Final Report

Assessing the Use of Liquid Biofuels in the Northwest Territories

Prepared for Government of Northwest Territories

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DISCLAIMER

Abstract:

At the request of the Government of the Northwest Territories (GNWT), the Saskatchewan Research Council (SRC), and its sub-contractor Blyth & Bathe, have investigated the replacement of liquid fuels with biofuels in the Northwest Territories (NWT). In the first phase, SRC and Blyth & Bathe identified petroleum fuel demand and required specifications, possible sources for biofuel procurement, and explored processes and their required feedstocks to produce biofuels for use in the NWT. In the second phase, the potential greenhouse gas emission reductions and costs of three biofuel use scenarios were explored. Finally, pilot demonstrations in other jurisdictions were investigated and the steps required to implement a pilot demonstration in NWT were identified.

EXECUTIVE SUMMARY

The Government of the Northwest Territories (GNWT) is interested in displacing fossil fuels with the goal of reducing energy costs and greenhouse gas (GHG) emissions. The GNWT has set a target of reducing its GHG emissions by 30% below 2005 levels by 2030 and intends to meet this objective by decreasing by 10% the per-capita emissions from transportation, as described in the NWT 2030 Energy Strategy. To meet its energy goals, the GNWT contracted the Saskatchewan Research Council (SRC), and its sub-contractor Blyth & Bathe, to investigate the potential use of liquid biofuels in the Northwest Territories (NWT).

A phased approach was taken to the project. In the first phase, current fuel supplies in the NWT were assessed, the required fuel specifications were identified, a supply assessment identified commercially available biofuels, and biofuel production options were investigated.

Annually, the NWT uses approximately 45 million litres of gasoline, 125 million litres of diesel for road transportation, and 70 million litres of heating oil. Of this, the GNWT's Fuel Services division delivers approximately 21.8 million litres of petroleum diesel to 16 communities in the NWT annually. This diesel is almost exclusively either Type A or B, and subject to CAN/CGSB-3.517.

Canada produces ethanol, biodiesel and wood pellets, and is currently importing renewable diesel. There are several technologies and processes that could convert biomass sources into the liquid fuels required for road transportation, electricity generation, space heating, and industrial use in the NWT. However, biofuel production processes are feedstock dependent, and the economics of the process can be greatly influenced by feedstock availability. Unfortunately, the NWT has little to no availability of most required feedstocks, apart from wood to produce pellets.

In the second phase, the economic and GHG emission impacts of importing biofuels for use in the NWT were investigated. The three most favoured options, as identified by the GNWT, were ethanol for road transportation, renewable diesel for road transportation, and renewable diesel for heating. SRC prepared environmental (life cycle greenhouse gas emission) and economic (cash flow) analyses for these options. Finally, the possibility of a pilot demonstration was investigated.

The life cycle greenhouse gas emission reduction potential of replacing current liquid fuels (gasoline, diesel) with alternative fuels in road transportation and residential space heating were estimated. Different blend scenarios of ethanol (with gasoline) and renewable diesel (with diesel) were examined. GHGenius, a publicly available lifecycle analysis (LCA) model with primary focus on road transportation fuels in Canada, was used for the analysis.

Replacing gasoline with E15 (15% ethanol blended with gasoline) and E85 (85% ethanol blended with gasoline) in light-duty vehicles resulted in 4.8% and 35% emission reductions, respectively. Long transport distances and ethanol produced in the US (as opposed to Canada) contributed to the modest emissions reduction results of ethanol scenarios. Replacing diesel with a renewable diesel blend (diesel and 5% renewable diesel) and neat (100%) renewable diesel resulted in 3% and 75% emission reductions, respectively. The technical feasibility of using renewable fuels in NWT was not examined in the LCA and possible costs related to changes to logistics, infrastructure and storage were not included. Alternative fuel options were compared to a baseline option based on current fuel use and prices in NWT. The estimated GHGs emission reduction potentials were applied to the cash flow analysis. The estimated costs are presented as an annual cost, the net present value (NPV) of a 20-year investment, and as a cost per unit of GHG emissions reduced ($/tonne CO_2e) in the table below.

Renewable Fuel Options	GHG Emissions Abatement (tonne CO2e/y)	Annual Cost ($/y)	NPV (20) (million $)	Cost of GHG Mitigation ($/tonne CO_2e)
E15 for transport	7,100	4,384,000	-83	618
E85 for transport	52,300	33,991,000	-679	650
RD5 for transport	15,000	1,741,000	-35	116
RD100 for transport	347,000	39,987,000	-452	115
RD5 for heating	8,400	975,000	-11	116
RD100 for heating	194,300	22,393,000	-253	115

Results of some recent biofuels pilot projects were reviewed. Despite the information gained in these previous demonstrations, there are some remaining unknowns about using renewable fuels in the NWT. Primary areas of concern are the ability of renewable diesel (hydrogen-derived renewable diesel, HDRD) to meet the required low temperature specifications, including whether blending with ultra-low sulfur kerosene will be required and at what rates. There are also concerns from local fuel users and suppliers about equipment compatibility. Although the performance of low ethanol blends is well understood, the lower energy density of ethanol by volume may cause issues with supply and storage. Higher blends of ethanol such as E85 may not be compatible with existing vehicles and equipment. Due to its extreme climate and remote location, the NWT has a higher risk exposure should problems develop with its fuel sources. For this reason, greater caution is needed when contemplating a transition to biofuels. SRC recommends starting with a low-risk pilot during the summer months, in a community where fuel is easily accessible should it be required.

The upcoming Clean Fuel Regulations, as well as climate action in Canada and in the US and abroad, will expand biofuels production in coming years. Continental sources of HDRD will likely be available, and one can expect additional research to be done to ensure biofuels work on the Northern context.

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1 INTRODUCTION

Due to its remote location, arctic and sub-arctic climates, and sparse population, the Northwest Territories (NWT) is substantially dependent on imported fossil fuels. These fossil fuels have considerable environmental and economic costs. The Government of the Northwest Territories (GNWT) is interested in displacing fossil fuels with the goal of reducing energy costs and greenhouse gas (GHG) emissions. The GNWT has set a target of reducing its GHG emissions by 30% below 2005 levels by 2030 and intends to meet this objective by decreasing by 10% the per-capita emissions from transportation. To meet its energy goals, the GNWT contracted the Saskatchewan Research Council (SRC), and its sub-contractor Blyth & Bathe, to investigate the potential use of biofuels in the NWT. Liquid fuels are used for electricity generation, space heating, road transportation, and industry needs.

SRC is Saskatchewan's leading provider of applied research, development and demonstration (RD&D) and technology commercialization. With over 350 employees, $63 million in annual revenue and 74 years of RD&D experience, SRC provides services and products to its 1,900 clients around the world.

Some portions of the project were subcontracted to Blyth & Bathe Inc., land use and environmental consultants located in the NWT. Their consulting experience spans the circumpolar region and includes every community in the NWT. This has led them to develop strong relationships with knowledge holders and decision makers in each region. Blyth & Bathe offer a broad suite of services with staff experienced in community based environmental monitoring, geophysics, environmental sciences, and anthropology.

A phased approach was taken to the project. In the first phase, current fuel supplies in the NWT were assessed, the required fuel specifications were identified, a supply assessment identified commercially available biofuels, and biofuel production options were investigated.

In the second phase, the economic and GHG emission impacts of biofuels use in the NWT were investigated. The three most favoured options, as identified by the GNWT, underwent economic (cash flow) and environmental (life cycle greenhouse gas emission) analyses. Finally, the possibility of a pilot demonstration was investigated.

2 PROJECT OBJECTIVES

The GNWT is seeking to investigate the feasibility (logistical, technical, environmental, and economic) of transporting, storing, using, procuring and/or producing liquid biofuels in the NWT. The use of biofuels for electricity generation, space heating, road transportation, and industry are explored.

3 CURRENT FUEL SUPPLY IN THE NWT

Market and Use

In the NWT the demand for refined petroleum products, such as diesel, is about 0.3% of the total Canadian demand (CER 2020). Given that the NWT population is no more than 0.001% of the total population of Canada, it is evident that residents of the NWT consume significantly more refined petroleum products per capita than the majority of Canadians. According to data published by the Canada Energy Regulator, the demand for petroleum products in 2018 was 572,000 L/d of diesel and 95,000 L/d of gasoline (CER 2020b)

Taking a look at GHG emissions highlights that some sectors are more emissions intensive than others and that the market for fuels skews heavily towards industry, mining and transportation. For example, resource extraction and freight transportation make up 75% of the total emissions while community-based emissions from power generation, heating and personal transportation are approximately 25% of emissions according to Canada's Greenhouse Gas Inventory (Government of Canada 2018).

Supply

The NWT's remote communities create difficult logistics challenges for fuel supply chains. This limits the supply and increases the price of fuels. The GNWT's Fuel Services Division (GNWT-FSD) oversees the purchase, transport, distribution, and storage of fuels for 16 communities that are not currently served by private companies and for 20 communities on behalf of the NWT Power Corporation (NTPC). In the bigger communities, these services are provided by a number of private companies. Depending on the size of the company, they may provide only a portion of the services in the supply chain. For example, there are companies that specialize in the distribution of fuels to the end user while others are only involved in the transportation from the southern refineries to the storage locations in the NWT.

Both the GNWT-FSD and the private companies, largely source their fuel from refineries in Alberta. These are transported by rail or truck throughout the year. During the ice-free season, fuel is shipped to communities with no road access by barge.

3.1 Fuel Supply to PPP Communities

The Petroleum Products Program (PPP) administered by the Fuel Services Division, "manages the purchase, transport and storage of bulk petroleum products for 16 NWT communities that are not serviced by the private sector" (Fuel Services 2020). The current fuel supply data for the communities served by the PPP is tabulated below **(Table 1).** All fuels are transported to Hay River from Edmonton either by rail line or by truck, and then trucked and/or barged to surrounding communities.

Table 1: Fuel Supply for PPP Serviced Communities

Community	Total Tank Capacity (L)	Non-motive Diesel (L)	Heating Diesel (L)	Motive Diesel (L)
Colville Lake	729,776	163,000	174,000	76,000
Délı̨nę	7,584,211	760,000	850,000	163,000
Fort Good Hope	5,726,973	763,000	768,000	121,500
Gamètì	1,492,441	342,000	375,000	83,000
Jean Marie River	275,099	102,500	78,500	25,200
Łutselk'e	3,032,478	444,000	552,000	42,700
Nahanni Butte	716,687	102,500	78,500	25,200
Paulatuk	2,398,083	401,500	636,000	12,000
Sachs Harbour	1,617,457	297,000	388,000	33,200
Sambaa K'e	366,285	102,500	44,600	87,000
Tsiigehtchic	366,381	223,500	281,000	58,600
Tulít’a	6,503,852	695,000	886,000	99,000
Ulukhaktok	3,118,332	612,000	916,000	77,000
Wekweètì	550,458		170,000	50,000
Whatì	1,830,509	457,000	487,000	133,000
Wrigley	747,640	218,000	178,000	51,000
Inuvik	9,074,927	6,450,000	-	-
Yellowknife	1,727,536	1,750,000	-	-
Total	**47,859,125**	**13,883,500**	**6,862,600**	**1,137,400**

The PPP delivers approximately 21.8 million litres of petroleum diesel to 16 communities in the NWT annually. Of this, 13.8 million litres are used in non-motive applications, 6.8 million litres are used for heating, and 1.1 million litres are used for road transportation.

3.2 Fuel Supply from Private Sources

Communities that are not supplied by the PPP are supplied through the private sector. This includes companies that produce diesel and gasoline, transportations companies that ship it in bulk from Alberta to Hay River, companies that transport smaller amounts to individual communities, and the companies in these communities that distribute petroleum products to individual consumers.

Blyth & Bathe contacted private petroleum distributors operating in the NWT to gather more refined estimates on the supply of petroleum products available in their areas. Unfortunately, the distributors contacted were not able to share fuel supply volumes at this time, due to a combination of an inability to look up total volumes, lack of person-hours, and/or privacy concerns. However, an overview of petroleum product demand in NWT in 2019 was available from Statistics Canada, as was an estimate of residential heating in 2018 from Navius Research**.** The GNWT was able to provide estimates for gasoline demand at 45 million litres, road transportation diesel at 125 million litres, and heating oil at 70 million litres; the estimates from all sources are compiled in **Table 2.** The information provided by the GNWT was used in this analysis.

Table 2: Estimated Annual Gasoline and Diesel Demand in NWT (Litres)

Volumes / Source	Stats Canada	Navius	GNWT
Gasoline - road only, 2019	43,341,000		45,000,000
Diesel - 2019	113,024,000		125,000,000
Diesel - residential heat,2018		70,000,000	70,000,000

3.3 Required Fuel Specifications

Fuel standards in Canada are governed by the Canadian General Standards Board (CGSB); ASTM International is the body in the United States. CAN/CGSB-3.517 is the standard that governs the properties of diesel fuel (Diesel Net 2020). The two main types of diesel currently used and/or distributed by the PPP are Diesel Type A & B. Type A is appropriate for high-speed diesel engines which are subjected to variable loads and low ambient temperatures. Type B is suitable for high-speed diesel engines subjected to relatively high uniform loads (Diesel Net 2020). Key specifications are highlighted in **Table 3.**

Table 3: Fuel Specifications for Diesel Type A & B

Name	CAN/CGSB 3.517-2017 Diesel Fuel, Type "A"	CAN/CGSB-3.517-2017 Diesel Fuel, Type "B"
Cloud Point:	-43°C	Must adhere to CAN/CGSB-3.517.2017, section 6.1.1
Electrical Conductivity	100 pS/m minimum at point of delivery for both fuels	
Fatty Acid Alkyl Esters	No FAAE content permissible for both fuels	

The cloud point portion of the specification is of particular importance in cold climates such as the NWT. Cloud point is the most-used metric for cold-weather operability; it varies over time and is designed to be lower than the operating temperature of the fuel. Cloud point is the temperature at which solid wax crystals first appear in diesel fuel. At this point the fuel has separated into two phases, liquid and solid, but it may still be able to flow. Pour point, another commonly reported metric, is the temperature at which the fuel can no longer flow or be pumped.

