biogas or, as they age and are replaced, new diesels could be made compatible with biodiesel B100 and/or ethanol ED95,
- Current hydro power is relatively affordable, at least in Fort Smith, which makes the other options less attractive economically.

There are proposals to expand the Taltson system and/or build a much larger hydro system on the Slave River, with the intention of transmitting the power over power lines to mines or other communities. Depending on the configuration of the power lines, this could eliminate the need for back-up diesel generators in Fort Smith. The current excess capacity and some of the potential new capacity could be used to meet energy demands that are currently being met with fossil fuels – such as heating and transportation. These options will be examined in the heating and transportation sections.

ELECTRICITY – THERMAL ZONE

EVALUATION OF OPTIONS – THERMAL ZONE – TABLE

Option (Full Supply Chain)	Technical Viability	Handle New Demand?	Cost	Human Health	NWT Employment	Community Self-Sufficiency	Other Environmental Impacts
Solar PV	NEGATIVE	NEUTRAL	NEGATIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE
Wind	NEGATIVE	NEUTRAL	NEGATIVE	NEUTRAL	POSITIVE	POSITIVE	NEUTRAL
New Hydro-Electric Generator	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Hydro-Electric - Storage	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Transmission line to SK or AB grid	POSITIVE	POSITIVE	NEGATIVE	NEUTRAL	POSITIVE	NEUTRAL	NEGATIVE
Geothermal Power (Steam)	NEGATIVE	POSITIVE	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Geothermal Power (Low Temp)	NEGATIVE	POSITIVE	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Local wood chips / pellets	POSITIVE	POSITIVE	NEGATIVE	NEGATIVE	POSITIVE	POSITIVE	NEGATIVE

Option (Full Supply Chain)	Technical Viability	Handle New Demand?	Cost	Human Health	NWT Employment	Community Self-Sufficiency	Other Environmental Impacts
Imported Wood pellets - steam / Rankin engine	POSITIVE	POSITIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE	NEUTRAL
Imported Wood pellets - gasification	POSITIVE	POSITIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE	NEUTRAL
Local Biogas	NEUTRAL	NEUTRAL	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Imported Compressed Biogas	NEGATIVE	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE
Imported Liquid Biogas	POSITIVE	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE
Imported Bio-diesel B100	NEUTRAL	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL
Imported Ethanol ED95	NEGATIVE	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL

EVALUATION OF OPTIONS – THERMAL ZONE – DISCUSSION

The “thermal zone” is a term used by the utilities and the public utilities board to refer to communities where hydro power is not available and electricity is generated with diesel or natural gas powered generators. These communities are much more diverse in terms of renewable resources and logistics than the two hydro zones.

There are several key factors that influence which renewable energy sources are available to communities in the thermal zone:

- All weather road vs. winter road / barge access only,
- Proximity to NWT forest resources,
- Geothermal potential
- Proximity to a good wind resource
- Proximity to a hydro line, local hydro resource or location suitable for pumped storage

The wide variety of possible combinations of the above factors means that the most appropriate solution could be different for each community.

Thermal zone communities are required to maintain enough separate diesel generators that 110% of the load can be met even if the largest generator is not working. As in the North and South Slave grids, this means that all renewable electricity systems need to be designed with required back-up.

In general, all the options discussed for the North and South Slave grids could be used in thermal zone communities with the following considerations:

- Solar and wind would increase the amount of renewable energy available but would need pairing with a suitable renewable energy powered back-up generator to get to 100% renewable electricity,
- Hydro power options with lengthy transmission lines would still need a back-up power source, unless two separate hydro systems could be developed with separate transmission lines
- Geothermal power resources are estimated to be more available in the Deh Cho region; as with hydro, they would need a backup,
- Wood chips or pellets could provide regular and backup power to replace the diesels in all communities. Communities without all season roads would need larger, seasonal storage silos, but these have already been demonstrated in Norman Wells,
- Steam boilers and turbines are better suited to the larger loads found in the regional centres,
- Rankine Cycle engines can supply smaller loads as can wood pellet gasifying engines,
- Existing community diesel generators could be modified to burn Biogas or, as they age and are replaced, new diesels could be made compatible with biodiesel B100 and/or ethanol ED95. More research is needed on long term storage of bio-diesel in communities without road access,

