IE3.1 Attachment 1

Evaluation of the Impact of Using Biodiesel and Renewable Diesel to Reduce Greenhouse Gas Emissions in City of Toronto's Fleet Vehicles

Final Report

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Executive Summary

The City of Toronto fleet operations (including TTC) consume approximately 102 million litres of diesel fuel annually, corresponding to annual greenhouse gas (GHG) emissions of over 300,000 tonnes of carbon dioxide equivalent (CO_2e). In the near term, switching from petroleum diesel to bio-based fuels with lower negative environmental impacts is a potential strategy to reduce GHG emissions and improve environmental quality. Responding to Motion PE17.6, the University of Toronto was engaged by City of Toronto Fleet Services to study both the feasibility and expected environmental impact of switching to higher bio-based diesel blends in City owned vehicles. This report presents those findings, including technical background on bio-based diesel fuels and their production; fuel properties and standards; cold weather operability and blending recommendations/constraints; analysis of Original Equipment Manufacturer (OEM) warranty approvals for the City of Toronto Fleet and TTC vehicles; summary of experience from other North American jurisdictions; expected impact of bio-based diesel fuels on life cycle GHG emissions, tailpipe pollutant emissions, and fuel costs; and finally, overall recommendations for the City of Toronto fuel procurement procedures.

This study considers two distinct classes of bio-based diesel fuels: biodiesel and hydrogenation derived renewable diesel (HDRD) (described in Sections 1 and 2). Both fuels can be derived from vegetable oils or animal fats, and represent renewable alternatives to petroleum diesel, but with some important differences in production process, chemical structure, and fuel properties. HDRD, often referred to as renewable diesel, is a 'drop-in' biofuel that is fully compatible with existing fuel infrastructure and can be blended at the refinery and shipped via pipeline, whereas biodiesel is blended with petroleum diesel at terminals as biodiesel is not shipped via pipeline. Given that HDRD is more expensive to produce than biodiesel, the latter is likely the more relevant option for the City in the near-term.

The most common feedstocks for biodiesel production in North America include canola oil, soy oil, rendered animal fat and used cooking oil. The choice of feedstock influences some of the final biodiesel properties (e.g., cloud point, which is discussed below). Overall, biodiesel should be blended with petroleum diesel to meet Canadian General Standards Board (CGSB) specifications. Section 3 describes the fuel standards related to biodiesel and HDRD. The CGSB biodiesel standards are the most stringent in the world. Hence, from an operability perspective, it is not necessary for fuel end users to be concerned with biodiesel feedstock origin as long as the final product (blended biodiesel) meets the CGSB standards. In contrast to biodiesel, HDRD properties depend more heavily on the production process than on the feedstock employed. Similar to the recommendation above, it is not necessary for fuel end users to be concerned with the HDRD feedstock or production process, provided that the final fuel product (whether or not blended with petroleum diesel) meets CGSB standards.

Petroleum diesel is governed by the CAN/CGSB-3.517 diesel fuel standard. Although the standard does not explicitly mention renewable diesel, HDRD nonetheless already meets the definition for diesel in the standard and thus faces the same property requirements as petroleum diesel. Biodiesel is governed by CAN/CGSB-3.524 (for pure biodiesel blendstock), along with CAN/CGSB-3.520 and CAN/CGSB-322 for blended biodiesel. The CAN/CGSB-3.524 standard includes several stricter requirements than its counterpart U.S.-based ASTM standard, as well as several additional requirements not present in the ASTM standard. For example, the CGSB standard includes a water limit and particulate contamination limit (not present in ASTM) to protect against the water and particles that can lead to premature filter changes. The inclusion of a Cold Soak Filter Blocking Tendency (CSFBT) test in addition to the Cold Soak Filtration Test (CSFT) (the former in CGSB but not in ASTM) provides further protection to mitigate the risk of materials from the biodiesel production process that could plug filters. CGSB specifications for oxidation stability guarantee long storage life. Thus, the recommendation for the procurement of the biodiesel for the City is that it must meet CAN/CGSB-3.524 (Biodiesel (B100) for Blending in Middle Distillate Fuels). Biodiesel that meets this specification and is blended per City of Toronto procurement document recommendations to meet the CGSB seasonal cloud point limits is unlikely to result in operational issues at B5, B10 or B20 blend levels (respectively, 5%, 10% and 20% biodiesel by volume, with the remainder of the blend being comprised of petroleum diesel).

Cold weather operability is one of the biggest concerns in Canada when considering any diesel fuel (petroleum diesel or biodiesel). Cloud point is the most commonly employed metric for cold weather operability; the cloud point of the fuel should generally be lower than the operating temperature of the fuel. The cloud points of petroleum diesel are seasonally-adjusted by petroleum fuel producers to meet the CGSB "Canadian Monthly Design Temperature Maps (2.5% low end)" for the season and region of use. The purpose of the Maps is to provide guidance based on historical temperature data for the various regions in Canada for operability and storage of petroleum fuels. This also applies to biodiesel blends. The cloud point specifications are set based on the design temperatures and are designed to be conservative, taking into account worst case conditions based upon historical data.

Our analysis (Section 4) suggests that biodiesel blends of up to 5% (i.e., 'B5') can be used year-round in Toronto, particularly if higher cloud point feedstocks such as tallow are avoided in the winter. In contrast, higher blends such as B10 cannot be used in winter without some correction for cloud point. From a technical standpoint, we are comfortable recommending B5 in winter, and higher blends such as B10 in spring and fall, and B20 in summer. HDRD can be produced with either a summer-grade or winter-grade cloud point, the latter requiring a cost premium over the former. Blends of up to 5% HDRD (either grade) can be used year-round in Toronto, while blends of 10% or more HDRD can be used in winter in Toronto only if the HDRD has a winter-grade cloud point.

Fuel turnover in City of Toronto storage tanks is usually sufficient to manage changing seasonal cloud point requirements, although the fuel supplier to the City of Toronto will need to carefully manage the cloud point of the fuel delivered, taking into account the cloud point of the fuel existing in the tank at the time of refill. This requirement would exist even for 100% petroleum-based diesel fuel. Storage tanks for diesel gensets are an important exception, and have less fuel turnover than other tanks. As a result of the need for long-term storage, we do not recommend using biodiesel blends (at any level) in gensets.

Beyond cloud point, OEM warranty approvals are a potential consideration for the maximum allowable biodiesel blends. HDRD meeting CGSB specifications is fully compatible with North American diesel engines. Most OEMs also began to issue official guidance, approvals and warrantees related to biodiesel after 2009, when biodiesel became more common, ASTM standards for biodiesel were fully developed, and engines were put through several years of testing using the fuel. Lack of explicit warranty for biodiesel blends does not imply that biodiesel blends will cause problems.

The City of Toronto Fleet Services fleet is comprised of vehicles that have OEM approval for a mix of B5 and B20 (see Section 5). Overall, approximately half the Fleet Services vehicles (accounting for cases where there are multiple vehicles of the same model and model year) are warranted up to B20 (mostly newer vehicles), leaving many vehicles that are not warranted for blends above B5 (mostly older vehicles). Approximately 80% of TTC buses have OEM approval for B20, with the remainder having approval for B5. In many cases, the vehicles that are not approved for B20 are arguably outside of the warranty period. In some cases, however, there are recent model year vehicles (e.g., 2011-2017 Freightliner heavy-duty vehicles with Detroit Diesel DD15 engines that remain warranted only to B5). A key question is management of risk to the City of Toronto if higher biodiesel blends are used compared to warranty statements or OEM approved blend level statements for their vehicles. As noted above, the CGSB B100 standard is the most stringent in the world. It is our opinion that higher biodiesel blends will not result in engine issues or increased maintenance, provided the biodiesel blended meets CAN/CGSB-3.524 and the blended biodiesel B6 – B20 blend meets CAN/CGSB-3.522.

This opinion is further backed up by our analysis of case studies from other jurisdictions. The biodiesel blends adopted in Canada and the U.S. range from B2 to B20. B20 is mostly used during the summer and in the winter the blends are lowered to B2 to B5. Three demonstration studies, summarized in Section 6, analyzed the feasibility and operability of biodiesel blends (B5 to B20) in cold climates. The studies show similar favorable results with no recorded on-road incidents affecting services due to the use of biodiesel blends. A 2006 U.S. Department of Transportation survey did report some minor problems, but these issues are more likely related to the quality of biodiesel used at the time, and would not be expected if using biodiesel that meets modern CGSB standards. Thus, in our judgment biodiesel blended as per the recommendations will not result in filter plugging or other maintenance issues. The full set of recommendations and procedures, including fuel procurement, maintenance, and handling are summarized in Section 10.

We estimate the potential GHG savings associated with biodiesel and HDRD (Section 7). Life cycle assessment is widely regarded as the preferred framework for evaluating the GHG emissions resulting from biodiesel and other fuels. Using the established GHGenius model, together with default assumptions from the Ontario Greener Diesel regulation, we find that biodiesel use in Ontario can lead to GHG reductions of 3.4-20% relative to petroleum diesel, depending on the feedstock (canola, soybean, yellow grease or tallow) and blend level (B5-B20). Results are similar for HDRD, which has only slightly higher GHG emissions than biodiesel, leading to GHG reductions of 3.1-20% relative to petroleum diesel. For context, if the City were to increase fleet-wide blend levels from B4 (year-round) to B5 in winter, B10 in spring and fall, and B20 in summer (akin to the in-progress pilot study), GHG reductions could range between 8.4% and 12% (depending on the feedstock), corresponding to emission reductions on the order of 30,000-43,000 tonnes CO_2e/year. Although these results are subject to some uncertainty, the finding that biodiesel offers lower emissions than petroleum diesel is robust across a variety of models from other jurisdictions. While we recommend that the City consider more specific GHG (carbon) intensity values reported directly by potential fuel suppliers, these results provide additional confidence in the GHG benefits of biodiesel.

Beyond GHG emissions, air pollutants such as sulphur oxides (SO_X), nitrogen oxides (NO_X), volatile organic compounds (VOCs), ammonia (NH3), carbon monoxide (CO) and fine particulate matter (PM2.5) affect air quality in ways that are harmful to human and ecosystem health. Whereas life cycle GHG emissions are characteristic of the fuel (and how it was produced), air pollutants also depend heavily on the specific vehicle in which the fuel is consumed, with modern vehicles generally having stricter emission control systems. Based on available literature (described in Section 8), biodiesel blends tend to result in lower emissions for PM, CO and HC compared to petroleum diesel. Results for NO_x were less consistent, with some studies suggesting a small increase of NOx emissions and others showing no change or a decrease in NO_x emissions when biodiesel blends were employed. Fewer studies have investigated the impact of HDRD on air quality, but existing work suggests that using HDRD results in lower emissions for most pollutants, especially in older vehicles with less emission control technology in place. In summary, there appear to be no major concerns, and will result in some benefits for air quality associated with both biodiesel and renewable diesel, especially on older vehicles with less emission control technology.

Finally, Section 9 of this report provides a preliminary analysis of potential market prices for biodiesel and HDRD. We report both market prices for biodiesel (publicly available in the U.S.) and HDRD (from industry sources), along with cost of production analysis for biodiesel and HDRD in the Canadian context. Including credits received by producers as a result of the U.S. Renewable Fuel Standard, the price of pure biodiesel (B100) in the US has ranged from 0.85 to 1.51 CAD per liter from 2009-2018 (November 2018 value is 1.07 CAD per liter). HDRD has fewer producers and less publicly available data than biodiesel. Current data suggests a price of approximately 1.5-1.6 CAD/L for pure HDRD, which is in keeping with our cost of production analysis, and showing a price premium of 0.43-0.53 CAD/L relative to the current (November 2018) B100 biodiesel price.

In summary, it is our expectation that using either biodiesel or HDRD would reduce GHG emissions, with little harm and more likely some benefits for air quality. Either option would likely add to the price of fuel, with HDRD commanding a greater premium than biodiesel. From a technical standpoint, as mentioned, we are comfortable recommending biodiesel blends up to B5 in winter, and higher blends such as B10 in spring and fall, and B20 in summer, though gensets should be limited to B0 due to longer fuel storage needs. For both biodiesel and HDRD, no additional maintenance or infrastructure costs are expected, provided that the fuel meets the relevant CGSB specifications.

Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
B2	2% Biodiesel blend by volume
B5	5% Biodiesel blend by volume
B10	10% Biodiesel blend by volume
B20	20% Biodiesel blend by volume
B100	Pure biodiesel (100% blend by volume)
CFS	Clean Fuel Standard
CGSB	Canadian General Standards Board
CME	Canola Methyl Ester
CO_2e	Carbon dioxide equivalent
EPA	Environmental Protection Agency
ECCC	Environment & Climate Change Canada
GHG	Greenhouse Gas
GWP	Global warming potential
HDRD	Hydrogenation derived renewable diesel
HEFA	Hydrogenated esters and fatty acids
HRD	Hydroprocessed renewable diesel
ILUC	Induced Land Use Change
LCA	Life Cycle Assessment
OEM	Original Equipment Manufacturer
RHD	Renewable Hydrocarbon Diesel
RIN	Renewable Identification Number

RFS	Renewable Fuel Standard
SME	Soy Methyl Ester
TME	Tallow Methyl Ester
UCO	Used cooking oil
ULSD	Ultra Low Sulphur Diesel
YGME	Yellow Grease (Methyl Ester)

1 Introduction

Petroleum is the primary fuel source for transportation in Canada (>95% by energy), with gasoline representing 53% and diesel representing 32% of all fuel consumption in 2014, by energy content [1]. In Toronto, the road transportation sector is a major emitter of greenhouse gases (GHG), responsible for 41% of Toronto's GHG emissions according to the City's 2013 GHG inventory [2]. The transportation sector is the only one to have shown an absolute increase in emissions since Toronto started tracking its GHG emissions in 1990. The use of petroleum-based gasoline and diesel in vehicles also produces air pollutants (NOx, particulate matter, etc.), which affect local air quality and human health. Within municipally owned and operated vehicles, there is a strong reliance on diesel fuel, which is used in heavy-duty engines in public transit buses and support vehicles, as well as City of Toronto Fleet Services' vehicles. The City of Toronto fleet operations consume approximately 102 million litres of diesel fuel annually (approximately 2% of all diesel consumed in Ontario), of which 90% is used in City-owned buses. This amount of diesel use corresponds to emissions of over 300,000 tonnes of carbon dioxide equivalent (CO_2e), meaning City-owned vehicles are responsible for around 4% of the entire City of Toronto's transportation GHG emissions.

In the near term, switching from petroleum diesel to a bio-based fuel with lower GHG emissions intensity is a potential strategy to reduce GHG emissions and improve environmental quality. Indeed, a number of federal and provincial policies (e.g., Ontario's Greener Diesel Regulation and Canada's forthcoming Clean Fuel Standard) provide incentives to shift toward increased use of bio-based fuels. Currently, the City of Toronto uses a 4% biodiesel blend (increasing to 5% by end of summer 2018) [3], however, there is an opportunity to increase the use of bio-based diesel products (biodiesel or hydrogenation derived renewable diesel (HDRD)) in the near future without substantial changes to existing infrastructure. Such a move could potentially help the City become a leader in green transportation among municipal fleets, and may contribute toward stated goals such as the TransformTO target to transition 45% of the City-owned fleet to low-carbon vehicles by 2030 [4]. Longer term, there is the possibility of adopting other low-carbon options including electric vehicles, such as in the TTC Green Bus Technology Plan [5][6]. The plan calls for procurement of only zero-emissions buses starting in 2025. The resulting TTC fleet will not have a fully emissions-free fleet until the end of 2040, leaving a potential role for transitioning to bio-based diesel fuels in the meantime.

To justify such a transition, it is essential a) that estimates of emissions associated with bio-based diesels are based on up-to-date and best available data and scientific/engineering methods, and b) to understand any limitations (physical, financial, or logistical) in the adoption of higher level blends of bio-based diesel fuels within the existing City of Toronto fleet. Responding to motion PE17.6, the University of Toronto was engaged by City of Toronto Fleet Services to study both the feasibility and expected environmental impact of switching to higher bio-based diesel blends in City owned vehicles. This final project report includes: 1) discussion of biodiesel and HDRD production and properties, 2) Canadian (CGSB) and U.S. (ASTM) fuel standards, 3) analysis of seasonal blending recommendations/constraints for bio-based diesel fuels, 4) analysis of biodiesel and HDRD approvals from vehicle engine manufacturers, 5) discussion of bio-based diesel fuel adoption in other North American jurisdictions, 6) an analysis of the life cycle GHG emissions and air pollutants associated with bio-based and petroleum-based diesel fuels within the City of Toronto context, 7) evaluation of fuel cost for biodiesel and HDRD, and 8) recommendations for City of Toronto fuel procurement.

1.1 Petroleum Diesel

Conventional diesel, or petroleum diesel, is derived from non-renewable, fossil-based crude oil. Petroleum diesel is made up of a mixture of hydrocarbon compounds, refined through fractionation and other refinery operations to achieve specific physical properties that change seasonally. There are numerous properties that can differentiate diesel fuels, among which the most important include the cetane rating and cloud point, described below:

- Cetane rating/number – This is analogous to the octane number for gasoline, and is a measure of the ease of diesel ignition and burn. The higher the value, the shorter the ignition delay. A higher cetane number allows engines with higher speeds to operate more efficiently, and generally corresponds to lower combustion emissions.
- Cloud point – A measure of the temperature below which solid hydrocarbon crystals first appear when the fuel is cooled. Measurements of cloud point detect the presence of wax crystals and thus determine the temperature at which the miscible components in the diesel fuel begin to fall out of solution, representing a change from a single liquid phase to a two-phase system containing solid and liquid [7,8]. It is the most commonly employed metric for cold-weather operability; the cloud point should generally be lower than the operating temperature of the fuel.

Other properties such as sulphur content were historically important, but are now less relevant given modern specifications that require use of ultra low sulphur diesel (ULSD). Petroleum diesel in Canada is typically blended at the refinery, and adjusted seasonally (and geographically) to ensure an appropriate cloud point for the region where the fuel will be used. Petroleum diesel is the bulk fuel used in biodiesel blending, and the properties of the petroleum fraction (such as cloud point) may likewise be adjusted to accommodate the blended biodiesel and ensure a finished product that meets specifications.

1.2 Biodiesel

Biodiesel can be derived from both vegetable and animal sourced oils and fats Vegetable oils with low free fatty acid content are typically converted into biodiesel via transesterification, whereas animal fats, used cooking oil, and other feedstocks high in free fatty acids require a combination of esterification and transesterification steps. These reactions produce an oxygenated fuel (i.e., contains oxygen atoms), making biodiesel chemically distinct from diesel (and renewable diesel), which are non-oxygenated. Biodiesel is also known by the chemical name of its key constituent, either Fatty Acid Methyl Esters

(FAME) or Fatty Acid Ethyl Esters (FAEE), pictured in Appendix A, Figure A-1. More specific names are also used when the feedstock is known; common biodiesel names include:

- Canola Methyl Esters (CME) in North America, Rapeseed Methyl Esters (RME) in Europe
- Soy Methyl Esters (SME)
- Yellow Grease Methyl Esters (YGME)
- Tallow Methyl Esters (TME)

The term "biodiesel" thus represents a distinct class of chemical structures. Renewable diesel (see Section 1.3), although also based upon bio-derived feedstocks, is not referred to as biodiesel because the chemical structures are different: alkanes in the case of renewable diesel, and esters in the case of biodiesel.

As a fuel, biodiesel can be used in its neat form, which is 100% biodiesel, also known as B100. Nonetheless, biodiesel is typically blended with diesel and the blends are noted as BX, where the X indicates the volume percent of biodiesel. For example, a 5% biodiesel blend by volume is referred to as B5. Biodiesel generally has poorer low temperature properties than diesel (i.e., a warmer cloud point), and so it can be more difficult for fuel providers to meet required cold-weather specifications when using higher level biodiesel blends in winter. It should be noted that this issue is not unique to biodiesel, as fuel refiners must already adjust the composition of conventional diesel to suit the season and geography, as described in Section 1.1. Similar steps are required with renewable diesel. Methods to overcome the challenges associated with cold climate applications of biodiesel and renewable diesel are discussed in greater detail in Section 4.

1.3 Renewable Diesel

Renewable diesel is an alkane-based biofuel that has physical properties close to those of diesel. It can be derived from the same feedstocks as biodiesel, converted via hydroprocessing – using technology from petroleum refining such as hydrotreating, hydrocracking, and isomerization to produce hydrocarbon (alkane) fuels. Given the similarities in chemical and physical properties, renewable diesel can be used interchangeably with diesel and can also be blended at any proportion, taking into account impacts on cold-flow properties due to the (typically) lower levels of branched hydrocarbons. However, renewable diesel requires additives to improve its lubricity when used in higher blends. Renewable diesel is also frequently referred to by other names including:

- Hydrogenation derived renewable diesel (HDRD) (we use this terminology hereafter in the report)
- Hydrogenated esters and fatty acids (HEFA) diesel
- Hydroprocessed renewable diesel (HRD)

- Green diesel (common name)

Although HDRD and biodiesel can be produced using similar feedstocks (vegetable oils and animal fats), the reactions, production processes, and fuel properties are distinctly different. Whereas biodiesel properties depend strongly on the feedstock from which it is derived (discussed further in Section 2.1.2), HDRD properties are more heavily controlled by production process parameters such as operating temperatures, pressures, and catalysts employed. Some disadvantages of HDRD production (as compared to biodiesel) are the need for additional hydrogen as part of the isomerization process, and also the high capital cost of hydroprocessing equipment [9]. This results in HDRD generally being more expensive than biodiesel. Unlike biodiesel, however, HDRD is a ’drop-in’ fuel that is fully compatible with existing fuel infrastructure, distribution systems, and diesel engines at any blend level. Additionally, there is a mechanism to produce HDRD with a winter grade cloud point (e.g., -20 °C or colder), albeit with yield losses and a corresponding price premium relative to summer grade HDRD.

For this study, as the intent is to have the blended fuel delivered to the City of Toronto, the decreased infrastructure needs for blending of HDRD is likely not a material issue. Given that HDRD is more expensive to produce than biodiesel, the latter is likely the more relevant option for City of Toronto in the near-term. There is a Startup company, FORGE Hydrocarbons that is getting ready to break ground on the first renewable diesel plant in Canada, located in Sombra, Ontario (although renewable diesel is already imported into Ontario). It is anticipated to be commissioned around mid-2020.

2 Biodiesel and HDRD Production and Properties

2.1 Biodiesel Detailed Overview

2.1.1 Biodiesel Production Pathways

Biodiesel can be produced from the oils contained in a wide range of plant and animal feedstocks, with the most prominent North American sources being canola oil, soybean oil, used cooking oil (yellow grease) and animal fats (tallow) [10]. The production process is similar for each feedstock, as outlined in Figure 2-1, but with some important differences. The production of biodiesel begins with a feedstock processing stage that prepares the incoming feedstock(s) for the subsequent conversion and recovery stages. Biodiesel production facilities utilizing oilseed crops such as canola and soybean would have an oil extraction process (alternatively, they could purchase oils from an oilseed crushing operation). The oil extraction process includes mechanical pressing and solvent extraction to extract crude vegetable oils. The crude vegetable oils are then pretreated for further refining through the removal of impurities including gums, moisture and entrained meal particles. Facilities utilizing waste feedstocks such as used cooking oil (also referred to as yellow grease) and tallow would not need the oil extraction step, but would still need a pretreatment process to deal with water, high levels of free fatty acids, and other impurities. The presence of more than 4% free fatty acids in the feedstock necessitates the inclusion of an acid esterification process as part of the “pretreatment” step. Whether it is vegetable oil or waste feedstock, the pretreatment process is a crucial step as the presence of impurities can foul the catalysts, reduce conversion efficiency and contaminate the final products, all of which can contribute to inconsistent product yields and biodiesel quality. The refined oils are transformed into biodiesel through transesterification, followed by product recovery that separates the biodiesel from the glycerine co-product and excess methanol/alcohol used to drive the reaction.

The underlying mechanism in the production of biodiesel is the transesterification reaction. During the reaction, vegetable oils or animal fats (also referred to as triglycerides) react with alcohol (e.g., ethanol (ethyl-group) or methanol (methyl-group)) in the presence of catalyst (typically sodium hydroxide, NaOH) to produce biodiesel and glycerine co-product. The glycerine co-product is a necessary result of the reaction chemistry (see Appendix A, Figure A-2), and is an important consideration for GHG accounting, as discussed in Section 7. The theoretical material balance for transesterification with methanol shows that every 100 kg of triglyceride requires 10 kg of methanol and the process yields 100 kg of biodiesel, as well as 10 kg of glycerine co-product. For more information related to biodiesel supply and availability in Canada, refer to Appendix C.