The CGSB standards are also explicit about additional parameters such as lubricity, cetane value, sulfur content and other parameters. Petroleum diesel in Canada is typically blended at the refinery and tested prior to distribution and sale to ensure it meets these requirements.

Canada relies on the ASTM D6751 testing standards for biodiesel. Other testing standards and certifications, such as BQ-9000® and CAN/CGSB-3.520 may also be applicable. (SRC 2012). Hydrogen derived renewable diesel is subject to the same fuel standards as No. 2 diesel or ULSD: CGSB 3.517 in Canada, ASTM D975 in the United States and EN 590 in Europe (Eco Resources 2012).

CAN/CGSB-3.5 is the standard for automotive gasoline, while low-percentage ethanol blends (E1-E15) are covered by CAN/CGSB-3.511 and higher ethanol blends (E20-25 and E50-E80) by CAN/CGSB-3.512 (CGSB Catalogue, 2021). According to CAN/CGSB-3.512, "Fuel produced to this standard is not for use in conventional vehicles designed to operate on gasoline containing up to 10% or 15% by volume ethanol". Special vehicles and equipment are required to operate on ethanol blends above 15%. Ethanol can be added to gasoline to improve volatility in cold weather conditions, which would be a benefit in the NWT. However, CAN/CGSB – 3.512 warns against their use in "regions where fuels are normally provided in bulk only periodically during the year", due to concerns with long-term stability of the fuels (2018).

3.3.1 Non-motive Diesel

Non-motive diesel is used primarily for electrical generation and industrial uses. NTPC commissioned a study on liquid biofuels in 2007 (NTPC 2007). This report found that NTPC's generators could only use fuel blended to include up to 30% biofuel with regular diesel (also known as B30). Blyth & Bathe contacted CAT and Detroit Diesel, the two main manufacturers of NTPC's generators. Both companies confirmed that modern diesel engines can run on 100% biodiesel (B100) but if the operator damages the equipment through mishandling of the fuel, their warrantees would be voided. This suggests that replacing aging generators could allow for opportunities to the transition to B100 generators.

NTPC (2007) points out that there are problems with cold temperature flow of biodiesel and with long-term stability. In communities that are resupplied throughout the year, this may not be an issue. However, in more remote areas that only receive one fuel shipment per year there is no tolerance for risk in the fuel supply.

While no specific fuel standards were given, some distributers of smaller diesel generators (~2MW) contacted by Blyth & Bathe stated that their warranties would be voided if biodiesel, even in modest blends such as B5 or B10 (5% and 10% biodiesel respectively), were used in the engines.

Blyth & Bathe contacted several private consumers in the mining industry to assess the technical fuel specifications that they require. Universally, they responded that they currently only consider Diesel Type

A & B. There was some interest in the potential for biofuels but without a significant economic incentive, none of the respondents felt there would be much uptake of the renewable options at this time.

4 SUPPLY ASSESSMENT OF COMMERCIALLY AVAILABLE BIOFUELS

Blyth & Bathe contacted various fuel distributors operating in the NWT. All the smaller distributors expressed concerns about placing biodiesel in their vehicles and storage tanks. However, most of the distributors were unaware of the difference between biodiesel and renewable diesel. Despite renewable diesel being chemically identical to petroleum diesel, almost everyone contacted expressed that they would need to take the same precautions that they would use with biodiesel to avoid mixing the renewable diesel in any of their infrastructure.

It is possible, that with some familiarization with the product that distributors would be comfortable shipping renewable diesel in their existing infrastructure. A possible work-around would be to have trucks haul the biofuel directly from a southern supplier, such as Archer Daniels Midland (ADM) in Lloydminster, to the purchaser's storage tank.

SRC performed a market scan to identify Canadian producers of biofuels and determine the amount of product they could potentially have available. The results are discussed by fuel type in the following sections.

4.1 Ethanol

Canadian ethanol plants are estimated to have produced 1,880 million litres in 2019. The amount of fuel ethanol consumed in Canada is much higher, with 2019 estimates of 3,200 million litres (Stats Can 2019). The remaining 1,400 million litres were imported, with ≥98% of imports coming from the United States. Since 2013 Canada has imported 40-45 percent of its fuel ethanol with negligible exports (Biofuels Annual 2019). This gives a national blend rate average of 6.6%, which slightly above the most common provincial blending requirement of 5% (Navius 2019). Over 80 percent of ethanol produced in Canada in 2018 used corn as a feedstock (Biofuels Annual 2019). Canadian ethanol plants are listed in **Table 4.**

Table 4: Canadian Ethanol Facilities

Ethanol Plants			
Facility Owner - Town	**Province**	**Year Commissioned**	**Annual Capacity** (ML)
Greenfield - Chatham	ON	1998	200
Greenfield - Johnstown	ON	2008	260
Greenfield - Tiverton	ON	1989	32

Greenfield - Varennes	QC	2007	190
Husky - Lloydminster	SK	2006	150
Husky - Minnedosa	MB	2008	150
IGPC - Chatham	ON	2008/2018	380
Kawartha - Ethanol	ON	2010	110
NorthWest - Unity	SK	2009	25
Permolex - Red Deer	AB	1997/2004/2008	45
Poundmaker - Lanigan	SK	1991	15
Suncor - St. Clair	ON	2006/2011	400
Terra Grain - Belle Plaine	SK	2008	150
Enerkem - Edmonton (Advanced Ethanol)	AB	2017	38
Total Ethanol	**14 plants**		**2,145**

4.2 Biodiesel and Renewable Diesel

In 2019 Canada produced 375 million litres of biodiesel, out of an estimated total capacity of 629 million litres (Advanced Biofuels Canada 2019). As with ethanol, demand for biodiesel and renewable diesel in Canada exceeds domestic supply; demand reached 1,000 million litres in 2018. The average national blend rate is slightly above two per cent. However, due to the U.S. biomass-based diesel (BBD) blenders tax credit, and the value of Renewable Identification Numbers (RINs), most of the biodiesel produced in Canada is exported to the US (Biofuels Annual 2019). Local demand is met through imports, the majority of which are from the United States, along with shipments of renewable diesel from Europe and Singapore (Navius 2019). Canadian biodiesel plants are listed in **Table 5.**

Table 5: Canadian Biodiesel Facilities

Biodiesel Plants	Province	Year Commissioned	Annual Capacity (ML)
ADM - Lloydminster	AB	2013	320
Consolidated - Delta	BC	2009	11
BIOX - Hamilton	ON	2007	60
BIOX - Sombra	ON	2009	50
Verbio - Welland	ON	2015	170
Darling - Montreal	QC	2005/2008	56
Innoltek - St. Jean	QC	2014	12
Total Biodiesel	**6 plants**		**629**

An additional 20 million litres of biodiesel capacity was previously available from the Milligan Biofuels plant in Foam Lake, Saskatchewan, but it ended operations in 2019.

4.3 Advanced Biofuels in Canada

“Advanced biofuels”, also known as “second generation biofuels”, refers to both cellulosic ethanol and renewable diesel. Canada’s production of advanced biofuels is extremely limited. Iogen has operated a 48,000 liter per year cellulosic ethanol demonstration plant in Ontario since 2004. Enerkem operates a 38 million litre per year MSW-to-biofuels and chemicals facility in Edmonton, Alberta. The plant originally produced only methanol but added a methanol-to-ethanol converter unit in 2017 (Biofuels Annual 2019).

Ensyn Technologies Inc. operates a 11 million liter per year plant in Renfrew, Ontario that produces renewable fuel oil. They have also partnered 50/50 with Arbec Forest Products to build a 40 million litres/year biocrude plant in Quebec. The process uses rapid thermochemical liquification to transform forest residues into biocrude which can be further upgraded to liquid fuel (Biofuels Annual 2019).

Cielo has built a demonstration plan to convert municipal solid waste to renewable fuels in Aldersyde, Alberta, which is currently in the commissioning stage (Cielo 2020). The renewable fuel oil and renewable diesel plants operating in Canada are listed in **Table 6.**

Table 6: Canadian Advanced Biofuel Facilities

Renewable Fuel Plants	Province	Year Commissioned	Annual Capacity (million L/y)
Renewable Fuel Oil (RFO) Plants			
Ensyn - Renfrew	ON	2014	11
Ensyn – Port Cartier	QC	2018	40
Total RFO	**2 plants**		**51**
HDRD Plants			
Cielo	AB	Unknown	Demonstration
True North Renewable Fuels Ltd.	SK	Unknown	1,000
Covenant Energy	SK	2023 (e)	300-325
HDRD from Co-Processing Refineries			
Parkland – Port Moody	BC	2020 (e)	150(e)
Tidewater Midstream	BC	2023 (e)	174 (e)
Second Generation Ethanol			
Enerkem - Edmonton	AB	2014	38
Enerkem - Varennes	QC	Recently announced	Unknown
Iogen	ON	2004	0.48

(e) = estimated

4.4 Federal Clean Fuel Standard

A number of jurisdictions are considering the adoption of a low-carbon fuel standard, which requires refined petroleum products to be blended with low-carbon fuels such as biofuels, as part of their climate policy. Canada has committed to establish a Clean Fuel Standard (CFS) by 2022 as one key policy to decarbonize domestic energy systems and help meet GHG emissions reduction targets. The CFS takes a lifecycle approach to GHG emission reduction. A lifecycle approach is commonly used to quantify the emissions across the entire lifecycle of a product or service, to inform product design, policy decision, etc. and used in existing regulations (e.g., Government of Ontario 2020; Government of British Colombia 2020). For liquid fuels, it means quantifying the emissions from extraction of raw material (oil), its refining, transportation of fuels, and their use (for transportation, heating, etc.).

In the U.S., the House Select Committee on the Climate Crisis recommended the development of a national low-carbon fuel standard (LCFS) that would replace U.S. Renewable Fuel Standard (RFS) after 2022 (HSCCC, 2020). In Canada, the carbon intensity reduction requirement will start at 3.6 gCO2e/MJ in 2022 and gradually increase to 12 gCO2e/MJ in 2030. Biofuels blending is one main compliance pathway under the proposed regulations (Government of Canada 2020). Liquid fuels imported by the GNWT are exempt from the Clean Fuel Regulations. It’s unclear how this change will affect the carbon intensity of fuel supplied from domestic refineries (i.e., Edmonton).

5. BIOFUEL PRODUCTION OPTIONS

A technology scan was performed to identify technologies and processes that can convert biomass sources into the fuels required for road transportation, electricity generation, space heating, and industrial use in the NWT. These technology options are discussed in more detail in Appendix A. A feedstock audit was also performed to determine what types of biomass are available as input for generating biofuels, and in what amounts. Detailed results are in Appendix B.

Canada produces ethanol, biodiesel, and wood pellets, and is currently importing renewable diesel. There are several technologies and processes that can convert biomass sources into the fuels required for road transportation, electricity generation, space heating, and industrial use in the NWT.

Biofuel production processes are feedstock dependent, and the economics of the process can be greatly influenced by feedstock availability. Unfortunately, the NWT has little to no availability of most required feedstocks, with the possible exception of wood pellets. Wood pellets can be combusted for heat or used to produce heat and power.

6 OPTIONS FOR FURTHER STUDY

Given the limited supply of raw materials to make biofuels locally, the GNWT has expressed interested in importing biofuels to reduce GHG emissions. The GNWT identified three options for further study:

1. The purchase of ethanol for use in road transportation,
2. The purchase of hydrogen-derived renewable diesel (HDRD) for use in road transportation, and
3. The purchase of HDRD for space heating.

In Phase 2 the economic and GHG emission reductions benefits of these three options were investigated, as were the steps required to implement a pilot biofuels program. Background information on ethanol and HDRD is presented below. The GHG emission reductions benefits of these three options are presented in section 7 and the economic analyses are presented in section 8.

6.1 About Ethanol

The Canadian federal government mandates 5% ethanol in the gasoline pool on average under the current Renewable Fuel Regulations. Some provinces have higher requirements; for example, BC requires 8.5%. As discussed in Section 4.4, the forthcoming Clean Fuel Standard will move away from a fixed blend percentage to a carbon intensity-based metric. As previously mentioned, fuel supplied to the NWT will be exempt. Commercially, fuel ethanol is produced through the fermentation of high-sugar crops. Canada consumes more ethanol than it produces, and imports are primarily from the US (see Section 4.1).

