Diesel Reduction Progress in Remote Communities

Modelling approach and methodology

Jeremy Moorhouse, Dave Lovekin
Vincent Morales, Ben Salek

July 2020

photo: Dave Lovekin, Pembina Institute

About the Pembina Institute

The Pembina Institute is a national non-partisan think tank that advocates for strong, effective policies to support Canada's clean energy transition. We employ multi-faceted and highly collaborative approaches to change. Producing credible, evidence-based research and analysis, we consult directly with organizations to design and implement clean energy solutions, and convene diverse sets of stakeholders to identify and move toward common solutions.

Acknowledgements

The authors wish to thank those who contributed to this work: Devin Vranckaert of the University of British Columbia Master of Engineering Leadership Program, for initial development of the community energy model; Mariano Arriaga, former post-doctoral fellow at the University of Waterloo Department of Electrical and Computer Engineering, for input and guidance from his research and modelling; and Natural Resources Canada, for support and guidance on the NRCan Remote Community Energy Database.

The Pembina Institute wishes to thank the New Relationship Trust and the Government of Canada for their financial support.

Diesel Reduction Progress in Remote Communities

Modelling approach and methodology

Contents

List of Figures

List of Tables

1. Introduction

The federal government, along with many provincial, territorial and municipal governments, has committed to support the reduction of diesel use in remote communities in an effort to increase energy security and local employment while reducing annual energy costs, greenhouse gas emissions and other air emissions. The latest collection of funding programs for reducing diesel use was presented at the 2018 Energy and Mines Ministers' Conference.[1] Collective progress by remote communities is being made on diesel reduction and the replacement of diesel-based energy systems with clean energy technologies and energy efficiency measures. However, there are few estimates of the cumulative diesel reduction impact of combined renewable electricity, renewable heat and energy efficiency measures over the past several years.

The Pembina Institute has filled this gap by collecting and quantifying cumulative national diesel reduction progress through this research and analysis. The main objective of this research was to estimate cumulative diesel reduction across remote communities from the past several years as a result of energy efficiency measures, renewable heat, renewable electricity and connecting remote communities to provincial or territorial electricity grids. The results of this research and analysis can be found in *Diesel Reduction Progress in Remote Communities: Research summary*.

This technical report captures the modelling scope, assumptions, methodology approach, gaps and limitations of the modelling and recommendations for future work.

1.1 Main modelling scope, data and definitions

Starting energy data sets

The two foundational data components for this analysis are Natural Resources Canada's Remote Community Energy Database (RCED)[2] and a report from the Waterloo Global

---

[1] Energy and Mines Ministers' Conference 2018, *Clean Technology Integration in Remote Communities: Policies, Programs, and Initiatives by Federal, Provincial, and Territorial Governments*. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/emmc/pdf/2018/en/18-00018-remote-communities-full-report-eng.pdf

[2] Natural Resources Canada, "Remote Communities Energy Database," 2019. https://atlas.gc.ca/rced-bdece/en/index.html

Science Initiative's Open Access Energy research.[3] The RCED includes details on community population, electricity generation type, diesel generator capacity, annual generation, diesel consumption and renewable electricity projects already established in remote communities. The Open Access Energy research and database includes heat demand estimates, fuel types for remote communities and estimates of renewable energy and diesel energy generation. However, these components do not provide consistent 2015 estimates, do not contain a complete list of current and planned renewable energy projects in remote communities, and do not provide an accurate quantification of annual energy demand or any cumulative diesel reduction estimates.

Remote community definition

The list of remote communities used in this modelling was based on the 277 remote communities listed in the RCED. Remote communities for this scope of research were further selected from this list with criteria defined in Section 2.1. From this additional criteria, a total of 243 remote communities were selected. Communities excluded were mainly industrial sites, seasonal communities, and communities with no population data. Further information on this subset of communities is provided in subsequent sections and a complete list can be found in Appendix A.

Baseline and timeframe

The year 2015 was selected as the baseline. The modelling estimated energy demand and energy supply from diesel (and other fossil fuels), and energy supply from renewable energy projects installed at that time. The modelling then analyzed annual energy demand and the changes in energy supply from diesel (and other fossil fuels), renewable energy projects installed, communities connected to provincial or territorial grids and decrease in energy demand as a result of two selected energy efficiency measures from 2015 until the end of 2020.

Fossil fuel energy sources

Most fossil fuels used in remote communities, including diesel, natural gas, propane and heavy fuel oil, are included in the analysis.

---

[3] Waterloo Global Science Initiative, *Open Access Energy* (2016). http://wgsi.org/sites/wgsi-live.pi.local/files/WGSI-COP22Brief-GlobalandCanadianEnergyAccessCHallenges.pdf

Sector energy demand

The analysis includes electricity and heat demand for residential, commercial, institutional and commercial buildings. It does not include remote industrial energy use, including mining or oil and gas operations.

Large hydro versus small hydro

The electricity analysis excludes communities that are connected to regional large hydro grids (greater than 50 MW) and powered for the most part by renewable energy from hydro. Thus 25 communities connected to Yukon Integrated System in the Yukon or to the Taltson and Snare/Bluefish grids in the Northwest Territories are not part of the electricity analysis; they are, however, included in the heat analysis. In a few occasions in *Diesel Reduction Progress in Remote Communities: Research summary*, renewable electricity and diesel reduction impact from large hydro is noted and quantified. Further iterations of this modelling should find ways to include large hydro from these regions while simultaneously showcasing progress in other areas.

A small number of remote communities in Quebec and B.C. are connected to small hydro systems (less than 50 MW). Although these communities are not considered diesel-dependent for electricity, they are isolated and remote; since small hydro systems are an important aspect of renewable energy progress these communities are included in the electricity analysis.

Diesel reduction pathways

The following four pathways are modeled and analyzed for diesel reduction progress:

1. **Renewable electricity:** Wind energy, solar photovoltaic, small hydro (<50 MW), biomass combined heat and power (power portion).
2. **Renewable heat:** Point source bioheat (residential wood stove, larger biomass energy systems), district heating bioheat, and biomass combined heat and power (heat portion).
3. **Energy efficiency:** Waste heat recovery (from diesel generators) and electric heat pumps.
4. **Grid connection:** Remote communities connected to provincial or territorial grids after 2015.