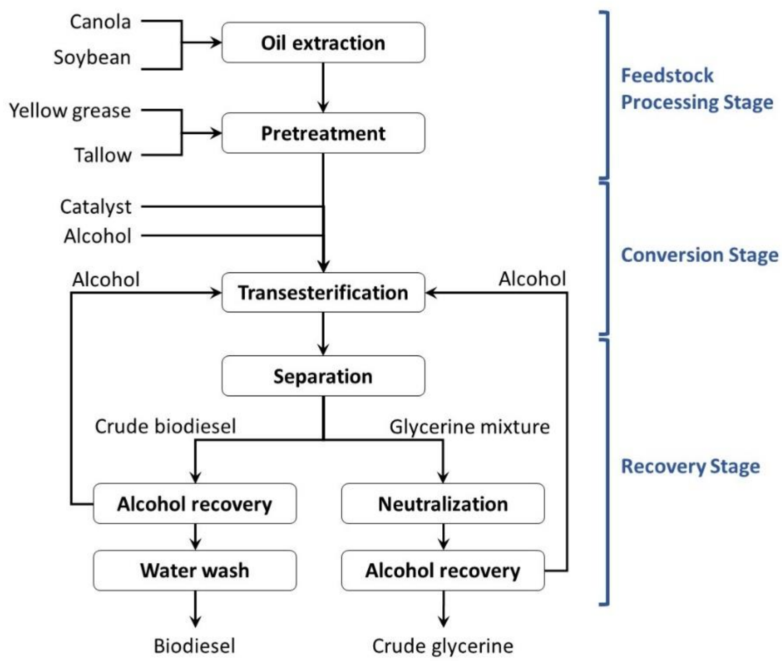

Figure 2-1: General process flow of commercial biodiesel production

2.1.2 Biodiesel Properties

Biodiesel represents a family of chemical compounds, comprising methyl (or ethyl) esters of fatty acids derived from vegetable oils, used cooking oil, or tallow. Each feedstock has varying fatty acid compositions (see Appendix B, Table B-1), that follow through to the final biodiesel product. Thus, fuel properties such as cloud point and cetane number will vary depending on the initial feedstock used, as well as the bulk petroleum diesel with which the biodiesel is blended. Other properties, like the biodiesel energy density (e.g., measured in MJ/L) are largely constant across feedstocks. For biodiesel blends up to B20, most users find similar power, torque and fuel economy (within 1-2%) to that provided by pure petroleum diesel [11]. Typically, pure biodiesel has poorer low temperature properties in comparison to petroleum diesel, irrespective of biodiesel feedstock origin (see Table 2-1 and Appendix B, Table B-2). The effects of feedstock on biodiesel cloud point would be taken into consideration when a biodiesel producer selects the feedstock. The biodiesel product made by fuel producers is nonetheless required to meet fuel standards and specifications (see Section 3 on Canadian General Standards Board (CGSB) specifications). Hence, from an operability perspective, it is not necessary for fuel end users to be concerned with biodiesel feedstock origin as long as the final product (blended biodiesel) meets the necessary standards, which are discussed in Section 3.

2.2 HDRD Detailed Overview

2.2.1 HDRD Production Pathways

The primary technology to produce hydrogenation derived renewable diesel (HDRD) is based on hydroprocessing, which is used in the petroleum industry to refine crude oil. Hydroprocessing converts both vegetable and animal sourced oils and fats into HDRD, thereby using the same feedstock sources as the biodiesel production pathway. The HDRD process is outlined in Appendix A (Figure A-3). The front end of the HDRD production process is similar to that of biodiesel where facilities utilizing oilseed crops such as canola and soybean would have an oil extraction process that includes mechanical pressing and solvent extraction. The crude vegetable oils undergo pretreatment for further refining. As with biodiesel, HDRD facilities utilizing waste feedstocks have no oil extraction phase, and instead begin the pretreatment process following feedstock collection. The pretreatment step removes impurities, thereby protecting activity of the hydroprocessing catalyst and ensuring both efficient conversion to HDRD, and consistent quality of the final products. In the conversion stage, the refined oils are transformed into HDRD through deoxygenation, followed by water removal, then selective hydrogenation, and finally product recovery in which the fuel product and co-products are separated through fractionation.

2.2.2 HDRD Properties

HDRD consists of hydrocarbon compounds, primarily alkanes. Although both HDRD and biodiesel are produced from common feedstocks, the composition of HDRD more closely resembles petroleum-derived diesel owing to the hydroprocessing conversion mechanisms. As a result, feedstock characteristics such as the fatty acid composition do not influence the properties of HDRD. Compared with petroleum diesel, HDRD is a cleaner burning fuel due to a lack of sulfur impurities, but the absence of both sulfur and aromatics in HDRD reduces its lubricity. Hence, similar to petroleum-derived fuels, HDRD requires fuel additives to improve its lubricity. For the most part, HDRD has higher cetane number and lower density than petroleum-derived diesel. HDRD is virtually free of metal contaminants as well as ash-forming compounds to give a clean combustion. In terms of stability, there is no more risk of microbial growth, precipitation and water formation during HDRD storage than for petroleum diesel.

2.3 Biodiesel and HDRD Cold Weather Properties

As previously described, biodiesel cloud point is primarily controlled by the biodiesel feedstock, while the cloud points of petroleum diesel and HDRD can be adjusted by varying the production process and blend components. With biodiesel, the cloud point is affected by the number of carbon atoms in the chain, and the degree of unsaturation of the feedstock. However, in the case of HDRD, the degree of unsaturation of the feedstock is immaterial, and the chain length of the free fatty acids is the only compositional factor that affects cold flow properties. A key factor affecting the cloud point of HDRD is the degree of isomerization (or branching) in the HDRD process, which varies according to the operating temperatures, pressures, and catalysts. The viscosity of HDRD is determined by the quantity of large straight chain alkanes, also referred to as n-alkanes. The incorporation of isomerization converts the n-alkanes into branched molecules, or isomers that give HDRD a much lower cloud point. The higher the ratio of isomers to n-alkanes, the lower the cloud point. Depending on the extent of isomerization, the cloud point of HDRD can be as low as some petroleum diesel. For example, the HDRD supplied to the Alberta Renewable Diesel Demonstration (ARDD) was -27 °C for winter [12]. Isomerization is widely used to formulate cold weather properties of diesel from crude oil to produce winter diesel.

Petroleum formulation is done within the refinery and is blended to meet the seasonal and regional CGSB cloud point specifications. For context, Table 2-1 presents typical cloud points for seasonal petroleum diesels (ULSD), pure biodiesel from various feedstocks, and seasonal HDRD.

Table 2-1. Typical Cloud Points of Biodiesel from Various Feedstocks and Seasonal HDRD

Sample	Typical Cloud Point (°C)
** ULSD Summer	0
* ULSD Fall / Spring	-14
*ULSD Winter	-27
** CME B100 (Canola derived)	-3
* SME B100 (Soy derived)	-1
* TME B100 (Tallow derived)	12
** HDRD Summer	-5
** HDRD Winter	-20

* Source: Data from ASTM Biodiesel Cloud Point Round Robin [13]

** Source: Industry Sources

It is generally accepted that the cloud point of summer (petroleum) diesel far exceeds the CGSB cloud point requirements for summer, which allows B20 biodiesel blends to be used in summer with no need for additional correction for cloud point or limitation in biodiesel blend level. In the “shoulder seasons” of spring and fall, cloud point limits become more relevant and so B10 blends are commonly used. Lower blends (i.e., B5) can be blended in the winter, but winter B5 blends may require the cloud point of the petroleum blendstock to be adjusted accordingly. For similar reasons, less expensive biodiesel feedstocks like tallow that produce warmer cloud point biodiesel are often used in the summer, while lower cloud point oilseed (soy and canola) feedstocks are beneficial in winter. Petroleum-based ultra low sulphur kerosene (ULSK) can also be used for cloud point correction, but the procedure complicates the blending and may increase the cost of the blended fuel. Thus, the assumption is that the biodiesel blend in the procurement document will be written such that the biodiesel blend will be supplied without the addition of ULSK. This may limit the biodiesel blend level to the general pattern as noted above. The above section is provided for information only, as the expectation is that the supplied biodiesel blend will be delivered as blended fuel that meets CGSB specifications. The information above and more detailed information in Sections 4.1, 4.2, and 4.3 is therefore provided as guidance for the preparation of procurement documents for the fuel supply.

3 Fuel Standards

3.1 Canadian Diesel and Biodiesel Standards

The Canadian General Standards Board (CGSB) provides a comprehensive set of specifications upon which end-users can rely, thereby simplifying the diesel or biodiesel procurement process. There is no provincial requirement in Ontario for diesel fuel to meet these specifications; however, fuel suppliers have mutually agreed upon CGSB specifications, making them a de facto standard within the province. Thus, all diesel fuels, including biodiesel blends, are expected to meet the CGSB standard specifications. It is recommended that the City of Toronto specify appropriate CGSB requirements in its procurement documents, which should be sufficient to guarantee quality as well as the necessary cold weather properties.

3.1.1 Petroleum Diesel and HDRD in CGSB Standards

The CGSB Middle Distillate Committee covers diesel fuel and heating fuel [14]. In particular, the CAN/CGSB-3.517 diesel standard governs the properties of petroleum diesel, defining diesel fuel as "middle distillate fuel composed of hydrocarbons and naturally occurring, petroleum-derived non-hydrocarbons that boils in the range of 130–400 °C and that is intended for use as a fuel in compression-ignition engines" [15].

It is recognized at CGSB that Renewable Diesel such as HDRD (Hydrogenation Derived Renewable Diesel) is chemically equivalent to petroleum derived diesel. CGSB is in the process of considering amendments to standard CAN/CGSB-3.517 (diesel fuel) [15] and related standards for heating fuel, kerosene and biodiesel blends to add a specific definition for HDRD.

Although CGSB diesel standards do not currently explicitly state that HDRD can be blended at any level, HDRD nonetheless already meets the definition for diesel in CAN/CGSB 3.517[15], and so the CGSB diesel standard implicitly allows HDRD at any level. The main concern about "blending HDRD at any amount" raised at the recent CGSB meeting (November, 2018) was with respect to ensuring adequate lubricity additive. However, section 6.22 of the CAN/CGSB-3.517 [15] states the requirement for lubricity and how it is to be achieved and tested and so it is our opinion that the lubricity is already addressed in the standard.

3.1.2 HDRD in ASTM Standards

The American Society for Testing and Materials International (ASTM International) Committee D02 on Petroleum Products, Liquid Fuels and Lubricants, covers petroleum diesel and heating fuel specifications and related test methods [16]. The ASTM D975 diesel standard defines hydrocarbon oil as, "a homogeneous mixture with elemental composition primarily of carbon and hydrogen that may also contain sulfur, oxygen, or nitrogen from residual impurities and contaminants associated with the fuel's raw materials and manufacturing processes and excluding added oxygenated materials" [17]. It is recognized at ASTM that Renewable Diesel such as HDRD is chemically equivalent to petroleum diesel. The ASTM definition (above) for diesel fuel has been modified in recent years in their diesel and diesel blend standards to accommodate both petroleum derived diesel fuel and HDRD.

3.2 CGSB Biodiesel Standards

The CGSB Middle Distillate Committee also covers biodiesel and biodiesel blends [14]. The CGSB biodiesel specifications include the following:

- CAN/CGSB-3.524 for B100 blend stock [18];
- CAN/CGSB-3.520 (B1 – B5 standard) that includes up to B5 in diesel blends [19];
- CAN/CGSB-322 (B6 – B20 standard) that includes blends of biodiesel from 6 – 20% [20].

The B100 blendstock specification limits are dictated for the most part by Original Equipment Manufacturers (OEMs, which manufacture vehicle engines) and Fuel Injection Equipment Manufacturers, along with input from petroleum producers that use biodiesel as a blendstock. There is a strong resemblance between the biodiesel specification ranges in the CGSB biodiesel specifications and those employed in the U.S. based on ASTM International standards. The key differences are noted in Section 3.2.3. The test methods in the CGSB B100 blendstock specification are for the most part the same as the ASTM B100 blendstock specification, with CGSB requiring more stringent limits for some categories. There are also some additional tests in the CGSB B100 blendstock specification that are above and beyond the ASTM B100 blendstock specification.

3.2.1 ASTM Biodiesel Standards

Committee D02 of ASTM International [21] covers Petroleum Products, Liquid Fuels and Lubricants and includes petroleum diesel, biodiesel and biodiesel blend specifications and related test methods [22].

ASTM’s biodiesel standard specifications include the following:

- ASTM D6751 for B100 blendstock [23];
- ASTM D7467 (B6 – B20 standard) that includes blends of biodiesel from 6 – 20% [24];
- ASTM D975 diesel specification allows up to 5% biodiesel (B5) [17].

3.2.2 Reasons for Differences in Biodiesel Standards

There are several reasons why there are differences in specifications amongst different jurisdictions. What is significant in the case of biofuel specifications is that the specifications have been driven from two sides. On the one side, the OEMs and Fuel Injection Equipment Manufacturers have weighed in with their needs to ensure that specifications facilitate the operation of their equipment and minimize the risk of deterioration from corrosion or other wear factors. On the other side, the petroleum companies that represent the fuel into which the biofuel is blended have weighed in to minimize the risk of deterioration from corrosion or other factors.

As noted above, the CGSB biodiesel standards are generally more stringent than the ASTM ones. The differences are a result of some OEMs requesting tighter specification limits on some test properties and in some cases, additional test properties. As an example of this, the Detroit Biodiesel Policy includes more stringent limits than ASTM D6751, has limits for oxidation stability and calcium + magnesium that are the same as the CGSB biodiesel specification, and additional test parameters (for total water and particulate contamination) as in the CGSB biodiesel specification [25].

The differences between CGSB and ASTM biodiesel standards also reflect to some degree that the fuel distribution system is different in Canada than in the USA. In the USA, the fuel system is fungible, meaning that as the fuel leaves the refinery gate, it is comingled with other product from other refineries and becomes indistinguishable. In Canada, in many cases the product custody remains with the producing refinery all the way to retail. In that sense, the Canadian refineries insist on tighter specifications than in the USA, citing higher risk to their brand in the Canadian fuel distribution system.

3.2.3 Differences in Biodiesel Specification Limits between CGSB and ASTM

As previously noted, although Canadian and U.S. standards are similar, there are some important differences between the CGSB biodiesel specification CAN/CGSB-3.524 and the ASTM biodiesel specification ASTM D6751. In some cases, the CGSB specification has more stringent limits and in some cases the CGSB specification has additional specification parameters not included in the ASTM biodiesel specification. Differences are noted in Table 3-1. The standards also include other test properties where both specify equivalent specifications limits. Key test properties are described in more detail in Appendix D.

Table 3-1: Differences in specification limits between Canadian and US biodiesel standards (CAN/CGSB-3.524 and ASTM D6751) [18][23]

Test Property	Test Units	CGSB Specification Limit	ASTM Specification Limit
Water Content	ppm mass	400 max	--
Particulate Contamination	mg/L	20 max	--
CFSBT (Cold Soak Filtration Blocking Tendency)		1.8 max	--
Oxidation Stability	hours	8 min	3 min
Alkaline I Metals (Sodium + Potassium)	ppm mass	4 max	5 max
Alkaline II Metals (Calcium + Magnesium)	ppm mass	2 max	5 max
Phosphorus content	ppm mass	4 max	10 max

The fact that there is a water content limit and a particulate contamination limit in the CGSB spec is significant as this protects against the water and particulates that can lead to premature filter changes. Additionally, there is a Cold Soak Filtration Blocking Tendency (CSFBT) test in addition to the Cold Soak Filtration Test (CSFT) in the CGSB spec, which provides further protection to mitigate the risk of materials from the biodiesel production process that could plug filters. The ASTM standard only includes the CSFT.

3.2.4 Description of Key Biodiesel Test Properties and Relationship to Engines

This section includes a more detailed description of some of the key biodiesel test properties and their relationship or potential impact on engines and engine parts.

Oxidation stability is one of the critical properties for biodiesel that affects the fuel stability, which is especially relevant for extended fuel storage. The oxidation stability is impacted by the starting feedstock and is generally inversely correlated to the biodiesel’s cloud point. Canola methyl ester (CME) has a higher degree of unsaturation (double bonds) than soy methyl ester (SME), and thus, without stability additives, CME typically has poorer oxidation stability. However, processing also impacts oxidation stability. Biodiesel is sometimes distilled to remove minor impurities, but the distillation process also removes anti-oxidants that are naturally present in the starting feedstock. These are typically added at the production plant. Finally, there are a number of oxidation stability additives that are highly effective in raising the oxidation stability value of the biodiesel. Thus, feedstock and biodiesel process technology can both have an impact on the final fuel properties. From the perspective of the end-user, however, stability is generally not a concern as long as the fuel meets the CGSB specifications. The CGSB specification for B100 blendstock includes an 8-hour limit (minimum stability time under accelerated testing conditions), and so oxidation stability additives are utilized to account for any inherent differences in oxidation stability stemming from different feedstocks or different processing techniques. The relationship between the oxidation stability test and real-world stability is non-linear, and so the 8 hour CGSB minimum requirement corresponds to a much longer storage time than the 3 hour limit prescribed by ASTM. Thus, the 8 hour Rancimat limit in the CGSB specification is sufficiently protective for long term stability.

Prior to the implementation of the Cold Soak Filtration Test into the ASTM and CGSB B100 blendstock specifications, the feedstock had some impact on product quality. There can be some naturally occurring compounds in plant oils called sterol glucosides that can result in formation of precipitates. There is a higher level of sterol glucosides in soy as compared to canola. In addition, the level of sterol glucosides can be higher in the different plant oils depending on the grade of the vegetable oil feedstock (crude degummed, vs. bleached & deodorized, etc.). The Cold Soak Filtration Test requirements have mitigated any such impact on product quality under modern specifications.

The Alkaline I Metals (Sodium + Potassium) and Alkaline II Metals (Calcium + Magnesium) are also controlled as they can poison the catalyst in the engine after-treatment systems. The Alkaline I & II metals in the CGSB specification are at the lower detection limits of the test methods, and are deemed sufficiently protective.

CGSB also provides guidance on cloud point specifications for both diesel fuels and biodiesel, adjusted for both season and region of use. These specifications exist to ensure appropriate cold weather operability and will be discussed in greater detail in Section 4.

3.2.5 Summary of Key Points related to Biodiesel Standards and Fuel Properties

The CGSB B100 standard contains among the most stringent biodiesel specifications in the world. The water limit and particulate contamination limit in the CGSB specification protect against the water and particulates that can lead to premature filter changes. The inclusion of a Cold Soak Filter Blocking Tendency (CSFBT) test in addition to the Cold Soak Filtration Test (CSFT) (the former in CGSB but not ASTM) provides further protection to mitigate the risk of materials from the biodiesel production process that could plug filters. CGSB specifications for oxidation stability guarantee long storage life. Thus, the recommendation for the procurement of the biodiesel for this project will be that it must meet the CAN/CGSB-3.524 B100 specification limits. Biodiesel that meets this specification and is blended per the procurement document recommendations to meet the CGSB seasonal cloud point limits (see Section 4) is unlikely to result in operational issues at B5, B10 or B20 blend levels.

4 Cold Weather Operability and Cloud Point Blending

Cold weather operability is one of the biggest concerns in Canada when considering any diesel fuel. The cloud points of petroleum diesel are seasonally-adjusted by petroleum fuel producers to meet the CGSB "Canadian Monthly Design Temperature Maps (2.5% low end)" for the season and region of use. The purpose of the Maps, which were prepared for the CGSB by Environment Canada, is to provide guidance based on historical temperature data for the various regions in Canada for operability and storage of petroleum fuels. This also applies to biodiesel and HDRD blends. The cloud point specifications are set based on the design temperatures and are designed to be conservative, taking into account worst case conditions based upon historical data.

4.1 Biodiesel Cold Weather Operability and Blending (General)

In a refinery, Ultra Low Sulphur Diesel (ULSD) is made up of more than one refinery stream and is blended for use based upon the seasonal and regional cloud point specification. The same is true when blending biodiesel. Blends of B2 and B5 are rarely a concern, although the cloud point of the blended fuel should still be verified to ensure that it meets the CGSB percentile temperature for the season and region of use. Existing studies have examined the blending of petroleum diesel and biodiesel and, as demonstrated in the numerous National Renewable Diesel Demonstration Initiative (NRDDI) studies, [8] no issues were observed with the cloud points of the biodiesel blends.

Blending biodiesel with petroleum diesel may reduce the low temperature operability of the fuel. Thus, the petroleum diesel used for blending may need to have a slightly lower (colder) cloud point to accommodate the biodiesel blend. When biodiesel is blended with petroleum diesel, the cloud point of the diesel fuel and the cloud point of the biodiesel are the two most important properties. *The blended fuel must meet the CGSB seasonal temperatures for cloud point for the region in which the fuel is being used*.

If blending is done into seasonal diesel, it must be done such that the seasonal cloud point temperatures are maintained. Therefore, the cloud points of the biodiesel and the petroleum diesel must be known. This may, in some cases, govern the level of the biodiesel blend. Operators who blend even low percentages of biodiesel with seasonal diesel in the winter or shoulder seasons must pay attention to the cloud point of the blended product to ensure that there are no operational issues. Therefore, it is important to know the cloud point of the diesel used for blending, the biodiesel intended for blending, and the regional seasonal cloud point for intended use of the biodiesel blend.

Biodiesel is typically blended with petroleum diesel in the same manner that ethanol is blended in gasoline, i.e., by metered blending. Splash blending into delivery trucks is not commonly practiced. It is understood that the biodiesel blends for this project will be delivered as blended fuel. Thus, although the cloud points of both the biodiesel and petroleum diesel into which it is blended are important, no operability issues are expected for blended fuel that meets appropriate seasonal CGSB standards.

Section 4.3.3 provides additional guidance concerning the seasonal blending of biodiesel in the City of Toronto.

4.2 HDRD Cold Weather Operability and Blending

Cold weather operability and seasonal blending applies to HDRD similarly to how it applies to biodiesel. The one difference between biodiesel and HDRD blending is that even "summer HDRD" typically has a relatively low cloud point (roughly -5 °C). For this reason, it can be used for blending at some levels in the shoulder seasons (spring and fall) in regions such as Toronto, whereas biodiesel from sources such as tallow and yellow grease are primarily for summer and only suitable for shoulder seasons at low blend levels. The other difference is that the "winter HDRD" from some suppliers has cloud points on the order of -10 °C and from other suppliers on the order of -20 °C and this allows for higher blend levels in shoulder seasons and in winter in regions such as Toronto. This will be discussed in greater quantitative detail in the following sections on Seasonal Cloud Point Blending.

4.3 Cloud point blending

4.3.1 Context for interpreting cloud point specifications

CGSB Cloud point specifications change every 15 days, and are based on 30-year average 2.5% low end design temperatures for each 15-day period. The 2.5 percentile design value is the temperature at, or below which, 2.5% of the hourly outside air temperatures are observed to occur for an indicated half month. This data is based on an analysis of hourly weather readings from weather stations across Canada. There are a few key points to keep in mind when it comes to cloud point blending.

Firstly, CGSB cloud point schedules are based on 2.5% low end temperature based on 30-year data from Environment Canada weather stations. These are effectively worst case temperatures to be protective. The majority of time there is, "cloud point giveaway", meaning that the actual ambient temperature is warmer than the 2.5% low end temperature. This is more often true in southern areas such as the Toronto area. Secondly, climate change is real and measurable and therefore the 30-year average 2.5% low end design temperatures were shown at recent CGSB meetings to be lower than recent temperatures. This is likely to result in more giveaway in cloud point until the 2.5% low end temperatures are recalculated. Thirdly, the fuels are blended to meet the required cloud point at terminals, for wide distribution to what refiners' call "terminal orbits" [26] (see Appendix E for Ontario example). This takes into consideration the lowest cloud point for the distribution for that region and season. Therefore, there is likely some "cloud point giveaway" in this respect also.

A final key factor is that cloud point is by definition not an exact number as it is measured using an instrument that has imprecision. ASTM D5773, "Standard Test Method for Cloud Point of Petroleum Products and Liquid Fuels (Constant Cooling Rate Method)" [27], is the most precise cloud point test method has a repeatability of 1.3 ℃ and a reproducibility of 2.5 ℃. This means that if the same operator were to run the same sample, the second result could be different by 1.3 ℃ and if two labs were to run the same sample, the results could differ by 2.5 °C. This does not mean that differences in cloud point when biodiesel (or HDRD) are blended should be ignored.