ELECTRICITY – REMOTE MINES

EVALUATION OF OPTIONS – REMOTE MINES – TABLE

Option (Full Supply Chain)	Technical Viability	Handle New Demand?	Cost	Human Health	NWT Employment	Community Self-Sufficiency	Other Environmental Impacts
Solar PV	NEGATIVE	NEUTRAL	NEGATIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE
Wind	NEGATIVE	NEUTRAL	NEGATIVE	NEUTRAL	POSITIVE	POSITIVE	NEUTRAL
New Hydro-Electric Generator	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Hydro-Electric - Storage	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Transmission line to Taltson	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Geothermal Power (Steam)	NEGATIVE	POSITIVE	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Geothermal Power (Low Temp)	NEGATIVE	POSITIVE	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	NEGATIVE
Local wood chips / pellets	POSITIVE	POSITIVE	NEGATIVE	NEGATIVE	POSITIVE	POSITIVE	NEGATIVE

Option (Full Supply Chain)	Technical Viability	Handle New Demand?	Cost	Human Health	NWT Employment	Community Self-Sufficiency	Other Environmental Impacts
Imported Wood pellets - steam / Rankin engine	POSITIVE	POSITIVE	POSITIVE	NEUTRAL	POSITIVE	NEGATIVE	NEUTRAL
Imported Wood pellets - gasification	POSITIVE	POSITIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE	NEUTRAL
Local Biogas	NEUTRAL	NEUTRAL	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Imported Compressed Biogas	NEGATIVE	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE
Imported Liquid Biogas	POSITIVE	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE
Imported Bio-diesel B100	NEUTRAL	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL
Imported Ethanol ED95	NEGATIVE	POSITIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL

EVALUATION OF OPTIONS – REMOTE MINES – DISCUSSION

While the North and South Slave hydro-electric systems were originally developed to serve mines, none of the currently operating mines in the NWT are connected to hydro power. With the exception of Diavik that has 9.2 MW³⁰ of wind power; all NWT mines generate their electricity with diesel generators. This makes them similar to the “Thermal Zone” communities, but usually with larger power demands.

The same factors influence which renewable energy sources are available to them:

- All weather road vs. winter road / barge access only,
- Proximity to NWT forest resources,
- Proximity to geothermal resources,
- Proximity to a good wind resource,
- Proximity to a hydro line, local hydro resource or location suitable for pumped storage

The wide variety of possible combinations of the above factors means that the most appropriate solution could be different for each mine.

Mines are private power generators and not required to maintain a specific amount of backup. However, the mines rely on electricity to function, so they do not want to risk losing power for any length of time. As in the North and South Slave grids, this means that all renewable electricity systems need back-up.

In general, all the options discussed for the North and South Slave grids could be used in remote mines with the following considerations:

- Mine life spans can vary from a few years to a few decades so, unlike communities, most power systems will not be replaced during the life of the mine. As new mines are built, it is important to install the renewable energy systems from the start, as it will be far less economical to switch power system when only a few years are left in a mine,
- While mines are not required to maintain a 110% back up capacity, mines are most profitable when running at full capacity, which requires a reliable source of electricity. Mines are better able to manage (i.e shut-down) non-critical loads, but some level of back-up would still be required,
- Solar and wind would increase the amount of renewable energy available but would require pairing with a suitable renewable energy powered back-up generator to get to 100% renewable electricity,
- The cost of running a hydro line from an expanded Taltson hydro facility would be more affordable if the cost could be spread over the full life of a mine (or mines),
- Geothermal power resources, as with hydro, would need a backup,
- Wood chips or pellets could provide regular and backup power to replace the diesels in all the mines. Mines without all season roads would need larger, seasonal storage silos, but these have already been demonstrated in Norman Wells,

- Steam boilers and turbines are better suited to the larger loads found in most mines,
- Rankine Cycle engines can supply loads of any size?
- Wood pellet gasifying generators are better suited to smaller loads,
- Existing mine diesel generators could be modified to burn Biogas.
- New diesel generators could be made compatible with biodiesel B100 and/or ethanol ED95. More research is needed on long term storage of bio-diesel in mines without all-season road access.

