LNG as a clean alternative fuel for Canada's remote communities.

Sarah Saad[1], Hanh Bui Thi[2], Aly Abdelaziz[3], Jake Fuss[4]

[1] Geoscience Department, University of Calgary, Calgary, Alberta, Canada T2N 1N4; Tel.: +1 403-220-5184; geoscience@ucalgary.ca

[2] Physics Department, Faculty of Science, University of Alberta, Edmonton, Alberta, Canada T6G 2E1; Tel.: +1 780-492-5286; physugrd@ualberta.ca

[3] Department of Civil Engineering, University of Toronto, Toronto, Ontario, Canada M5S 1A4; Tel.: +1 416-978-0120; civinfo@ecf.utoronto.ca

[4] The School of Public Policy, University of Calgary, Calgary, Alberta, Canada T2P 1H9; Tel.: +1 403-210-3802; swallin@ucalgary.ca

Key Words: LNG, diesel, remote communities, greenhouse gases, renewables, Fort Chipewyan

Abstract:

In remote Canadian communities, diesel is widely used as a reliable fuel source. However, this also comes with accompanying disadvantages including high greenhouse gas (GHG) and criteria air contaminant (CAC) emissions, the risk of environmental damage due to spills and leaks, and high market pricing. Therefore, the need for a diesel substitute is nowhere more evident than in these communities. Liquefied natural gas (LNG) is an option worthy of consideration as it is a reliable yet cleaner fuel, with much lower harmful emissions and contamination risks. Canada is one of the world's largest producers of natural gas [1] and with the advent of new horizontal drilling technologies production numbers continue to increase. Expanding the market to new end users in these communities would be beneficial to all. In this paper, we examine the possibility of supplying remote communities in Western Canada with LNG and compare this to the use of renewable energies, such as solar, wind, and geothermal. Fort Chipewyan, Alberta's largest remote community, will be used as a case study to determine the feasibility of converting to LNG as the primary fuel source and exploring options to reduce dependence on diesel.

1.0 Introduction

Residents of remote communities in Canada require access to convenient and reliable fuel sources. This also means that they are burdened with higher energy prices due to the challenges associated with the fuel of choice: diesel. These costs can be up to nine times higher than the Canadian average electricity price of $0.12/kWh [2]. Additionally, air and soil contamination associated with diesel combustion and spills/leaks have adverse effects on both the environment and the health of the local population. It is pertinent to find a more affordable, safe, and reliable energy alternative for these communities. This research aims to analyze the feasibility of fueling remote Canadian communities with liquefied natural gas (LNG), a reliable, cheaper, and cleaner source of fuel. Fort Chipewyan, Alberta's largest remote community, will be used as a case study for this paper.

2.0 Remote communities

2.1 Defining a remote community

The terms *off-grid community* or *remote community* are used to describe any long-term (> 5 years) settlement with a minimum of 10 dwellings which lacks connection to the electrical grid and the pipeline networks in North America [3]. Due to their remoteness, these communities face many challenges including transportation and energy supply.

2.2 Remote communities in Canada

There are approximately 188,525 people residing in 265 communities across the country that are classified as off-grid [4, 5] (Figure 1). Among them, 200 communities use diesel as the primary fuel source to provide all electrical and heating demands. An additional 25 communities use diesel as their secondary power source [5]. The combined total annual electrical usage of all remote Canadian communities is approximately 1,850 GWh [2]. The total annual fuel consumption among diesel-reliant communities is approximately 289 million L [5].

2.3 Fort Chipewyan: Alberta's largest remote community

Fort Chipewyan is located in Northeastern Alberta within the Regional Municipality of Wood Buffalo. Bound to the east by Lake Athabasca and to the west by Wood Buffalo National Park, it is an environmentally sensitive area (Figure 2). It has 853 residents living in 300 residential dwellings and a population density of 79.6 persons/km^2 [6] (Figure 3).

Fort Chipewyan has only seasonal accessibility via two winter roads: one to Fort McMurray, AB (290 km) and one to Fort Smith, NT (140 km). In the summer, transportation is available via water or air [7].

The main energy sources used in Fort Chipewyan are wood, diesel, propane, gasoline, and electricity [8]. Electricity in the area is provided by ATCO Electric which operates two power plants in the community run on four diesel-fueled gensets [5, 8] (Figure 3). Diesel supply for heating and transportation is provided by Fort Petroleum Ltd., who operate the storage tanks located 4.5 km from the townsite [9] (Figure 3). In 2017, the total annual diesel consumption for Fort Chipewyan was 4.7 million L [9, 10] (Table 1). The average cost of diesel in Fort Chipewyan is $1.20 CAD/ L or $33 CAD/GJ [11]. A study completed by the Pembina Institute in 2012 found that the total annual cost spent on energy in Fort Chipewyan was $3.9 million CAD [8]. Of this total, diesel and electricity made up 51%. These energy sources are also the leading contributors to Fort Chipewyan's greenhouse gas (GHG) emissions with 55% of GHGs contributed by electricity and 21% from diesel (heating) [8]. These values demonstrate the need for reliable and cleaner energy alternatives for Canada's remote communities.

3.0 Liquefied Natural Gas

3.1 What is LNG?

Liquefied natural gas (LNG) is a methane-dominant gas that has been transformed into its liquid state by cooling at atmospheric pressure. LNG is 1/600th the volume of the gaseous state, making transportation and storage more efficient [12].

The process begins with the pre-treatment of a feedstock of natural gas entering the system to remove impurities (H_2S, CO_2, H_2O, etc). Generally, pipeline gas is preferred over raw gas because less pre-treatment is necessary and the supply is continuous [13]. Gas then enters the liquefaction unit where it is cooled to between -145 and -163^{o}C [13]. Although the type or number of heating cycles and/or refrigerants used varies on the technology, the basic process involves circulating the gas through aluminum tube coils and exposure to a compressed refrigerant [13]. As the refrigerant is vaporized, the heat transfer cools the gas in the coils [13]. The LNG is then stored in a specialized double wall insulated tank at atmospheric pressure [13].