Most vehicle manufacturers allow for up to 10% ethanol in the fuel without any impact on warranty. The National Renewable Energy Laboratory conducted research in 2009 that found no effect on engine durability, vehicle driveability, or engine operation from use of E10, E15, and E20 ethanol blends (NREL 2009). In 2010 the US Environmental Protection Agency granted a waiver allowing up to 15% ethanol to be used in cars, light trucks, and SUV’s manufactured since 2001 (EPA 2020). Specialty vehicles are available that can run on up to 85% (aka E85).

For this study, SRC has considered a 15% ethanol blend scenario (i.e., E15) and an 85% (E85) blend scenario. Blending will most likely occur at refineries near Edmonton, with the blended fuel shipped by rail to Hay River and trucked from there to other communities, as is currently the case for gasoline. The estimated demand of 34 million litres of gasoline per year provided by the GNWT was used in the subsequent analysis.

6.2 About Renewable Diesel

Hydrogen derived renewable diesel (HDRD) and biodiesel are both made from biomass. Feedstocks for both products are similar, and can include vegetable oils, animal fats, and waste. However, due to the hydrogenation and isomerization processes it undergoes, HDRD is chemically indistinguishable from the straight chain and branched hydrocarbons found in diesel, while biodiesel is not. As such, HDRD is subject to the same fuel standards as No. 2 diesel or ultra-low sulfur diesel ULSD.

Fully saturated hydrocarbons, as found in HDRD and petroleum diesel, are not subject to oxidative stability issues (Eco Resources 2012). HDRD does not contain any oxygen compounds, sulfur, paraffins, or aromatics. The lack of aromatics can cause HDRD to have lower lubricity than petroleum diesel, and so additives are included to ensure the fuel meets lubricity standards. HDRD producers will correct the lubricity before sale so that their product meets the required fuel standards for the jurisdiction where it is sold.

According to representatives from Neste, the fuel they sell into the North American market is produced at their Singapore facility. Neste's standard product, "MY Renewable Diesel", has a -20°C cloud point. Some fuel destined for sale in Canada during the months of September through March has an adjusted cloud point of -27°C. Neste has the capability to alter cloud point properties during the isomerization step of HDRD production. They have previously made a -40°C cloud point fuel, though pointed out that -34°C would be the lowest potentially available at this time. If colder temperatures are expected, as they would be during winter in the NWT, the only option at this time would be blending with a lower cloud point #1 / ultra-low-sulfur kerosene (ULSK) fuel. As the market for low-cloud point diesel increases, it may become available from producers such as Neste, but there are many issues around logistics and pricing that have yet to be defined. Several Canadian companies have announced their intentions to manufacture HDRD (see Table 6), which will have a positive impact on the supply of low-cloud point HDRD.

In the 2019 Alberta Renewable Diesel Demonstration, the cloud point of a renewable diesel blend was adjusted using ultra low sulfur kerosene (ULSK) to meet the cold operability specifications in the CAN/CGSB 3.520 fuel standard. The test added 8-15% ULSK to the 2% HDRD blend, though they point out that this was not a comprehensive study of ULSK blends, and other results may vary. Given the experience in Alberta, and the cloud point of the HDRD currently available from Neste, the need to blend with ULSK is likely. The subsequent analysis investigates a blend of 5% HDRD with 15% ULSK and 80% petroleum diesel, which represents the most likely short-term implementation and 100% HDRD, which is the best-case implementation scenario. Blending with ULSK will affect the cloud point as well as the carbon intensity of the blended fuel.

For this analysis, it is assumed blending would take place at refineries in Edmonton, and the blended fuel product would be transported to NWT in the same manner as current diesel imports. The costs of blending and transportation are included in the sale price of the HDRD blend. As HDRD is fully compatible with petroleum diesel, we have assumed there will be no need for separate storage facilities.

7 POTENTIAL GREENHOUSE GAS EMISSION REDUCTIONS

7.1 Approach and Methodology

7.1.1 Goal and scope

The objective of this analysis was to estimate the potential GHG emissions reduction from implementation of the alternative fuel options. A life cycle assessment (LCA) approach was applied. LCA is commonly used to quantify the emissions across the entire lifecycle of a product or service, to inform product design, policy decision, etc. Examining emissions from fuel systems on a lifecycle basis is in line with existing and proposed provincial and federal clean/low carbon fuel regulations (e.g., Government of Ontario 2020; Government of British Columbia 2020; Government of Canada 2020). It accounts for all GHG emissions occurring along the fuel's supply chain (e.g., crude oil extraction, refining, transport, etc.).

In this work, alternative fuel options are compared to reference systems—baseline options based on the current situation in NWT. They are described below.

LCAs are carried out based on a functional unit, which specifies the basis on which the options are compared. In this study, the functional unit is defined as one megajoule (MJ) of fuel, as typically done in similar studies (e.g., University of Toronto 2019). This accounts for differences in energy content of the fuels (that is, various fuels contain different energy content per mass or volume).

7.1.2 System boundary

The system boundary establishes the processes included in the GHG emission calculations. The life cycle of fuels begins with the extraction/production of the feedstock (crude oil, biomass, used cooking oil, etc.), production of the finished fuels, transport, storage and distribution of the fuels, and use (combustion) of the fuels in vehicles, boilers, etc. For the biomass-based pathways, feedstock production includes fertilizers, farm equipment uses, collection and processing of feedstock (e.g., used cooking oil), etc. These life cycle stages are covered in the modeling tool used herein. Emissions related to vehicle construction and infrastructure are not included, as commonly done in similar studies (e.g., University of Toronto 2019). In that respect, the potential need for additional and separate storage and other infrastructure for alternative fuels is not considered.

7.1.3 Greenhouse Gas Emissions

The analysis considered the contribution of three GHGs: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Emissions are converted to and reported as CO_2-equivalent (CO_2e) calculated according to the guidelines of the Intergovernmental Panel on Climate Change (IPCC) 2007 Fourth Assessment Report 100-year global warming potentials (GWPs), in line with Government of Ontario (2020) and Government of British Columbia (2020). The GWPs are as follows: CO_2:1, CH_4: 25, and N_2O: 298. The respective emissions are multiplied by these factors to obtain CO_2e.

Carbon dioxide emissions during combustion of biomass-based fuels are considered carbon neutral, meaning that the CO_2 emitted during combustion was recently taken-up (sequestered) from the atmosphere by plants and are released back to the atmosphere during combustion.. This is the basis of the potential GHG emission reduction from biomass-based fuels when displacing fossil fuels. This approach is in line with national and international recognized GHG accounting methodologies (e.g., Government of Canada 2020). It should be noted that only CO_2 emissions are considered carbon neutral and other emissions from combustion of biomass-based fuels (e.g., methane) are not – the latter are therefore included to the GHG emission of the fuel pathways.

The production of biomass-based fuels emits GHGs from crop production, harvest, livestock, land use changes, etc. that are considered. As per Government of Canada (2020):

> *"Direct land-use change (DLUC) happens when a particular parcel of land is converted to grow crops for biofuel production. Indirect land-use change (ILUC) occurs when crops grown for biofuels displace traditional food and animal feed crops, leading to production of that displaced food crop elsewhere (i.e. other land is converted to grow the food crop)"*

These changes may lead to land-use-related GHG emissions (e.g., removal and burning of trees, soil carbon losses). Direct land use changes are considered in the current analysis, but ILUC are not considered, in line with low carbon fuel standards (Government of Ontario 2020; Government of British Columbia 2020). The proposed federal Clean Fuel Standard will account for direct land use change as part of the lifecycle GHG calculations but will not account for ILUC (Government of Canada 2020).

7.1.4 Fuel Systems Examined

Three reference systems are compared with alternative fuel options presented in **Table 7.**

Table 7: Reference and alternate fuel options

Reference Systems	Alternative fuel option
Gasoline in light-duty vehicles (LDV)	E15: Gasoline mixed with 15% (vol.) ethanol in LDV
	E85: Gasoline mixed with 85% (vol.) ethanol in LDV
Diesel in heavy-duty vehicles (HDV) and for residential heat	RD5: Diesel mixed with 5% (vol.) renewable diesel and 15% (vol.) ULS kerosene in HDV and residential space heating.
	RD100 Neat renewable diesel (100%) in HDV and residential space heating

The ethanol is assumed to be produced from corn in the United States. Since 2013, Canada has imported 40-45 per cent of the fuel ethanol consumed in the country—98 per cent of imports coming from the United States (Section 4.1). Increase in ethanol consumption in Canada, such as for the scenarios examined herein, is therefore assumed to be imported from the US. Renewable diesel is assumed to be hydrogen-derived renewable diesel (HDRD) produced at Neste' Singapore facility using two feedstocks: used cooking oil (yellow grease) and animal fats (tallow). Due to the alternative fuel properties, there may be technical challenges to the implementation of the Neat HDRD scenario in NWT. However, they are not considered in the GHG emissions analysis. Model parameters and assumptions for each system are presented below.

7.1.5 Modeling Tool

GHGenius version 5.0f is used for this analysis. This is the most recent version of GHGenius at the time of writing of this report. GHGenius is a publicly available lifecycle analysis model with primary focus on transportation fuels in Canada (GHGenius 2020). It is a mature model that is continuously updated. It is the approved modeling tool in BC Low Carbon Fuel Standard and Ontario Greener Diesel regulations (Government of Ontario 2020; Government of British Columbia 2020). A lifecycle model is being developed to support the implementation of the federal Clean Fuel Standard (Government of Canada 2020). GHGenius accounts for activities from the extraction of fossil fuels, crop production, DLUC, feedstock processing, transport of finished fuels, power generation, and combustion of the fuel. It does not account for ILUC.

7.1.6 Modeling Parameters and Assumptions

Parameters and assumptions used to model the different fuel pathways are presented below and in Appendix C. GHGenius is tailored for fuels mainly produced in Canada and the United States. Proxy data and assumptions were used whenever needed as described and justified below.

Ethanol is assumed to be imported from Iowa, the top ethanol producer in U.S.A. (Energy Information Administration 2018). Iowa's capital (Des Moines) is used as the starting point for shipping neat ethanol. Ethanol is shipped to Canada and then blended. Neste's HDRD plant is in Singapore while GHGenius assumes an HDRD plant in Canada. In this analysis, this difference is accounted for by modifying transport distance of the finished fuel and selecting the Atlantic Canada electricity grid which has GHG emissions similar to that of Singapore (Appendix C). There is no kerosene pathway available in GHGenius so the lifecycle emissions of kerosene were modeled based on GHGenius low-sulfur jet fuel (0.0015% S), the fuel available in GHGenius closest to kerosene. Fuel properties are taken from GHGenius and listed in Appendix C.

Transport parameters were modified to reflect modes of transportation and transport distances of the finished fuels to the NWT (Appendix C). Yellowknife is assumed as the destination for the analysis because it is the major population center in NWT (approximately half of NWT's population resides in Yellowknife). It is recognized that further transport would be required to other communities. Fuel is currently shipped to Hay River mainly by rail and truck and barge from there. This is reflected in the modes of transport modeled except for barging that is not included in the analysis. The latter two assumptions (i.e., Yellowknife as final destination and exclusion of barging) should not affect the calculation of GHG emission reduction potential as the assumptions are applied to both the reference and alternative systems.

GHGenius is mainly a transport-fuel life-cycle emissions model. It provides some emission data for stationary combustion such as residential heating by diesel, electricity and wood. However, it does not provide these data for HDRD and jet fuel (proxy fuel for kerosene). GHG emissions from combustion of diesel in heavy duty vehicles (combustion only – not lifecycle emissions) reported in GHGenius were compared with combustion emissions reported in ECCC (2020 Table A6.1-4). Based on ECCC (2020), combustion of light fuel oil in a residential setting emits 2,755.4 g CO_2e/L. This is 2% higher than combustion emissions from diesel heavy duty vehicles reported by GHGenius (2,714 g CO_2e/L). The lifecycle emissions for transport processed are used for the heating pathways in this analysis because, (i) the small 2% difference in combustion emissions between GHGenius and other sources, (ii) lack of lifecycle data for combustion of alternative fuels for heat in GHGenius, and (iii) the fact that upstream lifecycle emissions (production, shipping of the fuel, etc.) per L or MJ of fuel would be the same regardless of its final use (i.e., transport or heat).

7.2 Results and Discussion

Table 8 presents the lifecycle GHG emissions of the baseline and alternative fuels broken down by lifecycle stages. Lifecyle stages are presented as defined in GHGenius for consistency and ease of comparison with the model. As discussed above, jet fuel is used as a proxy for kerosene because kerosene is not available in GHGenius.

Results for gasoline and diesel lifecycle GHG emissions are in line with the baseline carbon intensities for the two fuels defined in Government of Canada (2020) (i.e., 96 g CO_2e/MJ for both gasoline and diesel). Ethanol (E100) emissions are at the higher end of the range of values previously reported (32-59 g CO_2e/MJ – Government of Canada 2020; Navius 2019). This is likely due to model parameters selection such as corn ethanol produced in Central US (as opposed to ethanol produced in Canada), long transport distances, etc. For example, modeling corn-ethanol produced in Ontario and delivered to NWT results in lower emissions (46.6 g CO_2e/MJ). The neat renewable diesel (HDRD) values estimated herein are within the range reported in the literature (-7.5 to 49 g CO_2e/MJ – Government of Canada, 2020; Neste 2016; Navius 2019; University of Toronto, 2019). Both low biofuel blends (i.e., E15 and RD5) have lower lifecycle emissions than their baseline fossil fuel counterparts (Table 8).