AIR TRANSPORT

Air transport is the most challenging energy demand to meet with 100% renewable energy. Flying requires an energy dense fuel and requires a higher degree of reliability. There is global push to find alternatives to jet-fuel, but the degree of “commercial availability” is not as advanced as in other sectors.

NOT COMMERCIALY AVAILABLE

The following options may be able to use renewable energy sources to meet air travel demands in the NWT, but they are not commercially available and therefore not evaluated in more detail.

Local sources of renewable energy

1. Electric battery powered airplanes charged from locally generated renewable electricity – solar, wind or hydro. Electric propeller driven aircraft have been commercially available since the 1990s, but are still limited in range and capacity and are not capable of carrying more than 2 people.^{31 32}
2. Electric jet turbine driven aircraft driven by hydrogen fuel cells are being investigated by Airbus³³ and Elon Musk (founder of Tesla Motors and SpaceX) is considering developing a battery powered electric jet³⁴. Neither is commercially available.
3. Airships and other lighter than air vessels powered by on-board solar panels and/or batteries. Airships powered by any form of energy and capable of operating between inhabited areas in the NWT are not commercially available. Lockheed Martin has announced a deal to sell 12 heavier than air airships, powered by fossil fuels, with the first delivery taking place in 2018³⁵. The purchasing company has said they see Canada’s north as a zone of operation for them. The large surface area on an airship could be covered in flexible solar panels if they were light enough, but there would still be a need for energy to be stored on-board for cloudy days. A Solar powered heavier than air airship is being developed in Canada but they are still in the prototype stage³⁶.

Imported sources of renewable energy

1. Compressed or Liquid Biogas is methane - chemically the same as natural gas, but sourced from anaerobic digestion of organic matter. Any technology that runs on natural gas should also be able to run on biogas, as long as the biogas is not contaminated.

Boeing did a conceptual study for NASA that studied the possibility of a Liquid Natural Gas (LNG) fuelled jet aircraft with advanced aerodynamics and engines that resulted in a system that was 60% more fuel efficient than a 737-800. The LNG storage tanks would require significant modifications to the structure of the aircraft.³⁷ LNG has been demonstrated in both piston

(Beechcraft) and turbine powered (Russian Tupolev) airplanes in the 1980s³⁸, but no such system is currently commercially available.

Aviat aviation in the US has produced a demonstration version of a piston engine powered plane that can run on both AvGas 100LL and compressed natural gas (CNG).³⁹

Biogas has significant potential in the NWT because it does not have the issues that bio-jet fuel has with cold temperatures and degradation over time (see the following discussion on bio-jet fuel). Methane is, however, a potent greenhouse gas and storage systems would need to be absolutely leak-proof. More research is recommended.

2. Aviation Gas Ethanol – 85% (AGE85) is a replacement for AvGas 100LL that contains 85% ethanol. AVGas 100LL has a maximum lead content of 2 g/gal yet it is still the highest source of lead emissions in the United States. Lead is considered a health hazard in any quantity, especially for children, where it can cause brain development issues. It is used in planes with piston engines to prevent “knocking”. 100LL will be phased out in the near future, which presents an opportunity to switch to a renewable fuel source as there will be a fuel switch happening anyway. Many piston engine aircraft can be certified to run on lead-free automotive gasoline, which although lead free, is not a renewable energy fuel.⁴⁰

Many existing engines could be upgraded to run on AGE-85. This would require similar modifications as would be required to adapt an automotive engine to run on 85% ethanol such as replacing fuel lines and seals that can be damaged by ethanol. Additionally the entire fuel delivery system from refinery to aircraft would need to be upgraded to ensure water does not contaminate the fuel (which can freeze and block fuel lines).⁴¹ AGE85 is not a 100% renewable energy fuel and is not commercially available.

COMMERCIALLY AVAILABLE - TABLE

The following options may be able to use renewable energy sources to meet air travel demands in the NWT, and they are commercially available and therefore evaluated in more detail.