Most domestic LNG is transported by land via cryogenic truck. These units consist of a vacuum system between two steel compartments to reduce the amount of heat transfer. Once on site the LNG must be stored in vacuum insulated or flat bottom tanks. For distribution, the LNG enters a regasification facility where it is pumped into a vaporizer and heated back into gaseous form. The gas then enters the pipeline distribution system and is delivered to the end user [13].

3.2 Sources for LNG

Although the feedstock gas for LNG is typically marketable gas sourced from the pipeline system, in some cases raw gas may be extracted from local resources. The ideal source would be located near the liquefaction plant and have a high methane content. Examples of deposits with high methane content include biogenic gas and gas hydrates. In Western Canada, these deposits are estimated to hold vast amounts of potential resources.

Biogenic or microbial gas is produced at shallow depths by methanogenic bacteria. The most prolific biogenic gas deposit in Western Canada is the Southeast Alberta Gas Field which holds an estimated 1.42×10^{12} m^3 of recoverable gas [14]. Although these gases are widely present in most basins, they are rarely of commercial value [14].

Gas hydrates are pure methane deposits formed at low temperature and high pressure conditions [15]. They are typically found in the shallow sea in arctic permafrost regions and continental slopes [15]. In Western Canada, deposits in the Mackenzie-Beaufort area and the continental slope off Vancouver Island are estimated to hold up to 1.1×10^{14} m^3 of gas [16]. However, the process of recovering gas from these deposits is difficult, due to the low energy density and high infrastructure costs, making it an unlikely source.

3.3 Benefits of using LNG

3.3.1. Environment

Comparatively, LNG outweighs diesel both economically and environmentally. The volume of GHG and criteria air contaminant (CAC) emissions associated with both the upstream and downstream sectors is greater for diesel than for natural gas [17–20] (Table 2). Substituting the 289 million L of diesel with LNG would lead to a significant reduction of CO_2 emissions [17, 21] (Table 2).

3.3.2. Cost savings

The initial costs of LNG conversion are high due to the construction of LNG facilities, specialized transportation and storage units, pipeline infrastructure, and equipment replacement/conversion. However, as a long-term energy solution, LNG is considered an economical option. Due to natural gas oversupply in North America, the prices remain relatively low and stable. In 2017, the U.S. Department of Energy market price for diesel was \$2.46/GGE[1] while for LNG it was \$2.32/GGE [22]. Therefore, replacing the 289 million L of diesel would lead to fuel cost savings of approximately \$45 million USD [22].

3.3.3. Safety

LNG is inherently a safe energy supply as it is non-toxic, non-corrosive with a low flammability range (5 to 15 %) [23, 24]. Moreover, LNG is not stored under high pressure, reducing the risk of explosion. The risk associated with spills/leaks is minimal because once exposed to air, LNG will vaporize to its gaseous form, leaving no residue. In case of overpressurization during transportation, trucks are equipped with safety devices such as pressure relief valves and emergency shut down systems [25].

3.4 LNG compared to other renewable energy sources

Renewable energy is an appealing option to replace the reliance on diesel in remote communities and in Canada, the contributions from these resources are increasing (Table 3).

3.4.1. Solar

Solar photovoltaic (PV) potential is variable across Canada, with the highest solar insolation in the southernmost portion of the prairies and the lowest in the north and coastal regions [26] (Figure 4a). The absence of harmful emissions and long equipment lifespan (about 25 years) make solar a favourable option [26]. The major technical concern is the inability to store energy for extended periods of time. This requires reliance on sunlight to generate electricity which is impractical in northern areas due to shorter daytime hours and cloud cover in the winter. Additionally, the high footprint required in areas of lower insolation may lead to habitat degradation [27, 28]. Economically, the levelized cost is high for PV compared to other options [29] (Table 3).

3.4.2. Wind

Wind energy does not generate GHG emissions and has no fuel cost. There are many optimal locations for wind energy across Canada [30] (Figure 4b). However, projects with wind-diesel hybrid systems have shown limited success in remote communities in Canada for over 25

---

[1] GGE = Gasoline Gallon Equivalent

years [31]. This is mostly due to the expensive installation and maintenance required when providing power to remote sites. Ideal locations for turbines are based on wind speeds at locations which may not be near a local power grid making expensive transmission lines necessary to tie into the local power grid. Moreover, intermittent wind will affect the reliability of power generation.

3.4.3. Geothermal

To produce electricity using geothermal resources, very high temperatures (>150°C) are required [32]. The most prospective locations are in Western and Northern Canada (Figure 4c). Because upfront capital costs are high, the demand for produced energy must be large [29]. Unfortunately, the majority of potential sources tend to be in remote locations with no access to the grid [32, 33]. Currently, there are no installed electrical-generating geothermal facilities in Canada [29].

4.0 Fueling remote communities with LNG

LNG's economical and environmental advantages warrant its consideration for fueling off-grid communities. To determine the feasibility of fueling remote communities with LNG, we consider Fort Chipewyan, AB, as a case study.

4.1 LNG feasibility in Fort Chipewyan

Replacing diesel with LNG in Fort Chipewyan would be a costly, long-term project. Economics, environmental concerns, and the input of Indigenous groups are important aspects to consider. This section focuses on key technical considerations in a scenario involving a transition to sole usage of LNG in Fort Chipewyan and the role that renewable energy can play.

4.1.1. Natural gas resources

With only 5.2 Mm^3 of gas produced in 2017 from the oil sands, Fort Chipewyan lacks a proximal gas resource [34]. The nearest gas infrastructure is the TransCanada pipeline which services Fort Mckay and the surrounding oil sands operations. In addition, the environmental sensitivity, government regulations, low overall energy demand, and high costs associated with operation and construction render it unfeasible to build a liquefaction plant in Fort Chipewyan. A more viable option is to transport the LNG from the most proximal LNG plant currently in operation - the Ferus Elmworth facility, located approximately 1,106 km away. The Elmworth facility purchases pre-treated gas from a gas-processing facility operated by Cenovus Energy.

Cenovus' Deep Basin assets include the Elmworth-Wapiti area, which produces natural gas from unconventional, horizontal drilling in the Montney, Falher, and Dunvegan tight gas plays. Cenovus' 2017 net-production in this area was 27,868 BOE/day, equivalent to 170,493,000 MJ/day [35]. As previously mentioned, Fort Chipewyan consumes approximately 4.7 million L of diesel annually, or 502,191.8 MJ/day.