For fossil fuel pathways, combustion (net vehicle operation) contributes most to emissions. For ethanol (E100), fuel production and land use changes are the main contributors, while fuel production (including feedstock upgrading), storage and distribution are the main contributors for neat HDRD. The biogenic emissions (from combustion of biofuel) are considered carbon neutral, hence the negative emissions shown for “C in end-use fuel from CO_2 in air” in Table 8 (i.e., the carbon in the biomass was sequestered from the atmosphere). As mentioned above, the lifecycle stages in Table 8 are presented as defined in GHGenius for consistency with the model used. Co-products produced along the finished fuels can displace the production of equivalent products made through other means. For example, animal feed is a co-product of the HDRD tallow pathway which can displace other feed such as soymeal (University of Toronto 2019). In LCA, co-product displacement (e.g., HDRD-derived animal feed displacing soymeal) is credited the displaced emissions (i.e., negative values “Emissions displaced by co-products” in Table 8). The contribution of finished fuel transport (“Fuel storage and distribution” in Table 8) is lower for fossil fuels (approx. 2%) than for neat biofuels, likely due to several factors such as energy density of biofuels, longer transport distances, etc. (see Appendix C).

Table 8: Lifecycle GHG emissions by fuel pathways (g CO_2eq/MJ)

Lifecycle stages	GHG emissions (g CO_2eq/MJ)									
	Gaso-line	Ethanol (E100 – corn, US Central)	E15 (15% US corn ethanol, 85% gasoline – % vol.) [1]	E85 (85% US corn ethanol, 15% gasoline – % vol.) [1]	Diesel (0.0015% S)	HDRD (Yellow Grease)	HDRD (Tallow)	HDRD blend (50% Yellow Grease and 50% Tallow - % vol.) [1]	Jet fuel (Proxy for kerosene)	RD5 blend (5% HDRD, 15% Jet fuel 80% diesel - % vol.) [1]
Vehicle operation	69.2	66.5	68.9	67.1	70.2	67.2	67.2	67.2	71.5	70.3
C in end-use fuel from CO_2 in air	0.0	-64.3	-6.9	-51.0	0.0	-65.6	-65.6	-65.6	0.0	-3.1
Net vehicle operation	69.2	2.2	62.0	16.0	70.2	1.6	1.6	1.6	71.5	67.1
Fuel dispensing	0.8	1.0	0.8	1.0	0.8	0.2	0.2	0.2	0.8	0.8
Fuel storage and distribution	2.0	6.3	2.5	5.4	2.0	10.5	10.5	10.5	2.1	2.5
Fuel production	9.7	27.2	11.6	23.6	9.2	10.4	10.4	10.4	9.6	9.3
Feedstock transport	0.7	1.4	0.8	1.2	0.7	0.5	1.7	1.1	0.7	0.7
Feedstock recovery	5.7	2.9	5.4	3.5	5.8	0.0	0.0	0.0	6.0	5.5
Feedstock upgrading	4.7	0.0	4.2	1.0	4.8	1.3	15.7	8.5	4.9	5.0
Land-use changes, cultivation	0.2	17.0	2.0	13.5	0.2	0.0	0.0	0.0	0.2	0.2
Fertilizer manufacture	0.0	8.2	0.9	6.5	0.0	0.0	0.0	0.0	0.0	0.0
Gas leaks and flares	2.2	0.0	2.0	0.5	2.2	0.0	0.0	0.0	2.3	2.1
CO_2, H_2S removed from NG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Emissions displaced by co-products	-0.2	-13.3	-1.6	-10.6	-0.2	-2.6	-14.0	-8.3	-0.2	-0.5
Total	95.1	52.9	90.6	61.6	95.8	21.9	26.1	24.0	98.0	92.7

Notes: [1] Calculated based on GHGenius results for the relevant pathways based on % volume of each fuel in the blend

Emission reduction potential from the use of the biofuel blends are presented in Table 9. Per MJ of fuel, E15 and RD5 can provide modest emissions reduction rates (4.8% and 3.2%, respectively). Long transport distances, lower energy content of ethanol per liter, and corn-ethanol produced in the US (as opposed to Canada) may contribute to the modest emissions reduction results relative to the percent blend of ethanol (15%). Blending Canadian ethanol would provide greater emission reduction rate. For example, assuming an E15 blend made of corn-ethanol produced in Ontario would provide a GHG emission reduction rate of 5.2 g CO_2e instead of 4.5 g CO_2e. Higher renewable fuel blends achieve greater emission percent reductions (Table 9). The highest percent reduction is achieved with replacement of diesel with neat (100%) HDRD. However, there are questions on the technical feasibility of using neat HDRD at the cold winter temperatures in NWT. Th possibility of blending with ultra-low sulfur kerosene to reduce the cloud point below -40 is discussed in Section 8. Relatively modest emission reductions are achieved with E85.

It is understood that the NWT will not be required to meet the proposed federal Clean Fuel Standard for liquid fuels, but it is discussed briefly for context. Under the federal standard, emission reduction requirement will start at 2.4 g CO_2e/MJ in 2022 (Government of Canada 2020). Both low biofuel blends examined (i.e., E15, RD5) would achieve the proposed federal standard (Table 9).

Table 9 also presents the absolute potential emission reductions from the implementation of various fuel replacement scenarios based on current fuel use. The emission reductions presented in Table 9 (tonnes of CO_2e) cannot be directly compared with GHG emission inventory values such as the National Inventory Report (Government of Canada, 2018) because the values calculated herein are lifecycle emissions while NIR values are combustion-only values (i.e., they do not include upstream emissions from production, processing, and transport of the fuel).

Table 9: Emission reduction potential of biofuel blends compared to reference fuels

Scenarios	**Light-duty vehicles**		**Heavy-duty vehicles**		**Residential heat**	
	Gasoline vs. E15	**Gasoline vs E85**	**Diesel vs RD5**	**Diesel vs neat HDRD**	**Diesel vs RD5**	**Diesel vs neat HDRD**
Emission reduction rates						
Baseline fuel (g CO_2e/MJ)	95.1	95.1	95.8	95.8	95.8	95.8
Alternative fuel (g CO_2e/MJ)	90.6	61.6	92.7	24.0	92.7	24.0
Emission reduction rate (g CO_2e/MJ)	4.5	33.5	3.1	71.8	3.1	71.8
% reduction	4.8%	35.2%	3.2%	74.9%	3.2%	74.9%
Emission reductions						
Volume of baseline fuel (million L) [1]	45	45	125	125	70	70
Emission reductions (ktonne CO_2e)	7.1	52.3	15.0	347.0	8.4	194.3

Note: [1] Data from Marshall (2020). Volumes for gasoline and diesel for transportation are consistent with those reported by Statistics Canada (2020)

Finally, it should be noted that LCA model scenarios are based on best data available, publicly available data, average data, model parameters selected, and assumptions, and are therefore associated with a certain level of uncertainty. LCAs do not quantify actual emissions. As such, the analysis presents emissions estimates and magnitude of potential reductions achievable with the implementation of the alternative fuel options. That said, the findings presented herein can inform decisions on the selection of alternative fuels.

8 EXPECTED ECONOMIC IMPACTS

This section examines the potential costs and/or economic benefits of replacing gasoline and diesel used for road transportation and home heating with renewable fuels. The analysis is done in aggregate, to provide an overall sense of the maximum potential costs/savings in the NWT.

8.1 Objective and Methodology

The objective of this analysis was to estimate the approximate costs to implement the three identified alternative fuel options across the NWT.

In this section, alternative fuel options are compared to a baseline option based on current fuel use and prices in NWT. The GHGs emission reduction potentials estimated in Section 6 are applied to the cash flow analysis where appropriate. The estimated costs are presented as a total cost after 20 years (NPV 20) and as a cost per unit of GHG emissions reduced ($/tonne CO_2e). Fuel volumes, prices, and other assumptions are discussed in the following sections. All prices have been converted to Canadian dollars, unless otherwise stated.

8.2 Fuel Systems Examined

Three alternative fuel options are compared against three reference systems. The reference systems are:

- Gasoline in light-duty vehicles
- Diesel in heavy-duty vehicles
- Diesel Heating: Diesel for space heating

The alternative energy options are:

- E15: Gasoline mixed with 15% (vol.) ethanol in light-duty vehicles
- E85: Gasoline mixed with 85% (vol.) ethanol in light-duty vehicles
- RD5: Diesel mixed with 5% (vol.) renewable diesel (HDRD) and 15% ULS kerosene in heavy duty vehicles
- RD5: Diesel mixed with 5% (vol.) renewable diesel (HDRD) and 15% ULS kerosene in space heating.
- RD100, i.e., Neat HDRD in heavy duty vehicles
- RD100, i.e., Neat HDRD in space heating

8.2.1 Fuel Prices

Current Petroleum Pricing:

The 2019 average fuel prices in various communities in the NWT are given in **Table 10.**

Table 10: Fuel Prices in various NWT Communities in 2019

Community	Diesel Heating	Diesel Motive	Gasoline	Naphtha	Jet A-1 Fuel
Colville Lake	$1.77	$1.91	$1.77	$5.60	

Community	**Diesel Heating**	**Diesel Motive**	**Gasoline**	**Naphtha**	**Jet A-1 Fuel**
Délı̨nę	$1.39	$1.54	$1.53	$6.06	$1.54
Fort Good Hope	$1.61	$1.75	$1.82	$5.15	
Gametì	$1.63	$1.77	$1.63		
Jean Marie River	$1.46	$1.60	$1.58		
Łutselk'e	$1.59	$1.70	$1.81	$6.20	
Nahanni Butte	$1.40	$1.54	$1.51		
Paulatuk	$1.79	$1.94	$1.98	$5.03	$1.54
Sachs Harbour	$1.74	$1.88	$1.79	$5.47	$1.82
Sambaa K'e	$1.63	$1.68	$1.54		
Tsiigehtchic	$1.62	$1.76	$1.74		
Tulita	$1.50	$1.63	$1.58	$5.70	
Ulukhaktok	$1.77	$1.93	$1.83	$5.09	$1.76
Wekweètì	$1.76	$1.99	$1.83		
Whatì	$1.50	$1.63	$1.61	$5.50	
Wrigley	$1.42	$1.55	$1.48		
Average	**$1.60**	**$1.74**	**$1.69**	**$5.53**	**$1.67**

(Arctic Energy Alliance 2019)

According to Stats Canada, the average price of diesel in Yellowknife for 2019 was $1.33/litre (Stats Can 2020). This is lower than the cost for the communities in Table 10, most likely due to the additional transportation requirements of these more remote communities.

Ethanol Pricing:

Ethanol is available commercially in several jurisdictions in Canada. As of August 2020, the Chicago Board of Trade (CBOT) spot price for ethanol was $0.44/L (1.28 USD/gal). Fuel prices are a combination of the manufacturing cost (reflected by the spot price), transportation and distribution costs (the landed price), and taxes. Note that because ethanol is roughly 33% less energy dense than gasoline per unit volume, consumers must purchase more of it to obtain the same amount of energy. This increases the relative importance of distribution costs. Some of these costs can be offset by ethanol's value in raising the octane of gasoline blends, allowing the use of lower-cost gasoline in blending (Navius 2019).

To estimate the transportation costs, a rail transportation charge of $0.006/km/barrel was added to the CBOT price, as described in Navius's 2019 report (Navius 2019). Using this method, the landed cost for ethanol in Hay River is $0.62/L. Marketing and tax costs must be added to the landed cost to give an estimate of final consumer costs. According to the BC fuel prices report, ethanol wholesale cost to refiners was on average $0.111/L less expensive than sub-octane gasoline from 2010-2018, and $0.323/L less expensive that sub-octane gasoline from January 2018-May 2019 (BC fuel prices report).

Given that ethanol in BC is less expensive than gasoline, and the relatively low landed costs calculated above, it seems reasonable to assume that retail prices for ethanol will be slightly cheaper than gasoline, even in the NWT. As a conservative estimate for this report, the purchase price of ethanol has been set to match the current average gasoline price of $1.69/L.

HDRD Pricing:

The cost of renewable diesel in the NWT is not currently available, as it is not sold commercially in the territory. However, HDRD is currently available in several North American jurisdictions, including California, Ontario, and British Columbia (BC).

Fuel prices depend on several factors including the cost of production, transportation (freight) and distribution, and taxes. In the case of HDRD there is also an opportunity cost to sell in alternative markets. Opportunity costs for Neste HDRD depend on bio-credit programs and other incentives, such as the California LCFS, worth $0.52/L ($1.50 USD/gal), and the EPA RFS2 D4 RIN, worth an additional $0.36/L ($1.05 USD/gal). This results in a minimum opportunity cost of $0.88/L

($2.55 USD/gal) over fossil diesel. HDRD suppliers into Canada will seek to recover their opportunity cost to sell the HDRD in alternative markets, such as California, which results in a significantly higher price for HDRD vs petroleum diesel. (Navius 2019, Neste 2020)

Recent HDRD prices in California, USA were between $0.95 and $1.32 per litre ($2.75 USD/gal and $3.85 USD/gal) (AFDC.energy.gov, Clean Cities Alternative Fuel Price Report). Diesel prices in California over the same period were approximately $1.15/L ($3.35 USD/gal), which equates to a $0.17 premium for renewable diesel. However, California renewable diesel will not meet NWT cloud point specifications, and there are additional transportation costs to consider.