2. Modelling methodology

This analysis uses a bottom-up approach to estimate annual electricity and heat demand, electricity and heat supply from diesel-equivalent energy and renewable energy, and corresponding diesel consumption for each remote community, along with diesel reduction from applied renewable energy and energy efficiency projects. The analysis used NRCan's RCED and the Open Energy Access database as the initial datasets and then modified them as necessary to develop a 2015 baseline, and progress made from each of the four pathways for each of the following five years (2016 – 2020) which includes a 2020 forecast representing the state of progress at the end of 2020.[4] Wherever possible the analysis uses energy use data as reported by the community; however, because of lack of data and granularity required, in many instances this modelling estimated annual energy consumption using population, number of households and average energy intensities for both heat and electricity. Renewable energy project data as of 2015 and diesel reduction pathway and project data from 2016 to 2020 was collected from a variety of sources such as community representatives, government (all levels), clean technology sector, press releases, public announcements and academic sources.

Using this data, it was then possible to estimate diesel-equivalent energy use and renewable energy use in 2015, the changes from 2016 to 2020 and the overall current status as of 2020.

2.1 Further modelling scope details

The following scope applies to both the heat and electricity analysis.

Remote community definition

With using the information in the RCED, this research also adopts the definition of remote communities defined by Natural Resources Canada as a community that is not connected to the North American electricity grid and the North American piped natural gas network and is a permanent or long-term (5 years or more) settlement with at least 10 dwellings.

---

[4] Project timeline implications resulting from COVID-19 were not included in the modelling; it was assumed projects targeted for completion in 2020 would still be completed. This assumption will need to be revisited in any subsequent work.

This analysis started with communities listed in NRCan's RCED and then filtered out communities using the following set of criteria:

- Settlements: Industrial and inactive communities were filtered out so the analysis only includes settlements.
- Seasonal communities excluded: Communities known as seasonal, or those with populations of five people or fewer (assumed to be seasonal), were excluded.
- No data: Communities with no data in the RCED, the Open Energy Access database or the Canadian census were excluded.
- Large hydro communities: Communities connected to regional large hydro grids (>50 MW) were excluded from the electricity analysis only. This excluded a total of 25 remote communities that are in the Yukon Integrated System in the Yukon or in the regional NWT electricity grids.

This resulted in 238 remote communities for the heat analysis and 213 remote communities for the electricity analysis.

2015 baseline and 2016–2020 forecast

The year 2015 was chosen as the baseline year since good data was available and well-aligned in both the RCED and the Open Energy Access database. Setting five years as a useful time period to assess diesel reduction from the four pathways allowed the analysis to look next at the years 2016 to 2020.

Pathways to diesel reduction

The analysis includes four pathways of diesel reduction – renewable electricity, renewable heat, select energy efficiency technologies and grid connection. Table 1 to Table 4 provide more detail on each of these pathways.

Table 1: Renewable electricity technologies included in the analysis

Technology	Comment
Solar PV	Solar electricity from individual home, business installations and community installations, ranging in size from under 10 kW to multiple MW (largest being under 3 MW). Storage options are noted, but not assessed in the analysis.
Small hydro	Hydro projects less than 50 MW, whether run-of-river or small-scale hydro with reservoir.
Wind energy	Wind energy turbine projects that generate electricity.

	Known projects are limited compared with solar.
Combined heat and power (CHP)	The electricity portion of combined heat and power projects using renewable resources. Biomass is the only feedstock currently used in CHP projects in remote communities.

Table 2: Renewable heat technologies included in the analysis

Technology	Comment
Point source biomass	Boilers that use biomass as the energy source to produce heat.
Residential wood stoves	While the amount of renewable energy provided by wood stoves is accounted for in the analysis, the number of individual wood stoves is not, as this data is not available.
District heating biomass	Heating systems that provide heat to more than one building using biomass as the energy source.
Combined heat and power (CHP)	The heat portion of combined heat and power projects using renewable resources. Biomass is the only feedstock used in CHP projects in remote communities.

Table 3: Energy efficiency technologies included in the analysis

Technology	Comment
Heat pumps	Air-source, ground-source and water-source heat pumps using electricity to produce heat.
Waste heat recovery from electric diesel generators	Heat captured from diesel electricity generators and used to heat buildings and water.

Table 4: Grid connections included in the analysis

Technology	Comments
Grid connection	Communities connected to provincial or territorial grids between 2016 and 2020 are included in the analysis. In these cases, diesel-equivalent reductions are estimated based on the fossil fuel intensity of the connected grid. For example, a community using primarily natural gas for electricity that is then connected to a grid that relies primarily on natural gas has only shifted natural gas reliance and hence no diesel-equivalent reductions would be realized.

2.2 Common modelling approaches

Several approaches are used in both the heat and electricity analysis. These include using diesel-equivalents and reconciling population estimates, along with a standardized approach to data and quality assurance and control processes.

Diesel equivalents

All fossil fuel energy, consumption and reductions from pathways is expressed in diesel-equivalents (diesel-eq). This approach allows fossil fuels other than diesel such as natural gas, propane and heating oil to be represented by a common unit.

Reconciling population estimates

The analysis used the following approach to establish 2015 and 2020 population estimates in the remote communities within scope.

- **Reported populations:** Wherever possible 2015 population estimates in NRCan's RCED were used.
- **Interpolation and forecast:** When population data was not available, Canadian census population data between 2011 and 2016 was used to estimate the 2015 population or to forecast the 2020 population (assuming linear growth).
- **Other interpolation:** In some cases, Canadian census data was not available for 2011 or 2016, or there were significant discrepancies between census data and NRCan RCED population data. In these cases, judgement was used to select which data would be used for interpolation and forecasts.
- **Only one data point:** If there was only one data point for a community (e.g. only 2016 census data) that one data point was used for both 2015 and 2020 population.
- **No data:** In cases where no data was available, the community was removed from the analysis.

Using this collection of methods, estimated remote community population increases from 189,000 in 2015 to 202,000 in 2020, with the majority of community populations increasing and only a small handful decreasing. Population is a main input in estimating heat demand in communities; further modelling iterations should improve on population estimates.

2.3 Estimating electricity demand

Generally, electricity demand was estimated by modifying NRCan RCED electricity estimates to 2015 and 2020 using population estimates, and then correcting for new renewable energy projects. To estimate the amount of renewable energy generated in 2015, we used the NRCan RCED data and project data from other sources such as the ones listed in section 2.3.2.