4.1.2. Transportation

Given that diesel has an energy density roughly 1.6 times higher than LNG, approximately 3.3 million kg of LNG (assuming ρ_{LNG} = 450 kg/m^3 [36]) is required to fuel Fort Chipewyan's annual energy demands. Fort Chipewyan has only winter road access and transport on this road is limited by weather-dependent maximum load capacities. We estimate the total number of hours per year that the maximum load capacity is over 35,000 kg (and therefore available for LNG transportation) is 1,080 hours. Assuming an LNG transport trailer weight of 14,966 kg, the LNG load capacity per truck is 20,034 kg [37]; this means 166 trips would be required to transport the needed amount of LNG from the LNG plant to Fort Chipewyan.

4.1.3. Storage and Distribution

The narrow window of accessibility to Fort Chipewyan requires storage of high volumes of LNG to ensure adequate supply during inaccessible months. The cost of LNG storage in remote communities is approximately $25 CAD/ USg of LNG [38]. Therefore, to store 320 days worth of LNG for Fort Chipewyan which has an average burn rate of approximately 5,768 USg/day, it would cost $46,144,000 million CAD. Additional costs include the facilities necessary to deal with boil-off gas which may accumulate during storage due to heat ingress (reliquefaction or burning gasification unit) [36].

To distribute LNG, a regasification plant must be constructed. From there, the gas would enter a simple pipeline distribution network within the community. Currently diesel is provided by truck on an as-needed basis. Since there is no infrastructure in place, Fort Chipewyan would need to invest in a regasification plant and a minimal distribution pipeline network.

4.1.4. Renewables

Average wind speeds in Fort Chipewyan are approximately 4 m/s which does not meet the minimum ideal speed of 6 m/s; therefore, wind power is a poor option [39] (Table 4). The average annual solar insolation in Fort Chipewyan is 6.29 kWh/m^2 [39]. With an optimal solar panel orientation, the annual PV production potential in this area is 1160 kWh/kW [26] (Table 4). Therefore, solar is not sufficient as a sole source of energy but could be used as a complimentary source.

4.1.5. Summary

With the current lack of infrastructure in Fort Chipewyan, a complete shift away from diesel is not a viable option. The high costs associated with shipping, storage, and distribution of LNG will continue to be an impediment until an all-season road is constructed. To reduce costs and limit the dependency on diesel, one option is to supply LNG to Fort Chipewyan over the winter months, and in the summer have a combination of solar and diesel energy. This would also aid in limiting the levels of GHG and CAC emissions.

4.2 LNG outlook for other remote communities in Canada

Canada is the fifth largest producer of natural gas in the world with numerous prolific fields [40] (Figure 5). With new technologies enabling economical extraction of resources from unconventional deposits, such as tight shale plays, marketable gas production continues to increase, with a Canadian total of 473 million m^3/day in 2017 [41]. Across Canada, interprovincial pipelines have the capacity to carry over 1.3 billion m^3 of gas per day [42]; however, this infrastructure is lacking in northern remote areas. The presence of significant volumes of natural gas and the necessity for alternative transportation of fuel to remote communities makes LNG an appealing option for Canada.

Five small-scale LNG facilities are in operation across Canada and six more in the planning and development stage [43, 44] (Table 5). For the economics to work, the majority of these companies have existing contracts with long-term, high energy-demand clients, such as industrial or mining projects. This makes supplying LNG to remote communities along the route more feasible.

There are currently two remote communities in Canada that use natural gas as their primary fuel source. Norman Wells, NT purchases excess electricity from a power plant fueled by natural gas from a local gas field [2, 45]. The power plant in Inuvik, NT is run using natural gas transported as LNG from the Ferus Elmworth facility, a distance of 2,749 km [2, 44].

5.0 Conclusions

As demonstrated, LNG is an achievable option for remote communities; however, economics is the major driver. There are five key stipulations which must be met in order for LNG to work as a primary fuel supply in remote communities:

1. Proximity to a high-energy demand industrial client.
2. All-season road access to decrease required storage volume.
3. Proximity to LNG facility to limit the transportation distance/cost.
4. Existence of a distribution network in the community.
5. Existence of aging generators and/or furnace machinery that are near replacement.

Figure 1a is a map of Canada showing the locations of major mining operations, natural gas pipelines, operating LNG facilities, all-season roads and off-grid communities. This map may be used as a tool to confirm if LNG is an option for specific locations (Figure 1b). The opening of the Fort Nelson LNG plants will allow for more remote communities, which meet the above requirements, to benefit from LNG including: Tuktoyaktak, Fort McPherson, Fort Simpson, and Fort Liard.

6.0 Acknowledgments

The authors would like to express their gratitude to the Project Instructor, Dr. Jeff Priest who provided insights to achieve the goals of this manuscript. The authors would also like to thank the following industry professionals who provided vast knowledge, insight and information that helped tremendously for this project: Paul Miller (Sonoma), Colin Nikiforuk (PTX Technologies), Matt Sveinbjornson (ATCO), Robert Walker (Ferus), Kevin Force (NRCan), Mike Johnson (NEB), Chris Doleman (NEB). In addition, the contributions from the Fort Chipewyan Indigenous contacts were paramount for our ability to understand the community, including: Lisa Tssassaze (AFCN), Jule Asterisk (Keepers of the Athabasca) and Mikisew Cree Group of Companies. The work presented here is part of a research project supported by NSERC.

7.0 Literature Cited

[1] National Energy Board. Natural Gas. [April 14, 2018]; Available from: https://www.neb-one.gc.ca/nrg/sttstc/ntrlgs/index-eng.html.

[2] Knowles J. Power Shift: Electricity for Canada's Remote Communities; 2016.

[3] Jimmy Royer; Natural Resources Canada. Status of Remote/Off-Grid Communities in Canada 2011.

[4] Arriaga M; Cañizares C; Kazerani M. Northern lights: Access to electricity in Canada's northern and remote communities. IEEE Power and Energy Magazine 2014;12(4):50–9.

[5] Natural Resources Canada (NRCan). Remote Communities Energy Database: The Atlas of Canada. Canada; 2017.