In 2019, the University of Toronto published a feasibility study on the use of renewable diesel in the City of Toronto's fleet. It included an HDRD price from Diamond Green Diesel of approximately $1.50 per litre, not including freight. The average diesel price in Toronto in 2019 was $1.17/L (Stats Can 2020), for a minimum difference of $0.33/L. The average price of Neste's HDRD product delivered to BC in 2019 was $1.70 per litre (Navius), $0.33/L more than the average petroleum diesel price during the same period (YCharts 2020).

According to a 2012 report, renewable diesel in Canada was selling at a premium of $0.39/L to petroleum diesel (Eco Resources 2012). From recent spot prices in Ontario and BC, a minimum of $0.33/L price differential is expected. These prices are compared in **Table 11.**

Table 11: Price Comparison

Location	Source	HDRD Price Premium ($/L)
California	(AFDC.energy.gov, Clean Cities Alternative Fuel Price Report).	0.17
Toronto	(U of T 2019)	0.33
BC	(Navius 2019) (YCharts 2020)	0.33
"Canada"	(Eco Resources 2012)	0.39

For the purposes of this study, renewable diesel prices are assumed to be $0.39/L above the average diesel price in the NWT. This is a conservative approach, similar to that taken to estimate ethanol pricing. Based on the $1.74/L average cost of motive diesel from Table 10, we set the HDRD price at $2.13/L.

Carbon Pricing:

A \$50/tonne CO_2e price for carbon emissions was used throughout this report. This was the carbon price legislated in the NWT from 2022 on. Prior to publication, the federal Government announced their intention to increase the carbon tax to a maximum of \$170, which will occur in 2030. No additional analytical work was conducted after the announcement; however, such an increase would likely strengthen the economic case for biofuels in Canada while also raising the costs of most petroleum fuels.

8.3 Cash Flow Results and Discussions

8.3.1 Scenario 1 – Ethanol for Road Transportation

Analysis of this scenario is based on the following parameters:

Gasoline demand = 45 million L/y

E15 = 15% ethanol in gasoline, by volume. Due to the differences in heating value of the two fuels, this will require 7.1 million L/y of ethanol

E85 = 85% ethanol in gasoline, by volume. Due to the differences in heating value of the two fuels, this will require 55.3 million L/y of ethanol

Ethanol Price = \$1.69/L

E15 GHG Emissions avoided (see Section 7) = 7.1 ktonnes CO_2e/year

E85 GHG Emissions avoided (see Section 7) = 52.3 ktonnes CO_2e/year

NWT carbon tax in 2022 and after= \$50/tonnes CO_2e

E15 Analysis: Low blends of ethanol in gasoline are compatible with existing passenger vehicles, storage tanks, and transport infrastructure, so there are no capital costs associated with this option, although this compatibility should be confirmed in a future pilot demonstration.

The estimated prices for ethanol and gasoline are the same on a volume basis. However, their heating values are significantly different. In other words, a car would drive further on a litre of gasoline than on a litre of ethanol. To account for this difference in the cost analysis, the annual gasoline requirement is replaced with a larger amount of ethanol blend, proportional to their relative heating values. The additional volume of E15 required has an increased cost of \$4.4 million/year.

The environmental impact of switching to a 15% ethanol-blend over gasoline has carbon costs implications. If the federal backstop carbon price of $50/tonne CO_2e is applied, a savings of approximately $355,000 per year can be achieved. Combined with the costs of increase volumes required, switching to E15 has a net present value of -$83M over 20 years. If the federal backstop carbon price is neglected, the cost of avoided emissions is $618/tonne.

E85 Analysis: In the case of E85, there may be some infrastructure changes required, particularly the phasing out of older vehicles. However, these costs are outside the scope of this analysis. Therefore, the only financial effects of switching to an 85% ethanol-blend considered here are the increased volume of fuel required and the avoidance of carbon costs. If the federal backstop carbon price of $50/tonne CO_2e is applied, a savings of $2.65M per year can be achieved. Combined with the $34M annual cost of the increased volume of fuel required, this scenario has a net present value of -$627M over 20 years. If the federal backstop carbon price is neglected, the cost of avoided emissions is $650/tonne CO_2e.

The costs and benefits of different levels of ethanol blends are compared in **Fig. 1.**

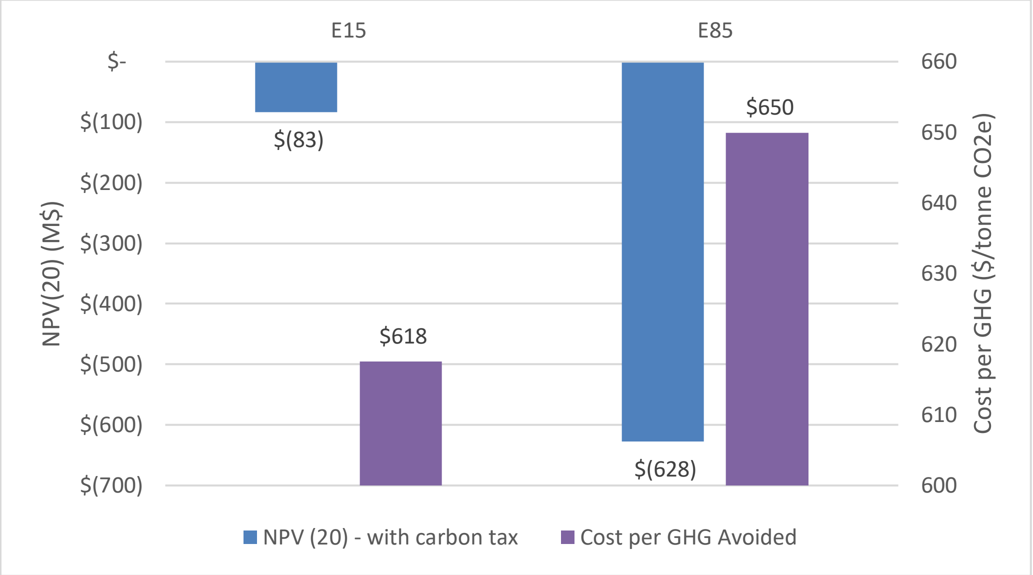

Fig. 1: Cost of Ethanol options in NWT

8.3.2 Scenario 2 – Renewable Diesel for Road Transportation

The analysis of this scenario uses the following parameters as a basis:

- Motive diesel demand = 125 million L/y

- RD5 = 5% HDRD + 15% ULSK blend. Due to the differences in heating value of the two fuels, this will require 6.2 million L/y of HDRD and 18.7 million L/y of ULSK
- RD100 = 100% HDRD. Due to the differences in heating value of the two fuels, this will require only 120.8 million L/y of HDRD
- Diesel price = $1.74/L
- HDRD price = $2.13/L
- Kerosene price = $1.74/L
- RD5 GHG emissions avoided = 15.0 ktonne CO_2e/y (see Table 9)
- RD100 GHG emissions avoided = 347 ktonne CO_2e/y (see Table 9)
- NWT carbon tax in 2022 and after= $50/tonnes CO_2e

RD5 Analysis: This analysis is based on a 5% blend of HDRD into diesel on a volume basis, with the addition of 15% ultra-low sulfur kerosene (ULSK) to adjust the cloud point to meet NWT specifications. As the only currently commercially available renewable diesels have a cloud point of -20°C, Neste was contacted about the possibility of supplying renewable diesel to a -40°C specification. They were unable to comment without further information on "the buyer's logistics to determine the extent of required infrastructure, respective cost and minimum volume". ULSK is slightly lower than the cost of diesel, but for the analysis the NWT diesel price will be used in place of the kerosene price. The additional blending cost associated with adding 15% ULSK will be enough to reduce any advantage from using lower cost raw materials. The cloud point of low-HDRD blends with varying amounts of ULSK will need to be confirmed with laboratory analysis prior to being deployed in the NWT.

Once again, a federal backstop carbon price of $50/tonne CO_{2e} is applied to the financial analysis. Even with the carbon tax savings, replacing 5% of the NWT motive diesel would cost $1.7M/year, which has an undiscounted net present value over 20 years of-$19.8M. If the federal backstop carbon price is neglected, the cost of avoided emissions is $116/tonne.

RD100 Analysis: As previously discussed, it is not currently possible to obtain commercial HDRD with a cloud point low enough to meet the NWT requirements. This analysis assumes a future in which the volume required in NWT and other jurisdictions is high enough to incent producers to supply an HDRD with a lower cloud point. Theoretically HDRD blends should be compatible with existing passenger vehicles, storage tanks, and transport infrastructure, so there are no capital costs associated with this option. Again, this compatibility should be confirmed in a future pilot program.

Once again, a federal backstop carbon price of \$50/tonne CO_2e is applied to the financial analysis. Replacing all the NWT motive diesel with HDRD would cost \$40.0M/year over the current cost of diesel. With the carbon tax savings applied, it has an undiscounted net present value of -\$452M over 20 years. If the federal backstop carbon price is neglected, the cost of avoided emissions is \$115/tonne CO_2e.

The costs to implement different levels of HDRD blends for road transportation in NWT are compared in **Fig. 2.**

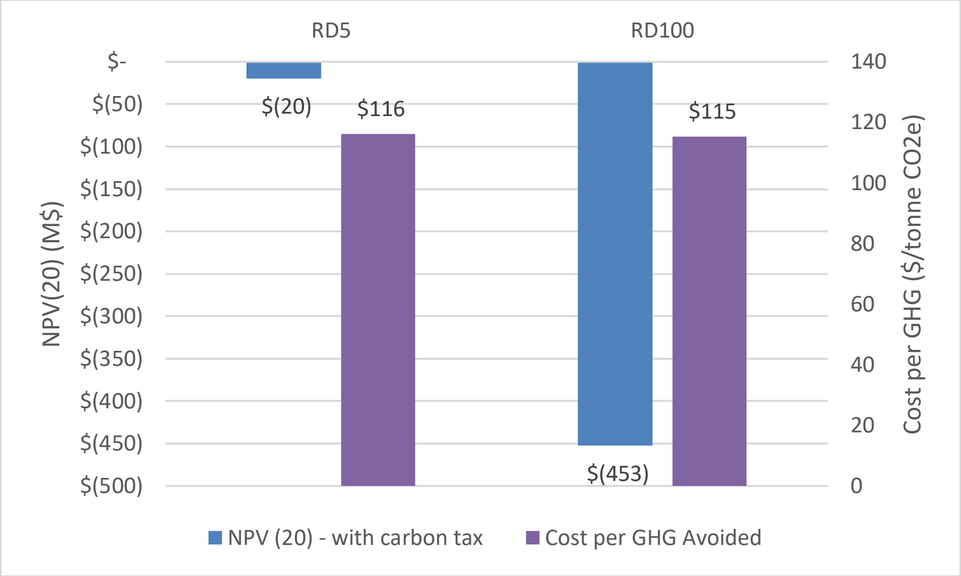

Fig. 2: Cost of HDRD road transportation options in NWT

8.3.3 Scenario 3 – Renewable Diesel for Heating

- Heating oil/ non-motive diesel = 70 million L/y
- RD5 = 5% HDRD, 15% ULSK blend. Due to the differences in heating values between diesel, HDRD, and ULSK fuels, this will require 3.5 million L/y of HDRD and 10.5 million L/y of ULSK
- RD100 = 100% HDRD. Due to the differences in heating values between diesel and HDRD, this will require only 67.7 million L/y of HDRD
- Diesel price = \$1.74/L
- HDRD price = \$2.13/L
- Kerosene price = \$1.74/L

- RD5 GHG emissions avoided = 8.4 ktonne CO2e/y
- RD100 GHG emissions avoided = 194 ktonne CO2e/y

RD5 Analysis: Blending NWT non-motive diesel with 5% HDRD and 15% ULSK would cost \$975,000/year, which has an undiscounted net present value over 20 years of -\$11M when a \$50/tonne carbon tax price is assumed. If the federal backstop carbon price is neglected, the cost of avoided emissions is \$116/tonne CO_2e.

RD100 Analysis: Replacing 100% of the NWT non-motive diesel would cost \$22.4M/year, which has an undiscounted net present value over 20 years of -\$254M when a \$50/tonne carbon tax price is assumed. If the federal backstop carbon price is neglected, the cost of avoided emissions is \$115/tonne CO_2e.

The costs to implement different levels of HDRD blends for road transportation in NWT are compared in **Fig. 3**.