4.3.2 Cloud Point Design Temperatures in Toronto

The 2.5% Low-End Design Temperature that determines the CGSB cloud point specification for a given time period in Toronto is based on data from three weather stations: Pearson Airport, Markham (Buttonville Airport), and Toronto Island Airport (Table 4-1) [28]. Based on this data, refineries need to blend diesel fuel to meet cloud point specifications, and fuel terminals need to be turned over to the half month cloud point limits to accommodate the changing cloud point specification requirements for the distribution region being served by those terminals. For a customer like the City of Toronto, if fuel is turned over less frequently, the fuel supplier to the City of Toronto will need to account for cloud point of the fuel already in the tank, as discussed further in Section 4.4; this requirement exists whether or not the fuel is blended with a bio-based diesel. In the case of the City of Toronto, the delivered fuel will need to meet the most stringent (i.e., coldest) temperature for the period that the fuel is to be consumed. Table 4-1 below shows the relevant cloud point specifications.

Table 4-1 : CGSB half-month cloud point specification for Toronto (Degrees °C) [28]

Half-Month	Downtown Toronto	Toronto Airport	Markham
January 1 - 15	-16.7	-20.4	-19.8
January 16 - 31	-17.0	-19.3	-20.6
February 1 - 15	-14.6	-17.4	-18.8
February 16 - 28	-12.2	-15.3	-17.3
March 1 - 15	-11.7	-14.2	-14.8
March 16 - 31	-6.9	-9.2	-9.2
April 1 - 15	-2.6	-4.5	-4.9
April 16 - 30	1.4	-0.7	-0.9
May 1 - 15	4.5	2.4	1.6
May 16 - 31	6.8	4.7	4.4
June 1 - 15	10.0	8.0	7.7
June 16 - 30	12.6	10.1	10.0
July 1 - 15	13.6	12.4	12.0

July 16 - 31	15.1	13.1	12.8
August 1 - 15	15.3	12.4	11.8
August 16 - 31	14.0	11.0	10.1
September 1 - 15	11.4	7.8	7.2
September 16 - 30	7.6	4.6	4.0
October 1 - 15	4.2	1.4	0.1
October 16 - 31	2.6	-0.1	-1.2
November 1 - 15	-1.7	-3.8	-4.8
November 16 - 30	-4.9	-6.9	-8.4
December 1 - 15	-9.8	-12.1	-13.9
December 16 - 31	-12.8	-15.3	-16.0

4.3.3 Biodiesel Cloud Point Blending for City of Toronto

In this section, we consider how different biodiesel blends influence the cloud point of the blended fuel, with the goal of understanding any limitations or additional requirements that may exist when using biodiesel in Toronto. Looking at Table 4-1 above, the coldest cloud point region for Toronto is -20.6 °C (in January). Hence, we looked at the impact of blending biodiesel from various feedstocks (canola, soy, tallow or yellow grease) with ULSD that has a cloud point of -21 °C (i.e., ULSD that just meets the most stringent Toronto cloud point requirement). Since the lowest cloud point for the Toronto area is -21 °C this ULSD provides the lowest cloud point case for the City of Toronto for which to test the limits of winter blending for biodiesel and HDRD.

shows cloud points for B2 blends with biodiesel from various feedstocks. As seen in**Table** 4-2, there is little depression (warming) in cloud point at B2 for a ULSD with a cloud point of -21 °C. All reported ‘changes’ are within the margin of error for the test discussed in Section 4.3.1. Especially when recalling the existence of some cloud point give-away (also discussed in Section 4.3.1), these results show that B2 blends from any of the feedstocks listed in Table 4-2 would not result in cloud point issues in winter in Toronto. The CME1, CME2 designation represents the fact that there were two different CME biodiesels that were used in the blending. The same follows for SME1, SME2 and TME1, TME2 and also YGME1 and YGME2.

Table 4-2: Cloud Points for B2 Blends with Biodiesel from Various Feedstocks

Blend Level	Biodiesel Used	Cloud Point (°C)	Change in cloud point relative to B0 (pure ULSD)
B2	CME1	-20.1	+0.9
B2	CME2	-20.1	+0.9
B2	SME1	-21.2	-0.2
B2	SME2	-20.7	+0.3
B2	TME1	-21.0	0.0
B2	TME2	-19.9	+1.1
B2	YGME1	-21.4	-0.4
B2	YGME2	-20.5	+0.5
B2	YGME3	-20.4	+0.6

Notes: Data from Phase Technology (http://www.phase-technology.com/) provided to Stu Porter, Biofuels Consulting Canada, Inc. CME = canola methyl ester, SME = soy methyl ester, TME = tallow methyl ester, YGME = yellow grease methyl ester.

Table 4-3 below shows Cloud Points for B5 Blends with Biodiesel from various feedstocks. As seen in Table 4-3, there is little depression (warming) in cloud point at B5 for a ULSD with a cloud point of -21 ℃. As with Table 4-2, the variation in cloud point depression is more varied with some biodiesel such as CME2 and YGME2 having more depression in cloud point than anticipated. The cloud point depression for the TME2 is what one would expect. The minimal warming of the TME1 is unexpected and arguably atypical of TME. Biodiesel blending practice for supply in Ontario is to limit TME to summer and shoulder seasons. However, Table 4-3 shows that with -21 ℃ cloud point ULSD the warming with even a TME in a B5 blend should not result in cloud point issues in Toronto in winter.

Table 4-3: Cloud Points for B5 Blends with Biodiesel from Various Feedstocks

Blend Level	Biodiesel Used	Cloud Point (Deg C)	Change in cloud point relative to B0 (pure ULSD)
B5	CME1	-20.2	+0.8
B5	CME2	-19.3	+1.7
B5	SME1	-20.3	+0.7
B5	SME2	-20.4	+0.6
B5	TME1	-20.8	+0.2
B5	TME2	-19.4	+1.6
B5	YG1	-20.7	+0.3
B5	YGME2	-19.6	+1.4
B5	YGME3	-20.1	+0.9

Notes: Data from Phase Technology (http://www.phase-technology.com/) provided to Stu Porter, Biofuels Consulting Canada, Inc. CME = canola methyl ester, SME = soy methyl ester, TME = tallow methyl ester, YGME = yellow grease methyl ester

Table 4-4 below shows cloud points for B10 Blends with Biodiesel from various feedstocks. Table 4-4 shows that in all cases with the various biodiesel samples from the different feedstocks, that there is a warming of the cloud point. If used in winter and in particular in January (in Toronto), a B10 blend would either require a lower (colder) cloud point than -21 °C in the ULSD used in the blend, or would require some correction for cloud point.

Table 4-4: Cloud Points for B10 Blends with Biodiesel from Various Feedstocks

Blend Level	Biodiesel Used	Cloud Point (Deg C)	Change in cloud point relative to B0 (pure ULSD)
B10	CME1	-18.4	+2.6
B10	CME2	-18.7	+2.3
B10	SME1	-19.5	+1.5
B10	SME2	-19.1	+1.9
B10	TME1	-18.9	+2.1
B10	YGME1	-18.8	+2.2
B10	YGME2	-18.1	+2.9
B10	YGME3	-17.8	+3.2

Notes: Data from Phase Technology (http://www.phase-technology.com/) provided to Stu Porter, Biofuels Consulting Canada, Inc. CME = canola methyl ester, SME = soy methyl ester, TME = tallow methyl ester, YGME = yellow grease methyl ester

The purpose of the B10 blending was to determine whether in Toronto in Winter B10 blends could be done without the need for correction of cloud point with ULSK. Table 4-4 above shows that B10 in Toronto would require correction for cloud point. B10 could fit within more temperature cloud point schedules in the shoulder seasons (spring and fall) and B20 could be done in summer when cloud point is not an issue. Overall, biodiesel blends up to B5 should not pose problems for cloud point even in the coldest period of the year in Toronto. Blends of B10 likely require greater attention in winter (lower cloud-point ULSD or other cloud point correction), to varying degrees depending on the biodiesel feedstock used. As a reminder, it is not necessary for the City of Toronto to stipulate specific feedstocks or cloud point corrections, provided that the delivered blended fuel meets CGSB seasonal cloud point specifications throughout the year.

4.3.4 HDRD Cloud Point Blending

There are currently limited HDRD suppliers to the Ontario market. The HDRD originates from only two HDRD producers; Diamond Green and Neste, who are not located in Canada. There is a Canadian HDRD producer, FORGE Hydrocarbons, that is constructing a plant in Sombra, Ontario but it won't be online until 2020.

Neste's HDRD summer cloud point is typically -9 °C and winter is typically - 20 °C. Diamond Green's HDRD summer cloud point is -5 °C and winter is -7 °C. The FORGE Hydrocarbons demonstration plant has only one grade, with a cloud point of -20 °C. The same cloud point is expected for their commercial plant in Sombra. HDRD is received into terminals and blended at 30%. The HDRD is blended at 30% and used until consumed.[1]

As noted previously in Table 4-1, the coldest cloud point region for Toronto is -20.6 °C in January. Hence, we looked at the impact of blending with -21 °C ULSD and HDRD from various sources. A summary of typical HDRD cloud points of Diamond Green, Neste and Forge is shown in Table 4-5. For the section that follows on HDRD blending, we use more generic labels as indicated in the table.

Table 4-5: Cloud Points for Typical HDRD from Various HDRD Producers[2]

HDRD producer (for blending tables below)	Matching real-world HDRD Producer	Typical Cloud Point (Deg C)
HDRD1	Diamond Green Summer	-5
HDRD2	Diamond Green Winter	-7
HDRD3	Neste Summer	-9
HDRD4	Neste Winter FORGE Hydrocarbons	-20

Table 4-6 shows the change in cloud point for 2% HDRD blends for HDRD respectively with the four different cloud points shown in Table 4-5. As seen in Table 4-6, there is essentially no depression (warming) in cloud point at 2% HDRD for a ULSD with a cloud point of -21 °C. The key point from this table is that it shows that 2% HDRD blends from any of the HDRD sources shown in Table 4-5 in winter in Toronto would not result in cloud point issues.

[1] Don Munroe November 2018 CGSB meetings

[2] Industry sources

Table 4-6: Cloud Points for 2% HDRD Blends based on the HDRD Cloud Points in Table 4-5

Blend Level	Sample Description	Cloud Point (Deg C)	Change in cloud point relative to B0 (pure ULSD)
2% HDRD	HDRD1	-20.7	+0.3
2% HDRD	HDRD2	-20.7	+0.3
2% HDRD	HDRD3	-20.8	+0.2
2% HDRD	HDRD4	-21.0	0.0

Data from Phase Technology (http://www.phase-technology.com/) provided to Stu Porter, Biofuels Consulting Canada Inc.

Table 4-7 shows the change in cloud point for the HDRD blends with the HDRD with the four different cloud points shown in Table 4-5 based on a 5% HDRD blend. As seen in Table 4-7, there is little depression (warming) in cloud point at 5% HDRD for any of the HDRD blends with a ULSD with a cloud point of -21 °C. Thus, blending 5% HDRD (from any of the sources above) with a -21 °C cloud point ULSD should not result in cloud point issues in Toronto in winter.

Table 4-7: Cloud Points for 5% HDRD Blends for HDRD based on the HDRD Cloud Points in Table 4-5

Blend Level	Sample Description	Cloud Point (Deg C)	Change in cloud point relative to B0 (pure ULSD)
5% HDRD	HDRD1	-20.2	+0.8
5% HDRD	HDRD2	-20.3	+0.7
5% HDRD	HDRD3	-20.4	+0.6
5% HDRD	HDRD4	-21.0	0.0

Note: Data from Phase Technology (http://www.phase-technology.com/) provided to Stu Porter, Biofuels Consulting Canada Inc.

Table 4-8 shows the change in cloud point for 10% HDRD blends, based respectively on HDRD with the four different cloud points shown in Table 4-5. Table 4-8 shows that in all cases with the HDRD with the first three (warmer) cloud points, that there is a warming of the cloud point. These blends would require either a lower (colder) cloud point than -21 °C in the ULSD used in the blend or would require some correction for cloud point if used in the month of January in Toronto at a 10% blend. However, as expected the HDRD with a cloud point of -20 °C (HDRD 4) would have no impact on the blended cloud point irrespective of the level blended with the ULSD.

Table 4-8: Cloud Points for 10% HDRD Blends based on HDRDR Cloud Points in Table 4-5

Blend Level	Sample Description	Cloud Point (Deg C)	Change in cloud point relative to B0 (pure ULSD)
10% HDRD	HDRD1	-19.4	+1.6
10% HDRD	HDRD2	-19.6	+1.4
10% HDRD	HDRD3	-19.8	+1.2
10% HDRD	HDRD4	-20.9	+0.1

Data from Phase Technology (http://www.phase-technology.com/) provided to Stu Porter, Biofuels Consulting Canada Inc.

4.3.5 Combined Biodiesel/HDRD Cloud Point Blending

Studies have shown that there are synergistic benefits when blending biodiesel and HDRD together. In other words, the expected cloud point of blending an HDRD and a biodiesel of similar cloud points can yield less depression (warming) in the resulting blend than either of them individually. A presentation was given recently at an NRCan Advanced Biofuels Workshop [29] that showed this. This phenomenon is due to the difference in chemical structure of the biodiesel and HDRD and the result of the combined biodiesel and HDRD blends can have a benefit in terms of the blended cloud point. In the presentation at the NRCan Advanced Biofuels Workshop given by REG [29], for a B5 blend that in Table 4-3 showed a depression (warming) of the cloud point of 1 °C or 5% HDRD blend that in Table 4-7 showed a depression (warming) of the cloud point of 1 °C, when these two are combined in a 10% biofuel blend the result could effectively be no change (warming) in cloud point for the blend.

4.4 City of Toronto Diesel Storage

As previously mentioned, the CGSB cloud point specifications are based on 30-year ECCC weather data at half month intervals. Therefore, at primary fuel storage terminals operators turn over their diesel fuel storage tanks twice a month to ensure that the cloud point specification for the region into which the diesel is being distributed is met. This is less of a concern for the City of Toronto as they are going to be delivered diesel fuel that meets the cloud point specification whether blended with biofuel or not by the fuel supplier. However, it is helpful to consider the turnover rate of the diesel fuel storage tanks as this has bearing on the cloud point and corresponding recommendations for the fuel supply to the City of Toronto.

The rates of turnover of the diesel fuel for the City of Toronto and TTC diesel fuel storage tanks are discussed in Section 4.4.1 and Section 4.4.2, respectively.

4.4.1 City of Toronto Diesel Storage Turnover

Table 4-9 shows the City of Toronto diesel fuel storage tanks and the number of times that they are typically refilled in summer, fall and winter. Based on the data from Table 4-9 the tanks are refilled regularly but rarely are they filled with than half the tank capacity and, in some cases, only one third of the fuel storage tank capacity. That means that the fuel supplier to the City of Toronto will need to carefully manage the cloud point of the fuel delivered, taking into account the cloud point of the fuel existing in the tanks. Although cloud point is not fully linear this can be managed and calculated by the fuel supplier. This is necessary whether the diesel being supplied to the City of Toronto is blended with biodiesel (or HDRD) or not. This is included in the conclusion procurement recommendations in Section 10.

One anomaly is Toronto Island, which is seasonal and presumably not operating in winter. The summer tank turnover is less important in terms of cloud point but provides some indication of increased fuel throughput in the summer months. The fall gives an indication of the turnover in the shoulder seasons and that does have cloud point implications, which as mentioned will need to be managed by the fuel supplier.

The winter turnover is most important. Based on the typical turnover as shown in Table 4-9, the turnover in winter is more frequent in most cases than in the fall but the same cloud point management as previously discussed needs to be employed.

The other item that what would appear to be an anomaly in Table 4-9 is the receipt of biodiesel blends at the Castlefield site in September 2018. That is because there is a pilot program underway (as of the time of writing) that started in July 1, 2018. The pilot included B20 deliveries to the Castlefield site for use by selected vehicles in the City of Toronto fleet and they have since transitioned to B10 during the colder months. The next RFQ/RFP will have a provision for biodiesel. The results of the fall/winter 2018 biodiesel pilot project will be included in the Final Report of Fleet Services.

Table 4-9: City of Toronto Diesel Storage Tank Turnover

Site Name	Tank ID	Fuel	Tank Size (L)	Average Fuel Drop Quantity (L)	Average Fuel Drops per Month (Summer)	Average Fuel Drops per Month (Fall)	Average Fuel Drops per Month (Winter)
10020 Booth Garage	1	Diesel	50,006	15,100	6	6	5
10040 Young St.	1	Diesel	15,049	7,200	5	4	6
11130 Fire Hall Lawrence Street	1	Diesel	3,802	1,500	5	4	4
12080 Exhibition Place	1	Diesel	20,066	8,400	6	5	5
12100 Toronto Island	2	Diesel	15,012	6,000	1	1	
20011 Disco	1	Diesel	25,099	110,100	8	7	6
20020 Bering	2	Diesel	25,035	19,700	4	4	3
20031 Castlefield	1	Diesel	25,035	10,300	5	5	7
20031 Castlefield	2	Biodiesel Blends	15,033	7,603		2	
22190 Scarlett Woods	2	Diesel	2,284	1,000	2	2	4
30011 Finch Ave.	1	Diesel	25,035	9,500	8	6	6
30021 Bermondsey	1	Diesel	25,035	8,200	12	5	9
30021 Bermondsey	2	Diesel	15,033	12,500	1	5	7
30031 Emery	1	Diesel	25,347	8,100	3	5	4
30060 Oriole	3	Diesel	25,347	14,000	5	2	5

40010 Ellesmere	1	Diesel	25,347	9,900	8	7	9
41030 Morningside	2	Diesel	24,981	11,000	2	2	4
42041 Nashdene	1	Diesel	25,044	9,800	4	2	2

4.4.2 TTC Diesel Storage Turnover

The TTC diesel storage tanks are shown in Table 4-10. The turnover rate for the TTC diesel storage tanks is high and most tanks are refilled weekly or more frequently.[3] Thus, fuel turnover is not a concern for TTC storage tanks.

Table 4-10: TTC Diesel Storage Tanks: Numbers, Locations and Capacities

Tank Identification Number	Location		Indoors or Outdoors	Nominal capacity of each tank of the storage tank system (L)
Arrow Road Garage - 700 Arrow Road				
1A1-352	Arrow Road Garage	North of Garage	Outdoors	45,600
1A1-353	Arrow Road Garage	North of Garage	Outdoors	45,600
Birchmount Garage - 400 Danforth Road				
1B1-362	Birchmount Garage	Outside, 25m south of garage	Outdoors	68,100
1B1-363	Birchmount Garage	Outside, 25m south of garage	Outdoors	68,100
Duncan Shops - 1138 Bathurst Street				
5H1-315	Duncan		Outdoors	45,460
5H1-316	Duncan		Outdoors	44,560
Eglinton Garage - 38 Comstock Road				

[3] Telephone conversation with TTC November 23, 2018

1C1-01	Eglinton Garage	North of Garage	Outdoors	50,000
1C1-02	Eglinton Garage	North of Garage	Outdoors	50,000
1C1-11	Eglinton Garage	North of Garage	Outdoors	45,600
1C1-DEF	Eglinton Garage		Indoors	2,650
Greenwood Yard - 400 Greenwood Avenue				
1G1-T002	Greenwood	South of shop	Outdoors	2,500
Lakeshore Garage - 580 Commissioners Street				
3L1-300	Lakeshore	NW of building	Outdoors	45,600
3L1-301	Lakeshore	NW of building	Outdoors	45,600
Malvern Garage - 5050 Sheppard Avenue East				
1M1-308	Malvern Garage	South of garage	Outdoors	45,600
1M1-309	Malvern Garage	South of garage	Outdoors	45,600
Mount Dennis Garage - 121 Industry Street				
6M-10	Mt. Dennis	East of Garage	Outdoors	45,425
6M-11	Mt. Dennis	East of Garage	Outdoors	45,425
6M-12	Mt. Dennis	East of Garage	Outdoors	45,425
Queensway Garage - 400 Evans Avenue				
1Q1-356	Queensway		Outdoors	45,864
1Q1-357	Queensway		Outdoors	45,864
Wilson Garage - 160 Transit Road (570 Wilson Ave.)				
1W1-T001	Wilson		Outdoors	50,000
1W1-T002	Wilson		Outdoors	50,000
1W1-T003	Wilson		Outdoors	45,450
Wilson Carhouse and Rail Infrastructure - 160 Transit Road				
4W1-TK1	Plant Building	South of building	Outdoors	4,500

The TTC also has a number of diesel gensets that are shown in Table 4-11. There is no scheduled genset fuel tank turnover and maintenance for the gensets is contracted out. The contractor tests the fuel and the fuel is recycled/treated as necessary. Due to ongoing testing and maintenance, the fuel is topped up repetitively and does not require turnover or repurposing.[4] In the case of gensets, we do not recommend using biodiesel (elaborated in Sections 6.3.4 and 10.6), so turnover is not discussed further.

Table 4-11: TTC Diesel Genset Storage Tanks: Numbers, Locations and Capacity

Tank No	Site	Location	Indoors or Outdoor	Capacity (L)
Gen-4RT-01	Midland Station	2085 Midland Ave.	Indoors	227
	Arrow Road Garage	700 Arrow Road	Outdoors	1,345
Gen-7RT-01	McCowan Station SRT	1275 McCowan Road	Indoors	227
Gen-2RT-01	Lawrence E Station	2444 Lawrence Ave East	Indoors	454
Gen-3RT-01	Ellesmere Station	1025 Ellesmere Road	Indoors	909
Gen-MCC-01	McCowan Maintenance Yard	1720 Ellesmere Rd	Indoors	1,110
Gen-16D-01	Birchmount RD ESB	710 Birchmount Garage	Indoors	935
Gen-19Y-02	Teddington ST ESB	7 Tedd ington St	Indoors	935
Gen-19Y-01	Yonge St - Lytton ESB	2672 Yonge St - Lytton ESB	Indoors	1,110
Gen-22Y-01	Church Ave ESB	2 Church Ave	Indoors	935
Gen-20Y-01	McDonald Cartier/401 ESB	Below Yonge St S. exit ramp	Indoors	2,200
Gen-3S-01	Glenayr Rd ESB	4 Glenayr Rd	Indoors	935
Gen-2S-01	DuPont and Spadina ESB	Inside, NW corner of DuPont and Spadina	Indoors	935

[4] Email correspondence with TTC November 27, 2018

Gen-LAK-01	Lakeshore	580 Commissioners Street	Indoors	680
Wil-Gen-01	Wilson	160 Transit Rd.	Indoors	1,110
Gen-Gun-01	Hillcrest	1138 Bathurst St. (Gunn Building)	Indoors	2,270
Gen-Hil-01	Hillcrest	1138 Bathurst St.	Indoors	2,440
Gen-1HF-01	Union Station (Harbourfront)	Union Station	Indoors	2,440
Gen-MCB-01	McBrien Building (Davisville)	1900 Yonge St.	Outdoors	1,344

5 Biodiesel Blend OEM Engine Approvals

5.1 General OEM Approvals

North American diesel engines have historically been designed and tested for use with petroleum diesel meeting ASTM diesel specifications, making them compatible with more stringent CGSB standards. By extension, these diesel engines are fully compatible with HDRD fuel meeting those same specifications. In contrast, engine manufacturers (OEMs) sometimes provide specific biodiesel specifications and/or blend limits with which their engines are compatible. There are several reasons why OEMs may have their own limits for biodiesel specifications. For some models of engine or engine parts, the OEM may have concerns about material compatibility with biodiesel. In other cases, there may simply be a conservative approach by some OEMs to mitigate the risk or perceived risk of customer complaints. This conservative approach may also be driven by the fuel injection equipment manufacturer, which would in turn impact the overall warranty or owner's manual instructions from the OEM.

Ultimately, the OEM owner's manual instructions and warranty instructions exist both to protect the customer and also to minimize customer complaints. The OEM positions may be based in some cases on the expectation of biodiesel meeting the ASTM D6751 specification. ASTM D6751 is the lowest standard in terms of oxidation stability requirements and lacks the specifications for particulate matter contamination and water content present in CGSB. Thus, as the CGSB biodiesel standard is generally more stringent than ASTM D6751, it is reasonable to state that biodiesel meeting the CGSB biodiesel specification will satisfy OEM warrantees developed for ASTM D6751 biodiesel.

The British Columbia Low Carbon Fuels Compliance Pathway Assessment provides a succinct explanation of how to interpret OEM warranty statements [30]:

> *OEMs provide warranties that identify fuels that have been tested to be compatible with their engines. Typically, OEMs and Tier 1 suppliers have a set of test fuels that are intended to cover a wide range of expected fuel qualities. […] In some cases, OEMs will include warnings about certain fuels that are known to cause issues. Other fuels may not have been tested, and the effects of those fuels on the engines are not known.*
>
> *Usually, a fuel that is not mentioned simply has not been tested or is obviously incompatible (e.g., gasoline engines are incompatible with diesel fuel, but the warranty does not always state this, as it is assumed that the consumer is aware of this fact). Warranties are not statements regarding when engines are expected to experience problems.*

This last point is critical – lack of explicit warranty for biodiesel blends does not imply these blends will cause problems. Indeed, Section 6.2 of this report demonstrates successful experience using B20 in vehicles not warrantied for B20.