[6] Statistics Canada. Census Profile, 2016 Census: Fort Chipewyan, Unincorporated place [Designated place], Alberta and Saskatchewan [Province]. [April 14, 2018]; Available from: http://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/details/page.cfm?Lang=E&Geo1=DPL&Code1=480243&Geo2=PR&Code2=47&Data=Count&SearchText=Fort%20Chipewyan&SearchType=Begins&SearchPR=01&B1=All&TABID=1.

[7] Regional Municipality of Wood Buffalo. Winter Roads. [April 14, 2018]; Available from: http://www.rmwb.ca/Municipal-Government/municipal_departments/Public-Operations/Roads/Winter-Roads.htm.

[8] Huot M, Cobb P. Fort Chipewyan Community Energy Baseline; 2012.

[9] Matt Sveinbjornson. ATCO - Interview; February 22, 2018.

[10] Bilal Abdu. Mikisew Cree Group of Companies - EMail Correspondence; March 27, 2018.

[11] Lisa Tssassaze. ACFN - Verbal Conversation; February 15, 2018.

[12] Chevron Policy - Government and Public Affairs. Learn about LNG: Liquefied Natural Gas. [April 14, 2018]; Available from: https://www.chevron.com/operations/liquefied-natural-gas-lng.

[13] World Bank Group. Comparison of Mini-Micro LNG and CNG for Commercialization of Small Volumes of Associated Gas. Washington, D.C: World Bank; 2015.

[14] Chen Z; Zhang S; Grasby S; Shuai Y. Biogenic gas accumulations in Canada and China: Geological characteristics and new insights. Bulletin of Canadian Petroleum Geology 2015;63(1):1–3.

[15] Grace J; Collett T; Colwell F; Englezos P; Jones E; Mansell R et al. Energy from gas hydrates—assessing the opportunities and challenges for Canada. Report of the Expert Panel on Gas Hydrates, Council of Canadian Academies 2008.

[16] Majorowicz J A; Osadetz K G. Gas hydrate distribution and volume in Canada. Bulletin 2001;85.

[17] AEP - Environment and Parks. Specified Gas Emitters Regulation. [April 14, 2018]; Available from: http://aep.alberta.ca/climate-change/guidelines-legislation/specified-gas-emitters-regulation/.

[18] Olatunji S; Fakinle B; Jimoda L; Adeniran J; Adesanmi A. Air Emissions of Sulphur Dioxide From Gasoline and Diesel Consumption in the Southwestern States of Nigeria. Petroleum Science and Technology 2015;33(6):678–85.

[19] Nett Technologies Inc. What Are Diesel Emissions? [April 14, 2018]; Available from: https://www.nettinc.com/information/emissions-faq/what-are-diesel-emissions.

[20] Health Canada. Guidance for fine particulate matter (PM2.5) in residential indoor air. [April 14, 2018]; Available from: https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidance-fine-particulate-matter-pm2-5-residential-indoor-air.html.

[21] Davies TW. Calculation of CO2 emissions. [April 14, 2018]; Available from: https://people.exeter.ac.uk/TWDavies/energy_conversion/Calculation%20of%20CO2%20emissions%20from%20fuels.htm.

[22] Bourbon; E; Allegheny Science and Technology; Bridgeport; West Virginia. Clean Cities Alternative Fuel Price Report 2017.

[23] Ferus. Ferus Natural Gas Fuels: LNG Infomration Sheet. [April 16, 2018]; Available from: http://www.ferus.com/download/LNG%20Information%20Sheet(2).pdf.

[24] Center for Chemical Process Safety. Emergency Planning Preparedness, Prevention & Response. Hoboken, NJ, USA: John Wiley & Sons, Inc; 2005.

[25] Ciliberti V, Sheehan T. LNG Safety Document; 2014.

[26] Natural Resources Canada (NRCan). Photovoltaic and solar resource maps. [April 14, 2018]; Available from: http://www.nrcan.gc.ca/18366.

[27] Natural Resources Canada (NRCan). About Renewable Energy. [April 14, 2018]; Available from: http://www.nrcan.gc.ca/energy/renewable-electricity/7295#solar.

[28] Solar Energy Development Programmatic EIS. Solar Energy Development Environmental Considerations. [April 14, 2018]; Available from: http://solareis.anl.gov/guide/environment/.

[29] Canada’s Adoption of Renewable Power Sources: Energy Market Analysis. Calgary, AB, CA: National Energy Board; 2017.

[30] Canadian Wind Energy Association. Installed Capacity. [April 14, 2018]; Available from: https://canwea.ca/wind-energy/installed-capacity/.

[31] Weis T; Ilinca A; Pinard J-P. Stakeholders’ perspectives on barriers to remote wind–diesel power plants in Canada. Energy Policy 2008;36(5):1611–21.

[32] Grasby S, Allen D, Bell S, Chen Z, Ferguson G, Jessop A et al. Geothermal energy resource potential of Canada; 2012.

[33] Barrington-Leigh C; Ouliaris M. The renewable energy landscape in Canada: A spatial analysis. Renewable and Sustainable Energy Reviews 2017;75:809–19.

[34] Alberta Energy Regulator. Alberta’s energy reserves and supply/demand outlook ST98: Executive Summary.

[35] Cenovus Energy Inc. Annual Information Form: For the Year Ended December 31, 2017. [March 18, 2018]; Available from: https://www.cenovus.com/invest/docs/2017/AIF.pdf.

[36] Dobrota Đ; Lalić B; Komar I. Problem of boil-off in LNG supply chain. Transactions on maritime science 2013;2(02):91–100.

[37] Chart Industries. LNG transport trailers; 2013.

[38] Paul Miller. Sonoma Resources Limited - Verbal Conversation; February 15, 2018.

[39] Environment and Climate Change Canada. Canadian Wind Energy Atlas: Global Map. [April 14, 2018]; Available from: http://www.windatlas.ca/maps-en.php.

[40] Canadian Association of Petroleum Producers. Natural Gas. [April 14, 2018]; Available from: https://www.capp.ca/canadian-oil-and-natural-gas/natural-gas.