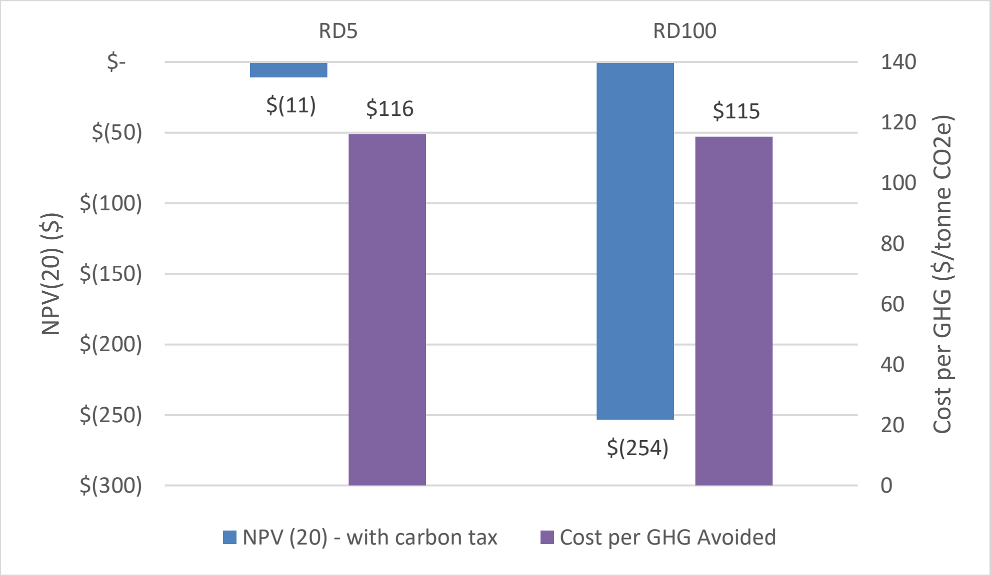

Fig. 3: Cost of HDRD heating options in NWT

9 PILOT REVIEW AND IMPLEMENTATION

As described in the previous section, renewable fuels have the potential to significantly reduce GHG emissions in the NWT. However, there are still unknowns in the implementation of these fuels in a northern climate. In this section, previous renewable diesel pilot or demonstration projects are reviewed, with particular focus on those in North America. Finally, a list of issues and considerations relevant to potentially initiating a pilot project in the NWT is compiled.

9.1 Review of Previous Pilot Projects

9.1.1 U of T Study

The University of Toronto and the City of Toronto worked together to explore the use of bio-based diesel blends in City owned fleet service vehicles. The fleet is primarily Toronto Transit Corporation buses, but also includes light, medium, and heavy-duty trucks, some gensets, and smaller equipment, such as Caterpillars. Both biodiesel and renewable diesel blends were investigated.

The project report considers biodiesel and HDRD production, properties, fuel standards, blending recommendations, vehicle engine manufacturer approvals, life cycle GHG emissions, and fuel costs. Winter-grade renewable diesel blends of up to 10% were recommended. They calculated that the use of 10% blends of HDRD in Toronto fleets could lead to GHG reductions of 6.3% to 9.8% relative to petroleum diesel. There is no indication of whether the City of Toronto has decided to pursue a pilot following this report, and several unknowns remain regarding supply, storage, and blending of HDRD.

There are currently only two HDRD suppliers to the Ontario market; Diamond Green Diesel and Neste Renewable Diesel. Forge Hydrocarbons is planning the construction of a plant in Sombra, ON, but there is no indication of when it will be operational.

Diesel storage for the City of Toronto fleet is turned over every 3 months, to accommodate seasonal changes. However, special cases such as gensets exist, where diesel may be stored for up to 2 years. The authors did not recommend HDRD for these applications. There was no investigation of long-term storage of renewable diesel.

Laboratory tests conducted as part of the study confirmed that blends of up to 5% HDRD had little depression in cloud point (warming) when blended with diesel with a cloud point of -21 °C. The cloud point requirement for the City of Toronto is -20C; it is unclear what the effects would be with lower cloud point diesels.

9.1.2 Alberta Pilot

The Alberta Renewable Diesel Demonstration (ARDD) was Canada's first cold-weather demonstration of the use of renewable diesel blends. A temporary commercial blending facility was constructed at Shell Canada's Sherwood Marketing Terminal in Edmonton, Alberta in 2007. Over the next year, the ARDD dispensed 1.6 million litres of blended fuel: 245,000 litres of B2 (2% FAME) and 400,000 litres of 2% HDRD in the winter season, and 540,000 litres of B5 (mixed feedstock FAME) and 425,000 litres of 5% HDRD in the spring/summer.

HDRD was blended with ultra-low sulfur kerosene (ULSK) to adjust the fuels' cloud points to meet the cold operability specifications in the CAN/CGSB 3.520 fuel standard. From December 2007 to March 2008 blending to meet the cloud point schedule required ULSK addition of 8-15% of the blend for 2% HDRD. No stalls, breakdowns, or other operational problems were experienced by vehicles running on blended fuel during the demonstration. "Fleet data from the ARDD showed that there was no meaningful difference in fuel mileage among FAME blends, HDRD blends and control fuel (ULSD) in winter or summer seasons" (ARDD 2018).

The temporary blending facility constructed in Edmonton consisted of "an offloading area, two double-wall storage tanks for the renewable diesels with spill containment, recirculation pumps, filters, interstitial space heaters and immersion heaters, a cabinet with fuel blenders installed at the diesel rack, and ancillary piping that was heat-traced and insulated to ensure the product was maintained above its cloud point" (ARDD 2018).

Biofuel blends were handled using the same infrastructure and handling procedures as for petroleum diesel, including standard trucks, tanks, and dispensing infrastructure. Deliveries were unloaded through standard 4" hoses. Storage tanks were designed to keep the HDRD product at least 5°C above its cloud point. One part of the demonstration used a 68,000L in-yard tank to test above ground storage facilities without issue.

The storage temperatures specified were chosen to ensure the renewable diesel remained in the liquid phase and do not reflect or represent a legislated requirement. Specific storage length, material, and temperature requirements are dictated by the manufacturer for pure HDRD but are unknown for other HDRD blends.

During their demonstration, the ARDD has shown 2% HDRD blends are fully operable in winter conditions when cloud points are adjusted to meet CAN/CGSB requirements. They also demonstrated that 5% blends using HDRD can be successfully made and used in shoulder and summer seasons. These HDRD blends performed adequately in the Edmonton area and using the procedures developed by the ARDD; other results may vary.

9.1.3 Finnish Pilot

"OPTIBIO" was a 3.5-year venture to demonstrate the use of renewable diesel in 300 city buses in Helsinki. The buses used blends of 30% and 100% HDRD fuels in everyday service. Data gathered during the pilot included:

Feedback from the operators

Fuel analyses

Lubricant analyses

Inspection of fuel injection equipment and engines

Emission stability (fuel as well as exhaust after-treatment devices).

The buses travelled 50 million kilometres between September 2007 and December 2010, of which 1.5 million kilometres was on 100 % HDRD. The project was considered a success and the authors concluded that diesel fuel could be replaced with 100 % HDRD without any modifications to the fuel system or vehicles, and without causing any operational problems (Nylund et al 2011). Temperatures in Helsinki can drop to -30°C in the winter.

9.1.4 Commercial Renewable Fuel Sales in North America

Renewable Diesel

Along with the demonstrations discussed in the previous section (see Table 6), renewable diesel is currently being sold commercially in several North American jurisdictions.

The City of Vancouver, as part of its commitment to reduce fleet emissions, has been fuelling the City's diesel fleet vehicles on 100% renewable diesel since 2018 (City of Vancouver 2020). According to the City's website, the HDRD is provided by Suncor, though it is presumably being produced elsewhere and imported. Federated Cooperative Ltd also sells HDRD blends in BC, as mentioned previously.

California consumed an estimated 200 million gallons of HDRD in 2017, which is attributed almost entirely to their low carbon fuel standard. The primary provider of HDRD is the Neste Corporation, which delivers renewable diesel from their Singapore production facility. Some production is supplied from Diamond Green and REG, both located in Louisiana (U of T 2019)

Several other States or government agencies have declared their intention to transition to renewable diesel, including the Oregon Department of Energy, City of Knoxville Fleet Services, City of Seattle Fleet and New York Department of Sanitation (U of T 2019).

Ethanol

Ethanol demonstrations were not included in this section, as ethanol is already commercially available in Canada. As described in Section 4, Canada has a national blend rate of 6.6% ethanol in the gasoline pool on average (Navius 2019). The US National Renewable Energy Laboratory tested ethanol blends up to 20%, as described in Section 7.1. Specialty vehicles are available that can run on up to 85% (aka E85). A demonstration of E85 blends may be of interest in the future.

9.2 Potential NWT Pilot Demonstration

Despite the previous demonstrations in Helsinki and Edmonton, there are some remaining unknowns about using renewable fuels in the NWT. Primary areas of concern are the ability of HDRD to meet the required low temperature specifications, including whether blending with kerosene will be required and at what blending rates. There are also concerns from local fuel users and suppliers about equipment compatibility.

Due to its extreme climate and remote location, the NWT has a low tolerance for risk when it comes to a renewable fuel demonstration. Any problem with the renewable fuel could cause a community to be without transportation or power for several days, which could be catastrophic if it occurs during the cold winter months. For this reason, it may be preferable to start with a pilot during the summer months and test cold weather performance in a future demonstration.

9.2.1 Location

There are multiple aspects to consider when determining the location of a pilot-scale demonstration site. To ensure the technical success of the proposed pilot demonstration, the authors recommend the following aspects be characteristic of the chosen pilot demonstration site:

High summer demand for diesel.

Readily accessible HDRD has a cloud point of -20°C, which would allow for operation in the NWT in the late spring / summer / early fall months (approximately May – September) without the need for substantial blending with diesel or kerosene.

To obtain a good pilot demonstration size and level of experience during the pilot demonstration, it would be beneficial for the proposed site to have a high summer demand for diesel fuel. Indicators of high demand could include:

Transportation fleets;

Industrial / commercial operations such as logging or mining;

Electrical generation could contribute to additional fuel load at the proposed pilot site, however, it would not be beneficial if the load consisted solely of a summer electrical load.

The minimum purchase volume for HDRD is 49,000L, likely driven by the capacity and weight limits of the fuel tanker. It would be ideal if the prospective pilot site had a projected summer fuel consumption greater than a multiple of 49,000L.

Diverse loads / vehicles.

Ideally, the HDRD would be used to fuel a variety of equipment in the demonstration including generators, light, medium, and heavy-duty vehicles, and other commercial equipment such as forklifts to fully prove out the fuel compatibility.

All-season road access.

To mitigate risks that could arise if problems occur due to operation of equipment with HDRD or unexpected periods cold weather, all-season road access to the proposed site is recommended.

All-season road access would also reduce risks associated with delivery timelines and weather dependence.

Separate fuel containment.

To prevent cross-contamination and unintended blending or use, having separate fuel containment to store HDRD through the summer is recommended.

9.2.2 Projected costs

There are several costs involved in demonstration project that would not be considered during full implementation. These can include:

Fuel costs – The projected price of HDRD in the NWT used in Section 8 was conservatively assumed $0.39/L above the average diesel price. A pilot involves smaller volumes, which lessens the ability to negotiate with suppliers for long-term contracts and possible volume discounts.

Transport costs – As there is still some concern within the local community about the compatibility of HDRD with regular diesel, a separate shipping container will need to be arranged. Early discussions with a NWT fuel transporter gave an estimated cost of $10,000.

Infrastructure costs – Until the compatibility with existing infrastructure is demonstrated, a pilot will need to install separate storage and dispensing equipment.

Performance monitoring costs – Vehicles and other diesel equipment experience periodic failures, so it will be important to monitor performance before and after the demonstration period to confirm whether the renewable fuels are the cause of any problems.

10 CONCLUSIONS AND NEXT STEPS

10.1 Summary of Analysis

Annually, the NWT uses approximately 45 million litres of gasoline, 125 million litres of diesel for road transportation, and 70 million litres of diesel for heating. The PPP delivers approximately 21.8 million litres of petroleum diesel to 16 communities in the Northwest Territories (NWT) annually. Of this, 13.8 million litres are used in non-motive applications, 6.6 million litres are used for heating, and 1.1 million litres are used for road transportation. This diesel is almost exclusively either Type A or B. Though there was some interest in the potential for biofuels among those interviewed by Blyth & Bathe, there were also concerns about cold weather storage and compatibility of renewable diesel with existing equipment.

Canada produces ethanol, biodiesel and wood pellets, and is currently importing renewable diesel, with plans for domestic production in coming years. There are several technologies and processes that can convert biomass sources into the fuels required for road transportation, electricity generation, space heating, and industrial use in the NWT.

Biofuel production processes are feedstock dependent, and the economics of the process can be greatly influenced by feedstock availability. Unfortunately, the NWT has little to no availability of most required feedstocks, apart from wood pellets. Wood pellets can be combusted for heat or used to produce heat and power.

The life cycle greenhouse gas emission (GHG) reduction potential of replacing current liquid fuels (gasoline, diesel) with alternative fuels in road transportation and residential space heating were estimated. Different blend scenarios of ethanol (with gasoline) and renewable diesel (with diesel) were examined. GHGenius, a publicly available lifecycle analysis (LCA) model with primary focus on transportation fuels in Canada, was used for the analysis. Three GHGs were examined: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) and reported as CO_2equivalent (CO_2e). Fuels were modeled to reflect current supply chains, while alternative fuels were modeled to reflect probable supply chains (e.g., corn-ethanol imported from the US and renewable diesel imported from an existing commercial supplier located in Singapore).

Both low biofuel blends (i.e., 15% ethanol blended with gasoline and 5% renewable diesel blended with diesel) have lower lifecycle GHG emissions than their fossil fuel counterparts. Replacing gasoline with E15 (15% ethanol blended with gasoline) and E85 (85% ethanol blended with gasoline) in light-duty vehicles resulted in 4.8% and 35% emission reductions, respectively. Long transport distances and ethanol produced in the US (as opposed to Canada) may contribute to the modest emissions reduction results of ethanol scenarios. Replacing diesel with a renewable diesel blend (diesel and 5% renewable diesel) and neat (100%) renewable diesel resulted in 3% and 75% emission reductions, respectively. The technical feasibility of using neat renewable diesel in NWT was not examined in the LCA.