2.3.1 Fossil fuel electricity demand

Fossil fuel electricity demand for 2015 was estimated using one of two approaches: using documented diesel-equivalent energy use, or diesel usage based on reported electricity demand converted to litres of diesel equivalent.

$$D_{eq} = \sum_{n=1}^{C_{el}} d_n \ OR \sum_{n=1}^{C_{el}} E_n \div \varepsilon_{avg}$$

D_{eq} = Diesel equivalent (litres)

C_{el} = Number of remote communities (213 for electricity)

d_n = Diesel consumption (litres)

E_n = Diesel energy use (kWh)

ϵ_n = Average diesel generator efficiency (3.5 kWh_e/litre)

In each community, when consumption data was available for years other than 2015, it was assumed that consumption varies proportionally with the population of the community. For example, if only 2012 consumption data was available and if the population of a community grew between 2006 and 2016, the same growth rate was applied to calculate the increase in electricity consumption to 2015.

2.3.2 Renewable electricity projects

Reduced diesel demand between 2016 and 2020 was estimated from reported or estimated renewable electricity generation. Renewable energy projects were identified using a variety of sources, including government press releases, government publications and databases, project developer data, available community data, non-profit organizations and academic sources. The primary sources are:

- NRCan RCED

- Yukon Renewable Energy and Energy Efficiency Update[5]
- NRCan Clean Energy for Rural and Remote Communities program[6]
- Communities, technology providers and vendors

These four sources account for approximately 70% of renewable electricity projects collected. The remaining sources were professional contacts, press releases and other provincial/territorial publications.

It was assumed that renewable energy projects would reduce demand from the primary electricity source in the community, which in most cases is diesel electricity generation.

Approach for capacity factors

Renewable energy project data often included capacity estimates (kW), but not annual renewable energy generation (kWh). When annual electricity generation was not known, generation for specific solar PV projects was estimated using average capacity factors as listed in Table 5. Average, minimum and maximum capacity factors were calculated from regional solar energy maps.[7]

Table 5: Solar capacity factors by jurisdiction

Province / Territory	Average	Max	Min
British Columbia	11%	14%	11%
Alberta	15%	15%	14%
Saskatchewan	15%	16%	15%
Manitoba	15%	15%	14%
Ontario	13%	14%	13%
Quebec	14%	14%	13%
New Brunswick	13%	13%	13%
Nova Scotia	12%	13%	12%
PEI	13%	13%	13%
Newfoundland	11%	14%	11%
Yukon	11%	12%	11%
NWT	12%	13%	12%

---

[5] Government of Yukon, *Renewable Energy and Energy Efficiency Update* (2018). http://www.energy.gov.yk.ca/pdf/emr-energy-strategy-update-2016-2018.pdf

[6] NRCan, "Clean Energy for Rural and Remote Communities funded projects." https://www.nrcan.gc.ca/climate-change/green-infrastructure-programs/clean-energy-rural-remote-commun/clean-energy-rural-and-remote-communities-funded-projects/22524

[7] Energy Hub, "Solar Energy Maps." https://energyhub.org/solar-energy-maps-canada/

Nunavut	12%	13%	11%

An average capacity factor of 20% was used for wind energy projects when annual energy generation data was not available. This is based on medium-sized turbines (100 kW to 1 MW).[8]

Annual electricity generation estimated using these capacity factors was validated by comparing it to available project data. Expert opinion was also sought to confirm the annual electricity generation estimates matched experience. These comparisons suggested that the solar capacity factors in Table 5 and the wind capacity factor seem to be reasonable estimates.

2.3.3 Grid connection

For communities connected to provincial grid between 2016 and 2020, it was modelled that all electricity demand after grid connection came from the regional electricity grid. The change in fossil fuel use was calculated based on the fossil fuel mix of the regional electricity grid. For example, local generation in Jasper (a remote community connected to the Alberta grid system in 2019) was primarily natural gas and diesel; connecting to Alberta's electricity grid displaced only some of this fossil fuel use, since coal and natural gas are used to generate 90% of Alberta's electricity.[9]

2.4 Estimating heat energy demand

There is no one main source in Canada that reports diesel and other fossil fuel use for building heat in remote communities in Canada. A bottom-up approach was hence used to estimate annual heat energy demand based on default energy use per household, type of energy demand per community and number of households in each community. This approach follows the approach used in the Open Energy Access research.

However, this research, as part of the scope definition, included heat demand estimates for commercial, community and institutional (CC&I) buildings such as hotels, government buildings and community centres. There is generally no data available on the number of such buildings or their heat demand in remote communities. To estimate this energy demand, a percentage increase of residential demand based on a sample of

---

[8] U.S. Department of Energy, *Distributed Wind Market Report* (2017). https://www.energy.gov/sites/prod/files/2018/08/f54/2017_dwmr_081018.pdf

[9] Canada Energy Regulator, "Provincial and Territorial Energy Profiles – Alberta." https://www.cer-rec.gc.ca/nrg/ntgrtd/mrkt/nrgsstmprfls/ab-eng.html

communities was used. The heating energy use approaches for residential and CC&I are described in more detail below.

2.4.1 Residential buildings

Residential primary heat energy demand is estimated using the following equation:

$$D_h = \sum_{n=1} \frac{(H \times Q_n \times \alpha)}{\varepsilon_{heat}}$$

D_h = Diesel consumption for heating in community (litres)

H = Household density (residential households per community)

Q_n = Estimated average heating demand for buildings in community (kWh)

α = Estimated fraction of heating from diesel

ϵ_{heat} = Average diesel heat efficiency 6.98 litres / kWh (10.74 kWh / litre × 65% efficiency)

Household density *(H)* is estimated based on an average number of people per household from Canadian census data multiplied by the community's population for 2015 and 2020. Population estimates follow the same approach outlined in section 2.2. Based on census data available, the average home occupancy calculated is 3.03 residents per household for remote communities. Since the average home occupancy is an important variable and is based on limited census data, it should be revisited in future modelling.

Home heating demand (Q_n) varies for every household based on a number of factors including type of heating source, the efficiency of the heating device, the efficiency of the building (e.g. the state of the building, the amount of insulation in the walls), individual behaviour (e.g. heating preferences, leaving windows open) and the local climate. Wherever possible community-specific estimates were used, but in most instances, this type of data is unavailable. Therefore, heat demand was estimated by region depending on climate conditions — the same approach as the Open Energy Access research. Table 6 summarizes the default heat demand per heat region.

Table 6: Annual heat demand by region type

	Heat demand (kWh / household)		
Climate condition	Diesel	Wood	Other
Mild	25,700	29,555	25,700
Cool	57,325	65,923	57,325
Cold	66,547	76,529	66,547
Northern	72,536	83,417	72,536

Nunavut is the one exception to this approach. For communities in Nunavut, community-specific heat values available in the Open Energy Access research were used.