[41] National Energy Board. Marketable Natural Gas Production in Canada. [April 14, 2018]; Available from: https://www.neb-one.gc.ca/nrg/sttstc/ntrlgs/stt/mrktblntrlgsprdctn-eng.html.

[42] National Energy Board. Canada’s Pipeline Transportation System 2016; Available from: https://www.neb-one.gc.ca/nrg/ntgrtd/trnsprttn/2016/cnds-ppln-trnsprttn-systm-eng.html.

[43] Chris Doleman. National Energy Board - EMail Correspondence; February 15, 2018.

[44] National Energy Board. Market Snapshot: Small-Scale LNG Plants Strategically Located to Meet Emerging Domestic LNG Demand. [April 14, 2018]; Available from: https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/snpsht/2015/02-03lng-eng.html?=undefined&wbdisable=true.

[45] The Standing Senate Committee on Energy, the Environment and Natural Resources. Powering Canada's Territories.

[46] Alberta Energy Regulator. Products and Services Catalogue: Enhanced Pipeline Graphics File. [April 14, 2018]; Available from: http://www1.aer.ca/ProductCatalogue/557.html.

[47] Statistics Canada. Intercensal – Road network files. [April 14, 2018]; Available from: http://www12.statcan.gc.ca/census-recensement/2011/geo/RNF-FRR/index-j-eng.cfm?year=17.

[48] Natural Resources Canada (NRCan). Liquefied Natural Gas Terminals: North American Cooperation on Energy Information. [April 14, 2018]; Available from: https://open.canada.ca/data/en/dataset/e08eec16-7c7a-4253-9bee-ea640d400a54.

[49] DMTI Spatial. MADGIC GIS Data: Pipelines. [April 13, 2018]; Available from: http://libdata.ucalgary.ca/index.php?dir=DMTI_2016/CanMapContentSuite/.

[50] Hatfield Consultants. Tourism and Recreation in the Regional Municipality of Wood Buffalo. [April 14, 2018]; Available from: http://www.ramp-alberta.org/resources/tourism.aspx.

[51] Regional Municipality of Wood Buffalo. Communities in the Regional Municipality of Wood Buffalo. [April 14, 2018]; Available from: https://www.rmwb.ca/living/Communities.htm.

[52] Google Maps. Fort Chipewyan, AB. [April 14, 2018]; Available from: https://www.google.ca/maps/place/Fort+Chipewyan,+AB/@58.7196353,-111.1582065,14z/data=!3m1!4b1!4m5!3m4!1s0x53b68c384a43a55d:0x4b3fc83c4f19c857!8m2!3d58.719637!4d-111.140697.

[53] Regional Municipality of Wood Buffalo. Draft Fort Chipewyan Area Structure Plan. [April 14, 2018]; Available from: https://www.rmwb.ca/Doing-Business/Land-Development/Area-Structure-Plans/Draft---Fort-Chipewyan-Area-Structure-Plan.htm.

[54] Heffernan K; Dawson F. An overview of Canada’s natural gas resources. Canadian Society for Unconventional Gas (May 2010) 2010.

[55] National Energy Board. Canada's Energy Future: Energy Supply and Demand Projections to 2040; Available from: https://www.neb-one.gc.ca/nrg/sttstc/lctrct/rprt/2017cnddptnrnwblpwr/2017cnddptnrnwblpwr-eng.pdf.

[56] Lovekin D, Dronkers B, Thibault B. Power purchase policies for remote Indigenous communities in Canada: Research on government policies to support renewable energy projects.

[57] Statistics Canada. Table 128-0014: Electricity generated from fossil fuels annual (gigawatt hours). [April 01, 2018]; Available from: http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=1280014.

[58] Canada’s role in the global LNG market: Energy market assessment. Calgary: National Energy Board; 2017.

[59] National Energy Board. Market Snapshot: Canada's LNG Landscape. [April 16, 2018]; Available from: https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/snpsht/2017/07-03cnclnglndscp-eng.html?=undefined&wbdisable=true.