In general, not many OEMs have warranty statements covering biodiesel blends dating back to before 2010. There are a couple of reasons for that. Firstly, the biodiesel use and related mandates in the U.S.

were low pre-2005. Further, engine and vehicle testing and design are multi-year processes, resulting in a lag between these activities and warranty statements. In that sense, there is some lag between when some OEMs issue warranty statements that does not always have to do with whether or not there are compatibility issues. Another reason for the lack of warranty statements is that the ASTM D6751 standard was evolving between 2007 and 2010 and some OEMs may have waited for that to be finalized before issuing warranty statements.

As further noted in the British Columbia Low Carbon Fuels Compliance Pathway Assessment, "a common concern about the transition to gasoline and diesel with higher biofuel content is the performance of these fuels in vehicle engines and fuel systems. This concern is commonly articulated as a statement that the use of higher biofuel blends will void a given vehicle's engine warranty" [30]. In reality, OEMs "do not warranty fuel – any fuel. They warrant only the materials and workmanship of their product and, in the United States, are precluded by the Magnuson-Moss Warranty Act from voiding manufacturer warranties based on fuels used" [30].

Thus engine problems resulting from a particular fuel are the responsibility of the fuel supplier and not the engine manufacturer. As explained by the National Biodiesel board: "Any reputable fuel supplier (biodiesel, petrodiesel, or a blend of both) should stand behind its product and cover any fuel quality problems if they occur. […] Therefore, the most important aspect regarding engine warranties and biodiesel is whether an engine manufacturer will void its parts and workmanship warranty when biodiesel is used, and whether the fuel producer or marketer will stand behind its fuels should problems occur" [31].

5.2 On-Road City of Toronto Vehicles

Summary lists of the City of Toronto Fleet Services' on-road light-duty, medium-duty and heavy-duty vehicles are shown, respectively, in Table 5-1, Table 5-2, and Table 5-3. The more detailed on-road vehicle lists are included in Appendix F. The number of vehicles in each category (model year, make, class, etc.) and fuel blend that the vehicle is approved to use based on OEM warranty statements are indicated.

It is found that all light-, medium- and heavy-duty City of Toronto Fleet Services vehicles are warranted for B5 and some vehicles in each vehicle category are warranted to B20. In general, newer vehicles are more likely to be warranted for B20 (e.g., post-2007 for Fiat Chrysler and post-2010 for Ford), but there are both newer vehicles warranted only for B5 (e.g., International 4300 trucks up to 2018, and other Navistar vehicles), and older vehicles warranted up to B20 (e.g., 2001-2003 Freightliner FL80 trucks). For some vehicle brands, additional detail about the engine manufacturer is important (e.g., Freightliner trucks with Cummins engines are approved for use with B20 biodiesel blends, while those equipped with Detroit Diesel engine models DD13, DD15, DD16 are approved for B5 biodiesel blends. [31]). It is noted that Detroit Diesel Series 60 engines are warranted to B20 if the fuel meets the CGSB standard. In several cases, the OEM warranty also specifies that the biodiesel must meet either ASTM or Detroit Biodiesel Policy [25]. Specific examples of warranty statements are provided in Appendix G.

Overall, approximately half the Fleet Services vehicles (accounting for cases where there are multiple vehicles of the same model and year) are warranted up to B20, leaving many vehicles that are not warranted for blends above B5.

Table 5-1: Summary of City of Toronto Fleet Services Light-Duty Vehicles, Number of Vehicles, Description and Biodiesel Blend that is Approved

#	Year	Make	Unit Type	Category Class (see ref [32])	Category Description	Blend Approved
8	2006	MERCEDES	LIGHT DUTY	CLASS1		B5
1	2011	VW	LIGHT DUTY	CLASS1		B5*
4	2009 – 2010	CHEVROLET	LIGHT DUTY	CLASS 2		B5
3	2005	CHEVROLET	LIGHT DUTY	CLASS 3		B5
44	2004 – 2009	DODGE	LIGHT DUTY	CLASS 2		B5
198	2007 – 2016	DODGE	LIGHT DUTY	CLASS 2		B20
98	2002 – 2010	FORD	LIGHT DUTY	CLASS 2		B5
154	2011 – 2017	FORD	LIGHT DUTY	CLASS 2		B20
10	2005 – 2009	GMC	LIGHT DUTY	CLASS 2		B5
21	2011 – 2013	MERCEDES	LIGHT DUTY	CLASS 2		B5

* Approves B5 (and up to B20 in IL and MN where blends higher than B10 are common)

Table 5-2: Summary of City of Toronto Fleet Services Medium-Duty Vehicles, Number of Vehicles, Description and Biodiesel Blend that is Approved

#	Year	Make	Unit Type	Category Class[32]	Category Description	Blend Approved
3	1990 – 195	FORD	MEDIUM DUTY	CLASS 3		B5
31	2000 – 2010	FORD	MEDIUM DUTY	CLASS 3		B5
2	2012	FORD	MEDIUM DUTY	CLASS 3		B20
1	1991	GMC	MEDIUM DUTY	CLASS 3		B5
1	2006	BLUE BIRD	VISION	CLASS4/5	Bus	B5
33	2001 – 2007	CHEVROLET	MEDIUM DUTY	CLASS 4/5		B5
3	2008	DODGE	MEDIUM DUTY	CLASS 4/5		B5
33	2008 – 2015	DODGE	MEDIUM DUTY	CLASS 4/5		B20
120	2001 – 2010	FORD	MEDIUM DUTY	CLASS 4/5		B5
15	2006 – 2007	FREIGHTLNR	MEDIUM DUTY	CLASS 4/5	Street Sweeper	B20
135	2011 – 2017	FORD	MEDIUM DUTY	CLASS 4/5		B20
1	2002	FREIGHTLNR	MEDIUM DUTY	CLASS 4/5	MT45	B5
1	2016	FREIGHTLNR	MEDIUM DUTY	CLASS 4/5	MT55	B20
1	2015	FREIGHTLNR	MEDIUM DUTY	CLASS 4/5	M2106 - Cube van	B20
5	2007	GMC	MEDIUM DUTY	CLASS 4/5		B5
6	2008 – 2010	HINO	MEDIUM DUTY	CLASS 4/5	185 Cube Van	B5
4	2013	INTERNATIONAL	MEDIUM DUTY	CLASS 4/5	TERRA STAR	B5
12	2011- 2015	ISUZU	MEDIUM DUTY	CLASS 4/5		B20
13	2007 – 2008	STERLING	MEDIUM DUTY	CLASS 4/5	BULLET	B5
2	2001 – 2006	THOMAS BUS	MEDIUM DUTY	CLASS4/5	CLASS 4/5 BUS	B20

Table 5-3: Summary of City of Toronto Fleet Services Heavy-Duty Vehicles, Number of Vehicles, Description and Biodiesel Blend that is Approved

#	Year	Make	Unit Type	Category Class[32]	Category Description	Blend Approved
17	2001 – 2010	FORD	HEAVY DUTY	CLASS 6/7		B5
2	2012 – 2017	FORD	HEAVY DUTY	CLASS 6/7		B20
1	2012	FREIGHTLNR	HEAVY DUTY	CLASS 6/7	CHASIS - Bus (Cummins)	B20
3	2016	FREIGHTLNR	HEAVY DUTY	CLASS 6/7	M2106 - Cube van	B20
2	2010	FREIGHTLNR	HEAVY DUTY	CLASS 6/7	M2106 Dump Truck	B20
7	2016 – 2017	FREIGHTLNR	HEAVY DUTY	CLASS 6/7	M2106 Dump Truck	B20
2	2003	FREIGHTLNR	HEAVY DUTY	CLASS 6/7	FL70	B20
13	2002 - 2009	GMC	HEAVY DUTY	CLASS 6/7		B5
1	1996	INTERNATIONAL	HEAVY DUTY	CLASS 6/7	4700	B5
3	2005 - 2006	INTERNATIONAL	HEAVY DUTY	CLASS6/7	4200	B5
1	2005	INTERNATIONAL	HEAVY DUTY	CLASS6/7	4300	B5
85	2010 - 2018	INTERNATIONAL	HEAVY DUTY	CLASS6/7	4300	B20
2	2016	INTERNATIONAL	HEAVY DUTY	CLASS6/7	4400	B5
3	2001	INTERNATIONAL	HEAVY DUTY	CLASS6/7	4700	B5
1	2002	PETERBILT	HEAVY DUTY	CLASS6/7	330	B20
2	2007	STERLING	HEAVY DUTY	CLASS 6/7	LT8513	B5
3	2003 - 2004	STERLING	HEAVY DUTY	CLASS 6/7	LT9513	B5
31	2004 - 2009	STERLING	HEAVY DUTY	CLASS 6/7	ACTERRA	B5
1	2003	STERLING	HEAVY DUTY	CLASS 6/7	ACTERRA M8500	B5
24	2008	AUTOCAR	HEAVY DUTY	CLASS 8	EXPEDITOR	B20
2	1991	FORD	HEAVY DUTY	CLASS 8		B5
17	2011 - 2017	FREIGHTLNR	HEAVY DUTY	CLASS 8	CASCADIA 125 - Detroit Diesel DD15	B5

12	2011 - 2012	FREIGHTLNR	HEAVY DUTY	CLASS 8	CORONADO (Detroit Diesel 60)	B20
1	1995	FREIGHTLNR	HEAVY DUTY	CLASS 8	FL80	B5
4	2001 - 2003	FREIGHTLNR	HEAVY DUTY	CLASS 8	FL80	B20
29	2005 - 2010	FREIGHTLNR	HEAVY DUTY	CLASS 8	FLD120	B20
8	2006 - 2009	FREIGHTLNR	HEAVY DUTY	CLASS 8	M2 106	B20
35	2010 - 2017	FREIGHTLNR	HEAVY DUTY	CLASS 8	M2 106	B20
16	2013 - 2015	FREIGHTLNR	HEAVY DUTY	CLASS 8	M2 108 SD (Cummins)	B20
22	2009 - 2010	FREIGHTLNR	HEAVY DUTY	CLASS 8	M2 112 (Cummins)	B20
1	1995	GMC	HEAVY DUTY	CLASS8		B5
8	2008	GMC	HEAVY DUTY	CLASS8		B5
1	1991	INTERNATIONAL	HEAVY DUTY	CLASS 8	5 TON	B5
9	2005 - 2007	INTERNATIONAL	HEAVY DUTY	CLASS 8	4200	B5
3	2011 - 2016	INTERNATIONAL	HEAVY DUTY	CLASS 8	4300 Bus	B5
8	2008 - 2009	INTERNATIONAL	HEAVY DUTY	CLASS 8	4300	B5
7	2008 - 2014	INTERNATIONAL	HEAVY DUTY	CLASS 8	4300	B20
4	2009 - 2010	INTERNATIONAL	HEAVY DUTY	CLASS 8	4400	B5 *
10	2001	INTERNATIONAL	HEAVY DUTY	CLASS 8	4700	B5 *
4	2016	INTERNATIONAL	HEAVY DUTY	CLASS 8	7400	B5
3	2011 - 2017	INTERNATIONAL	HEAVY DUTY	CLASS 8	7400	B20
4	2016	INTERNATIONAL	HEAVY DUTY	CLASS 8	7500	B5
5	2010 - 2017	INTERNATIONAL	HEAVY DUTY	CLASS 8	7500	B20
5	2015	INTERNATIONAL	HEAVY DUTY	CLASS 8	7600	B5
5	2010 - 2015	INTERNATIONAL	HEAVY DUTY	CLASS 8	7600	B20
11	2012 - 2014	INTERNATIONAL	HEAVY DUTY	CLASS 8	WORKSTA 7300	B20
2	2017	INTERNATIONAL	HEAVY DUTY	CLASS 8	WORKSTA 7600	B20

1	2009	INTERNATIONAL	HEAVY DUTY	CLASS 8	DURASTAR4300	B20
1	1992	MACK	HEAVY DUTY	CLASS 8	600	B5
4	2008	MACK	HEAVY DUTY	CLASS 8	600	B5
5	2012 - 2015	MACK	HEAVY DUTY	CLASS 8	GU813	B20
51	2012 - 2015	MACK	HEAVY DUTY	CLASS 8	LEU613	B20
14	2015	MACK	HEAVY DUTY	CLASS 8	MRU613	B20
1	2010	PETERBILT	HEAVY DUTY	CLASS8	320	B20
2	2004	PETERBILT	HEAVY DUTY	CLASS8	330	B20
81	2004 - 2009	STERLING	HEAVY DUTY	CLASS 8	ACTERRA	B5
10	2003 - 2004	STERLING	HEAVY DUTY	CLASS 8	ACTERRA M8500	B5
4	2006 - 2008	STERLING	HEAVY DUTY	CLASS 8	LT7500	B5
27	2002 - 2008	STERLING	HEAVY DUTY	CLASS 8	LT7501	B5
1	2004	STERLING	HEAVY DUTY	CLASS 8	LT8513	B5
1	2003	STERLING	HEAVY DUTY	CLASS 8	M8500	B5

5.3 Off-Road City of Toronto Vehicles and Equipment

Off-road vehicles exhibit some similar trends to on-road vehicles with respect to biodiesel warranties. Information has been found on approximately half the off-road vehicle inventory provided for this study. Of these, all are warranted for B5, and approximately 80% are warranted for B20. As with on-road vehicles, it is the newer off-road vehicles that are generally more likely to be warranted for B20. The full list of the City of Toronto Fleet Services' off-road vehicles and equipment is found in Appendix H, with additional information from specific approval statements in Appendix I.

5.4 TTC Vehicles and Equipment

The TTC bus fleet and subway equipment and gensets, as per June 2018, are included in this section (Table 5-4 and Table 5-5, respectively). As per previous sections, the equipment list is summarized along with the OEM warranty statements for B5 or B20.

Unlike the City of Toronto vehicle fleet, the TTC buses have 80% of their fleet being warranted for B20. The only exception is the Detroit Diesel Series 50 engines. These engines are not specifically covered by

Detroit Diesel warranty statements. However, due to their age, they are not even listed on the Detroit Diesel Biodiesel Biofuel Position Statement. Therefore, there is likely little if anything that these legacy buses still have in terms of active engine warranty. According to a personal communication with a Detroit Warranty specialist *: "There has been a number of times whereby some jurisdictions and cases such as this wished to green their fleet and lower GHGs but were limited based on the Detroit Diesel warranty or approval statements or bulletins may not cover a biodiesel blend above B5. In such cases the OEMs have granted "evidence of satisfactory performance" clauses or statements"*[5]. What this effectively means is that the owners of the vehicles (in this case the City of Toronto) are not prohibited from using higher blends but if any additional maintenance should occur it is on the owner of the vehicles (in this case the City of Toronto).

Table 5-4: Summary of the TTC Buses, Number of Vehicles, Description and Biodiesel Blend that is Approved

# Vehicles	Year	Make	Model	Engine	Category	Blend Approved
220	2002 - 2004	Orion	VII	Detroit Diesel Series 50	Bus	B5
262	2004 - 2005	Orion	VII	Detroit Diesel Series 50	Bus	B5
150	2006	Orion	VII	Cummins	Diesel - Electric Hybrid Bus	B20
80	2006	Orion	VII	Cummins	Bus	B20
100	2007	Orion	VII	Cummins	Bus	B20
544	2007 - 2009	Orion	VII NG	Cummins	Diesel - Electric Hybrid Bus	B20
120	2010	Orion	VII NG	Cummins	Bus	B20
97	2011 - 2012	Orion	VII NG	Cummins	Bus	B20
153	2013 - 2014	Nova	Arctic 60	Cummins	Bus	B20
105	2015 - 2016	Nova	Arctic 60	Cummins	Bus	B20
490	2016 - 2017	Nova	Arctic 60	Cummins	Bus	B20

Note: The VII NG denotes Next Generation. Not to be confused with natural gas.

[5] Telephone interview with a Detroit Warranty specialist November 26, 2018.

Table 5-5 below lists the summary of TTC gensets and smaller equipment. There is not a large list of this auxiliary equipment. Of the equipment list, approximately half is warranted for B5 and the remainder B20. The delineation in this case is that the genset equipment is B5 and the remainder is B20. The B5 in gensets is based on a combination of the OEM warranty statements and the fact that the NRDDI (National Renewable Diesel Demonstration Initiative) Manitoba Gensets and Long Term Storage Study showed that B5 blends meeting CAN/CGSB-3.520 for use in gensets can be successfully stored for up to two years [33]. If fuel turnover cannot be guaranteed at regular intervals shorter than 2 years, restricting the biodiesel blend to B0 is advisable. The genset fuel storage and use is discussed further in subsequent sections of this report.

Table 5-5: Summary of the TTC Gensets and Smaller Equipment Number of Units, Description and Biodiesel Blend that is Approved

#	Date into Service	Engine Manufacturer	Model	Category	Blend Approved
3	2016 - 2017	Caterpillar	C4.4 ACERT	Gen-Set (Aux Propul, Elec/Hyd/Air Tools)	B5
4	1999 - 2000	Cummins	B3.9-P110(BAL)	Auger Drive / Hydraulics	B5
2	2001	Cummins	B5.9-P200	Propulsion / Hydraulics	B5
1	2007	Cummins	B3.3	Crane Hydraulics	B20
3	2015 - 2016	Cummins	QSL9 CM2350 L102	Propulsion / Hydraulics	B20
1	1997	Detroit Diesel	60 Series	Propulsion / Water Pump Drive	B5
1	1997	Detroit Diesel	60636K33	Propulsion	B5
1	1998	Detroit Diesel	6063GK32	Propulsion / Water Pump Drive	B5
1	2006	Detroit Diesel	6063MK32	Propulsion / Vacuum / Water Pump	B20
1	2007	Detroit Diesel	6063HV33	Propulsion Gen-Set	B20
4	2011 - 2012	Detroit Diesel	6063HV33	Propulsion / Vacuum / Water Pump	B20
2	2000	Detroit Diesel	60636K32	Propulsion	B20

2	2002 - 2003	Deutz	BF4M1013C	Gen-Set / Crane Hydraulics	B5
1	2005	G.M.	3.0L-LPG	25kW Gen-set	B5
1	2017	G.M.	90 5.7L V8	50kW Gen-set	B5
1	2007	Kubota	Z482-E	Aerial Lift Battery Charger	
1	1990	Lister Petter	LPWS3	Hydraulics	B5
1	1986	Mercedes	OM 352 A	Auger Drive	B5
1	2009	Mercedes	OM 904 LA	Propulsion / Crane Hydraulics	B5
15	2008 -2010	Perkins	1104D-E44TAG1	Gen-Set (Aux Propul, Elec/Hyd/Air Tools)	B5
1	2011	Yanmar	3TNV88-BGGE	Anchor Bolt Drill Hydraulics	B20
1	2011	Yanmar	L100 V6 CA IT IAA	Hydraulics	B20
3	2011	Yanmar	L100V	Hydraulics	B20

5.5 Recommendations based on Analysis of Vehicle Fleets and Equipment

A key question is management of risk to the City of Toronto if higher biodiesel blends are used compared to warranty statements or OEM approved blend level statements for their vehicles. As discussed above, OEMs warrant their manufactured parts and equipment; they do not warrant fuel. Most OEMs began to issue official guidance, approvals and warrantees after 2009, when biodiesel became more common, ASTM standards were fully developed, and engines were put through several years of testing. As noted above, the CGSB B100 standard is the most stringent in the world. Thus, ensuring that the fuel supplier delivers fuel that meets the CGSB standard (CAN/CGSB-3.524 standard for B100 as a blendstock) is the best strategy to ensure compliance with OEM warranty statements and blend guidelines. Moreover, this is the requirement of the CGSB blend specifications and the biodiesel blending practice in Canada.

The City of Toronto Fleet Services and the TTC buses are comprised of vehicles that have OEM approval for a mix of B5 and B20. In many cases, the vehicles that are not approved for B20 are arguably outside of the warranty period. In some cases, however, there are recent model year vehicles (e.g., 2011-2017 Freightliner heavy-duty vehicles with Detroit Diesel DD15 engines) that remain warranted only to B5). It is our opinion that higher biodiesel blends will not result in engine issues or increased maintenance, provided the biodiesel blended meets CAN/CGSB-3.524 and the blended biodiesel B6 – B20 blend meets CAN/CGSB-3.522. This is discussed in more detail in Section 10.

6 Biodiesel and renewable diesel adoption in North American jurisdictions

There are several reasons for jurisdictions to adopt biodiesel and renewable diesel blends. These include government policies, volumetric mandates, subsidies, potential to reduce GHG emissions, diversify energy sources, and/or promote rural economic development. Policies to reduce GHG emissions from transportation fuels include renewable fuel mandates, low carbon fuel standards (LCFS), and cap-and-trade programs. In Canada, five provinces have adopted renewable fuel mandates for both gasoline and diesel fuels, including the Ontario Greener Diesel Mandate [34]. British Columbia is the only Canadian jurisdiction with an existing LCFS; however, the federal government (Environment and Climate Change Canada) is developing a LCFS known as the Clean Fuel Standard [35]. In the US, aside from renewable fuel mandates and LCFS, the use of biodiesel among regulated fleets has been promoted, to some extent, by the Energy Policy Act of 1992 and the U.S. Department of Energy Alternative Compliance rule [36] [37].

Policies have resulted in the use of biofuels in several North American jurisdictions, transit agencies and municipal fleets. However, some organizations may be hesitant to adopt biofuels due to real or perceived concerns about price, cold weather performance and maintenance costs. The following sections review some cases of biodiesel and renewable diesel usage in public transportation and municipal fleets, mandates in some of the coldest North American jurisdictions, and describe previous demonstration studies that have investigated the use of these fuels.

6.1 Cases of biodiesel blend use in North American jurisdictions

The following sections summarize the experience of several Ontario municipalities using biodiesel blends. The information was gathered from currently available literature, and a subset of the information through personal communication.

6.1.1 Ontario

Several municipalities in Ontario have adopted biodiesel blends for their fleet and/or transit buses. The Ontario Urban Transit Fact Book 2015 [38] details the consumption by municipality of biodiesel blends. Ontario consumed around 30.1 million L of B5 and 9.9 million L of B20 in 2015. The breakdown by municipality is detailed in Table 6-1. In 2015, Mississauga consumed the most B5, at 18.7 million L, followed by Brampton at 6.6 million L. Brampton consumed 5.8 million L of B20, followed by York Region at 2.9 million L.

Table 6-1: Consumption of Biodiesel by Ontario Municipality in 2015 [38]

Municipality	Blend	Volume (L)	Number of active buses using biodiesel
Brampton	B5 B20	6,608,460 5,759,801	295
Guelph	B5 B20	1,376,288 1,376,288	80
Kingston	B5 B20	122,110 -	-
Mississauga	B5 B20	18,660,712 -	167
Thunder Bay	B5 B20	1,853,144 -	48
York Region	B5 B20	1,521,158 2,855,444	101

More recent information (2018) was obtained through phone interviews and reveals that:

- In Brampton, until mid-2015, the City's diesel-powered vehicles and equipment used blends ranging from B5 to B20 (seasonally adjusted) [39]. The buses ran on a B3 blend. The reasons for the City of Brampton taking a pause in biodiesel blending for city vehicles were related to price; no operational issues were reported. They are currently considering restarting the biodiesel blending program.
- In York Region, B5 is used year round by fleet vehicles, with B20 used in the summer by 22% of their transit vehicles.
- Oshawa uses a B10 blend year round for all diesel powered equipment, except fire trucks.
- Guelph/Kitchener/Waterloo and Mississauga use B5 or B4 blends.
- The City of Toronto currently uses a B4 blend (that was increased to B5 in summer 2018).
- Ottawa currently uses a B4 blend.

6.1.2 Other Canadian and U.S. Jurisdictions.

Several jurisdictions in Canada and the U.S. use biodiesel blends in buses and other vehicles. The case in Minnesota is often cited as an example of successful biodiesel use. Since May 1, 2018, the Minnesota Biodiesel program [40] requires that No. 2 diesel fuel sold in Minnesota contains at least 20 percent biodiesel from April 1 to September 30, with the blend lowered to 5 percent for October through March, unless state officials and technical experts determine that accepted federal standards deem certain *higher blends* as suitable for year-round use in the state. In 2014, Minnesota implemented its B10 mandate (April 1 to September 30) with no major issues reported. The success is attributed to good fuel handling practices by those who sell, blend and deliver the biodiesel blends, and good fuel storage practices by end users. A B20 Handling Guide [41] is publicly available, and describes best management practices for storage tanks and material compatibility, cold weather operability, and fuel tank maintenance. Biodiesel in Minnesota comes from a range of feedstocks: 45 percent of the biodiesel comes from soybean and 55 percent comes from other oils, fats and greases. However, there is no indication if a specific feedstock is used in the winter. It is important to keep in mind that there are key differences in the ASTM and CGSB standards for biodiesel, as indicated in Section 3, and the biodiesel in Minnesota meets the ASTM standard. There are also differences in biodiesel blending methods in the US compared to Canada (use of additives and No.1 diesel in the US), and some caution is needed when translating the Minnesota experience to operations in Toronto. Factors to consider include that the climate is colder in Minnesota compared to Toronto, and Toronto would procure fuel under the more stringent CGSB standard.