Option (Full Supply Chain)	Technical Viability	Cost	Human Health	NWT Employment	Environmental Impacts
100 % Bio Jet Fuel – all season road from Alberta	NEUTRAL	NEUTRAL	NEUTRAL	NEUTRAL	NEUTRAL
100% Bio-Jet Fuel – seasonal re-supply	NEGATIVE	NEUTRAL	NEUTRAL	NEUTRAL	NEUTRAL

COMMERCIALLY AVAILABLE - DISCUSSION

Bio - Jet Fuel produced from renewable feedstocks is commercially available and in use at blends of up to 50% with regular Jet Fuel.

Jet fuels produced from renewable feedstock have been available for several years. Alaska Airlines is flying regularly scheduled flights using 20% bio-jet fuel⁴² and SAS has signed a contract for a regular supply of 50% bio-jet-fuel at the Oslo airport.⁴³ While most bio-jet fuels are a mixture of up to 50% bio-fuel and fossil fuel based kerosene, the National Research Council of Canada flew a civilian jet with 100% bio-jet fuel in 2012⁴⁴ and a private company flew a military training jet using 100% bio-diesel in 2008.⁴⁵

Bio-jet fuel and bio-diesel are fairly similar and therefore face similar challenges. Two of the main issues with 100% bio-diesel are stability over time and cold temperature performance. Saturated feedstocks like palm oil produce bio-diesel with poor cold temperature performance, but are more stable. Unsaturated feedstocks produce bio-diesel with better cold temperature performance, but they oxidise and go rancid more quickly. Cold temperatures slow down oxidisation, but it is not clear by how much⁴⁶. In communities with all season roads, bio jet fuel, modified for cold temperatures, could be supplied in smaller batches to prevent issues with the fuel degrading over time.

More research is needed on bio-jet fuels that do not gel at temperatures below minus 40 deg C and can be stored for several years without degrading.

Bio-jet fuel is designed to replace regular jet fuel, which is used in all jet aircraft in the NWT, plus in Twin Otters, most helicopters and other “turbo-prop” aircraft. Smaller piston engine aircraft typically run on Aviation Gasoline - 100LL that cannot be directly replaced with bio-jet fuel (see earlier discussion on AGE85 & AVGAS 100LL). Some piston engine planes have had new “diesel” piston engines installed that could run on bio-jet -fuel⁴⁷.

In terms of comparing one option against another, bio-jet fuel is the only option that is commercially available, so all evaluations are scored “NEUTRAL”.

IN-TOWN TRANSPORT

Two broad categories of vehicles could meet transportation demand within NWT communities – electric, powered from renewable electricity or biofueled, running with internal combustion engines.

Travel distances within NWT communities are relatively short and populations are small compared with larger urban centres. The small populations make electrified mass transit systems difficult to justify, but

the shorter distances mean that personal electric vehicles already have the range to meet daily transportation demands – even when cold temperatures reduce the capacity of batteries.

The previous section on electricity shows that there are numerous options for generating additional renewable electricity that would be required to power electric vehicles. This section assumes that the community has already switched to 100% renewable electricity. Whether it makes sense to use that electricity to power vehicles depends on what is available in each community. In general, if a community is generating most of its electricity from liquid biofuels or biogas and it is making use of the waste heat from those power plants, it would probably be more efficient to use electric vehicles.

EVALUATION OF OPTIONS – IN TOWN TRANSPORT - TABLE

Option (Full Supply Chain)	Technical Viability	Cost	Human Health	NWT Employment	Community Self- Sufficiency	Other Environmental Impacts
Electric vehicle – Hydro	POSITIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Electric vehicle – Solar	NEGATIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Electric vehicle – Wind	NEGATIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Electric – Geothermal	NEGATIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Electric vehicle – wood chips / pellets	POSITIVE	NEUTRAL	NEUTRAL	POSITIVE	POSITIVE	NEUTRAL
Local Biogas	NEUTRAL	POSITIVE	NEUTRAL	POSITIVE	POSITIVE	NEUTRAL
Imported Compressed Biogas	NEUTRAL	POSITIVE	NEUTRAL	NEUTRAL	NEGATIVE	NEUTRAL
Imported Liquid Biogas	NEGATIVE	POSITIVE	NEUTRAL	NEUTRAL	NEGATIVE	NEUTRAL
Imported Bio-diesel B100	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE
Imported Ethanol E100	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE

Option (Full Supply Chain)	Technical Viability	Cost	Human Health	NWT Employment	Community Self- Sufficiency	Other Environmental Impacts
Imported Ethanol ED95	NEUTRAL	NEGATIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE

EVALUATION OF OPTIONS – IN TOWN TRANSPORT - DISCUSSION

Renewable electricity options and biofuels options for internal combustion engines are discussed in more detail in the electricity section. Considerations related to vehicles are:

- Electric vehicles are much more efficient than internal combustion engine powered vehicles. Even if electricity is more expensive than biofuels, it could still be cheaper on a per km basis to use electricity,
- Battery prices are coming down quickly, but electric vehicles are still more expensive than bio-fuelled vehicles,
- Solar and wind electricity can be used to power electric vehicles, but need seasonal storage or other renewable energy sources to ensure enough energy is available when it is needed,
- Biogas burns cleaner than diesel or gasoline, but electric vehicles using hydro, solar or wind would produce zero emissions, which would be positive benefits for the local environment and human health,
- Wood burning central power plants powering electric vehicles might produce relatively low levels of local pollution compared to vehicles that burned bio-fuels in an on-board engine because they have the space to install pollution control equipment that might not fit on each vehicle,
- Biodiesel (B100) and ethanol-diesel (ED95) burn cleaner than regular diesel, but still produce more emissions than biogas,
- Larger vehicles, such as trucks, can be converted to run on liquefied methane (and therefore could also run on liquefied biogas), but more research is needed on whether it is feasible to store liquefied methane on smaller passenger vehicles,
- Compressed natural gas vehicles are common and could just as easily burn biogas,
- Biodiesel B100 has cold flow and long term storage concerns that require more research,
- 100% E100 ethanol is used widely in Brazil, but may have issues with absorbing water that may lead to ice in fuel lines. Pure ethanol has cold-starting problems below zero deg C – more research is needed,
- ED95 ethanol is used in buses in Sweden, but more research is needed to confirm that it can work at the extremely low NWT temperatures and whether it is available in North America

LONG DISTANCE, GROUND BASED TRANSPORT

The following options may be able to use renewable energy sources to meet long distance passenger travel and goods transport demands in the NWT, and they are commercially available and therefore evaluated in more detail.

EVALUATION OF OPTIONS – LONG DISTANCE TRANSPORT - TABLE

Option (Full Supply Chain)	Technical Viability	Cost	Human Health	NWT Employment	Community Self-Sufficiency	Other Environmental Impacts
Electric vehicle – Battery	NEGATIVE	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Electrified Highway / Railway	NEGATIVE	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Local Biogas	NEUTRAL	POSITIVE	NEUTRAL	POSITIVE	POSITIVE	NEUTRAL
Imported Compressed Biogas	POSITIVE	POSITIVE	NEUTRAL	NEUTRAL	NEGATIVE	NEUTRAL
Imported Liquid Biogas	POSITIVE	POSITIVE	NEUTRAL	NEUTRAL	NEGATIVE	NEUTRAL
Imported Bio-diesel B100	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE
Imported Ethanol E100	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE

Option (Full Supply Chain)	Technical Viability	Cost	Human Health	NWT Employment	Community Self- Sufficiency	Other Environmental Impacts
Imported Ethanol ED95	NEUTRAL	NEGATIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE

EVALUATION OF OPTIONS – LONG DISTANCE TRANSPORT - DISCUSSION

While distances inside NWT communities are relatively short, the distances between them and between fuelling stations are longer than in much of the rest of Canada. Cold temperatures reduce the capacity of batteries, making long distance electric powered transport even more challenging. A network of recharging stations could be built, including along winter ice roads. Vehicles exist with “swappable” battery packs that can be switched out instead of waiting to be re-charged.