Each community and every building also use different mixtures of fuels for heating (α) including heating oil, diesel, propane, natural gas, wood and electricity. Data on heating fuel use is also widely unavailable at the community or building level. Default heating type ratios were used based on the Open Energy Access research and then modified when community-specific data was available — for example, some northern communities do not have access to wood while others use natural gas for heating. The NRCan RCED indicates heating preference for some communities. Table 7 includes the default heating types.

Table 7: Heating types – mixed use assumption

	Diesel / heating oil	Wood	Other
Default heating mix (wood stove dominant)	35%	55%	10%
Oil preference heating mix	70%	20%	10%
Single energy preference (usually diesel or natural gas)	100%	0%	0%

2.4.2 Commercial, community and institutional buildings

There are no datasets or consistent information to estimate heating energy demand or fuel types for commercial and institutional buildings, nor is there consistent accounting of the number of commercial, community and institutional buildings in remote communities. To fill this gap, an increase factor was developed based on a small handful of remote communities that had detailed energy use estimates. From the analysis, the average increase in heat demand from CC&I buildings was 45%. It was further assumed that the energy use preferences (diesel, wood and other) are similar for CC&I buildings as residential buildings.

This approach provides an order of magnitude estimate, but the following important limitations are noted:

- **Differences between communities:** Based on data available, heat demand can vary from 13% to 73% higher than residential demand depending on the community. This is driven by the specific CC&I services that are provided in a community. Central hub communities and communities with hospitals, larger airports, government offices or that provide more services for tourists may have higher energy demand. This approach does not account for these differences at a community level, but does at a regional level, since the 45% is based on select communities that have different energy profiles.
- **Energy preference may be different:** This approach does not account for differences in energy type preferences between residential and CC&I consumers. CC&I consumers may have larger individual heat loads, for example, so may prefer diesel heating to wood heating, even if wood heating is available and preferred for residential use.
- **Significant changes to residential energy demand impact commercial, community and institutional estimates:** This approach assumes CC&I energy demand follows changes in the residential sector. This may not reflect reality since CC&I buildings in remote communities often receive the most energy efficiency attention and upgrades. For this modelling, this is generally not an issue since the data shows no significant change in regional energy efficiency. However, as more projects are installed and the model evolves, this approach will become less representative.

2.4.3 Renewable heat projects

Renewable energy heat projects include point source biomass systems, biomass district heating (which provides heat for groups of buildings), biomass combined heat and power, and residential wood stoves. Following the same approach as for renewable electricity projects, renewable heat project data was collected from a variety of sources and annual heat generation was estimated based on suggested capacity factors if this data was not available. The primary sources are:

- NWT Energy Initiatives Report 2018-19[10]
- NRCan Bioheat database[11]
- Yukon's Energy Context[12]

These sources account for over half of renewable heat projects collected. The remaining sources were professional contacts, press releases and other provincial/territorial publications.

Heat generation per project was then used to estimate reduced fossil fuel demand at the community level. Wood stoves are the exception. Individual wood stove installations were not tracked and quantified over the 2016–2020 period as this data is simply not available. Instead, wood stove heat demand is based on the changes in number of households per community, and the percentage wood heat is of the total energy demand in the community. Table 8 summarizes the approach per technology type.

Table 8: Renewable heat project type, and approach for inclusion

Technology	Approach
Point source biomass	Assumed point source biomass projects displaced fossil fuel heating systems such as diesel, heating oil or propane.
Biomass district heating	Assumed district heating systems displaced fossil fuel heating systems such as diesel, heating oil or propane.
Biomass combined heat and power	Assumed the heat portion of biomass combined heat and power projects reduced fossil fuel heating systems such as diesel, heating oil and propane.
Wood stoves	Wood stove use increases or decreases based on the change in number of households in a community using the fixed energy heating type ratios listed in Table 7. Unlike point source biomass and biomass district heating, individual wood stove installations were not tracked.

2.4.4 Heating capacity factor estimates

Annual heat generation data was rarely available for the renewable heating projects identified in Canadian remote communities. The capacity installed (kW) of these projects was most often known. To estimate the annual heat generation (kWh) of these

---

[10] Government of the Northwest Territories, *Energy Initiatives Report 2018-19* (2019). https://www.inf.gov.nt.ca/sites/inf/files/resources/7467_inf_report_web.pdf

[11] Natural Resources Canada, "Bioheat Database," spreadsheet. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/Bioheat_Database_forTranslationEN.xlsx

[12] Government of Yukon, *Yukon's Energy Context* (2019). http://www.energy.gov.yk.ca/pdf/emr-yukon-energy-context.pdf

projects, an average capacity factor was calculated. A capacity factor represents the average amount of time in a year during which the installation generates heat as percentage of its maximum capacity.

The capacity factor used for projects with missing data is based on the performance of the projects for which comprehensive data was available. Very few projects had direct annual generation data available, but more projects were reported with a measured or estimated amount of litres of fuel (mostly diesel) avoided annually. Using the average diesel efficiency mentioned in Section 2.4.1, the annual heat generation for these projects was estimated. Knowing the capacity installed of these projects, the capacity factor of these projects was estimated according to the following formula:

$$E_{thermal} = C_p \times C_f \times 365.25 \times 24$$

$E_{thermal}$: annual heat generation (in kWh)
C_p: thermal capacity installed (in kW)
C_f: capacity factor (in %)
365.25 × 24: number of hours in an average year

The average capacity factor of these bioheat projects (excluding outliers) was calculated at 22%, based on the capacity factors of twenty-six projects, all located in the Northwest Territories and Yukon. This was used as a default capacity factor for all the projects reported with incomplete data.

It is important to acknowledge that this modelled capacity factor is not as good as actual performance data, and may not be representative of projects in other regions due to climate differences. In the future, as more projects get installed in conjunction with good data collection processes, different capacity factors could be applied for each province and territory or according to the number of heating degree days in each community.

The discrepancy between the modelled and the real performance of heating projects varies for each project. Indeed, the heat load covered by bioheat installations varies across projects, which impacts capacity factors. For example, certain biomass boilers are oversized to be able to cover the load of future buildings that will be connected later. In the meantime, the capacity factor of these oversized projects is reduced. The experience of communities dealing with modern heating technologies may also impact the discrepancy between modelled and actual performance. In communities that are getting used to the technology, some outages and extra maintenance might negatively affect the annual heat generation of the bioheat installations, therefore reducing capacity factors.