Since 2013, the Société de transport de Montréal (STM) has fueled its buses with B5 based on waste oil and animal fat [42]. The Fargo-Moorhead Metropolitan Area Transit (MAT) in North Dakota has been using biodiesel fuels in its buses (MATBUS) since 2005. MATBUS uses B20 during the summer months and B2 during the winter. They have had a positive operational experience, with few (if any) issues reported [43]. Other cases in milder climates include the jurisdictions that have adopted LCFSs like British Columbia and California and the Oregon Clean Fuels Program. It was estimated that 400 million gallons of biodiesel and renewable diesel were consumed in California in 2016. The vast majority of biomass-based diesel consumed in California is imported, and volumes are expected to grow [44].

6.2 Cases of Renewable Diesel Use in North American Jurisdictions

Vancouver. The City of Vancouver will transition all of the City's diesel vehicles that currently run on B5 (around 557 vehicles, which represent about 55 % of its fleet) to 100% renewable diesel, provided by Suncor, by the end of 2019. The City has committed to reducing fleet emissions to 50% below 2007 level by 2030 [45].

Concerning the financial implications, the Request for Proposal states that, "based on current fuel prices and volumes, the City is forecasting a savings of approximately $1,761,900 over the initial five (5) year term. However, it is important to note that the 2019 Annual Fuel Budget is expected to increase from

2018 Budget to reflect the significant change in fuel rates over the past year. The savings resulting from the procurement process will partially offset the 2019 Budget rate increase" [46].

The LCFS in BC has compliance obligations and penalties for not meeting those obligations. There is for example, a penalty of $200/tonne for non-compliance. It is possible that this factored into this contract and is also possible that the long-term nature of the contract in Vancouver (5 years) enabled some more aggressive pricing for this supply contract. Based on our research and prices for HDRD from producers that we have found, the supply of 100% HDRD to the City of Toronto would come with a considerable price increase (see Section 9).

California. California's heavy-duty vehicle transportation sector is responsible for at least half of the U.S. renewable diesel consumption, even thzough it consumes only about 10 percent of U.S. petroleum fuel. Under LCFS-covered applications (on-road heavy-duty vehicles and intra-state locomotives) more than 200 million gallons of renewable diesel were consumed in 2016. Almost all of the renewable diesel consumed within California's LCFS is imported from abroad, or shipped by rail from other states. The largest provider is Neste Corporation that delivers renewable diesel from their Singapore production facility. The primary domestic suppliers of renewable diesel appear to be Diamond Green and REG, both located in Louisiana [47].

There are examples of major public heavy-duty vehicle fleets and private fleets that have switched considerable portions of their operations to renewable diesel instead of petroleum diesel in California. Public fleets include the California Department of General Services, the Cities of San Francisco, Oakland, San Diego, Walnut Creek, Carlsbad, and Contra Costa County [47]. It was announced in May 2018 that the San Leandro has made an environmental decision to move all of its district vehicles to 100% renewable diesel instead of conventional diesel. According to [48], this move is expected to reduce GHG emissions by up to 80%. San Leandro operates approximately 160 vehicles. This comes three years after San Francisco made the change to HDRD to run just under 2,000 vehicles, accounting for more than 5.5 million gallons [48]. One of the private fleets that has switched to HDRD (as of November 8, 2018) is Ecology, one of the largest trucking and transportation companies in California. It has a fleet of more than 600 trucks is reporting cleaner fuel filters, fewer maintenance problems and reductions in tailpipe emissions [49].

Other US States. Other government agencies that have already switched or are considering to switch to renewable diesel are the Oregon Department of Energy, City of Knoxville Fleet Services, City of Seattle Fleet and New York Department of Sanitation [47]. An example of a major private heavy-duty vehicle fleet that has switched significant portions of their operations to consume renewable diesel is United Parcel Systems (UPS) [47].

6.3 Summary of Previous Studies on Cold Weather Operability, Long Term Storage and Maintenance of Biodiesel Fleets and Gensets

6.3.1 Cold weather operability, review of studies

The Biodiesel Integration Strategy Pilot (BISP) study (2008-2009) assessed the feasibility and experience of using B10 in the JK Trucking fleet in the Canadian environment [50]. The fleet for the study comprised 52 units, including 46 International 9900Is with Cummins engines (Model Years 2004 to 2007) and four International 9900Is with 2006 Cat engines; all vehicles were approved for B20 under OEM warranty statements. The fleet was equipped with bunk and engine heaters to eliminate the need for the units to operate on a nightly basis. As a result, the units were subject to a cold start each morning. During the study (December 2008 to March 2009), the fleet traveled a total of 1.7 million kilometers throughout Western Canada and the Western United States, and consumed 383,562 liters of B10. Sourcing of biodiesel was based on available supply, a realistic and real world scenario of biodiesel procurement; thus a wide variety of feedstock sources were utilized for the biodiesel consumed during the course of the demonstration. The performance of the fleet was tracked with an electronic control module, which collected unit movement and performance data. In addition, there were a number of data sources including GPS mapping. Temperatures were recorded through software that correlated the weather station near the GPS location of the vehicle, and recorded the temperature in real-time. The coldest temperature registered was -41.7 ^{o}C. The key results of this study with B10 were:

(i) there were no unit shutdowns;

(ii) there were no engine performance, mechanical or maintenance issues related to the use of biodiesel; and,

(iii) there was no change in operation.

The study concluded that biodiesel blends can be integrated into Canadian operations through all seasonal conditions, provided quality biodiesel is used, proper injection blending techniques are employed, and equipment is adequately maintained per normal specifications.

The Biodiesel Demonstration and Assessment with the Société de transport de Montreal (BIOBUS) assessed the viability of biodiesel as part of the routine operation of a bus fleet, particularly in cold weather [51]. The study ran for one year (March 2002 to March 2003) and tested the use of B5 and B20 in 157 buses in real-world conditions in Montréal. The fleet was composed of 75 two-stroke Detroit Diesel engines and 82 four-stroke Cummins diesel engines with mechanical or electronic fuel injection. Based on National Biodiesel Board (NBB) information regarding the timing of warrantees for Cummins and Detroit Diesel engines, the majority (if not all) of the vehicles tested in this study were not warranted to B20 [52]. The total 550,000 liters of biodiesel consumed in B5 and B20 blends were composed of biodiesel produced from various feedstocks (24% vegetable oil, 28% animal fat and 48% used cooking oil). When not running, the buses were parked in a garage at 15 ^{o}C. The Société de transport de Montreal database of on-road service calls was used to assess the impact of biodiesel on the bus fleet operations. Statistics were retrieved from the database on driver calls to report technical problems. It was found that biodiesel blend use resulted in no recorded on-road incidents affecting customer services. The study showed successful use of B20 with vehicles not warranted for this fuel blend. The study concluded that the use of B5 and B20 is viable in a region like Montreal where daytime winter temperatures remain below -20 °C and overnight temperatures drop to -30 °C. It also recommended that transit vehicles not parked in a garage heated during winter (harsh Quebec winter) should probably use a lower concentration of biodiesel, such as B5 or less.

The Biodiesel Use and Experience among U.S. State Department of Transportation (DOT) Agencies [53], is a survey that collected information about performance, maintenance and economic data from 48 DOTs within the U.S with experience related to biodiesel blends. The survey results indicated that there were few cold weather operability issues among state transportation agencies that had adopted the fuel. Only two states reported filter plugging, which had occurred during a cold weather period. We note that biodiesel meeting the current CGSB standards should be sufficient to address even these few cases of cold flow operability noted in the DOT survey.

6.3.2 Long Term Storage and Use of Biodiesel, review of studies

The Long term storage and use of biodiesel in fleets [54] assessed the long term storage and distribution of biodiesel for trucking use in Manitoba. Since 2006, Manitoba Hydro has been running biodiesel at one of their sites and have historically used B20 in the summer and B5 in the winter. The fleet was stored indoors in a partially heated building (6 to 8 °C) during the winter to protect hydraulic systems, an issue not related to the fuel blend. The storage tanks were belowground. No issues related to the fleet operation and dispenser or truck filter plugging as a result of biodiesel use were reported. This study sought to understand if prior issues with filter plugging that had been reported in the U.S. were related to long term storage, biodiesel blending and handling or biodiesel B100 quality. The Manitoba study included laboratory tests and field tests on commercial biodiesel. The study confirmed successful blending, handling, long term storage and use of biodiesel blends in extreme Canadian conditions, with no dispenser filter plugging or truck filter plugging issues.

6.3.3 Maintenance

One of the maintenance issues reported when changing from petroleum diesel to a biodiesel blend is the plugging of filters following the first few fills using biodiesel, due to the solvent properties of the biodiesel fuel. In the survey of the U.S. state DOTs [53], some states reported fuel filter plugging problems, at the pump or engine, in excess of when petroleum diesel was used. However, all the states reported that the problems resolved once the filters were replaced, and did not reoccur. No other maintenance issues specific to the usage of biodiesel blends were reported by any of the surveyed states. There were no pump problems, no fuel system leaks or fuel line leaks when using or testing biodiesel. None of the states reported any change in viscosity, oil acidity, engine wear, or other oil-related activities and none of the states adjusted oil change maintenance schedules when using biodiesel blends.

In the Biodiesel Demonstration and Assessment with the Société de transport de Montreal [51], mechanical maintenance was the same before, during and after the transition to biodiesel for most buses, including both older and newer models. In the same vein, the "long term storage and use of biodiesel in fleets" study reported no difference in maintenance frequency in vehicles using the biodiesel blends.

Collectively, these studies indicate that other than the possibility of a one-time replacement of fuel filters after biodiesel is introduced, the frequency of maintenance and cost are the same when using biodiesel blends and petroleum diesel.

6.3.4 Use and Storage of Gensets with Biodiesel

The National Renewable Diesel Demonstration (NRDDI) study, Demonstration of the Use of Biodiesel in Electric Generators in Remote Canadian Locations and Long-term Storage in Fleets and Gensets, included storage of B5 for up to two years [33]. The context of the study was for gensets in Brochet in Northern Manitoba where fuel is delivered on ice roads and therefore needs to have two-year storage. The fuel was stored outdoors and the gensets and immediate fuel tank was indoors. The study showed that for the B100 meeting the CGSB B100 standard CAN/CGSB-3.524 and blended B5 meeting CAN/CGSB-3.522 that B5 is suitable for genset use and storage for up to two years. What we cannot state is whether higher blends of biodiesel are suitable for gensets and for any higher blends what the storage limitation is for genset use as there are no studies or data from which to make that determination.

6.4 Summary of experience in Canadian and U.S. jurisdictions

The biodiesel blends adopted in Canada and the U.S. range between B2 and B20. B20 is mostly used during the summer and in the winter the blends are lowered to B2-B5. The three demonstration studies summarized above analyzed the feasibility and operability of biodiesel blends (B5 to B20) in cold climates [50,51,54]. The studies show similar favorable results with no recorded on-road incidents affecting service due to the use of biodiesel blends.

From the U.S. DOT survey, it appears that the use of biodiesel blends resulted in some filter plugging events [53]. However, the issue resolved as the filters were replaced, and this is a minor cost. More importantly, such issues would likely not have occurred with biodiesel meeting modern CGSB standards. The demonstration studies did not report incidents of filter plugging in the pump or engine. No other maintenance issue specific to the usage of biodiesel was reported. Furthermore, no difference in maintenance frequency for vehicles using biodiesel blends was reported compared to when using petroleum diesel. Concerning long term storage of biodiesel blends, B5 and B10 blends were shown to be feasible to be stored up to one year without any change in quality [54].

For gensets the NRDDI study showed that for the B100 meeting the CGSB B100 standard CAN/CGSB-3.524 and blended B5 meeting CAN/CGSB-3.522 that B5 is suitable for genset use and storage for up to two years [33].

Concerning renewable diesel, in North America it is mainly consumed in California to satisfy the LCFS. It is estimated that around 200 million gallons a year were consumed in 2017 and that the main distributor is Neste. Several other North American jurisdictions have transitioned or are planning to transition to renewable diesel, several up to 100% renewable diesel. Projects are underway to expand California's renewable diesel market. To the best of our knowledge no issues have been reported with the use of renewable diesel in these jurisdictions.

6.5 Lessons Learned Applicable to City of Toronto

Based on the information in the prior sections, biodiesel blends can be used successfully year around, even in climates colder than Toronto. It is important that the biodiesel (and resulting blend) meets the applicable CGSB standards, is properly managed, and equipment is adequately maintained per regular maintenance schedules. Renewable diesel should meet the same CGSB standards as for petroleum diesel. In our judgment, biodiesel and renewable diesel utilized as per the recommendations given in Section 4 should not result in additional maintenance issues for the City of Toronto compared to use of petroleum diesel.

7 Life Cycle-based Greenhouse Gas Emissions of Bio-based Diesel

7.1 Introduction

Life cycle assessment (LCA) is a widely utilized approach to quantify resource inputs (e.g., energy/fuels, water) and emissions (e.g., GHGs, air pollutants) across the entire life cycle of a product or service [55]. LCA offers insights that can improve product design, reduce resource use, inform investors regarding the environmental performance of technologies, and inform policy decisions. LCA has been utilized for several decades by industry and government (e.g., Natural Resources Canada). In addition to informing policies, LCA has been incorporated into a number of policies/regulations, primarily those related to reducing GHG emissions of transportation fuels, to determine which fuels qualify for incentives or mandates (California Low Carbon Fuel Standard, British Columbia Low Carbon Fuel Standard, Canadian Clean Fuel Standard).

In the case of fuels, a typical LCA would include activities related to feedstock production (e.g., crude oil recovery and extraction or growing biomass feedstock), fuel production (e.g., oil refining or biofuel production), transportation and distribution, and combustion of the fuel in a vehicle.[6] An LCA includes both the use-phase emissions, those related to fuel combustion in the vehicle, and the supply chain emissions, those associated with the production and distribution of the fuel (e.g., energy and material inputs to production processes; fuel consumption for fuel distribution). Traditional ("attributional") LCA focuses on quantifying environmental flows directly associated with a given product. The International Organization for Standardization (ISO) has a series of guidelines outlining basic requirements for conducting an LCA [56]. Though useful, these guidelines provide only a set of minimum requirements with some aspects of the analysis remaining subject to the analyst's judgment. While the concept of LCA is fairly straightforward, a robust LCA can be resource intensive and complex to complete. It requires various assumptions and methodological choices (e.g., selection of which processes are included within the GHG intensity calculations, how to allocate emissions among products in a multi-product system) along with extensive input data (e.g., how much energy is required to process the fuel, what emissions are associated with production of process chemicals, how and what distance the fuel is transported). Because life cycle GHG intensity cannot be measured, and must instead be modeled, there is some amount of unavoidable variability and/or uncertainty in all LCAs.

There exist a number of publicly available attributional LCA tools focused on transportation fuels including: GHGenius, developed by Natural Resources Canada (NRCan) and $(S\&T)^2$ Consultants (Canada) ($(S\&T)^2$ 2018) [57][58]; Greenhouse Gases, Regulated Emissions, and Energy use in Transportation model (GREET), developed by Argonne National Laboratory (US) [59]; and BioGrace (EU) [60]. At the time of

[6] In the case of biofuels, combustion emissions are often treated as carbon neutral, since the carbon released at combustion is assumed to be offset by the carbon absorbed by the plant or animal as it grows.

writing, the Ontario Greener Diesel Regulation [34] states that to calculate emissions for compliance, obligated fuel suppliers must use the GHGenius model, version 4.03a [57]. In July 2018, GHGenius 5.0 [58] was released, and so an update to the regulation to use GHGenius 5.0 may take place in the future.

Note that some researchers and policy makers have suggested a need to analyze broader system changes that occur when a new product is introduced, or its production is increased ("consequential" LCA). Thus, some LCA methods also include indirect emissions associated with the economy-wide response to policies or product adoption. For example, biofuels can increase or create a demand for agricultural or forestry products and thereby induce changes in global land use patterns to supply this demand, which could result in the same or a net increase or decrease in the quantity of carbon stored in terrestrial carbon stocks (soils, biomass), with potential GHG consequences. The induced land use change (ILUC) values, included in some policies, aim to capture emissions from land transformations resulting from increased use of biofuels. So far, Canadian policies like the British Columbia LCFS, Canadian Clean Fuel Standard, and Ontario Greener Diesel regulation have opted to exclude ILUC emissions from their calculations. The European Fuel Quality directive likewise excludes ILUC from consideration, but does require ILUC estimates to be reported. In contrast, several U.S. policies have explicitly included ILUC in their GHG calculations, including the California LCFS, Oregon LCFS and federal Renewable Fuel Standard (RFS). Owing to lack of data, and for consistency with both the current Canadian policy landscape and with the GHGenius model, the present study does not account for emissions from ILUC.

In this report, to be consistent with the Ontario Greener Diesel Regulation, the life cycle GHG emissions of biodiesel and HDRD are estimated using GHGenius version 4.03a for the year 2018. In addition, the results are compared with those resulting from the latest GHGenius version (5.0) because an update to the Ontario Greener Diesel Regulation to use GHGenius 5.0 may take place.

The purpose of the GHG emissions intensity assessment presented here is to provide general guidance on the approximate magnitudes of life cycle emissions of the various feedstock/biodiesel pathways, not to provide definitive values for specific production pathways. It should be noted that the biodiesel supplier(s) to the City would be required to calculate and report the life cycle GHG emissions intensities of any fuels supplied (as per the Greener Diesel Regulation). The City could also specify in their fuels contract any specific requirements related to the GHG emissions intensity of the supplied fuels.

7.2 Life Cycle Assessment of Bio-based Diesel

7.2.1 Goal and Scope

The aim of this LCA is to establish and compare GHG emissions related to the life cycle of bio-based diesel for both biodiesel and HDRD from different sources (canola, soybean, yellow grease and tallow), and estimate the GHG intensities of 100% bio-based diesel and fuel blends (5%, 10%, 20%) compared to petroleum diesel baseline life cycle emissions. The functional unit specifies the basis on which the fuels are compared and is selected to be one megajoule (MJ) of fuel.

7.2.2 System Boundary

The system boundary defines which processes are included within the GHG intensity calculations. The scope of this study encompasses the life cycle emissions that comprise those associated with both fuel production and use (combustion in the vehicle), as depicted in Figure 7-1. The life cycle emissions include feedstock production (e.g., fertilizer production/use, farm equipment fuel use), feedstock transport to the fuel production facility, fuel production (which requires electricity, heat and auxiliary chemicals), fuel transport to a distribution centre for blending and storage, blended fuel transport to end users and fuel use. Carbon dioxide emissions from biofuel combustion are assumed to be carbon neutral. The premise of carbon neutrality is that carbon from biomass sources has been recently sequestered from the atmosphere and is now released to the same carbon sink, the atmosphere. As such, the direct carbon dioxide sequestered during biomass growth and re-released during biomass combustion is assumed to be exactly offset and so is excluded from the final GHG calculation. Emissions associated with vehicle production (vehicle cycle emissions) are not included in the scope, nor are the emissions embodied in infrastructure.

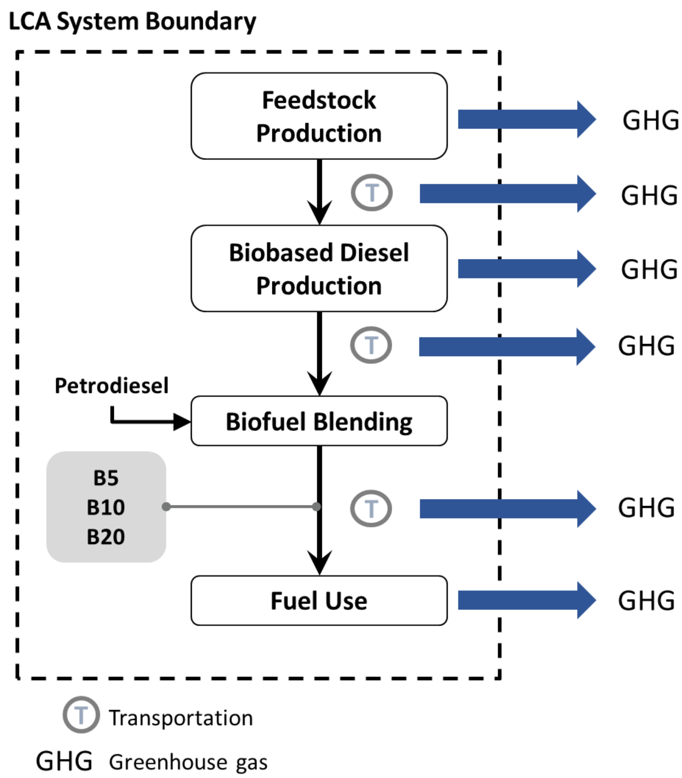

Figure 7-1 LCA System boundary of bio-based diesel production and use in a vehicle

7.2.3 Impact Category

Global warming potential (GWP) has been selected as the impact category for this LCA. GWP is an impact category that measures the contribution of GHG emissions to radiative forcing and rising atmospheric temperatures. Our analysis considers contributions from carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These GHGs are converted into common units of CO_2e based on the Intergovernmental Panel on Climate Change (IPCC) 2007 Fourth Assessment Report 100-year GWPs based on the guidelines of the Ontario Greener Diesel Mandate. The GWPs are CO_2: 1, CH_4 25 and N_2O 298.

7.2.4 Base Case Scenarios

We model biodiesel life cycle GHG emissions using GHGenius 4.03a default parameters, together with modelling assumptions specified by the Ministry of Environment and Climate Change[7] for the Ontario Greener Diesel Regulation. For each feedstock, GHGenius allows the user to specify the year and region of study (for both the feedstock production and bio-based diesel production), agronomic inputs (e.g., fertilizer use and crop yield), process inputs (e.g., energy and chemical inputs at the bio-based diesel production facility, conversion yield, co-product quantity), co-product accounting methods, and other parameters like transportation mode and distance. Other aspects such as emission factors associated with chemicals and fuels are generally fixed. The Greener Diesel Regulation generally also specifies co-product treatment methods, and agronomic inputs for a given feedstock and region, while other parameters remain available for user input.

Feedstock production activities, co-product treatment and other factors can have important effects on GHG emissions. For example, for oilseed (e.g., canola and soy) production, agronomic inputs, land management practices can influence the GHG results. Changes in soil organic carbon are due to land management practices and vegetation changes. The soil organic carbon value in GHGenius is region specific; thus, the origin of the feedstock is important. For our analysis, we assume the bio-based diesel will be produced in Canada from local feedstock, and we selected regions for feedstock production considering both regional feedstock availability and the City of Toronto location.

We model four feedstock scenarios for the two bio-based diesel pathways (transesterification, which produces biodiesel, and hydroprocessing, which produces renewable diesel/HDRD), using canola, soybean, yellow grease and tallow as the feedstock. The first two are oil seed crops and the last two are 'waste' feedstock. Yellow grease is produced from used cooking oil, which is generated from food production and tallow is produced from animal carcasses and is a by-product of the rendering process.

For our analysis, canola production and oil extraction are assumed to be in Western Canada (where canola is produced), while soybean production and oil extraction, yellow grease and tallow and

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[7] Subsequently renamed the "Ministry of Environment, Conservation and Parks" in June 2018.

associated rendering, are assumed to be sourced from and take place in Central Canada. All bio-based diesel production (transesterification and hydroprocessing) (irrespective of feedstock) is assumed to be in Central Canada. The names of the location designations are as per GHGenius. The co-product treatment procedures used in the base case scenarios are the default settings within GHGenius, compliant with the Ontario Greener Diesel Regulation. Protein meal from canola and soybean is assumed to be used as an animal feed. Mass allocation is applied to distribute upstream GHG emissions between the oil and the meal for canola and soybean feedstock. The mass allocation method distributes GHG emissions of each product in the same proportion as the ratio of the product's mass to the mass of all of the products.