8.0 Tables and Figures

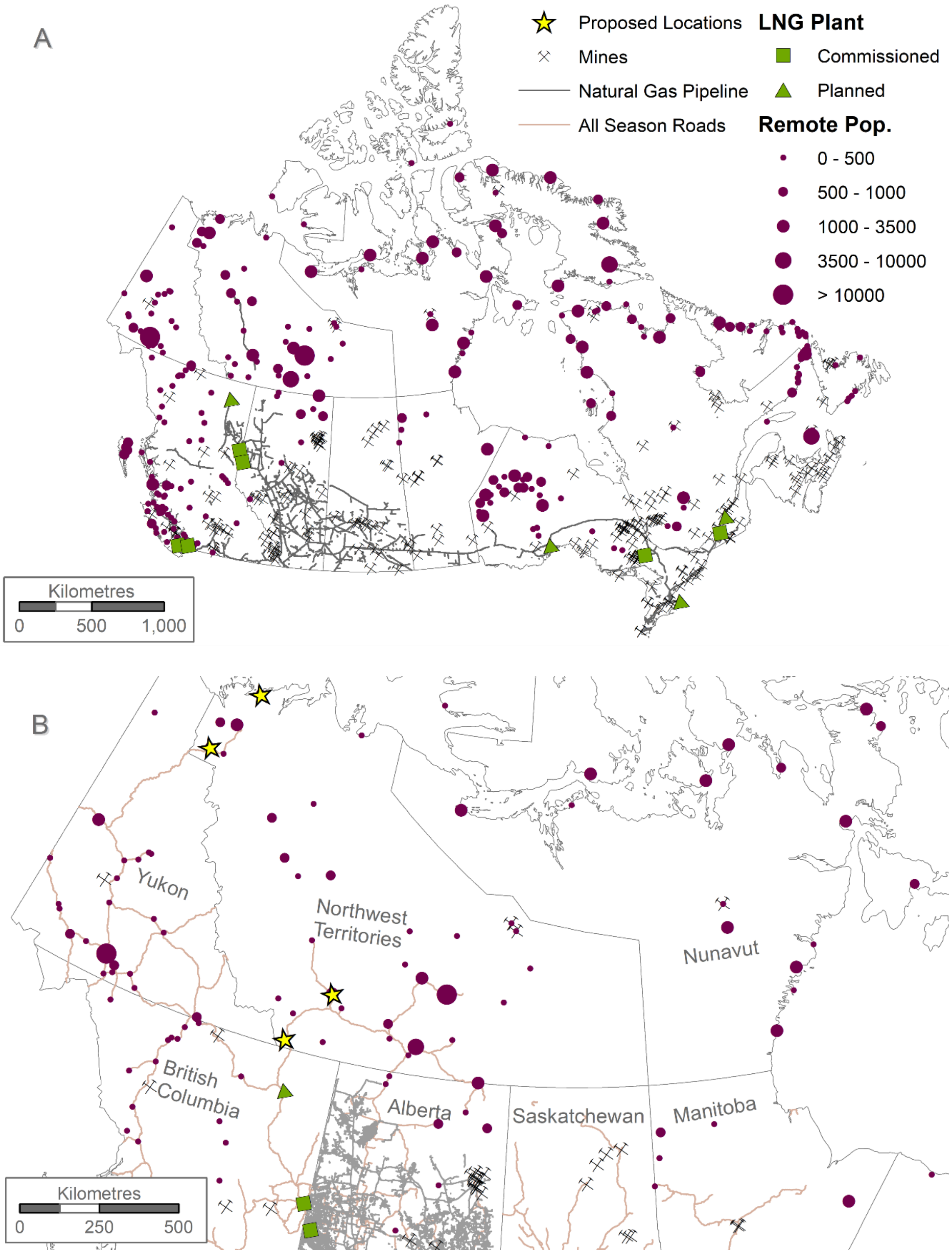

Figure 1 – (A) Shows the location of remote communities, mines, LNG plants (square: existing; triangle: planned) and NEB regulated natural gas pipelines. (B) Shows Western Canada overlaid with Alberta gas pipelines and all-season roads. Stars indicate locations of proposed communities where LNG may be feasible. Map resource obtained from [46–49].

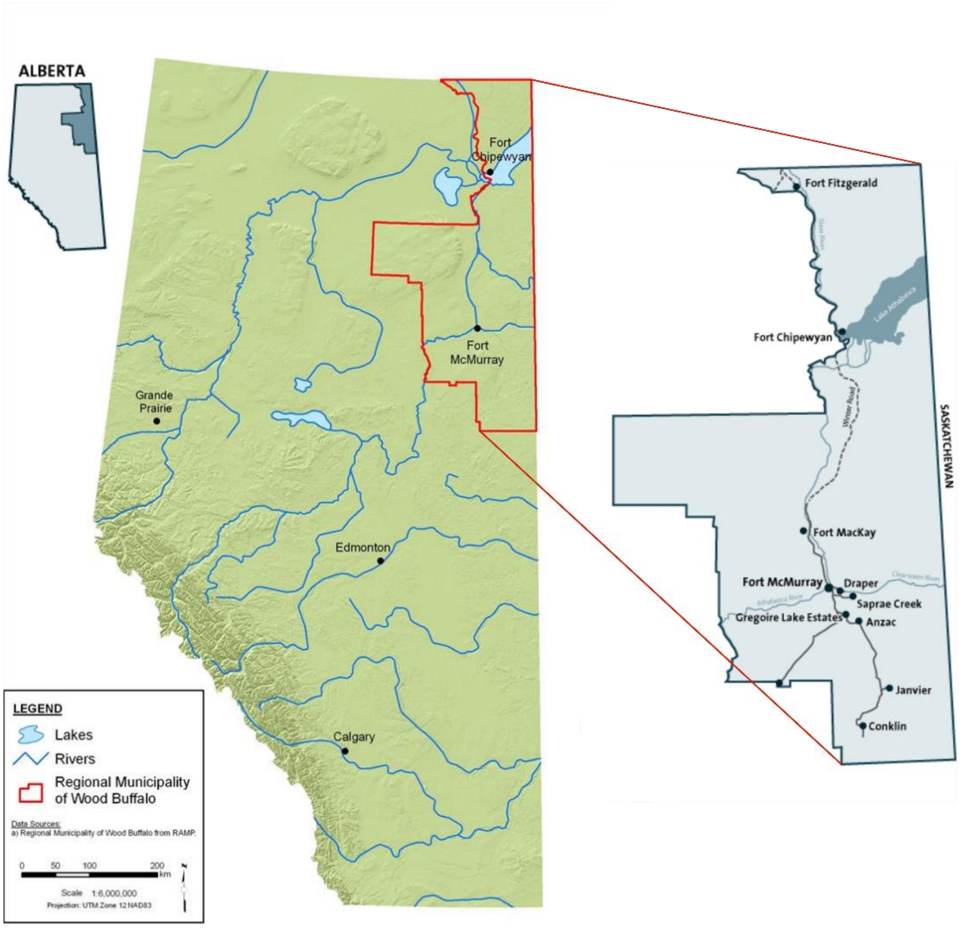

Figure 2 – Location of Fort Chipewyan with enlarged map showing Regional Municipality of Wood [50, 51].