LCA model scenarios are based on best data available, publicly available data, averaged data, model parameters selected, and assumptions, and are therefore associated with a certain level of uncertainty. LCAs do not quantify actual emissions. As such, the analysis presents emissions estimates and magnitude of potential reductions achievable with the alternative fuel options. That said, the findings presented herein can inform decisions on the selection of alternative fuels.

In the economic analysis, alternative fuel options were compared to a baseline option based on current fuel use and prices in NWT. The GHG emissions reduction potentials estimated in Section 7 were applied to the cash flow analysis. The estimated costs are presented as an annual cost and as a cost per unit of GHG emissions reduced (\$/tonne CO_2e) in **Table 12.**

Table 12: Cost Analysis

Renewable Fuel Options	Annual Cost (million $)	NPV (20) (million $)	Cost of GHG Mitigation ($/tonne CO_2e)
E15 for transport	4.4	-83	618
E85 for transport	34.0	-628	650
RD5 for transport	1.7	-20	116
RD100 for transport	40.0	-453	115
RD5 for heating	0.97	-11	116
RD100 for heating	22.4	-254	115

Results of some recent renewable fuel demonstrations were reviewed. Despite the information gained in these previous demonstrations, there are some remaining unknowns about using renewable fuels in the NWT. The primary areas of concern are the ability of HDRD to meet the required low temperature specifications, including whether blending with ULSK will be required and at what rates. There are also concerns from local fuel users and suppliers about equipment compatibility.

10.2 Current Challenges

Although ethanol and HDRD have the potential to significantly reduce greenhouse gas emissions caused by road transportation and residential heating, there are several challenges associated with biofuels adoption in the NWT today. These risks generally fall in to one of two categories: technical or economic.

Including low-blend percentages of ethanol in the gasoline pool has very impact on the infrastructure already in place (i.e., low technical risk), but has a significant cost and also relatively low environmental benefit. Blending at E85 increases the environmental benefit (by decreasing emissions), but also increases both costs and technical risks. The reaction of the vehicles and infrastructure in the NWT to high-blend percentages of ethanol are currently unknown. Further testing may mitigate this risk. In the future, second generation ethanol produced in Canada from cellulose or municipal solid waste will increase the environmental benefits of ethanol at all blend percentages.

Replacing petroleum diesel with hydrogen derived renewable diesel made from waste fats and oils would have a large environmental benefit. However, there are technical unknowns with the use of

HDRD in the NWT, particularly its reaction to cold weather conditions. Although HDRD is purportedly interchangeable with petroleum diesel and able to be manufactured to meet a -40°C cloud point, further testing is recommended to guarantee its operability in the NWT. The estimated costs to implement HDRD, either blended or neat, are currently much higher than that for petroleum diesel. As carbon pricing increases and more global and domestic manufacturers offer HDRD the cost to implement 100% HDRD in the NWT may become more competitive.

10.3 Looking Ahead

The Federal government has committed to the implementation of a Clean Fuel Standard in Canada, which will require reducing the carbon intensity of liquid fossil fuels, starting at 3.6 gCO_2e/MJ reduction in 2022 and gradually increasing to 12 gCO_2e/MJ in 2030. Biofuels blending is one main compliance pathway under the proposed regulations (Government of Canada, 2021). The U.S. is considering a similar initiative; the House Select Committee on the Climate Crisis recommended the development of a national low-carbon fuel standard (LCFS) that would replace U.S. Renewable Fuel Standard (RFS) after 2022 (HSCCC, 2020).

Fuel imported by the GNWT is exempt from the CFS. However, as the CFS comes into effect it will affect fuel suppliers across Canada, including those that supply to the NWT. Long term impact of the CFS is unknown: it may indirectly lead to change in biofuels supply in NWT or petroleum diesel may continue to be supplied in the form it is today. The fast-growing interest in biofuels across North America is also anticipated to help advance some of the technical challenges that currently make biofuels not a viable option in the NWT, particularly cold-weather performance. Whether the U.S. proceed with a national LCFS or not, Canada and U.S.'s unambiguous climate agenda are likely to bolster additional research and development in advanced biofuels as well as to accelerate biofuels production and use in Canada and across the continent.

10.4 Next Steps

Using renewable fuels for road transportation and heating in the NWT has the potential to significantly reduce GHG emissions in the territory. The economics of using ethanol blends in the gasoline pool are currently unfavourable. The economics of replacing diesel with renewable diesel are also unfavourable but may become worthwhile as the cost of carbon emissions rises and the cost of renewable diesel drops.

Due to its extreme climate and remote location, the NWT has a low tolerance for risk when it comes to renewable fuels. For this reason, the authors recommend a phased implementation. To start, a pilot during the summer months can confirm that equipment and infrastructure are compatible with renewable diesel blends. The proposed pilot demonstration would be implemented at an appropriate site that has a large diesel demand in the summer, is accessible year-round by road, has separate fuel containment available, and operates a diverse array of equipment (generators, forklifts, light and heavy-duty vehicles, etc.).

A second phase demonstration can test cold weather performance of renewable diesel. Given the experience in Alberta and the cloud point of the HDRD currently available from Neste, the need to blend with ULSK is likely. The cloud point of various HDRD blends should be researched, both via a literature review and in the laboratory. Once a satisfactory blend is identified, it can be demonstrated in the NWT during the winter months. If arctic grade HDRD becomes available in Canada before the second phase, it will be possible to eliminate this research and move directly to a winter pilot demonstration.

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APPENDIX A: BIOFUEL PRODUCTION OPTIONS

A.1 Biofuels for Road Transportation

Options include:
Biodiesel

Hydrogen Derived Renewable Diesel (HDRD)

Renewable diesel via the Fischer-Tropsch process

Biocrude from pyrolysis oil or hydrothermal liquefaction

Ethanol

Biodiesel

Biodiesel is composed of fatty acid methyl esters (FAME) derived from biologically produced oils or fats, including vegetable oils and animal fats. Biodiesel is typically made using a chemical process known as base catalyzed transesterification of oil. It can be used directly in a diesel engine, either neat or mixed with petroleum diesel; however most North American manufacturers only warranty their vehicles for blends up to 5% (also called B5). Neat biodiesel (B100) has a lower energy content than petroleum diesel, by about 8%. Biodiesel has been known to have a shorter shelf life than most petroleum diesels; long-term storage and storage with temperature variations can lead to fuel degradation. Biodiesel can form crystals in cold weather which can lead to filter plugging, but the temperature at which this occurs is dependent on the specific biodiesel, and cold weather additives can be used. Pure biodiesel acts like a detergent additive, loosening and dissolving sediments in storage tanks, and possibly damaging rubber and other components in older vehicles (EIA 2020). These disadvantages are less common when low biodiesel blends such as B5 are used.

Renewable Diesel

Renewable diesel (also called “green” diesel and drop-in diesel) is a second-generation biofuel produced from either lipids, such as vegetable oils, animal fats, and greases, or cellulosic material, such as crop residues, woody biomass, and energy crops. Unlike biodiesel, which is an ester and has different chemical properties from petroleum diesel, renewable diesel is chemically the same as petroleum diesel, i.e., composed of hydrocarbons. There are three possible pathways for producing renewable diesel. One is hydroprocessing of lipid biomass. The second pathway involves gasification of lignocellulose to produce syngas (carbon monoxide and hydrogen) and then utilizing the Fischer–Tropsch (FT) process to convert this gas to liquid hydrocarbons. The third route is pyrolysis or liquefaction of lignocellulose to bio-oil and then upgrading through hydroprocessing.

Currently most renewable diesel is produced from the hydroprocessing of lipids, using feedstocks such as canola, camelina, palm oil, used cooking oil, and tallow. It is a two-step catalytic process, involving hydroprocessing and hydroisomerization; catalyst and hydrogen are required. The fuels produced through hydroprocessing are often referred to as hydrotreated esters and fatty acids (HEFA), hydrotreated vegetable oil (HVO) and hydrogenation-derived renewable diesel (HDRD). The renewable diesel produced through this route meets the US and Canadian standards and has the advantages of higher cetane number (>70), very low aromatic content, and lower sulfur content than its petroleum counterpart.

Fischer-Tropsch

The Fischer–Tropsch (FT) process starts with gasification of biomass to syngas. After cleaning, the syngas is used for FT synthesis to produce long-chain hydrocarbons that are converted into drop-in diesel through hydroisomerization/cracking. There are two advantages of this route: (i) the FT portion of this processes is commercialized (when using syngas derived from natural gas and coal), and (ii) any type of organic feedstock can be used, especially forest and agricultural residues. However, the use of FT technology for renewable diesel is still in its early stages of scale-up from pilot plants to commercial operability, and the capital cost can be high.

Pyrolysis

Pyrolysis and hydrothermal liquefaction are the most common thermochemical processes for biocrude production, followed by hydroprocessing to upgrade the biocrude into renewable diesel. Fast pyrolysis is a process in which a finely ground biomass feedstock is rapidly heated to 450 to 600°C in the absence of oxygen and then rapidly cooled to produce bio-oil (also called pyrolysis oil). Pyrolysis oil is a multi-component mixture of polar compounds including alcohols, acids, aldehydes and phenols. It is miscible in water (and contains high amounts of water) and is not readily miscible with hydrocarbons or petroleum crudes. It is corrosive, polymerizes readily, and thus it needs special requirements for its handling and processing.

Hydrothermal Liquefaction

Hydrothermal liquefaction (HTL) is a thermochemical conversion process by which biomass feedstock is converted into a crude bio-oil (biocrude) and aqueous-phase products at a temperature from 280 to 450°C and under moderate to high pressure (5–40 MPa). Both pyrolysis oil and HTL crude require extensive upgrading in order to be useful as transportation fuel. Several pilot and commercial plants are operational to produce biocrudes. However, production of a drop-in-grade diesel through this route is not commercialized yet, as subsequent upgrading of biocrude suffers from shortened catalyst life.

Ethanol

Ethanol is most commonly produced via fermentation of sugar or starch containing crops, such as corn. "Second-generation" ethanol, or cellulosic ethanol, produced from non-food sources is at the demonstration stage. Ethanol has some advantages as a fuel: it has a low freezing point, is blendable with gasoline, and has a high-octane content. There are also disadvantages, primarily in terms of infrastructure, and the possibility of water contamination. Gasoline vehicles produced since 1980 can operate on ethanol blends of up to 10% (E10) without alteration. Some specialty vehicles are designed to run on blends of up to 85% ethanol (E85).

A.2 Biomass-based Electricity Generation

Biomass-based electricity generation options include:

Biomass Combustion

Combined heat and power (CHP)

Integrated Gasification Combined Cycle

Pyrolysis oil

Organic Rankine Cycle

Anaerobic Digester

Biomass Combustion

Direct combustion of biomass involves using a direct-fired combustion system to burn biomass to produce high-pressure steam that drives a turbine generator to make electricity. These plants operate similarly to coal-fired power plants but replace coal with wood pellets or other renewable materials. Design details such as fixed or fluidized bed combustors can vary, as can the type of biomass to be combusted; typically, woody biomass is used. Storage and handling of the biomass feedstock is one of the major logistical challenges faced by this technology.

Combine Heat and Power

A combined heat and power (CHP) plant, also known as cogeneration plant, uses a heat engine or a power station to simultaneously generate electricity and heat. Large CHP systems can provide heating water and power for a town or an industrial site. MiniCHP is installed to provide between 5 and 500 kWe for a building or medium sized business. MicroCHP is a distributed energy resource (DER), usually installed to provide less than 5 kWe for a single house or business. Large CHP plants typically use combustion paired with a gas and/or a steam turbine for electricity generation while smaller CHP units use reciprocating or Stirling engines.

MicroCHP and MiniCHP installations may use one of several technologies to produce power, including microturbines, internal combustion engines, Stirling engines, closed cycle steam engines, and fuel cells. A microturbine is a small-scale version of a turbine like that found in an automotive turbocharger or a jet engine. It consists of a compressor, a mixing chamber, and an expander. Fuel is compressed and burned in a combustor. The flue gas then expands in a turbine which is connected to a generator which makes power. Microturbines are classified based on their components, e.g. one shaft or two, and on whether they use a heat exchanger to recover heat from the exhaust stream, i.e. unrecuperated vs. recuperated. They are gaining popularity in small-scale distributed power generation applications due to their compact size and low number of moving parts.

The Stirling engine is a heat engine that operates by compressing and expanding a gaseous working fluid, typically air, hydrogen, or helium. The gas is compressed in the cold portion of the engine and expanded in the hot portion, causing a piston to shuttle back-and-forth. A linear alternator converts the mechanical motion of the piston into electrical power.

In typical CHP installations, the input chemical energy is converted into usable heat (40 to 45%) and electricity (30 to 35%), while the remaining 15 to 20% is unrecoverable. CHP requires the heat to be used on site or nearby. The combustion feedstock could include any of the liquid fuels discussed in the previous section, biomass, or syngas, as discussed below.