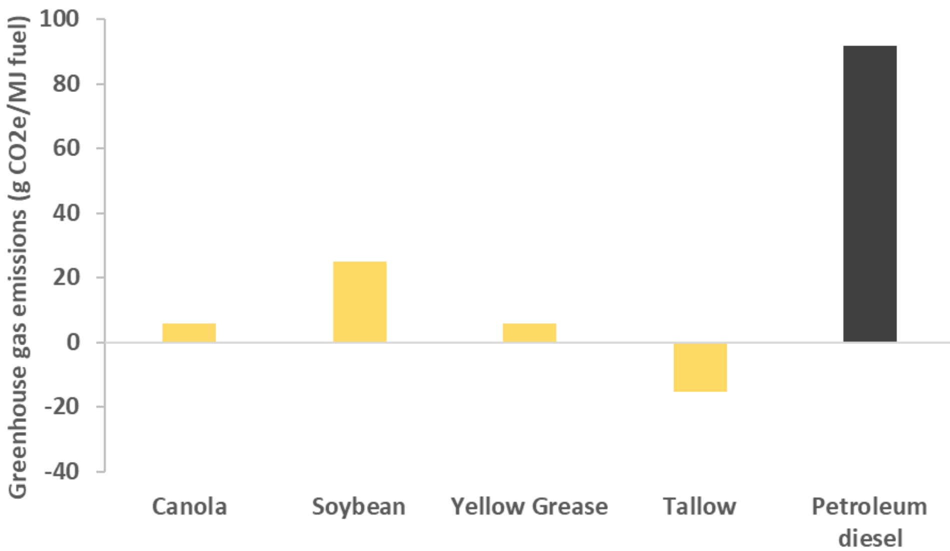
Yellow grease and tallow are considered waste products, hence the emissions from their production (e.g., restaurants in case of yellow grease or slaughterhouses in case of tallow) are excluded from the analysis in the base case. Only the transportation of the feedstock from the facilities generating the material to the renderer is considered in the analysis. The animal carcass rendering process to produce tallow also produces a high protein (50%) bone meal used as an animal feed [58]. The bone meal is assumed to displace soymeal by default in GHGenius resulting in an emissions credit. The co-product of biodiesel production (transesterification) is glycerine. By default within GHGenius, 50% of the crude glycerine generated is assumed to displace animal feed while the other 50% is assumed to displace petroleum-derived glycerine. The co-products of HDRD production (hydroprocessing) are gaseous and liquid fuel products. Both the fuel products are assumed to displace petroleum-derived gaseous and liquid fuels, resulting in co-product emission credits that act to reduce the modeled GHG emissions associated with the bio-based diesel. In the Ontario Greener Diesel regulations, the types of co-product (e.g., crude vs refined glycerine) and yields of co-product are producer specific information. Note that each producer pathway is unique, the results presented in this report do not represent any specific producer. The process data default values for biodiesel production in GHGenius come from a comprehensive survey of commercial biodiesel production plants conducted by the National Biodiesel Board (NBB) in 2009 [61]. Thus, the results based on this data represent average industrial data. Note that GHGenius widely employs time series to estimate default values (agricultural feedstock yield; biofuel production inputs and yield), with values from a reference year extrapolated to the present and future based on observed historical trends.

7.2.5 Biodiesel LCA results

The GHG intensities for canola, soybean, yellow grease, and tallow as neat biodiesel (B100) for the base case scenarios are presented in Figure 7-2, with additional breakdown by life cycle stage shown in Figure 7-3. The figures show emissions from feedstock production (feedstock recovery and transmission, land-use changes, cultivation, fertilizer manufacture), fuel production, along with fuel distribution and use. The results also include negative values for credits associated with co-products (meal and glycerine), substantially reducing net GHG emissions from biodiesel production. Life cycle emissions for the base case scenarios range from a high of 24.9 g CO_2e/MJ biodiesel from soybean to a low of -7.5 g CO_2e/MJ for tallow (co-product credits from displaced animal feed and glycerine exceed process emissions), compared to 91.9 g CO_2e/MJ from petroleum diesel. As a reminder, this analysis treats biogenic CO_2 as carbon neutral, and excludes any potential emissions from induced land use change.

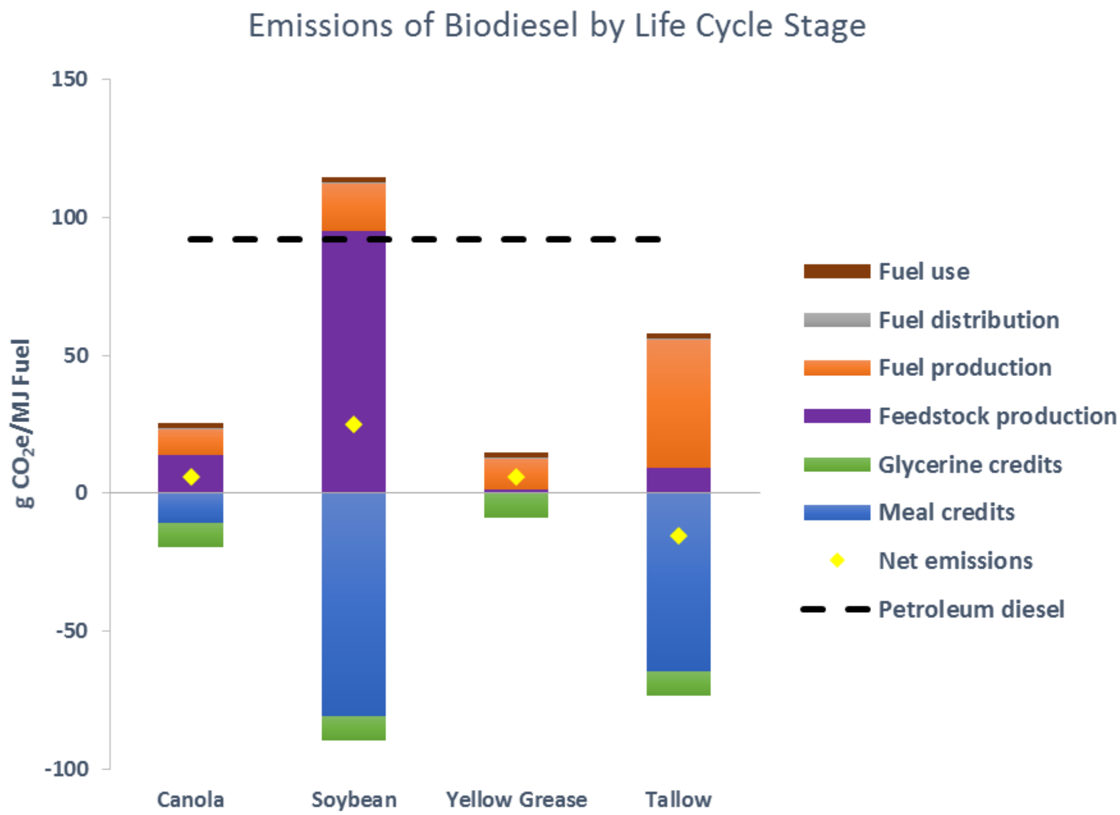
Yellow grease (5.8 g CO_2e/MJ) and tallow have low GHG emissions because they are considered wastes and therefore the emissions from the upstream supply chain are excluded from the analysis.

For canola and soybean, feedstock production is the life cycle phase that emits the most GHG emissions. As modeled here, canola biodiesel has lower emissions (5.6 g CO_2e/MJ) than soybean biodiesel among the high quality oilseed crop-based feedstocks, and this is largely attributed to canola having lower feedstock production emissions. While Canola grown in Western Canada has higher agronomic inputs than soybean, the modeling in GHGenius suggests that canola farming practices lead to an increase in soil carbon, which acts as a carbon sink, thereby giving canola a significant GHG emissions credit that results in low feedstock production emissions. An additional difference between the oilseeds is that canola oilseed contains 42% oil, while soybean typically has only 19% oil. This results in less canola meal (co-product) being generated compared to soybean meal, which affects meal credit calculations.



**Reference petroleum-derived diesel for base case scenarios based on GHGenius 4.03a* [57] *as per Ontario Greener Diesel Mandate.*

Figure 7-2: Net GHG emissions (g CO_2e/MJ fuel) for canola, soybean, yellow grease, and tallow neat biodiesel (B100).



* *Reference petroleum-derived diesel for base case scenarios based on GHGenius 4.03a* [57] *as per Ontario Greener Diesel Mandate. Negative values (emission credits) are subtracted from positive values (emission sources), to produce net emissions (in yellow), which are equal to those shown in Figure 7-2.*

Figure 7-3: GHG emissions (g CO_2e/MJ fuel) for canola, soybean, yellow grease, and tallow neat biodiesel (B100) by life cycle stage.

Overall, the biodiesel produced from the four feedstocks analyzed in this work has lower life cycle emissions than petroleum diesel (91.9 g CO_2e/MJ). While there is some uncertainty associated with these results, studies from other jurisdictions generally agree that biodiesel compares favourably to petroleum diesel from a GHG emissions perspective. For example, for the BC LCFS, the GHG (carbon) intensity values for BIOX (a Canadian biodiesel producer) range from – 15.7 to 28.9 CO_2e/MJ B100 (no feedstock information provided) [62]. Other models (less tailored to the Ontario context) have reported either higher GHG values and/or a different preference ordering among the four feedstocks considered here [63–66], but results typically remain below 50-60 g CO_2e/MJ biodiesel even where emissions from ILUC are included. Appendix J includes a limited sensitivity analysis of some key uncertainties in the biodiesel production processes and their effects on life cycle GHG emissions in the Ontario context.

7.2.6 Biodiesel Blends

Currently, biodiesel is most often used as a blend with petroleum diesel. We calculate GHG intensities for biodiesel blends of B5, B10, and B20, as these are deemed most relevant to the City of Toronto context. The base case GHG intensities for each feedstock are presented for each blend level in Table 7-1 (in g CO_2e/MJ of fuel). Emissions are presented in Appendix J, Table J-1 in units of g CO_2e/L of fuel. The emission reductions for B5 range from 3.4% to 5.0%, for B10 6.7% to 10.0%, and B20 from 13.6% to 20.1%. For context, if the city were to increase fleet-wide blend levels from B4 (year-round) to B5 in winter, B10 in spring and fall, and B20 in summer(akin to the in-progress pilot study), GHG reductions in the base case could range between 8.4 and 12.1% depending on the feedstock.

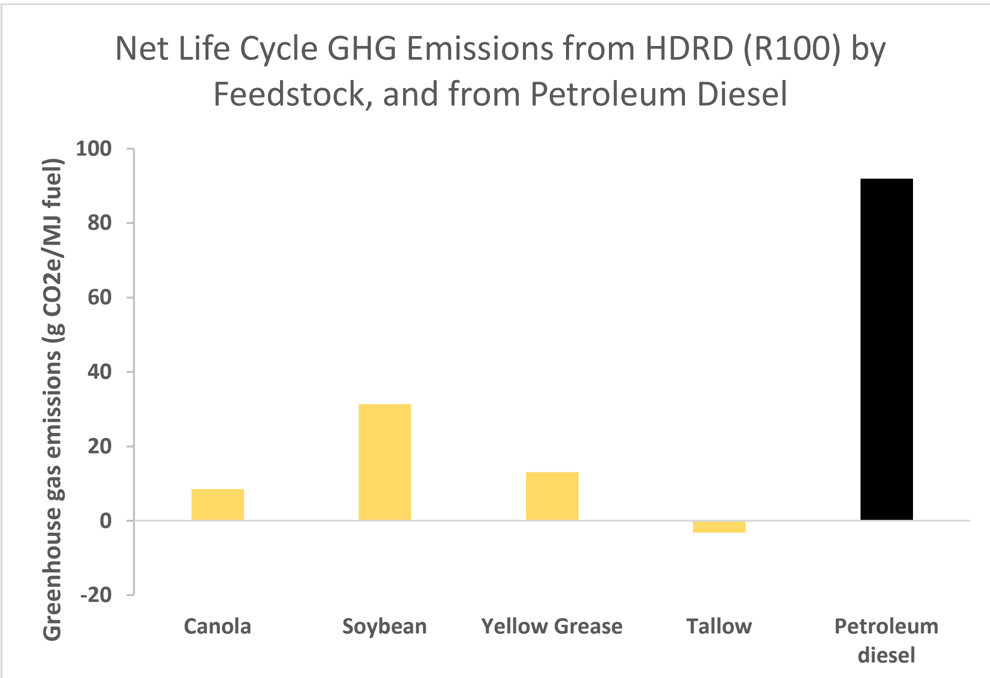
Table 7-1: GHG emission results for biodiesel blends for base case scenarios. Data presented in g CO_2e/MJ fuel and value in parenthesis is the percent reduction from the petroleum diesel reference (petroleum diesel reference value is 91.9 g CO2e/MJ).

	B5	B10	B20
Canola	87.9 (4.3%)	83.9 (8.7%)	75.8 (17.5%)
Soybean	88.8 (3.4%)	85.7 (6.7%)	79.4 (13.6%)
Yellow grease	87.9 (4.3%)	83.9 (8.7%)	75.9 (17.4%)
Tallow	87.3 (5.0%)	82.7 (10.0%)	73.4 (20.1%)

7.2.7 HDRD results

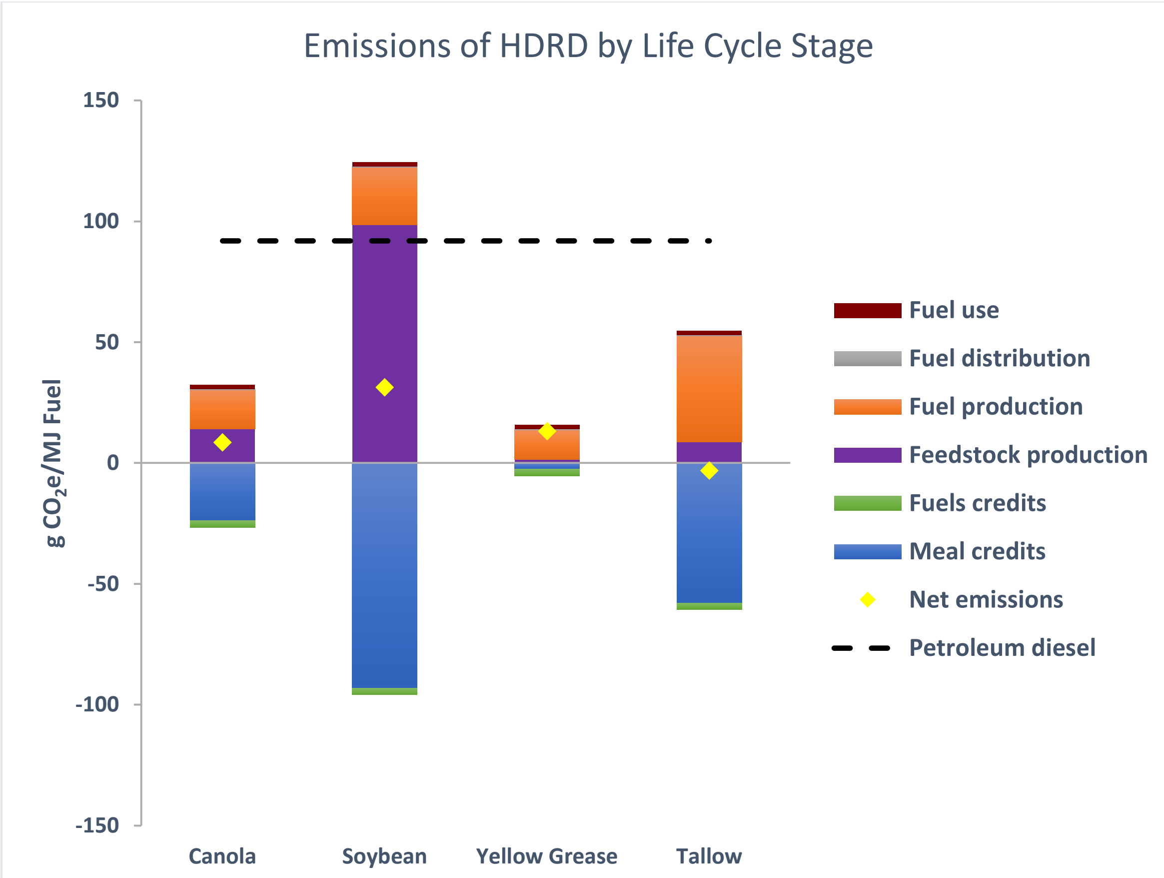
The GHG intensities for canola, soybean, yellow grease, and tallow as neat HDRD (R100) for the base case scenarios are presented in Figure 7-4. The breakdown of emissions by life cycle stage is shown in Figure 7-5. As for the biodiesel cases, the HDRD results also include negative values for credits associated with co-products (meal and fuel), substantially reducing net GHG emissions from HDRD production. Life cycle emissions for the base case scenarios range from a high of 31.3 g CO_2e/MJ biodiesel from soybean to a low of -3.1 g CO_2e/MJ for tallow (co-product credits from displaced animal feed and fuel exceed process emissions), compared to 91.9 g CO_2e/MJ from petroleum diesel.

The same trends as for biodiesel are observed for HDRD among pathways: Yellow grease and tallow have low GHG emissions because they are considered waste feedstocks. Canola HDRD generally has lower emissions than soybean HDRD and this is largely attributed to changes in soil carbon due to management practices in Western Canada giving Canola a significant GHG emissions credit that results in low feedstock production emissions.



**Reference petroleum-derived diesel for base case scenarios based on GHGenius 4.03a* [57] *as per Ontario Greener Diesel Mandate*

Figure 7-4: Net GHG emissions (g CO_2e/MJ fuel) for canola, soybean, yellow grease, and tallow neat HDRD (R100)

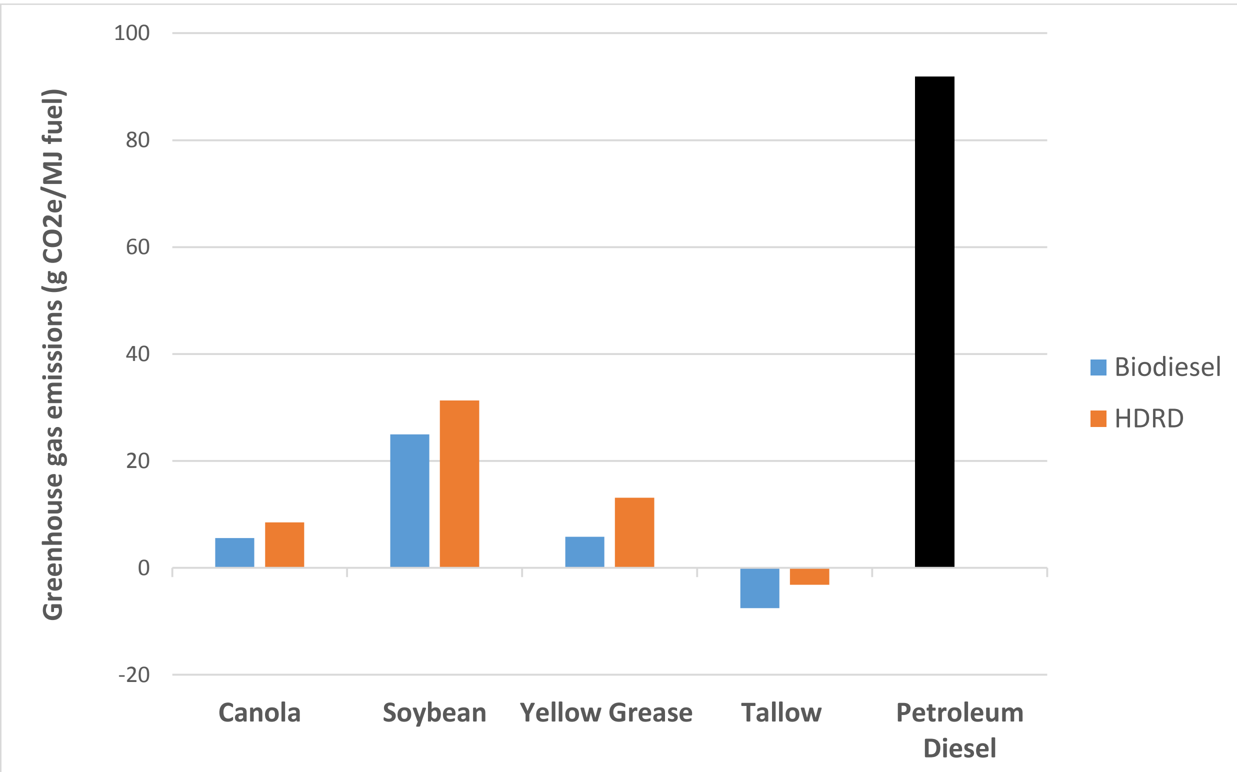


* *Reference petroleum-derived diesel for base case scenarios based on GHGenius 4.03a* [57] *as per Ontario Greener Diesel Mandate. Negative values (emission credits) are subtracted from positive values (emission sources), to produce net emissions (in yellow), which are equal to those shown in Figure 7-4.*

Figure 7-5: GHG emissions (g CO_2e/MJ fuel) for canola, soybean, yellow grease, and tallow neat HDRD (R100) by life cycle stage

Similar to biodiesel, the HDRD produced from the four feedstocks analyzed in this work has lower life cycle emissions than petroleum diesel (91.9 g CO_2e/MJ). Studies from other jurisdictions generally agree that HDRD compares favourably to petroleum diesel from a GHG emissions perspective. For example, for the BC LCFS, the GHG (carbon) intensity values for Diamond Green Diesel LLC (US) range from 9.1 to 26.3 CO_2e/MJ R100 (no feedstock information provided) [62]. Other companies like Neste Renewable Fuels in Finland have reported a wider range of GHG values, between 4 and 64 g CO_2e/MJ (no feedstock information provided). Neste Renewable Fuels in the Singapore production facility have reported a wider range of GHG values, between 9 and 95 g CO_2e/MJ (no feedstock information provided). Overall the values from these two companies are below petroleum diesel (91.9 g CO_2e/MJ), except for one value from Neste Singapore (no feedstock information provided).

Comparing the two main bio-based diesel pathways, HDRD has slightly higher GHG emissions (between 3 and 7 g CO_2e/MJ biofuel) than biodiesel across all feedstocks (Figure 7-6), mainly due to the hydrogen input for HDRD in the fuel production stage. The use of renewable hydrogen or advanced reforming technologies could reduce this impact. The fuel co-product credits in the HDRD cases are slightly lower than the glycerine credits in the biodiesel cases.



**Reference petroleum-derived diesel for base case scenarios based on GHGenius 4.03a* [57] *as per Ontario Greener Diesel Mandate*

Figure 7-6: Comparison of net GHG emissions (g CO_2e/MJ fuel) from Biodiesel (B100) and HDRD (R100) by feedstock

7.2.8 HDRD Blends

We calculate GHG intensities for HDRD blends of R5, R10, and R20. The base case GHG intensities for each feedstock are presented for each blend level in Table 7-2 (in g CO_2e/MJ of fuel). Emissions are presented in Appendix J, Table J-2 in units of g CO_2e/L of fuel. The emission reductions for R5 range from 3.1% to 4.9%, for R10 6.3% to 9.8%, and R20 from 12.6% to 19.8%. These results are slightly lower (1 to 2%) than the comparable results for the biodiesel blends. For context, if the city were to use fleet-wide blend levels of R5 in winter, R10 in spring and fall, and R20 in summer (akin to the in-progress pilot study), GHG reductions in the base case could range between 7.6 and 11.6% depending on the feedstock.

Table 7-2: GHG emission results for HDRD blends for base case scenarios. Data presented in g CO_2e/MJ fuel and value in parenthesis is the percent reduction from the petroleum diesel reference (petroleum diesel reference value is 91.9 g CO_2e/MJ).

	R5	**R10**	**R20**
Canola	88.0 (4.3%)	84.0 (8.6%)	76.0 (17.3%)
Soybean	89.0 (3.1%)	86.2 (6.3%)	80.3 (12.6%)
Yellow grease	88.2 (4.1%)	84.4 (8.1%)	76.9 (16.4%)
Tallow	87.4 (4.9%)	82.9 (9.8%)	73.7 (19.8%)

7.2.9 Scenario Analyses for Biodiesel and HDRD LCAs

Scenario analysis can lead to important insights regarding the likelihood that one option is preferred over another. Three additional scenarios were examined and compared with the base cases for biodiesel and HDRD. The first scenario updated data for key parameters in the LCA such as agronomic yields, fertilizer inputs, energy for farming, crushing, pre-treatment, and biodiesel process energy inputs. The second scenario examined the origin of the bio-based fuels, modeling the GHG emissions of the biofuels produced in the central US from soybean, yellow grease and tallow. This scenario is relevant, since currently Canada imports considerable portions of biodiesel and all renewable diesel. Finally, we ran a scenario in GHGenius 5.0a to compare with GHGenius 4.03a. The results of these additional scenarios are shown in Appendix J. Globally, the results vary little and all the GHG emissions are still below those of petroleum diesel (91.9 g CO_2e/MJ).

7.3 LCA and GHG Emissions Summary

Life cycle assessment is widely regarded as the preferred framework for evaluating the GHG emissions resulting from biodiesel, HDRD and other alternative fuels. Using GHGenius together with default assumptions and updated data, we find that biodiesel and HDRD use in Ontario can lead to GHG reductions of 3.2-20% relative to petroleum diesel, depending on the feedstock (canola, soybean, yellow grease or tallow) and blend level (5%-20%). As a result, potential GHG savings are in the tens of thousands of tonnes of CO_2e/year. The findings that biodiesel and HDRD offer lower emissions than petroleum diesel are robust across a variety of models from other jurisdictions, and even if some prominent estimates of emissions from induced land use change were to be included. While we recommend that the City consider more specific carbon intensity values reported directly by potential suppliers, these results provide additional confidence in the GHG benefits of biodiesel and HDRD.