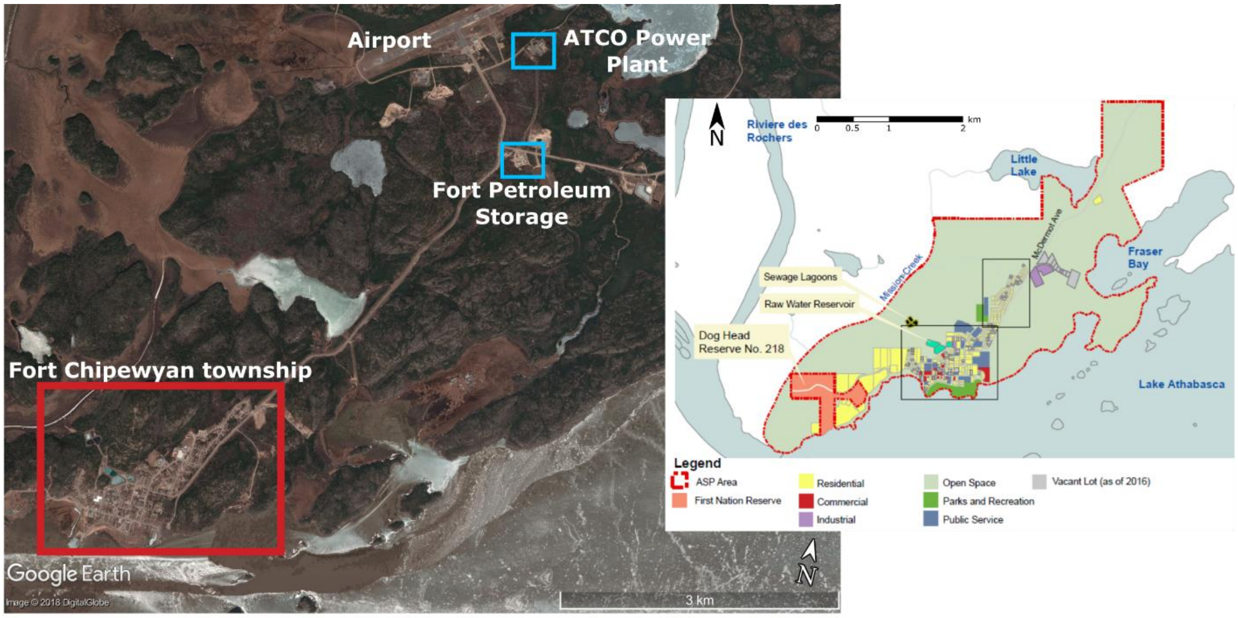

Figure 3 – Detailed map of Fort Chipewyan townsite (red) showing location of ATCO power plant and Fort Petroleum diesel storage facilities (blue). Detailed map of land usage in Fort Chip townsite (right). Modified from [52, 53].

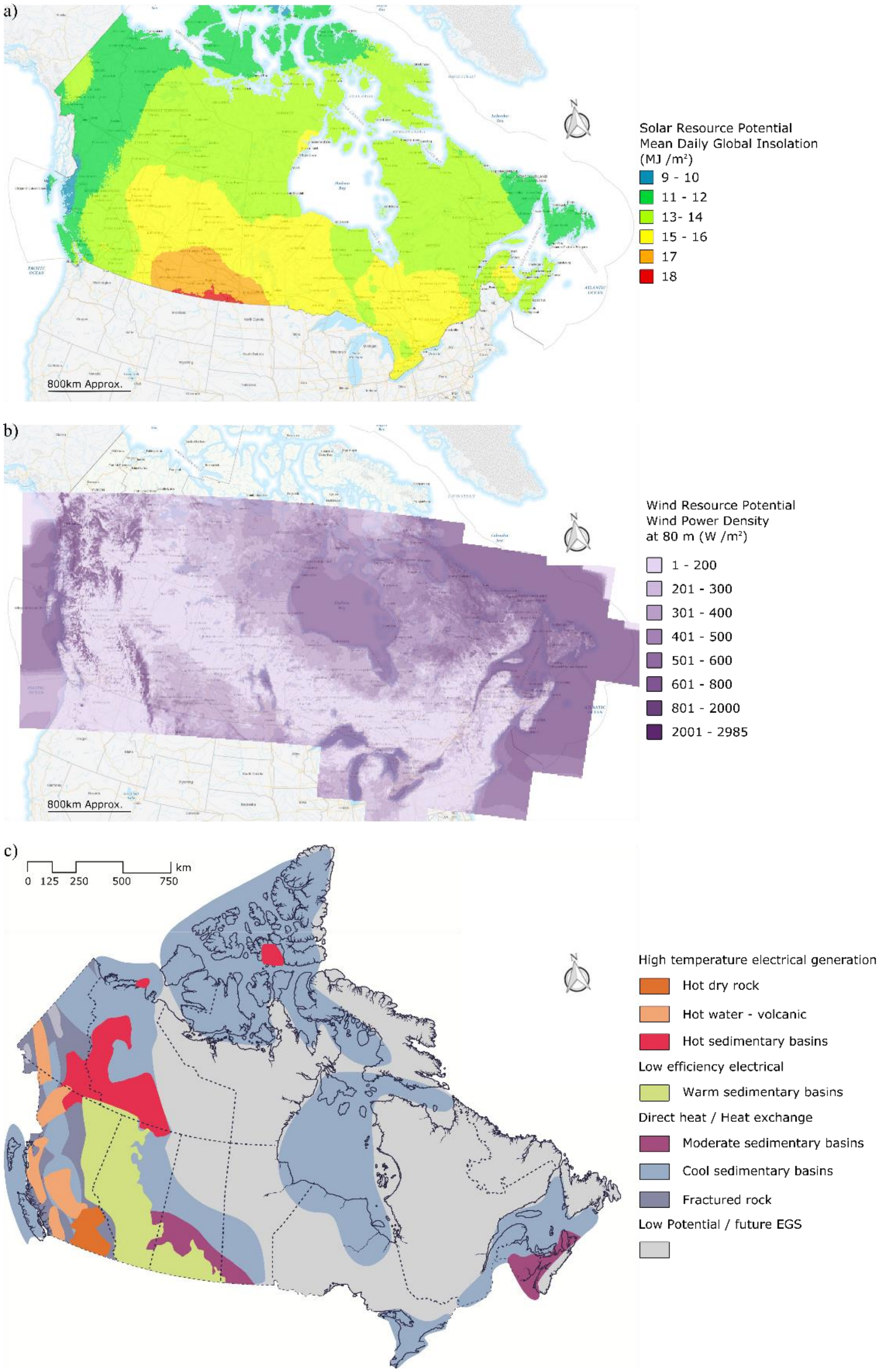

Figure 4 – Renewable energy potential in Canada for (a) solar PV, (b) wind, and (c) geothermal. Modified from 5 and 32.