Note that for bioheat projects displacing propane, available data on the amount of propane displaced (in GJ) was converted to heat generation using a propane efficiency factor of 4.35 kWh / litre of propane. This is based on the energy content of propane (25.3 MJ / litre) and the conventional boiler efficiency (62 %) referenced by the Office of Energy Efficiency.[13]

2.5 Estimating energy efficiency

The range of energy efficiency solutions that can be utilized to reduce diesel demand is vast. As a starting point, only two energy efficiency technologies — electric heat pumps (ground, water and air source) and waste heat projects (waste heat recovery from diesel generators) — were included in this modelling. As with renewable energy projects, the analysis assumes these projects reduce fossil fuel energy sources such as diesel, heating oil and propane. For waste heat recovery projects, public estimates of energy saved in kWh or litres of fossil fuel avoided per project or per community were used where available. When installed capacity data was available for heat pump projects, a capacity factor of 37% was used to determine their annual heat generation. This capacity factor is based on a research paper using data from Sweden.[14]

2.6 Estimating diesel reduction

Diesel reduction estimates are based on converting all fossil fuel demand (diesel, heating oil, propane or natural gas) into one diesel-equivalent value. Diesel-equivalent changes between 2015 and 2020 are calculated at a community level and totalled for each region; the difference between 2015 and 2020 provides an estimate of total diesel equivalent changes over this time. This approach is affected by population changes as well as renewable energy project installations. A community with significant population growth between 2015 and 2020 may experience an increase in diesel use even if

---

[13] Office of Energy Efficiency, *Heating with gas* (Natural Resources Canada, 2012). https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/energystar/Heating_With_Gas.pdf

[14] Helge Averfalk, Paul Ingvarsson, Urban Persson, Mei Gong, Sven Werner, “Large heat pumps in Swedish district heating systems,” *Renewable and Sustainable Energy Reviews* 79 (2017). https://www.sciencedirect.com/science/article/pii/S1364032117307839

renewable energy projects were installed, since the renewable energy project(s) may not be large enough to offset the increase in total energy demand.

This approach does not account for other economic changes. For example, a community may have experienced increased or decreased economic activity which could influence heating behaviour, but this has not been modelled or captured.

2.7 Modelling limitations

While the approach described above is an improvement upon existing research and studies, it still has several limitations:

1. **Renewable energy project list:** A comprehensive review of remote community renewable energy project installations was performed including internet research, expert consultation and federal, provincial and territorial government review. However, a small subset of projects are likely still missing, since not all remote community projects receive public attention.
2. **Electricity used for heat:** Community reported electricity use does include electricity for heating. However, the portion of electricity used for heating was not estimated. The heat demand approach also includes electricity use as part of the "other" category in some of its heating types (up to 10% of the energy mix). Therefore a small amount of electricity demand might be double counted if it is used for heating.
3. **Commercial, community and institutional heating:** Commercial, community and institutional heat demand is based on an average of only a handful of communities based on previous analysis performed. These communities may not be representative of CC&I heat demand at the community level, or across different regions.
4. **Heat demand:** Heat demand per community is based on a coarse estimate of four proxy heat demand profiles which is then applied across communities based on similar locations (representative of similar climates). Ideally heat demand would be measured community estimates or based on heating degree days per remote community. As well, the allocation of heat loads across diesel, wood, and other heating fuels (Table 7) was made based on very limited data paired with broad knowledge of fuel used in regions. More accurate heating supply data will help improve these assumptions.
5. **Population data and approach:** Population estimates are an important driver of heat demand. However, 2015 and 2020 estimates are based on trends in

census data or other credible data sources. This approach can lead to errors if census estimates are wrong, or historical trends are not representative of future trends.

3. Summary and conclusions

3.1 Overall summary

This modelling and analysis has provided new and more accurate information on annual energy demand for both electricity and heat in remote communities across Canada, as well as progress on annual and cumulative diesel reduction through four pathways: selected energy efficiency, renewable electricity, renewable heat and connecting remote communities to provincial grids.

Total energy demand in remote communities in 2020 is estimated at 5,121 GWh of energy; 1,023 GWh for electricity demand and 4,098 GWh for heat demand.

In 2020, 19% of electricity demand comes from renewable electricity sources including solar PV, wind, small hydro and CHP. For heat, 21% of heat demand comes from renewable heat sources including wood stoves, point source bioheat, district heating biomass. The renewable energy mix for both electricity and heat are shown in Figure 1.

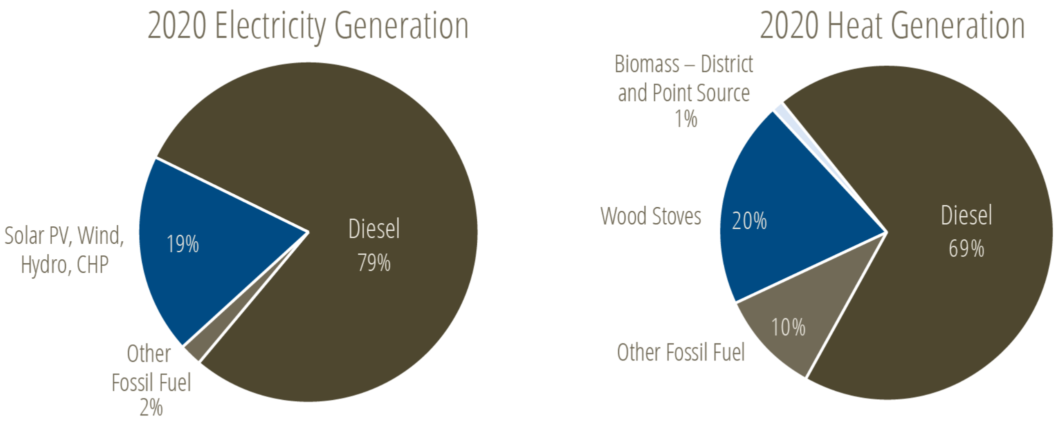


Figure 1. Annual energy production – electricity and heat

The energy generation contribution from these renewable energy sources, as well as energy saved from energy efficiency and energy generation sourced from provincial grids is seen in Figure 2.