8 Vehicle Air Pollutant Emissions when Fueled with Bio-based Diesel

Air pollutant emissions are harmful to human and ecosystem health. The World Health Organization states that air pollution is now the world's largest single environmental health risk [67]. In Canada, transportation, off-road vehicles and mobile equipment are among the largest emitter of air pollutants [68]. The emissions released through human activities are classified into six key air pollutants: sulphur oxides (SO_X), nitrogen oxides (NO_X), volatile organic compounds (VOCs), ammonia (NH_3), carbon monoxide (CO) and fine particulate matter ($PM_{2.5}$) [68].

Exhaust emissions of diesel vehicles are a major contributor to air pollutant emissions. They account for 1% of the approximate composition of diesel exhaust gas [69][70] with NOx emissions having the highest proportion (50%) of diesel pollutant emissions followed by PM. The concentrations of CO and hydrocarbons (HC) (HC is a VOC) are lower because diesel engines are lean combustion engines, and only a small amount of sulfur oxides (SOx) is emitted depending on the specifications of the fuel [69].

Technological advances in engine design, catalysts and particulate matter filters, as well as changes in the composition of diesel fuels and engine lubricants have reduced air pollutant emissions from diesel vehicles [71]. In post 2006 diesel vehicles, multicomponent emissions reduction systems (engines, fuel injection systems, ultra-low-sulfur fuels, lubricants, and exhaust after-treatment devices) have been incorporated to meet regulations like the Canadian on-road vehicle and engine emission regulations [72] and the U.S. EPA emissions standards [73]. The following section summarizes studies that assessed air pollutant emissions of biodiesel and renewable diesel as compared to petroleum diesel.

8.1 Biodiesel: Air Pollutant Emissions

Studies have investigated the effect of biodiesel and its blends on vehicle exhaust emissions as compared to petroleum diesel. We focus on those completed in Canada and the U.S. along with the studies ranging from recent to the early 2000s and covering different classes and ages of vehicles, they differ with respect to engine technology, operating conditions, kinetics, displacement, power output, calibration, composition of diesel and biodiesel and blend percentage. According to a 2012 US Environmental Protection Agency (EPA) report [74], in general, use of biodiesel leads to considerable reductions in particulate matter (PM), carbon monoxide (CO) and hydrocarbon (HC) emissions (e.g., B20 soybean-based reduced by 10% PM, 21% HC and 11% CO). However, some contradictory results have been observed in terms of NOx emissions [75]. The major trends for the specific air pollutant emissions are described below.

NOx: NOx includes emissions of nitric oxide (NO) and nitrogen dioxide (NO_2). NO_X and VOCs are the main contributors to the formation of ground-level ozone (smog). Total NOx and SOx emissions have also been reported to be responsible for acid rain, which can harm the environment and living organisms [68].

NOx emissions from biodiesel blends (B5-B20) vary considerably from study to study. Compared to petroleum diesel, differences in NOx are reported to be either statistically insignificant or there are very small increases. As mentioned above, the reviewed studies represent recent as well as older studies and examine different vehicles, biodiesel with distinct properties, etc. These aspects should be considered in interpreting the applicability of the studies to the City of Toronto context (e.g., the studies would not likely be using biodiesel that meets current CGSB standards). Historical studies include a 2002 U.S. EPA report reviewed engine dynamometer studies and stated that B20 (soybean based) resulted in a 2% increase in NOx emissions. Nearly half of engines in the study where from a single manufacturer (Detroit Diesel Corporation) [74]. A 2006 National Renewable Energy Laboratory (NREL) report assessed eight heavy-duty diesel vehicles including three transit buses, two school buses, two Class 8 trucks, and one motor coach (Cummins, International and Detroit Diesel engines, years 2000-2006)[76] running on B20 (soybean based). The results ranged from -5.8% to +6.2%, with a neutral average of 0.6% ± 1.8%, for all engine/vehicle technologies and test cycles. The authors could not determine a reason for the wide range. A 2011 study commissioned by the California Air Resources Board tested emissions from soy- and animal-based biodiesel blended with CARB-certified ULSD in two different on-road diesel engines (2006 Cummins ISM and 2007 Detroit Diesel Corporation (DDC) MBE 4000) [77]. The results showed a higher increase in NOx (approximately 4%) for soy-based B20 compared to a slight increase (1.6%) for animal-based B20. The 2003 BIOBUS study [51] reported that biodiesel with a higher cetane number, tends to reduce NOx emissions, and reported results for an engine with electronic fuel injection, whose NOx emissions were about 3 to 5% lower for B20 (animal fat or used cooking oil based) compared to petroleum-diesel.

Others factors reported to affect NOx emissions are the engine technology, calibration, and selective catalytic reduction (SCR) systems. Newer vehicles designed to meet strict air emissions standards include SCR systems. A recent study from NREL [78] evaluated the NOx emissions of a range of transit buses (six buses spanning engine model years 1998 to 2011) representing the majority of the US transit fleet in 2012 and as well including hybrid and SCR systems. The tests evaluated five different fuels (US EPA certification diesel, CARB diesel, B100 derived from soy oil, and B20 blends of each diesel with the biodiesel) and three standard transit duty cycles. The results showed that a B20 blend of either certification diesel or CARB diesel did not consistently show a statistically significant increase in NOx emissions compared to the petroleum diesel, except a 2008 Cummins ISL and an Allison Hybrid Cummins ISL, which showed increased NOx emissions with the B20 blend. In contrast, a 2011 Cummins ISL, showed a significant reduction in NOx emissions with a B20 blend. The main conclusion of the study was that the engine emissions certification level had the most effect on NOx. The importance of the NOx certification level for NOx emissions was reinforced by the study of Clark et al. (2008) [79]. In this study, 2002 to 2007 Cummins ISL 280 were assessed, and the most recent buses had the lowest NOx emissions as expected as engines in the newer buses were designed to meet lower NOx certification levels. The authors stated that it was unclear if the very small rise in NOx emissions for B20 was statistically significant.

Several research groups, including NREL, have investigated diesel emissions control systems. For example a urea SCR system showed considerable NOx emissions reductions and its performance was not affected by the use of biodiesel [80]. Another study assessed a NOx adsorber catalyst and the vehicle chassis tests showed some NOx benefits when operating on B20 [81]. Other research is focused on developing new additives to address the issue of NOx emissions. For instance, the California Air Resources Board (CARB) tested a NOx mitigating biodiesel additive (CATANOX) developed by Targray and demonstrated NOx emissions equivalent to those of standard diesel. California regulators have announced the certification of this additive [82].

PM: PM is a mixture of solid particles and liquid droplets found in the air. PM particles includes $PM_{10,}$ with diameters that are generally 10 micrometers and smaller; and $PM_{2.5}$: with diameters that are generally 2.5 micrometers and smaller. Fine particulate matter ($PM_{2.5}$) and ground-level ozone (O_3) are key components of smog. $PM_{2.5}$ can be emitted directly or can be formed through chemical reaction involving NOx, SOx, and VOCs [68]. PM is linked to respiratory health issues such as asthma and in premature death in people with heart or lung disease. Note that generally the studies that have investigated the effect of biodiesel and its blends on vehicle exhaust emissions refer to PM.

Lower PM emissions have been generally reported with the application of biodiesel blends in diesel combustion engines due to the high cetane numbers of biodiesel [76][77][74]. As for the case of NOx emissions, Clark et al. [79] found that the engine emissions certification level had a dominant effect on PM. Similar to SCR technology, Diesel Particulate Filter (DPF) aftertreatment contributes to lowering of PM rates in light-duty vehicles.

CO: CO is a poisonous gas and breathing air with a high concentration of CO can inhibit the blood's capacity to carry oxygen to organs and tissues [68]. Most of the literature has reported a reduction in CO emissions with the application of biodiesel in diesel engines [83] [74] [77] [76] due to the oxygen present in biodiesel leading to a more complete combustion [83].

VOCs and HC: VOCs are carbon-containing gases and vapours released into the atmosphere. There are hundreds of VOCs that are emitted and that affect health and the environment [68]. HC are compounds of hydrogen and carbon only and fall within VOCs. HC are produced by incomplete combustion of hydrocarbon fuels.

The majority of studies reviewed showed a decrease in HC emissions for biodiesel blends compared to petroleum diesel [77][74] [76]. The different degrees of reduction in HC emissions were also related to the biodiesel blend level; for example [74] found that using B100 and B20 can greatly reduce the HC emissions of a diesel engine, by 67% and 21%, respectively.

In summary, there appear to be no major concerns, and likely some benefits for air quality, for biodiesel blends compared to petroleum diesel, especially on older vehicles with less emission control technology. Generally, reductions were shown for PM, CO and HC. Results for NOx were less consistent; some studies report a small increase of NOx emissions with biodiesel blends, while other studies suggest there is a decrease or no change in NOx emissions. Concern about NOx emissions resulting from biodiesel use will probably diminish with improvements in engine technology, calibration, after-treatment systems, and additives.

8.2 Renewable Diesel: Air Pollutant Emissions

To our knowledge, in comparison with biodiesel, fewer studies have investigated the effects of renewable diesel and its blends on vehicle exhaust emissions. As is the case with the biodiesel studies, the renewable diesel studies differ with respect to engine technology, operating conditions, and blend percentage considered.

A multimedia evaluation of renewable diesel by the California Environmental Protection Agency indicated that the use of renewable diesel and the resulting air emissions do not pose a significant adverse impact on public health or the environment [84]. In addition the report states that : "In general, this study found that most emissions from renewable diesel are reduced from diesel fuel meeting ARB motor vehicle fuel specifications (CARB diesel), including PM, NOx, CO, CO_2, total hydrocarbons (THC), and most toxic species" [84].

McCormick [85] further stated that because renewable diesel produces lower emissions of most criteria air contaminants, its use can help engine manufacturers meet emissions standards, as well as result in lesser negative impacts on human health and the environment compared to petroleum diesel.

According to an extensive recent review [47], results on emissions from renewable diesel vary considerably depending on whether the vehicle is equipped with emission controls. The review's authors conclude that renewable diesel provides significant NOx and PM exhaust emission reductions from heavy-duty engines and vehicles that are not equipped with state-of-the-art emissions controls. In the newer engines that incorporates SCR and DPF technology, the benefits of renewable diesel are insignificant or nonexistent. In the particular case of SCR-equipped heavy-duty vehicles and engines there is insufficient data to definitively conclude whether renewable diesel provides NOx-related benefits.

In summary, there appear to be no major concerns with renewable diesel emissions compared to petroleum diesel. The benefits for air quality appear to depend on whether the vehicle has emissions controls; renewable diesel provides significant NOx and PM reductions from heavy-duty engines and vehicles that are not equipped with state-of-the-art emissions controls.

9 Biodiesel and HDRD prices

The first section of this chapter describes market prices of biodiesel and HDRD in the US, because little information is available for Canada. A second approach to estimate prices is through a financial analysis. The second part of the chapter assesses the cost of production and financial viability of biodiesel and HDRD production from canola oil, soybean oil and yellow grease, in the Canadian context. The results from both analyses give a range of prices for biodiesel and HDRD.

9.1 Market prices

Information about wholesale biodiesel prices is publicly available in the US. Historical prices (2009-2018) for US biodiesel (B100 SME) [86], New York Harbor Ultra-Low Sulfur No 2 Diesel [87], and wholesale diesel in Canada [88] are shown in Figure 9-1. The price for US biodiesel is also shown both with and without the revenue producers receive from selling 'RIN D4' credits [89], which is an extra revenue source that US biofuel producers receive resulting from the federal US Renewable Fuel Standard. In some US states, producers also benefit from additional credits, for example due to the LCFS credit from California; these state credits are not modeled explicitly here. The RIN and other such credits close the gap between the production cost and sales price for the fuel, relative to the price of fossil fuel. The RIN price, and LCFS credit, are typically paid by an obligated party (refiner/blender) and received by the biofuel producer, and thus increases the value/price of the biofuel. Like petro-diesel, biodiesel prices are volatile, and ranged from 0.85 to 1.51 CAD per liter[8] between 2009 and 2018. As of November 2018, the biodiesel price was 1.07 CAD per liter. In the US, soybean oil is the main feedstock used to produce biodiesel. One of the main drivers of biodiesel and soybean prices is the price of petroleum oil. Biodiesel wholesale prices without the RIN D4 range from 0.66 to 1.13 CAD per liter. Wholesale diesel prices in Canada range from 0.49 to 1.03 CAD per liter between 2009 and 2018.

[8] Prices in USD were converted to CAD with the corresponding monthly average exchange rate.

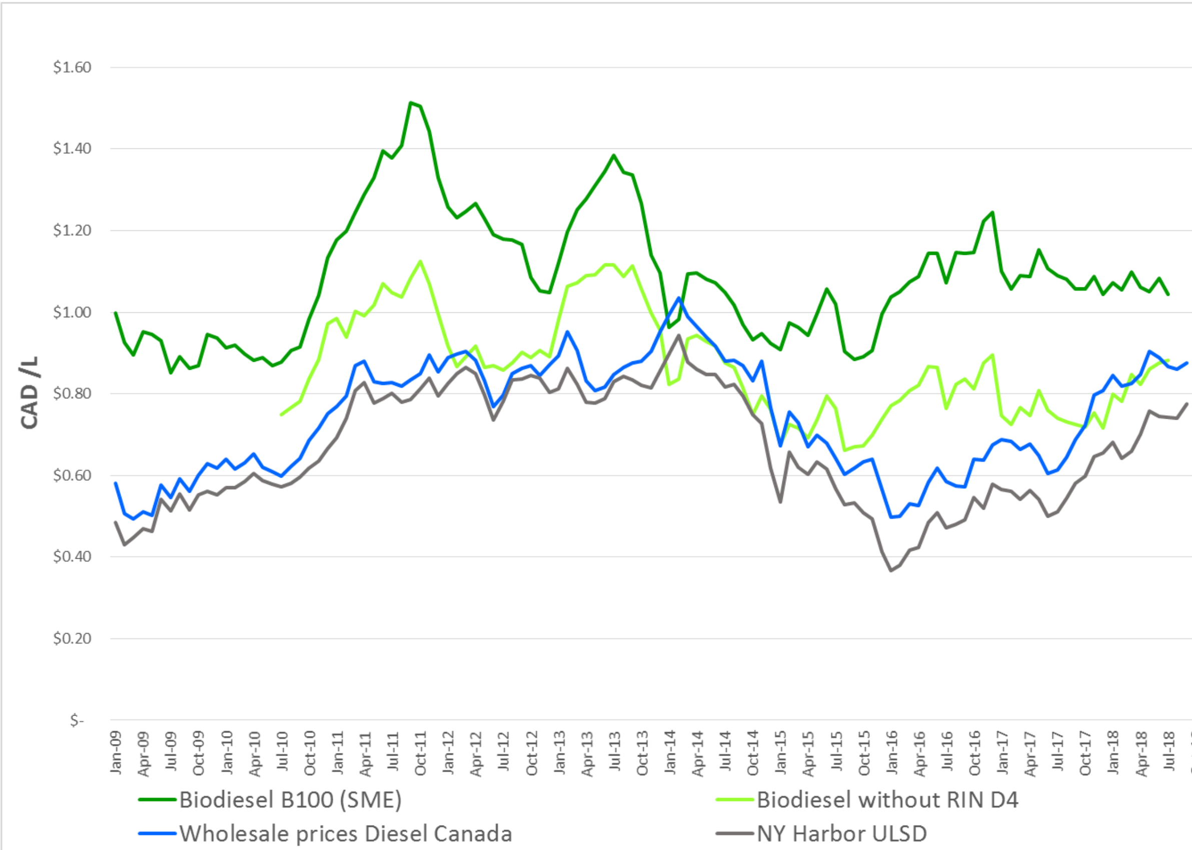


Figure 9-1 Historical prices (2009-2018) of US biodiesel (B100 SME) [86], New York Harbor Ultra-Low Sulfur No 2 Diesel [87], wholesale Diesel in Canada [88], and the RIN 4 [89]. U.S. prices converted to CAD using relevant monthly average exchange rates.

Publicly available information about production costs or wholesale prices for HDRD is very limited. In general, and to the best of our knowledge, renewable fuels cost more to produce than petroleum-based fuels, due to several factors such as greater economies of scale and lower feedstock prices in the petroleum industry. According to some authors [47] HDRD costs about 20 to 30 percent more to produce than petroleum diesel, although this is highly dependent upon the price of oil and vegetable oil feedstock. It appears that the cost to produce HDRD is dropping and it is expected to drop further as new facilities are planned for construction [47].

A reasonable way to estimate the price of HDRD would be to assume that the cost of HDRD is essentially the replacement cost for HDRD that would otherwise be supplied to the California market. California sets the standard for fuel prices due to its low carbon intensity transport fuel mandate, which will expand next year [90]. Any entity outside of California that seeks to purchase biodiesel and HDRD would have to pay at least as much as a company could earn by selling into California – accounting for the corresponding tax benefits, LCFS credits and RINs. According to Intercontinental Exchange market data (November 2019) [91], in California, there is a 4 US cent tax and a 2.4 US cent pump tax so essentially 6.4 US cents per liter in taxes from which HDRD is exempt. In November 2018, D4 RINs (the relevant category for HDRD) had a value of 19.2 US cents per liter [89]. The LCFS Credit is worth roughly 0.4 USD per liter [92]. Thus, overall, HDRD benefits from 65.6 US cents per liter worth of credits and tax benefits. As of November 2018, the ULSD spot price was roughly 0.53 USD per liter. Adding in the credits and benefits, HDRD delivered to the California market today therefore has a value of 1.2 USD per liter (1.6 CAD per liter). That is in keeping with the Diamond Green price of 1.15 USD per liter (1.5 CAD per liter) F.O.B. Norco Louisiana[9], once the transportation costs and California fuel tax exemption are factored in. Note that this calculation is done on a short-term basis; the price could change because of fluctuations in diesel price, RINs, or LCFS credits.

9.2 Financial analysis

A second approach to calculate prices is through a financial analysis. This section assesses the cost of production and financial viability of biodiesel and HDRD production from canola oil, soybean oil and yellow grease, in the Canadian context. Biodiesel facilities were assessed at two scales: 60 million litres per year (MLY) and 140 MLY. Two different co-products were assessed for the 60 MLY plant: crude glycerin and refined glycerin. The HDRD facility was assessed at a larger scale (189 MLY) relative to biodiesel. The cases assessed are listed below:

1) Biodiesel facility of 60 MLY, with crude glycerin as co-product

2) Biodiesel facility of 60 MLY, with refined glycerin as co-product

3) Biodiesel facility of 140 MLY, with crude glycerin as co-product

4) HDRD facility of 189 MLY, with light hydrocarbons as co-product

The assessment was performed using a proprietary financial model. Pre-tax Return on Investment (ROI) was used to measure the profitability of the proposed projects. The ROI used in this assessment is the average annual pre-tax return on equity invested over an 11-year project. This 11-year period includes 13 months of plant construction and start-up followed by 10 years of commercial operation. The equity investment is assumed to be 40% of the total project cost. In addition to the estimation of the production costs, the selling price of biodiesel or HDRD was estimated for a threshold ROI of 0% and 15% (threshold level to warrant investment). It is noted though that some biofuels producers will not necessarily meet the ROI. Details of the assumptions of the analysis are shown in Appendix K.

9.2.1 Production costs

The estimated production costs for the different cases are shown in Table 9-1**.** Depending on the feedstock, co-product and scale, the biodiesel production cost ranges between 0.76 and 1.17 CAD per

[9] Communication with Diamond Green

liter. The fuel production cost is sensitive to the price of the oil feedstock, resulting in higher production costs for canola and soybean. Biodiesel and HDRD from soybean oil have the highest production cost. HDRD has higher production costs compared to the biodiesel cases mainly due to the use of hydrogen in the process. Depending on the feedstock, the production cost ranges between 0.88 to 1.33 CAD per liter.

Table 9-1 Estimated production costs (All values in table are in CAD per liter)

	Biodiesel 60 MLY, crude glycerin	Biodiesel 60 MLY, refined glycerin	Biodiesel 140 MLY, crude glycerin	HDRD 189 MLY
Canola oil as feedstock	1.11	1.11	1.11	1.26
Soybean oil as feedstock	1.17	1.17	1.16	1.33
Yellow grease as feedstock	0.76	0.77	0.76	0.88

9.2.2 Assessment of selling price of biodiesel and HDRD for a threshold ROI of 15%

A second analysis was performed to determine the selling price of biodiesel for a threshold ROI of 15% (threshold level to warrant investment) (Table 9-2). Depending on the feedstock, scale and feedstock, the selling price of biodiesel ranged between 0.89 and 1.39 CAD per liter. HDRD selling prices are higher than biodiesel selling prices for a threshold ROI of 15%, and range between 1.06 and 1.48 CAN per liter, depending on the feedstock.

Table 9-2. Comparison of biodiesel and HDRD prices for a threshold ROI of 15%

	BIODIESEL 60 MLY Crude glycerin	BIODIESEL 60 MLY Refined glycerin	BIODIESEL 140 MLY Crude glycerin	HDRD 189 MLY LPG
From Canola CAD/liter	1.33	1.29	1.24	1.42
From Soybean CAD/liter	1.39	1.35	1.32	1.48
From Yellow grease CAD/liter	0.99	0.95	0.89	1.06

Based on this production cost analysis (including an expected ROI), the expected price for biodiesel could range between 0.76 and 1.39 CAD/L, excluding incentives. The corresponding projected price for HDRD could range between 0.88 and 1.48 CAD/L depending on the feedstock.

As noted above, pricing based on the California market is currently about 1.6 CAD per liter of HDRD, and the Diamond Green price is 1.5 CAD per liter, FOB Louisiana. Given that the California market price is at the upper end or above that from the production cost analysis, we can conclude that the current market price is not an artificially low artifact of market conditions. Thus, the Diamond Green and CA market prices (1.5 to 1.6 CAD per liter) should reasonably represent the expected price that the City of Toronto would have to pay for HDRD.

Similarly, the current spot biodiesel price (1.07 CAD per liter) is at the upper end of the expected production cost range for biodiesel, but at the low end of the price range when a 15% ROI is included. Thus, the current market price may face some upward pressure in order to sustain profit margins. The City of Toronto could reasonably expect to pay the current market price (or slightly above) for biodiesel. As described before, biodiesel prices are volatile and depend on several factors such as oil prices, feedstock prices and policies. In the same time, as shown in Figure 9-1, petroleum prices are very variable.

10. Conclusions and Procurement Recommendations

10.1 Infrastructure Considerations

Since the biofuel (biodiesel blend or HDRD blend) will be delivered to the City of Toronto as blended fuel, there are no infrastructure implications for the City of Toronto. As will be noted later in the Procurement Recommendations, the City of Toronto procurement documents should request that the delivered biofuel blend meet the CGSB seasonal cloud point specifications. Therefore, there is no need to heat fuel storage tanks, nor additional infrastructure required by the City of Toronto.

10.2 Biodiesel Blend Recommendations

Our recommendation is that provided the biodiesel meets CAN/CGSB-3.524 and the B5 blends meet CAN/CGSB-3.520 and B10 or B20 blends meet CAN/CGSB-3.522, including meeting the cloud point specifications, that higher blends will not result in increased maintenance costs or warranty issues. Other jurisdictions such as Minnesota mandate B20 in summer and there have been no reports of increased maintenance events with heavy-duty trucks. There are however, a couple of decision points that impact the biodiesel blend level for the City of Toronto.

1. One is the technical limitation that is based on cloud point blending for the month (or half-month) that the fuel is delivered. It is recognized that there are “diesel fuel distribution orbits” that diesel fuel is distributed to that will include the Toronto area but may extend beyond Toronto. It is the responsibility of the successful respondent to the procurement RFP to manage the blended cloud point such that the cloud point requirements in Table 4-1 are met.
2. Another is the OEM Warranty considerations. In the case of some of the older vehicles, the warranty has expired and so it is arguably a moot point. Detroit Diesel (now Daimler) is the only OEM for more recent vehicles that still only approves B5 for some models. In discussion with Detroit Diesel warranty representatives, there may be the possibility of using higher than B5 blends at your own risk. Other jurisdictions have used higher than B5 blends under this scenario. Therefore, the decision to use blends higher than B5 is not high risk in our judgment and is unlikely to increase maintenance costs, based upon the information available and historical use of biodiesel. It may be more a function of the level of comfort by the City of Toronto in this regard.
3. The third is the cost of biodiesel. Biodiesel is lower cost than HDRD, but the biodiesel blend level may be dictated by economics. The California market also has some impact on this price.

The option of blending both HDRD and biodiesel together has been shown to have synergistic benefits in blending, which was presented again recently at the Alberta government All Season Operability Workshop (December 4, 2018).