Highways could also be electrified, allowing electric buses and transport trucks⁴⁸ to run on fixed routes. It would be relatively simple to create shipping terminals on the edge of each town, but the relatively low volume of traffic might not generate enough money to pay for the massive infrastructure required. Electrifying highways could share costs for a long distance transmission lines from the South Slave hydro grid, but more research is needed on technical feasibility. The rail line from Alberta to

Hay River could be electrified and additional electrified railways could be built.

Overall, biofuels would be much simpler to implement for long distance transport. Most of the existing fuelling infrastructure could be adapted to biofuels, as could existing vehicles. As mentioned previously, biodiesel and ethanol have some cold temperature issues that require more research, but biogas, either in compressed or liquid form does not.

BARGED TRANSPORT OF GOODS

The following options may be able to use renewable energy sources to meet barged goods transport demands in the NWT, and they are commercially available and therefore evaluated in more detail.

EVALUATION OF OPTIONS – BARGE TRANSPORT - TABLE

Option (Full Supply Chain)	Technical Viability	Cost	Human Health	NWT Employment	Community Self-Sufficiency	Other Environmental Impacts
Solar – Electric (supplemental only)	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Local Biogas	NEUTRAL	POSITIVE	NEUTRAL	POSITIVE	POSITIVE	NEUTRAL
Imported Compressed Biogas	POSITIVE	POSITIVE	NEUTRAL	NEUTRAL	NEGATIVE	NEUTRAL
Imported Liquid Biogas	POSITIVE	NEUTRAL	NEUTRAL	NEUTRAL	NEGATIVE	NEUTRAL
Imported Bio-diesel B100	NEUTRAL	NEUTRAL	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE
Imported Ethanol E100	NEUTRAL	NEUTRAL	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE
Imported Ethanol ED95	NEGATIVE	NEUTRAL	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE

EVALUATION OF OPTIONS – BARGE TRANSPORT - DISCUSSION

Barging of goods only happens in the summer—it is the only energy demand that peaks at the same time as the solar resource. A typical tug burns 500 litres of fuel per hour, which works out to about 2 MW or 7,000 solar panels. While a purely solar powered tug would be impractical, some tugs have electric drive motors, powered by on-board diesel generators, so solar could supplement the main power source.

The fact that tugs do not operate in the coldest portions of winter (they do operate at below freezing temperatures) and that the engines are essentially kept indoors also alleviates some concerns about biofuels that are sensitive to cold temperatures. Space is not as big a concern as on highway vehicles, so it might not be more economical to use compressed biogas instead of liquid.

MINE ORE HANDLING

EVALUATION OF OPTIONS – MINE ORE HANDLING - TABLE

Option (Full Supply Chain)	Technical Viability	Cost	Human Health	NWT Employment	Community Self- Sufficiency	Other Environmental Impacts
Electric vehicle – Hydro	POSITIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Electric vehicle – Solar	NEGATIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Electric vehicle – Wind	NEGATIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Electric – Geothermal	NEGATIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Electric vehicle – wood chips / pellets	POSITIVE	NEUTRAL	NEUTRAL	POSITIVE	POSITIVE	NEUTRAL
Local Biogas	NEGATIVE	POSITIVE	NEUTRAL	POSITIVE	POSITIVE	NEUTRAL
Imported Compressed Biogas	NEUTRAL	POSITIVE	NEUTRAL	NEUTRAL	NEGATIVE	NEUTRAL
Imported Liquid Biogas	NEGATIVE	POSITIVE	NEUTRAL	NEUTRAL	NEGATIVE	NEUTRAL
Imported Bio-diesel B100	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE

Option (Full Supply Chain)	Technical Viability	Cost	Human Health	NWT Employment	Community Self- Sufficiency	Other Environmental Impacts
Imported Ethanol E100	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE
Imported Ethanol ED95	NEUTRAL	NEGATIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE

EVALUATION OF OPTIONS – MINE ORE HANDLING - DISCUSSION

Modern mine ore handling and other machinery have enormous power requirements and many have electric drive motors powered by on-board diesel generators. This equipment operates entirely within a few kilometers of the mine site, so range is not as big a concern as with long-haul transportation. Mines have used electric vehicles in underground mining for many years and swappable batteries are used to keep the machines running while batteries are charging. More research is needed on whether battery operated mine-haul trucks exist at the same size as are currently used in NWT mines. Permanently wired electric material conveying equipment such as conveyor belts or electrified roads would also be options.