As shown in Figure 2, energy generation provided by the four pathways (with the energy efficiency pathway representing energy *saved*) is approximately 110,000 MWh. Energy generation contribution from these pathways are most significant from 2018 to 2020. Corresponding additional diesel-eq fuel avoided from the combination of these four pathways is represented by the negative line trending down. In 2020, the four pathways collectively contribute to 12.3 million litres of diesel-eq fuel that is not burned.

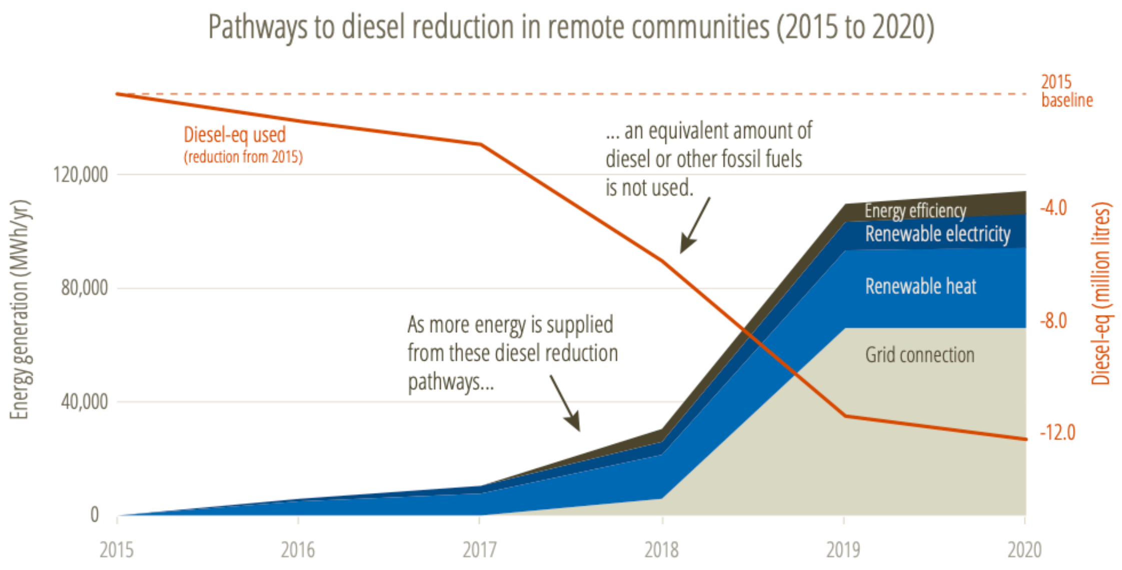


Figure 2. Progress of diesel reduction in remote communities 2015 to 2020

The breakdown of this combined annual diesel reduction of 12.3 million litres per year from these four pathways totals 12.3 million litres per year, is shown in Table 9.

Table 9: Annual diesel reduction by pathway

Pathway	Diesel-equivalent consumption reduction (million litres per year)
Energy efficiency	1.1
Renewable electricity	3.5
Renewable heat	4.1
Grid connection	3.6
Total	12.3

Even with this cumulative annual reduction in diesel-equivalent fuel, the estimated annual diesel-equivalent fuel required in remote communities is 682 million litres per year: 221 million litres per year for electricity and 461 million litres per year for heat.

For an overview of results from this modelling, refer to *Diesel Reduction Progress in Remote Communities: Research summary*.

3.2 Limitations and data gaps

There are several areas of limitations and data gaps in this modelling that could be improved in subsequent iterations:

Population data – Much extrapolation was required to estimate population changes from 2015 to 2020 because census data was limited. Using provincial or territorial population data and better estimation techniques to model population changes would be helpful to get more accurate heat demand estimates.

Household density – The number of persons per household is based on some broad datapoints and could use regional refinement to estimate heat demand more accurately.

Estimating commercial, community and institutional building heat demand – Data on heat demand for CC&I buildings is also extremely limited and this modelling approach uses the change in residential heating demand to estimate CC&I. More accurate information on community-specific CC&I heat demand would improve this modelling.

Fuel mix and energy makeup in residential buildings – The ratio of heat sources (heating oil versus wood heating versus electric heating) varies from jurisdiction to jurisdiction and community to community. The heat demand for buildings can vary greatly too with age and quality of building. A better approach to estimating heat demand from residential buildings based on other methods such as heating-degree-days would improve the accuracy of the heat estimates.

Heat capacity factor for bioheat systems – Little information is available on annual heat energy generated from bioheat systems; this had to be estimated from installed capacity. With more and more bioheat systems being operational in remote communities, getting accurate data on annual heat delivered from these systems would be useful to better estimate annual heat demand where data is not available.

3.3 Future modelling work

A variety of future modelling work could be explored now that a national inventory and model of remote community energy demand and supply from renewable energy projects have been established. Some of these future modelling scenarios are highlighted below.

Improvement of modelling assumptions and data – Modelling is an iterative process and this research and analysis has made significant strides in better estimating annual energy demand and supply for diesel-equivalent and renewable energy sources. Further improvements to modelling assumptions, extrapolations and filling in missing data, as described above in Section 3.2, will provide more accuracy and insight into diesel reduction progress across Canada.

Include more energy efficiency measures – There are numerous ways to reduce energy demand through better energy efficiency methods. As a starting point, only two considerations were included in this modelling: waste heat recovery and heat pumps. The many other methods that are making progress across Canada include energy efficiency projects, deep home retrofits, wood stove replacement programs (swapping out old inefficient wood stoves with newer more efficient wood stoves) and smart energy monitoring and demand-side management methods. These can all contribute to significant energy savings. Further modelling work should quantify and include the energy savings from these methods to more accurately capture the significant diesel reduction progress made from energy efficiency.