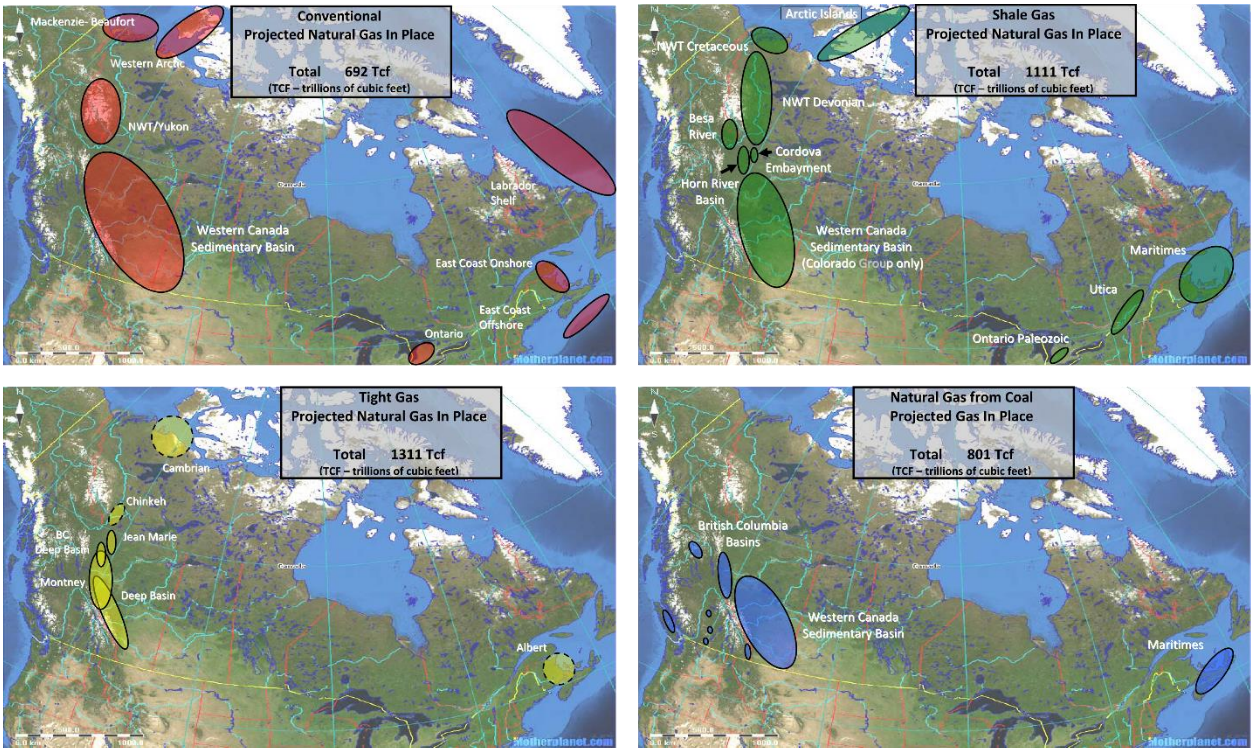

Figure 5 – Natural gas deposits in Canada. The total amount of gas in place is 3915 Trillion Cubic feet (Tcf) [54].

Table 1 – Energy usage breakdown for Fort Chipewyan in 2017 [9, 10, 49].

	Diesel volume (L)	kWh	Energy (MJ)
Electricity	3,183,100	12,843,338	124,140,900
Heating	1,414,795	-	55,177,005
Transportation	153,608	-	5,990,712
Total	4,751,403	-	185,308,617

Table 2 – GHG and CAC emission comparisons [17].

	Carbon dioxide ($kg\ CO_2/m^3$)	Methane ($kg\ CH_4/m^3$)	Nitrous oxide ($kg\ N_2O/m^3$)
Diesel			
Production	138	10.9	4.0×10^{-3}
Combustion	2663	0.133	0.4
Total	2801	11.03	0.404
Natural Gas			
Extraction	0.043	2.3×10^{-3}	4.0×10^{-6}
Processing	0.090	3.0×10^{-4}	3.0×10^{-6}
Combustion	1. 918	3.7×10^{-5}	3.5×10^{-5}
Total	2.051	2.64×10^{-3}	4.2×10^{-5}

Table 3 – Comparison of fossil fuel and renewable energy electrical capacity, generation and levelized costs in Canada [29, 55–57].

	Contribution to total generation (%)	Installed capacity (MW)	Generation (GWh)	Average levelized costs ($/kWh)
Solar PV	0.6	2,662	3,007	0.23
Wind	4.4	12,239	28,561	0.13
Geothermal	0	0	0	0.24
Diesel	1.3	-	2312.7	0.30
Natural Gas	9.7	21,500	63,623.3	0.08

Table 4 – Potential of solar and wind energy in Fort Chipewyan [26, 39].

	Solar PV [26]		**Wind** [39]	
	Mean daily global insolation (kWh/m^2)	PV production potential (kWh/kW)	Mean wind speed (m/s)	Mean wind energy (W/m^2)
Winter	3.32	55	4.42	72.12
Spring	8.90	138	4.6	80
Summer	9.07	128	4.39	67.25
Fall	3.83	65	3.81	47.12
Annual	6.29	1160	4.54	76.25

Table 5 – Canadian small-scale LNG plants in operation or planned [44, 58, 59].

Facility	Operator	Status*	Year opened	Capacity (USg/day)	End users*
Tilbury Delta (BC)	FortisBC	OP	1971	52,834 expandable to 412,108	RC, Ind, export, domestic transportation
Mt Hayes Ladysmith (BC)	FortisBC	OP	2011	70,000	Storage
Ferus Elmworth (AB)	Ferus NGF	OP	2014	4,512	RC, Ind, Tran
Hagar LNG (ON)	Union Gas	OP	1968	25,000	RC, Tran
Montreal LSR plant (QC)	Gazmetro	OP	1965	29,851	RC, Ind (Renard Mine), Tran
Dawson Creek LNG (BC)	Altagas	2018	2018	50,192	RC, Ind
StoltLNGaz (QC)	SLNGaz	2018	-	79,323	RC, Ind
Ft Nelson LNG (BC)	KT Energy	2018	-	20,000	RC, Ind, European export
Nipigon LNG (ON)	Northeast Midstream	2019	-	-	RC, Ind, Tran
Sonoma LNG (AB)	Sonoma Resources	2019	-	80,000	RC, Ind
Fort Nelson (AB)	Ferus NGF	2020	-	300,000	Ind (Casino mine, YK; Selwyn Chihong mine, NT)
Thorold LNG (ON)	Northeast Midstream	-	-	28,500	Utility & Tran (Ontario and northern US)

* OP: Operational; RC: Remote communities; Ind: Industrial; Tran: Transportation