As with vehicles in NWT communities, the advantages of batteries over bio-fuelled engines would depend on the source of renewable energy that was being used at the mine. If a mine is generating most of its electricity from liquid biofuels or biogas it would be more efficient to use those fuels directly in mine haul vehicles as well.

SPACE HEATING

EVALUATION OF OPTIONS – SPACE HEATING - TABLE

Option (Full Supply Chain)	Technical Viability	Cost	Human Health	NWT Employment	Community Self- Sufficiency	Other Environmental Impacts
Insulation	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Passive Solar	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Solar w. Thermal storage	NEUTRAL	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Wind w. Thermal storage	NEUTRAL	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Hydro	POSITIVE	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Geothermal	NEGATIVE	NEGATIVE	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Ground Source Heat Pumps (in the South Slave)	POSITIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Air Source Heat Pumps	POSITIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	POSITIVE
Water Source Heat Pumps	NEGATIVE	NEUTRAL	POSITIVE	POSITIVE	POSITIVE	POSITIVE

Option (Full Supply Chain)	Technical Viability	Cost	Human Health	NWT Employment	Community Self-Sufficiency	Other Environmental Impacts
Local cord wood or wood chips	POSITIVE	POSITIVE	NEUTRAL	POSITIVE	POSITIVE	NEUTRAL
Local Biogas	NEGATIVE	NEUTRAL	NEUTRAL	POSITIVE	POSITIVE	NEUTRAL
Local Wood Pellets	POSITIVE	NEUTRAL	NEUTRAL	POSITIVE	POSITIVE	NEUTRAL
Imported Wood pellets	POSITIVE	POSITIVE	NEUTRAL	NEUTRAL	NEGATIVE	NEUTRAL
Imported Compressed Biogas	NEUTRAL	NEGATIVE	NEUTRAL	NEUTRAL	NEGATIVE	NEUTRAL
Imported Liquid Biogas	NEGATIVE	NEGATIVE	NEUTRAL	NEUTRAL	NEGATIVE	NEUTRAL
Imported Bio-diesel B100	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE
Imported Ethanol E100	NEGATIVE	NEGATIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE
Imported Ethanol ED95	NEUTRAL	NEGATIVE	NEGATIVE	NEUTRAL	NEGATIVE	NEGATIVE

EVALUATION OF OPTIONS – SPACE HEATING - DISCUSSION

Although technically not a “source”, the number 1 option in terms of switching to renewable space heating system is insulation and air tight construction.

Any energy source can be easily converted into heat, which means there are a lot of options to evaluate:

- Space heating demand is highest at night and during the winter, so solar heat would need to be stored during the summer for winter use. Heat can be stored in extremely large tanks of water or in the ground. For example, the Drake Landing solar community in Alberta stores solar heat in boreholes⁴⁹. Passive solar design, with high levels of insulation and south facing windows can reduce heating loads.
- If wind energy is fairly consistent throughout the heating season, wind generated heat can be stored in high mass ceramic “Electric Thermal Storage” (ETS) heaters for up to 16 hours⁵⁰.
- ETS heaters can also be used to store excess hydro electricity that might be available during low demand times, but they typically only store enough heat for a few days at a time. Current NWT hydro systems are not well matched to this type of short-term storage.
- Seasonal heat storage systems would be better suited to make use of excess hydro during the summer. For example, excess hydro could be stored as heat in the flooded Con Mine in Yellowknife and recovered with heat pumps during the winter.
- Hydro electricity can be used to provide space heating directly through electric baseboard heaters, but this is usually an expensive option at current rates. Excess hydro-electricity is already being sold on the South Slave grid at a more affordable “interruptible” rate and there is capacity to sell more. Future expansion of hydro facilities could sell power for heating at a competitive price to raise additional revenue.
- Ground source heat pumps require about 1/3 of the electricity to provide the same heat as electric baseboards. They cost more up-front and work best in areas with softer ground and warmer ground temperatures. They are a particularly good match with communities on the south slave grid, where there is excess, relatively affordable hydro power, softer ground and higher ground temperatures. Ground source heat pumps could also work in areas where a reservoir of warm water already exists – such as at the Con Mine heating system proposed by the City of Yellowknife.
- Air source heat pumps also use less electricity than baseboards, but work best in temperature above minus 20 deg C. They are cheaper than ground source heat pumps and could be an affordable option in communities on the south slave grid, where winter temperatures are not as severe.
- Water source heat pumps need a large source of “warm” water to draw heat from. As water at 4 deg C is heavier than other water, there should be reservoirs of 4 deg C heat at the deepest portions of lakes, during the winter. More research would be required to find out if there are any reserves like that close enough to NWT communities.
- Heat pump options are only viable in communities with hydro or wind power. If electricity was generated from biofuels or geothermal, it makes more sense to use the biofuels or geothermal directly in space heating, avoiding the inefficiencies of producing electricity in a generator,