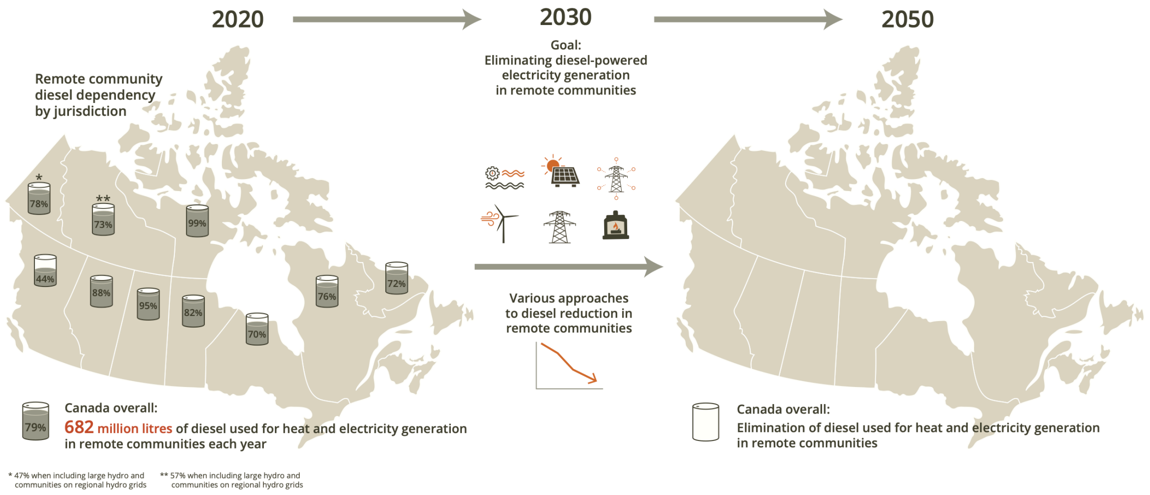
Incorporating electricity diesel reduction in territorial hydro grids – The inclusion of renewable energy and energy efficiency measures in the 25 communities that are connected to territorial large hydro grids will give further insight into the energy generation from these renewable sources. Since these communities are only partially reliant on diesel and other fossil fuels for electricity (estimated between 10 and 20%), diesel-eq reductions will be less significant, but still an important aspect to include.

Modelling and including planned projects within the next few years –Across Canada, several major renewable energy projects are in the engineering and development stage and are planned to be installed over the next three to four years. These include small hydro systems, wind energy projects, CHP projects and large bioheat projects, along with variable speed generator systems, upgraded more efficient diesel generators and smart grid technologies. With the knowledge that many projects will be commissioned over these next years, modelling their contribution to diesel reduction will provide important insight into these projects already in development.

Modelling of deeper penetration renewable electricity projects – There is also much research underway in key communities on deeper penetration projects – wind, solar and small hydro that could offer anywhere between 40% and 60% renewable energy penetration. Modelling their potential contribution to diesel reduction will also provide important insight into possible future reduction opportunities.

Modelling of expected grid-tied communities – Ontario, the NWT, Nunavut and Quebec are all making progress in connecting some of their remote communities to the provincial and territorial grids. These connections can bring significant reduction or elimination of diesel consumption for electricity, opening up new possibilities to tackle diesel consumption for heat through fuel and technology switching. Although not within scope of this research, electrification for transportation also becomes an interesting avenue to explore.

2030 and 2050 scenario planning – With this next level of modelling and research complete — coupled with the federal government's commitment to eliminating diesel-powered electricity in northern and remote communities by 2030, and further commitments for Canada to be net-zero in greenhouse gas emissions by 2050 — there is a great opportunity to look at the various scenarios and approaches that could support a complete clean energy transition for remote communities. Some of this work is commencing by looking at various sectors in Canada and the stage is set to ensure remote communities and clean energy get the deserved attention on what a complete energy transition would look like.



* 47% when including large hydro and communities on regional hydro grids

** 57% when including large hydro and communities on regional hydro grids

Appendix A. Remote communities

Community Name	Province/Territory	Electricity	Heat
Chipewyan Lake	AB	✓	✓
Fort Chipewyan	AB	✓	✓
Garden River	AB	✓	✓
Jasper	AB	✓	✓
Anahim Lake	BC	✓	✓
Atlin	BC	✓	✓
Bella Bella	BC	✓	✓
Bella Coola	BC	✓	✓
Dease Lake	BC	✓	✓
Dease River 4	BC	✓	✓
Eddontenajon	BC	✓	✓
Germansen Landing	BC	✓	✓
Gilford Island	BC	✓	✓
Good Hope Lake	BC	✓	✓
Gwawaenuk	BC	✓	✓
Hagensborg	BC	✓	✓
Hesquiaht	BC	✓	✓
Jade City	BC	✓	✓
Kingcome Inlet/ Ukwanalis Village	BC	✓	✓
Kitkatla	BC	✓	✓
Klemtu	BC	✓	✓
Kluskus	BC	✓	✓
Kulkayu	BC	✓	✓
Kwadacha	BC	✓	✓
Lasqueti Island	BC	✓	✓
Liard First Nation	BC	✓	✓
Lower Post	BC	✓	✓
Masset	BC	✓	✓
Nuchatlaht	BC	✓	✓
Ocean Falls	BC	✓	✓
Old Masset	BC	✓	✓
Owikeno	BC	✓	✓
Port Clements	BC	✓	✓
Queen Charlotte	BC	✓	✓
Sandspit	BC	✓	✓
Savary Island	BC	✓	✓

Sechelt Creek	BC	✓	✓
Seymour Arm	BC	✓	✓
Seymour Inlet	BC	✓	✓
Shearwater	BC	✓	✓
Skidegate Landing	BC	✓	✓
Telegraph Creek	BC	✓	✓
Timfor	BC	✓	✓
Tlatlasikwala	BC	✓	✓
Tlell	BC	✓	✓
Toad River Area	BC	✓	✓
Tsatsisnukwomi/ Harbledown Island	BC	✓	✓
Tsay Keh Dene	BC	✓	✓
Xeni Gwet'in First Nation	BC	✓	✓
Barren Lands	MB	✓	✓
Brochet	MB	✓	✓
Lac Brochet	MB	✓	✓
Shamattawa	MB	✓	✓
Tadoule Lake	MB	✓	✓
Black Tickle	NL	✓	✓
Cartwright	NL	✓	✓
Charlottetown	NL	✓	✓
Forteau	NL	✓	✓
François	NL	✓	✓
Grey River	NL	✓	✓
Hopedale	NL	✓	✓
L'Anse-au-Clair	NL	✓	✓
L'Anse-au-Loup	NL	✓	✓
Little Bay Islands	NL	✓	✓
Lodge Bay	NL	✓	✓
Makkovik	NL	✓	✓
McCallum	NL	✓	✓
Nain	NL	✓	✓
Natuashish 2	NL	✓	✓
Norman's Bay	NL	✓	✓
Paradise River	NL	✓	✓
Pinware	NL	✓	✓
Port Hope Simpson	NL	✓	✓
Postville	NL	✓	✓
Ramea	NL	✓	✓
Red Bay	NL	✓	✓