Integrated Gasification Combined Cycle

Biomass can be gasified to produce a mixture of output gases called syngas which can be further burned for energy or heat. During gasification only some of the fuel is burned, differentiating it from combustion. A limited amount of oxygen is introduced into the gasifier to provide the heat needed for the reaction and the remaining fuel is converted to syngas, comprised of carbon monoxide, hydrogen, and some methane. Small modular gasification units are typically paired with one or more internal combustion engines, which are equipped with heat recovery. In this way, combustible waste material can be converted to useful power and heat.

Gasification has some challenges, however. The syngas generated has low energy content, meaning that specially tuned engines are required. It can also contain a lot of tars, which need to be removed before the gas can be burned in the engine. Some of the feed material is converted to biochar, which is an ash-like product high in carbon. Fortunately, biochar has been used as a soil conditioner and can be used as cover on landfills or in waste composting processes. Gasifiers also tend to be high-capital-cost items, making the economics of small-scale waste-to-power projects difficult.

Pyrolysis oil

Pyrolysis, as discussed earlier, is a thermal technology that chemically decomposes organic materials (biomass, coal, etc.) by heat in the absence of oxygen. Pyrolysis of biomass produces bio-oil (60 to 75% wt.), bio-char (10 to 25% wt.) and gases (10 to 20% wt.). Bio-oil has higher energy density than biomass and a high heating value at 16 to 20 MJ/kg. Pyrolysis bio-oil can be burned in a specially tuned engine generator set (genset) to produce heat and power. It is not necessary to upgrade the oil to a full renewable diesel. In addition, bio-oil can also be used as a fuel substitution for boilers, district heating and stationary engines.

Organic Rankine Cycle

Organic Rankine Cycle operates similarly to the steam cycle used to generate power in a typical power plant but uses an organic liquid in place of the water/steam. The biomass or biofuel is combusted to generate heat, which vapourizes a high-pressure organic liquid. This organic vapour is then expanded to low pressure through a turbine which releases mechanical work. The turbine is connected via a shaft to a generator which produces electricity. The organic liquid is then condensed, and the loop closed. One of the most promising aspects of ORC is its ability to produce power from low-grade heat. This is due to the lower boiling point of the organic liquids used as the working fluid when compared to water. ORC has been implemented at the commercial scale in the MW power range but has yet to see widespread adoption in smaller kW sizes.

Other renewable sources of electricity are available, such as solar, geothermal, renewable natural gas, and wind power, but are outside the scope of this project.

A.3 Biomass-based Space Heating

Options for biomass-based space heating include:

- Combined heat and power
- Biomass combustion (wood pellet heating)

Combined Heat and Power

Combined heat and power (CHP) processes can provide heat to a local community at the same time as producing power. Please refer to the previous section for a discussion on the different CHP processes.

Biomass Combustion

Wood pellet furnaces could replace existing oil-fired furnaces. Wood is already the most commonly used source of biomass for energy in NWT, and in recent years the use of wood pellets for residential, commercial, and institutional heating has increased. Wood pellets are usually manufactured from waste wood from the forestry and logging industry. Wood pellets generally burn more efficiently and more complete than ordinary wood fuel. The customer base could range from single residents to community or town sites.

APPENDIX B: FEEDSTOCK AUDIT

B.1 Feedstocks for Renewable Fuels

The production of renewable fuel requires an adequate supply of a suitable feedstock. The type, availability, location and pricing of feedstock are often challenging for the economical production of renewable fuels. It's important to note that the feedstock options for renewable fuel production are technology specific.

Agricultural crops provide a source of plant oils and lignocellulosic biomass. Plant-based lignocellulosic biomass is suitable for renewable diesel or biocrude production via pyrolysis, gasification (technology dependent), or hydrothermal liquefaction (HTL). Plant oils are frequently used as feedstock for both renewable diesel and biocrude. They presently serve as a major feedstock for hydrogenation-derived renewable diesel (HDRD) production. Animal fats are another available feedstock for renewable diesel production (Ikura et al. 2007).

Three types of forestry residues are available for use as renewable diesel or biocrude feedstock: (1) forestry harvesting waste and (2) milling waste, either hardwood or softwood; and (3) pulp and paper waste. A report by the Environmental Protection Agency (EPA 2007) evaluating forest residues in the eastern United States estimated that 1.8 tonnes of forestry harvesting waste are available for every 28 cubic meters of harvested timber. Milling waste availability depends on mill type. Oriented strand board (OSB) mills frequently use all the waste products on site for heat and power generation. Milling waste from sawmills and plywood mills can be inexpensive; however, the applicability is limited to certain renewable diesel and biocrude technologies. A report by the EPA (2016) estimates that only 2 – 3% of mill wastes are available as a biomass to fuel source, and the rest are used for other purposes, generally to produce power.

Milling waste is often a feedstock for the pellet market. There is also a large surplus of wood unsuitable for high-value forest products in BC due to the mountain pine beetle, which has eradicated more than 600 million cubic meters of pine in recent years (Clean Energy BC 2017). Recently, the pellet market has been depressed, in part due to excess forestry waste with the pine beetle kill; however, that may not be the case long term.

Municipal solid waste (MSW) consists of all urban waste, both residential and commercial, that is directed to the landfill. The challenge with using MSW as a feedstock for production of renewable diesel or biocrude is the required sorting and handling, which can be quite complex and costly. Statistics Canada (2016) reports that the average MSW disposed of per capita for Canada is 720 kg/year.

Several other low-cost organic residues options are available, such as sewage sludge, algae, sugarbeet molasses, dried distiller's grains from bioethanol production, and canola meal. These may be suitable for pyrolysis or gasification to renewable diesel. However, given their low oil/fat content and present low production rates, these are not expected be the most feasible feedstock choice.

B.2 Feedstocks Available in the NWT

Feedstock choice for biofuels production is often driven by geography. According to Agriculture and Agri-food Canada's BIMAT, there are no sources of biomass within 250 km of Yellowknife, Hay River, Inuvik, Fort Smith, Behchokǫ̀, or Fort Simpson, NWT, nor does the Northwest Territories have any active pulp and paper mills. See **Fig. B1** and **Table B1** (Statistics Canada 2019).

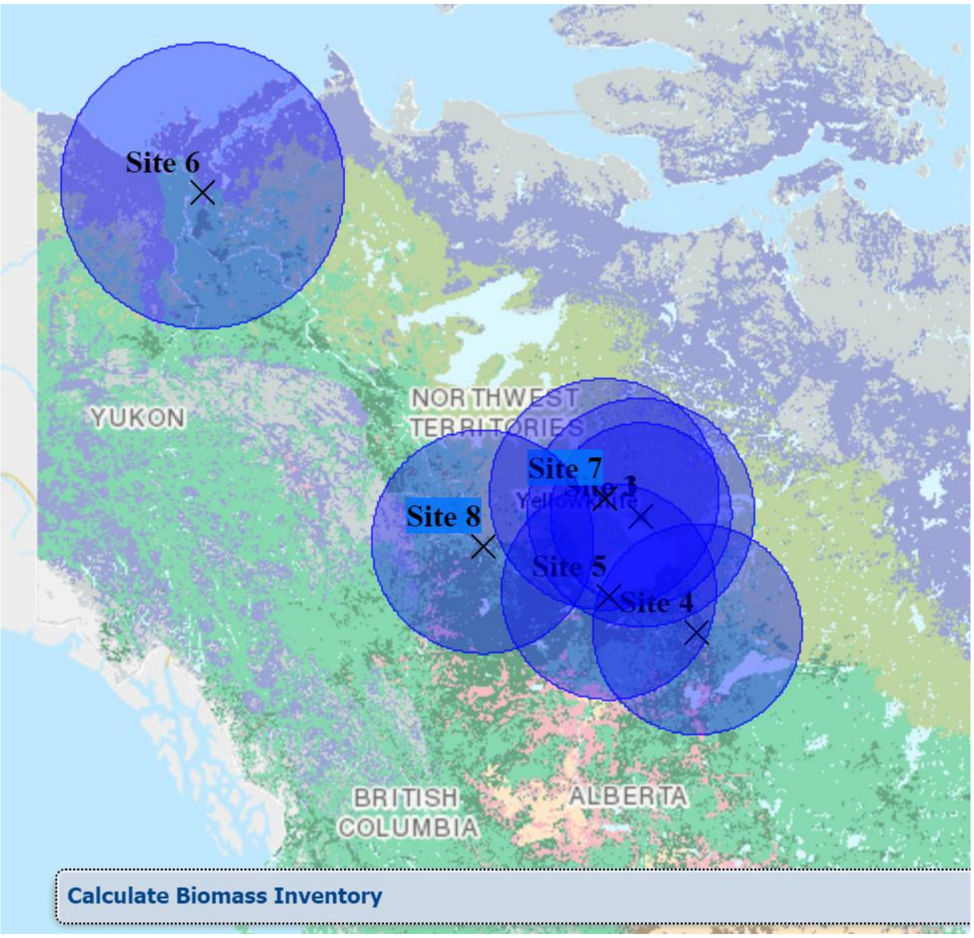

Fig B1: BIMAT output for NWT

Table B1: Pulp Mills by Province/Territory

Province/territory	Employment size category (number of employees)			
	Micro (1-4)	Small (5-99)	Medium (100-499)	Large (500+)
Alberta	0	1	6	1
British Columbia	3	5	15	3
Manitoba	0	1	1	0
New Brunswick	1	0	7	0
Newfoundland and Labrador	0	0	1	0
Nova Scotia	0	1	2	0
Northwest Territories	0	0	0	0
Nunavut	0	0	0	0
Ontario	5	15	12	1
Prince Edward Island	0	0	0	0
Quebec	5	26	25	5
Saskatchewan	1	0	1	0
Yukon	0	0	0	0
Canada	15	49	70	10
Percent distribution %	10.4	34	48.6	6.9

However, there are several wood pellet distributors in the Northwest Territories, including a pellet distribution plant by Green Energy NWT Inc. in the Sahtú Region, (Energy North 2020). According to GNWT, approximately 20% of heat produced in communities is currently done with wood pellets, of which 30,000 tonnes are imported annually (GNWT 2015). The GNWT's 2012 Biomass strategy led to a number of government buildings switching over to pellet boilers. This opened up distribution networks and dramatically lowered the cost of pellets in communities like Fort Smith, Hay River and Yellowknife. Most of these pellets are currently sourced from La Crete, Alberta.

B.3 Forestry Waste in British Columbia

As indicated in Table 7, BC has a large forestry industry, including several mills. As an example, approximately 3,257,000 tonnes (Agriculture and Agri-Food Canada 2017) of forestry residue is available within 200 km of Prince George comprising both milling waste and harvest waste. At present, Canfor, located in Prince George, has as agreement with an Australian company to build a pilot plant to make biocrude using their mill waste.

APPENDIX C – LIFE CYCLE MODELING INPUT PARAMETERS

Table C1. Fuel properties (Source: GHGenius 2020)

Fuel and property	Value
Gasoline density (g/L)	739.2
Gasoline higher heating value (MJ/L)	34.69
Ethanol density (g/L)	789.3
Ethanol higher heating value (MJ/L)	23.58
Diesel density (g/L)	843.2
Diesel higher heating value (MJ/L)	38.65
HDRD density (g/L)	770.3
HDRD higher heating value (MJ/L)	36.51
Jet fuel density (g/L)	808
Jet fuel higher heating value (MJ/L)	37.4

C.1 Input Parameters used in GHGenius:

- For gasoline and, diesel and jet fuel (proxy for kerosene):
    - Alberta
    - Canadian crude split: Canada West
    - Generic Power Region for Canada: Alberta
- For ethanol:
    - US Central
    - Ethanol feedstock: corn
- For HDRD:
    - Alberta (as described above)
    - HDRD feedstocks: Yellow grease (used cooked oil) and tallow (animal fat)
    - Generic Power Region for Canada: Atlantic. The GHG emission intensity of electricity generation in Singapore is 419 g CO_2/kWh (Government of Singapore, 2019) while the GHG intensity of Atlantic Canada's power grid is 405 g CO_2/kWh (based on Canada Energy Regulator, 2020a and 2020b). Atlantic Canada power grid emission intensity is therefore an adequate proxy of Singapore's grid emissions.
- Other parameters used in all fuel pathways:
    - Year: 2020

- Global warming potentials: IPCC's Fourth Assessment Report, 2007 (100-year time horizon)
- Vehicular energy use: GHGenius default
- Transportation of feedstock: GHGenius default
- Transportation of finished fuels: default except those in Table 9
- Feedstock production and other parameters: GHGenius default

Table C2: Modes of transportation and transport distances of the finished fuels

Modes of transportation	Value	Source
Singapore – Vancouver	Ship	Neste, 2020
Vancouver – Edmonton	80% rail, 20% truck	Authors' assumption based on current fuel shipping to NWT
Edmonton – Yellowknife	80% rail, 20% truck	Authors' assumption based on current fuel shipping to NWT [1]
Des Moines, Iowa – Edmonton	80% rail, 20% truck	Based on AAR, 2020
Transport distances	**Value**	**Source**
Singapore – Vancouver (km)	12831	Estimated using Google Maps
Vancouver – Edmonton (km)	822	Estimated using Google Maps
Edmonton – Yellowknife (km)	1452	Estimated using Google Maps
Des Moines, Iowa – Edmonton (km)	2354	Estimated Google Maps