- If electricity was being generated from biofuels or geothermal, the generators should be set up to recover waste heat using a combined heat and power (CHP) plant. This could be done either on a large scale, feeding a district heating network that could supply heat to buildings over a neighbourhood or an entire community. Or it could be done on a smaller scale with a single generator providing heat and power to a single building.
- Cord wood has been used to heat homes in the NWT for generations and is still the cheapest form of local renewable energy. High efficiency wood stoves do not produce the local air pollution that stoves once did. Cord wood can also be burned in boilers that include thermal storage tanks to heat larger buildings. Cord wood can be transported between areas and would need some new infrastructure if it was to be used on a large scale.
- Wood chips are easier to handle than cord wood for larger boilers and are the best way to make use of larger volumes of local wood. Wood chips are also a potential option for steam power generation in larger centres, which would be more efficient if run in combined heat and power (CHP) mode.
- As mentioned in the electricity section, biogas could be produced in larger communities by capturing it from the local landfill and/or anaerobic digestion of local organic waste. Similar smaller facilities could work in other communities as well. Biogas could be used to heat nearby buildings, or used in a CHP generator. Capturing and generating local biogas would create local employment and would generate additional environmental benefits because gases captured from landfills reduce local methane emissions and the solids produced by the bio-digester could be used as a soil amendment (similar to compost). More research is needed to determine the scale of the local resource.
- Wood pellets, either locally produced or imported, also have the capacity to provide renewable heating energy to the entire NWT. Pellets are denser than chips and can be economically transported over large distances. A new supply chain would need to be developed to reach every community and mine, but wood pellets can be transported and handled using the same equipment that is used to handle grain throughout western Canada,
- Imported biofuels could also be used for heating and/or in CHP plants. As mentioned in the electricity section bio-diesel and ethanol have cold temperature problems that need further research, but biogas should work in any situation where natural gas would work.

HOT WATER & INDUSTRIAL PROCESS HEATING - DISCUSSION

The main difference between hot water or other industrial heating loads and space heating is that space heating is only required in the heating season, while the other loads are year-round. All the renewable energy sources mentioned in the previous section could also provide heat year-round.

Electric hot water tanks are the lowest maintenance way to heat hot water and possibly a good way to make use of hydro, wind or even solar PV if there is enough available. If the local supply of electricity is generated from geothermal or biofuels, it makes more sense to use waste heat from the power plant first and then use geothermal or biofuel energy directly to fulfill any remaining hot water demands.

Solar hot water systems can also be used to supply hot water during the sunniest parts of the year but they would need another source of renewable energy to supply heat during the rest of the year.

The renewable energy supply chains that were evaluated the most positively in each sector result in the 100% Renewable Energy scenario that is described at the beginning of this report, just following the executive summary.

ENDNOTES

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⁸ McGill University & UNESCO Chair for Dialogue on Sustainability, 2015, *Acting on Climate Change - Solutions from Canadian Scholars* <http://sustainablecanadialogues.ca/en/scd/acting-on-climate-change>

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¹¹ Passenger vehicles use more energy in-town during NWT winters because the vehicles do not warm up during the short commutes (or they spend a very long time warming up) and because more people drive during cold weather. Once a vehicle gets to highway speeds, it has generally warmed up and fuel efficiency is similar to the summer.

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