Rigolet	NL	✓	✓
St Lewis	NL	✓	✓
St. Brendan's	NL	✓	✓
St. Mary’s Harbour	NL	✓	✓
West St. Modeste	NL	✓	✓
Aklavik	NT	✓	✓
Behchokǫ̀	NT		✓
Colville Lake	NT	✓	✓
Délı̨ne	NT	✓	✓
Detah	NT		✓
Enterprise	NT		✓
Fort Good Hope	NT	✓	✓
Fort Liard	NT	✓	✓
Fort McPherson	NT	✓	✓
Fort Providence	NT	✓	✓
Fort Resolution	NT		✓
Fort Simpson	NT	✓	✓
Fort Smith	NT		✓
Gamètì	NT	✓	✓
Hay River	NT		✓
Hay River Dene 1	NT		✓
Inuvik	NT	✓	✓
Jean Marie River	NT	✓	✓
Kakisa	NT	✓	✓
Łutselk'e	NT	✓	✓
Nahanni Butte	NT	✓	✓
Ndilǫ	NT		✓
Norman Wells	NT	✓	✓
Paulatuk	NT	✓	✓
Sachs Harbour	NT	✓	✓
Sambaa K'e	NT	✓	✓
Tsiigehtchic	NT	✓	✓
Tuktoyaktuk	NT	✓	✓
Tulita	NT	✓	✓
Ulukhaktok	NT	✓	✓
Wekweètì	NT	✓	✓
Whatı̨̀	NT	✓	✓
Wrigley	NT	✓	✓
Yellowknife	NT		✓
Arctic Bay	NU	✓	✓

Arviat	NU	✓	✓
Baker Lake	NU	✓	✓
Cambridge Bay	NU	✓	✓
Cape Dorset	NU	✓	✓
Chesterfield Inlet	NU	✓	✓
Clyde River	NU	✓	✓
Coral Harbour	NU	✓	✓
Gjoa Haven	NU	✓	✓
Grise Fiord	NU	✓	✓
Hall Beach	NU	✓	✓
Igloolik	NU	✓	✓
Iqaluit	NU	✓	✓
Kimmirut	NU	✓	✓
Kugaaruk	NU	✓	✓
Kugluktuk	NU	✓	✓
Naujaat	NU	✓	✓
Pangnirtung	NU	✓	✓
Pond Inlet	NU	✓	✓
Qikiqtarjuaq	NU	✓	✓
Rankin Inlet	NU	✓	✓
Resolute	NU	✓	✓
Sanikiluaq	NU	✓	✓
Taloyoak	NU	✓	✓
Whale Cove	NU	✓	✓
Armstrong	ON	✓	✓
Bearskin Lake	ON	✓	✓
Biscotasing	ON	✓	✓
Collins	ON	✓	✓
Deer Lake	ON	✓	✓
Fort Hope	ON	✓	✓
Fort Severn	ON	✓	✓
Gull Bay	ON	✓	✓
Hillsport	ON	✓	✓
Kasabonika	ON	✓	✓
Keewaywin	ON	✓	✓
Kingfisher Lake	ON	✓	✓
Kitchenuhmaykoosib	ON	✓	✓
Muskrat Dam Lake	ON	✓	✓
Neskantaga	ON	✓	✓
North Spirit Lake	ON	✓	✓

Oba	ON	✓	✓
Ogoki	ON	✓	✓
Peawanuck	ON	✓	✓
Pikangikum	ON	✓	✓
Poplar Hill	ON	✓	✓
Sachigo Lake	ON	✓	✓
Sandy Lake	ON	✓	✓
Sultan	ON	✓	✓
Summer Beaver	ON	✓	✓
Wapekeka Reserve 1	ON	✓	✓
Wawakapewin	ON	✓	✓
Weagamow Lake	ON	✓	✓
Webequie	ON	✓	✓
Whitesand	ON	✓	✓
Wunnumin Lake	ON	✓	✓
Akulivik	QC	✓	✓
Aupaluk	QC	✓	✓
Blanc-Sablon	QC	✓	✓
Bradore-Bay	QC	✓	✓
Cap-aux-Meules	QC	✓	✓
Chevery	QC	✓	✓
Clova	QC	✓	✓
Fatima	QC	✓	✓
Grande-Entrée	QC	✓	✓
Grosse-Île	QC	✓	✓
Harrington Harbour	QC	✓	✓
Havre-Aubert	QC	✓	✓
Havre-aux-Maisons	QC	✓	✓
Inukjuak	QC	✓	✓
Ivujivik	QC	✓	✓
Kangiqsualujjuaq	QC	✓	✓
Kangiqsujuaq	QC	✓	✓
Kangirsuk	QC	✓	✓
Kawawachikamach	QC	✓	✓
Kitcisakik	QC	✓	✓
Kuujjuaq	QC	✓	✓
Kuujjuarapik	QC	✓	✓
La Romaine	QC	✓	✓
La Tabatière	QC	✓	✓
Lac-Rapide	QC	✓	✓

Les Îles-de-la-Madeleine	QC	✓	✓
L'Étang-du-Nord	QC	✓	✓
L'Île d'Anticosti	QC	✓	✓
L'Île-d'Entrée	QC	✓	✓
Lourdes-de-Blanc-Sablon	QC	✓	✓
Matimekosh	QC	✓	✓
Middle Bay	QC	✓	✓
Mutton Bay	QC	✓	✓
Obedjiwan	QC	✓	✓
Puvirnituq	QC	✓	✓
Quaqtaq	QC	✓	✓
Rivière-Saint-Paul	QC	✓	✓
Saint-Augustin	QC	✓	✓
Salluit	QC	✓	✓
Schefferville	QC	✓	✓
Tasiujaq	QC	✓	✓
Tête-à-la-Baleine	QC	✓	✓
Umiujaq	QC	✓	✓
Vieux-Fort	QC	✓	✓
Whapmagoostui	QC	✓	✓
Kinoosao	SK	✓	✓
Beaver Creek	YT	✓	✓
Burwash Landing	YT	✓	✓
Carcross	YT		✓
Carmacks	YT		✓
Champagne	YT		✓
Dawson City	YT		✓
Destruction Bay	YT	✓	✓
Faro	YT		✓
Haines Junction	YT		✓
Johnsons Crossing	YT		✓
Keno	YT		✓
Marsh Lake	YT		✓
Mayo	YT		✓
Old Crow	YT	✓	✓
Pelly Crossing	YT		✓
Ross River	YT		✓
Stewart Crossing	YT		✓
Tagish and Marsh Lake	YT		✓
Teslin	YT		✓

Watson Lake	YT	✓	✓
Whitehorse	YT		✓