10.3 Biodiesel Supplier Recommendations

Currently, the two main suppliers to the Ontario market are REG and World Energy BIOX. The BIOX biodiesel plant in Hamilton is logical as they are close to Toronto and have an across the fence arrangement with Shell for biodiesel supply to the Ontario market.

10.4 HDRD Blend Recommendations

There are some limitations on HDRD blends based on cloud point. As noted in the example tables in Section 4, the cloud point of the HDRD will impact the cloud point of the blended fuel. This will also be governed by the month of delivery for the blended fuel and corresponding CGSB cloud point specification (Section 4 Table 4-1). The cloud points for 5% HDRD and 10% HDRD blends are shown in Table 4-7 and 4-8, respectively. No OEMs have any statements on blend level limitations for HDRD, although this is not a limitation due to the function equivalence between HDRD and petroleum diesel.

It should also be noted that winter HDRD typically commands a higher price than summer HDRD, due to the lower cloud point. This may also impact the HDRD blend level in shoulder seasons and winter. The caveat to that is that FORGE Hydrocarbons, although not yet at commercial scale, has one cloud point and thus will presumably have the same price year round.

10.5 HDRD Supplier Recommendations

Currently, the two main suppliers to the Ontario market are Neste and Diamond Green Diesel. The most recent price obtained from Diamond Green Diesel was $4.35 USD/gal F.O.B Norco, Louisiana. That is $1.15 per litre USD. Converted to CDN this is approximately $1.50 per litre, not including freight to Toronto or wherever the blending is being done. The latest HDRD price for Neste product delivered to BC was $1.70 per litre. In both cases, the price for HDRD is being driven by the California market, which provides significant incentives to biofuel producers; these incentives are ultimately built into the price for fuel delivered to other markets. The FORGE Hydrocarbons plant in Sombra, Ontario is anticipated to deliver HDRD at a lower cost, but the plant will not be online until 2020, and therefore too late for the City’s next procurement contract. Thus, the limitation on HDRD blending level is not technical, but rather economic.

10.6 TTC Specific Considerations

The City of Toronto and the TTC will need to discuss their willingness to blend above B5. As noted above, our judgment is that blending above B5 will not result in operational or maintenance issues if blended to meet the CGSB cloud point specifications. However, it is recognized that Fleet Services and the TTC are sensitive to their customer base and hence may have some hesitancy to blend above B5. This may impact the decision by the City of Toronto in the overall procurement contract and could result in a maximum of B5, in combination with some HDRD to achieve higher biofuel content.

The TTC gensets will be limited to B0 because they don't have fuel turnover at regular intervals, but rather, are simply topped up as needed. This mode of operation means that Fleet Services will prefer B0 (or HDRD) for its gensets as well. This is a small volume and since each of the City of Toronto and TTC will be delivered fuel to the respective fuel storage tanks by the awardee of the procurement contract, this is manageable.

10.7 Fuel Blending:

Our recommendation is that the manner in which the biofuel is blended by the respondents to the RFP should not be prescriptive. In-line blending is preferred. However, our recommendation is that rather than being prescriptive, since the biofuel will be supplied as a blend with diesel fuel, the respondents to the RFP need to provide sufficient information in their submission to demonstrate that the fuel delivered to the City of Toronto will be homogeneous and blended according to accepted biofuel blending practices.

10.8 Carbon intensity values:

The analyses in Sections 7 and 8 suggests that both biodiesel and HDRD can play a role in reducing life cycle GHG emissions from diesel fuel consumption, with no major concerns and likely some benefits for air quality. The City may wish to consider more specific carbon intensity values reported directly by potential suppliers for further analysis of the expected GHG emission reductions resulting from use of higher blends of biodiesel or HDRD.

10.9 Overall recommendations:

From a technical standpoint, as mentioned, we are comfortable recommending B5 in winter, and higher blends such as B10 in spring and fall, and B20 in summer. However, practical considerations such as OEM warranty and cost as noted above must be considered. The City of Toronto will need to come to terms with these practical considerations prior to issuing the RFP for the procurement contract.

The procurement document should have the flexibility to provide the respondents with the ability to maximize biofuel use as economically as possible, while meeting the seasonal cloud point requirements and biofuel content prescribed by the City of Toronto.

It should be noted that this diesel fuel supply contract would enable some obligated parties to meet their requirements under the Ontario Greener Diesel Mandate. Although that cannot be easily monetized, there is value, which the respondents will need to include in their economic considerations.

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Appendix A: Chemical Structures of Biodiesel and Renewable Diesel

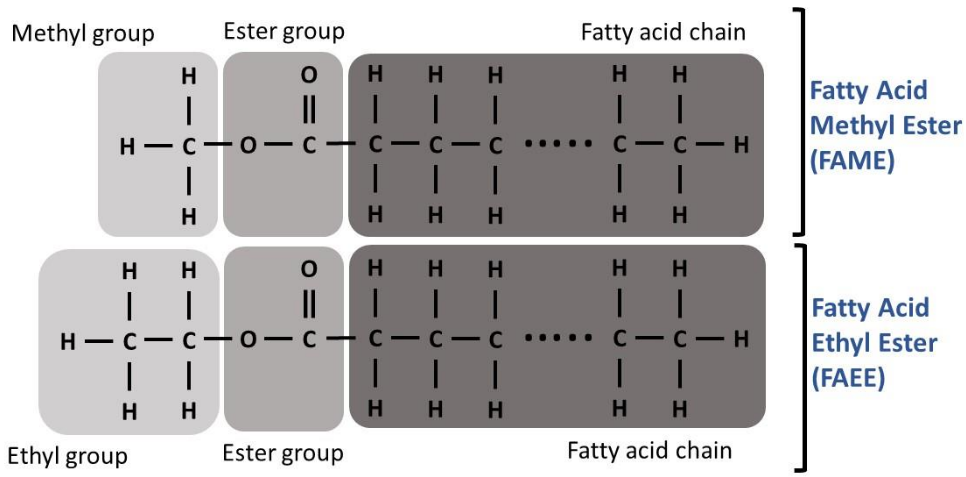

Figure A-1: A breakdown of two common biodiesel compounds into its structural groups.

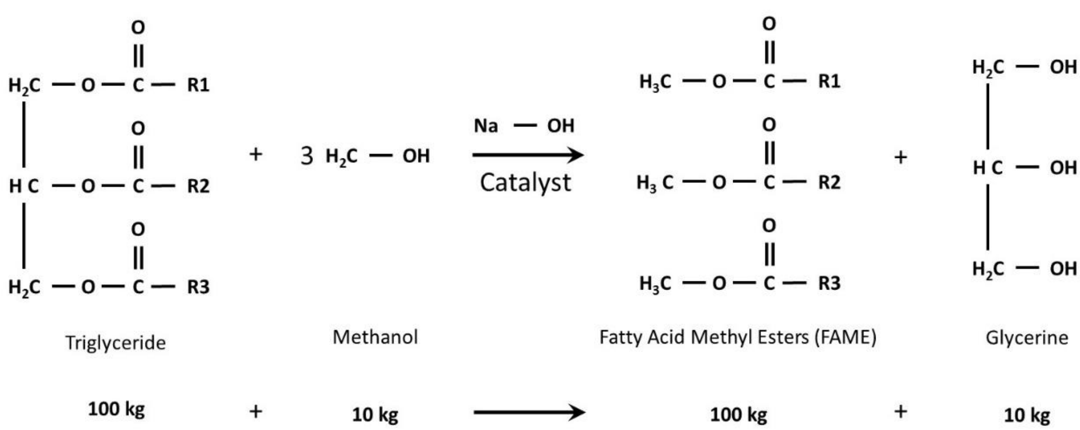

Figure A-2: The material balance and stoichiometric reaction of biodiesel production through transesterification

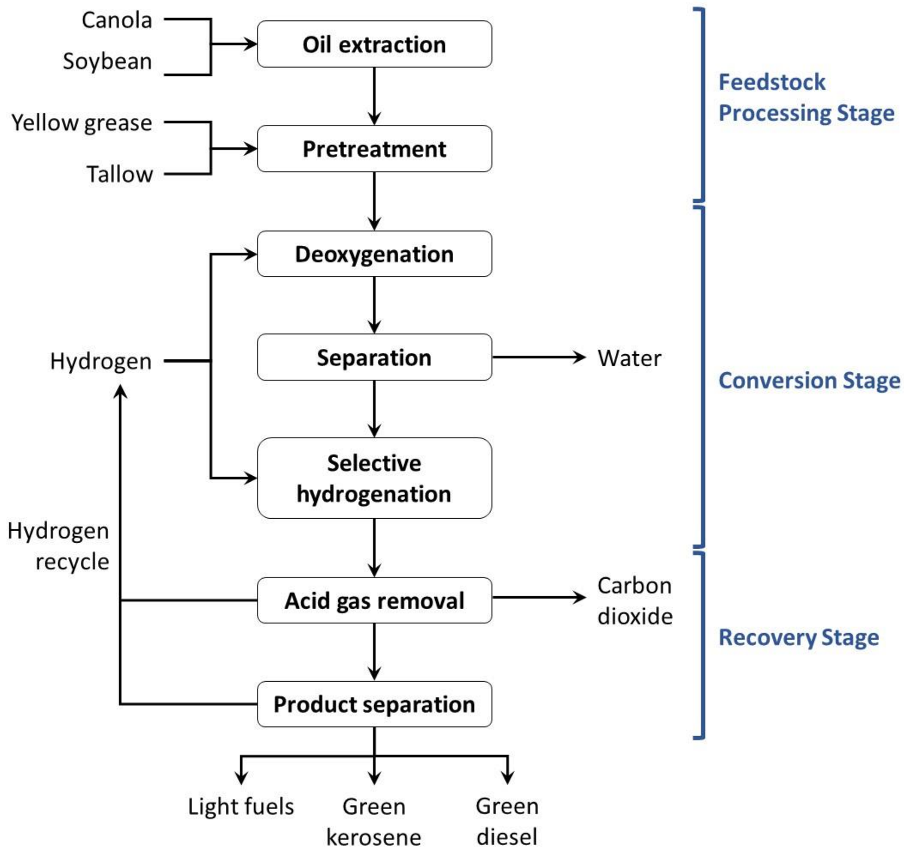

Figure A-3: General process flow of HDRD production

In the conversion stage, the deoxygenation step removes oxygen molecules from the feedstock via three parallel reactions: a) decarbonylation, where oxygen is removed through the loss of carbon monoxide (CO); b) decarboxylation, where oxygen is removed through the loss of carbon dioxide (CO_2); c) hydro-deoxygenation, where oxygen is removed through the loss of water (H_2O). The elimination of oxygen through hydrodeoxygenation preserves the number of carbons in the fatty acids but requires input of hydrogen gas as a reactant. Through these reactions, most of the glycerol backbone in the original triglyceride (Figure A-1) is converted to propane, while most of the carboxyl carbons are converted to CO or CO_2. The ratio of these products (CO, CO_2 and propane) varies with the catalyst and operating conditions being used. Since triglyceride compositions are dominated by fatty acid components with an even number of carbon atoms, removal of the carboxyl group results in biodistillates containing odd-numbered alkanes. The ratio of odd to even numbered alkanes in the renewable diesel is indicative of the selectivity of decarboxylation/decarbonylation reactions relative to hydrodeoxygenation. This fact could provide a useful way to determine the renewable diesel content in a blend of petroleum diesel fuel. As part of the conversion process, the reacted product stream goes through a selective hydrogenation as a polishing step to isomerize, and remove residual impurities such as oxygen or sulfur. The conversion reactions generate HDRD as well as other fuel co-products such as light fuels and green kerosene, all which would need to be accounted for when estimating the GHG emissions.

Appendix B: Biodiesel properties

Table B-1: Fatty acid profiles of biodiesel feedstocks[10,11,12,13]

Fatty acid (wt.%)	Canola (Rapeseed)	Soybean	Yellow Grease	Tallow
C14:0	0	0	0	2.5
C16:0	3.0	11.0	13.1	32.3
C18:0	1.0	4.0	3.8	25.2
C18:1	17.0	22.0	36.2	37.1
C20:1	11.0	0	0	0
C22:1	45.0	0	0	0
C18:2	14.0	53.0	43.3	2.9
C18:3	9.0	8.0	3.6	0
% Oil content (dry-basis)	42	19	-	-

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Table B-2: Select properties of Typical No. 2 diesel and Typical B100.

Fuel Property	Typical Petroleum Diesel	Typical B100
Higher heating value, MJ/L	38.6	33.3
Lower heating value, MJ/L	36.1	35.7
Kinematic viscosity at 40 °C (104 °F)	1.3 – 4.1	4.0 – 6.0
Specific gravity at 15.5 °C (60 °F)	0.85	0.88
Density, lb/gal at 15.5 °C (60 °F)	7.1	7.3
Carbon, wt %	87	77
Hydrogen, wt %	13	12
Oxygen, by dif. wt %	0	11
Boiling point, °C	180 – 340	315 – 350
Flash point, °C	52 – 60	100 – 170
Cloud point, °C	-35 – 5	-3 – 15
Pour point, °C	-35 – -15	-5 – 10
Cetane number	40 – 55	47 – 65

Appendix C: Biodiesel Availability in Canada

The Canadian production capacity for biodiesel in 2015 was 657 million litres per year, with nearly half the installed production capacity being located in Ontario.[14] Table C-1 provides more detailed Canadian biodiesel production and disposition statistics (using a different data source, [15] which provides slightly different installed capacity than the number quoted above). In 2017, Canada was forecast to produce 550 million litres of biodiesel, with over half that volume being exported (mostly to the U.S., due to their federal incentives) and a nearly equivalent volume being imported (primarily from Washington State, Iowa, North Dakota and Louisiana). Primary feedstocks for production in Canada are canola, animal fat (tallow), and used cooking oil. In 2017, used cooking oil was forecast to be the dominant feedstock with 46% of total feedstock supply, followed by canola at 29%, soybean oil and 20% and tallow at 5%. Renewable diesel is not currently produced in Canada, but approximately 250 million litres are imported annually.[16] Note that the City of Toronto is expected to procure a blended fuel, and will not likely be responsible for contracting with a specific biodiesel producer.

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[14] http://ricanada.org/wp-content/uploads/2015/03/Canadian-Ethanol-and-Biodiesel-Facilities-Producer-Tables-for-Website.pdf.

[15] https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Ottawa_Canada_8-9-2016.pdf.

[16] Ibid.

Table C-1: Canadian biodiesel production and use statistics and feedstocks 2008-2017

Biodiesel, Million Litres										
Biodiesel										
Calendar Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Production	95	110	115	120	100	140	290	340	400	550
Imports	20	15	100	170	261	307	269	300	270	270
Exports	95	105	110	80	85	123	225	240	380	300
Consumption	20	20	96	210	291	308	334	400	290	520
Production Capacity										
Number of Plants	5	7	13	9	8	8	8	9	10	10
Nameplate Capacity	131	162	258	225	223	400	400	400	550	600
Capacity Use (%)	73%	68%	45%	53%	45%	35%	73%	85%	73%	92%
Feedstock Use for Biodiesel (1,000 MT)										
Canola Oil	2	3	3	7	7	35	152	220	220	220
Animal Fats	85	78	78	63	26	30	36	37	37	37
Used Cooking Oil	3	20	27	46	65	65	84	143	293	343
Soybean oil	0	1	1	1	0	1	0	0	50	150

Source: Canadian government and industry sources with FAS/Ottawa analysis.

Appendix D: Description of Test Properties

Acid Number

The acid number is used to determine the level of free fatty acids or processing acids that may be present in biodiesel. Biodiesel with a high acid number has been shown to increase fueling system deposits and may increase the likelihood for corrosion. Acid number measures a different phenomenon for biodiesel than petroleum-based diesel fuel. The acid number for biodiesel measures free fatty acids or degradation by-products not found in petroleum-based diesel fuel. Increased recycle temperatures in new fuel system designs may accelerate fuel degradation, which could result in high acid values and increased filter plugging potential. The Acid number limit in CGSB and ASTM biodiesel specifications has been shown to mitigate this risk.

Oxidation Stability

Products of oxidation in biodiesel can take the form of various acids or polymers, which, if in high enough concentration, can cause fuel system deposits and lead to filter clogging and fuel system malfunctions. Additives designed to retard the formation of acids and polymers can significantly improve the oxidation stability performance of biodiesel.

Free Glycerin

The free glycerin method is used to determine the level of glycerin in the fuel. High levels of free glycerin can cause injector deposits, as well as clogged fueling systems, and result in a buildup of free glycerin in the bottom of storage and fueling systems. The Acid number limit in CGSB and ASTM biodiesel specifications has been shown to mitigate this risk.

Total Glycerin

The total glycerin method is used to determine the level of glycerin in the fuel and includes the free glycerin and the glycerine portion of any unreacted or partially reacted oil or fat. Low levels of total glycerin ensure that high conversion of the oil or fat into its mono-alkyl esters has taken place. High levels of mono-, di-, and triglycerides can cause injector deposits and may adversely affect cold weather operation and filter plugging. The Acid number limit in CGSB and ASTM biodiesel specifications has been shown to mitigate this risk.

Phosphorous

Phosphorus can damage catalytic converters used in emissions control systems and its level must be kept low. Catalytic converters are becoming more common on diesel powered equipment as emissions standards are tightened, so low phosphorus levels will be of increasing importance. Biodiesel produced from U.S. sources has been shown to have low phosphorus content (below 1 ppm) and the specification value of 10 ppm maximum is not problematic. Biodiesel from other sources may or may not contain higher levels of phosphorus and this specification was added to ensure that all biodiesel, regardless of the source, has low phosphorus content.

Calcium and Magnesium

Calcium and magnesium may be present in biodiesel as abrasive solids or soluble metallic soaps. Abrasive solids can contribute to injector, fuel pump, piston, and ring wear, as well as to engine deposits. Soluble metallic soaps have little effect on wear, but they may contribute to filter plugging and engine deposits. High levels of calcium and magnesium compounds may also be collected in exhaust particulate removal devices, are not typically removed during passive or active regeneration, and can create increased back pressure and reduced time to service maintenance. The limit in CGSB and ASTM biodiesel specifications has been shown to mitigate this risk. The specification limit in the CGSB biodiesel specification is the test method lower detection limit.

Sodium and Potassium

Sodium and potassium may be present in biodiesel as abrasive solids or soluble metallic soaps. Abrasive solids can contribute to injector, fuel pump, piston and ring wear, and also to engine deposits. Soluble metallic soaps have little effect on wear, but they may contribute to filter plugging and engine deposits. High levels of sodium or potassium compounds may also be collected in exhaust particulate removal devices, are not typically removed during passive or active regeneration, and they can create increased back pressure and reduced period to service maintenance. The limit in CGSB and ASTM biodiesel specifications has been shown to mitigate this risk. The specification limit in the CGSB biodiesel specification is the test method lower detection limit.

CSFT (Cold Soak Filtration Test)

The ASTM D7501 Standard Test Method for Determination of Fuel Filter Blocking Potential of Biodiesel (B100) Blend was developed to detect any minor impurities that may cause filter blocking or otherwise seed additional formation of precipitates. This includes sterol glucosides, saturated monoglycerides or residual soaps. The CSFT limit in CGSB and ASTM biodiesel specifications has been shown to mitigate this risk.

CSFBT (Cold Soak Filter Blocking Tendency)

The CSFBT is complementary to the Cold Soak Filtration Test (CSFT). The CSFBT can detect trace constituents of low solubility that are not detected by ASTM D7501. Minor components of some biodiesel, including saturated monoglycerides, can separate above the cloud point of a biodiesel fuel blend. The CSFBT test quantifies the propensity of these materials to separate from a biodiesel, diluted with iso-paraffinic solvent.

Sulfated Ash

Ash-forming materials may be present in biodiesel in three forms: (1) abrasive solids, (2) soluble metallic soaps, and (3) unremoved catalysts. Abrasive solids and unremoved catalysts can contribute to injector, fuel pump, piston and ring wear, and also to engine deposits. Soluble metallic soaps have little effect on wear but may contribute to filter plugging and engine deposits. The test has been retained despite the fact that the CSFT and metals limits in the CGSB and ASTM biodiesel specification in large part addresses the risks noted above.

Carbon Residue

Carbon residue gives a measure of the carbon depositing tendencies of a fuel oil. While not directly correlating with engine deposits, this property is considered an approximation.

Lubricity

In certain items of fuel injection equipment in compression ignition engines, such as rotary/distributor fuel pumps and injectors, the fuel functions as a lubricant as well as a source for combustion. Blending biodiesel fuel with petroleum-based compression-ignition fuel typically improves fuel lubricity.

Appendix E: Diesel Distribution Supply Zones for Ontario

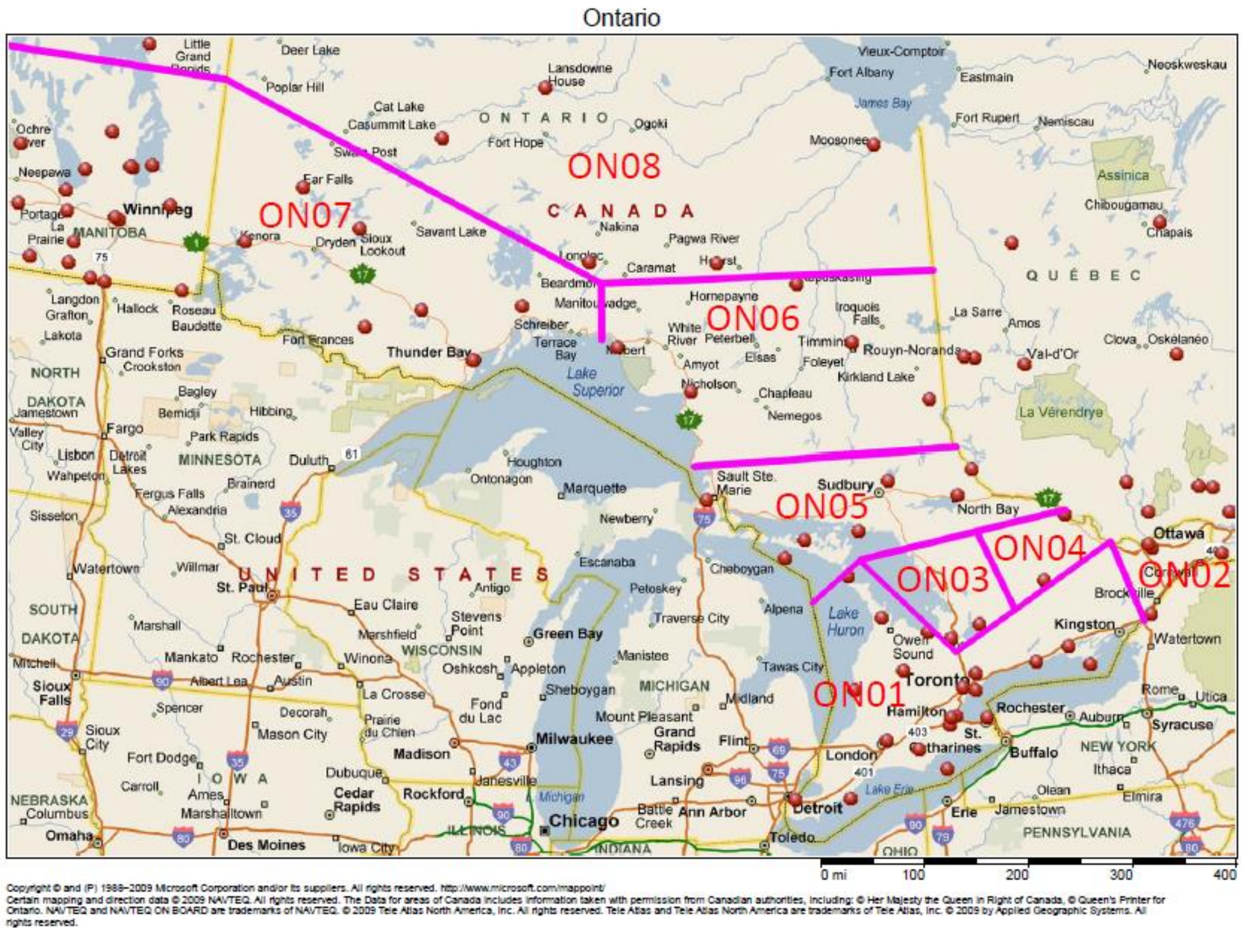

Figure E-1: Low Temperature Operability Zones for Ontario ('Terminal Orbits') [26]

Table E-1: 2.5 % Low End Design Temperature (Ontario) [26]

Ontario Zone Comparison 2014

MONTH	PERIOD	ON01 Cloud Pt °C	ON02 Cloud Pt °C	ON03 Cloud Pt °C	ON04 Cloud Pt °C	ON05 Cloud Pt °C	ON06 Cloud Pt °C	ON07 Cloud Pt °C	ON08 Cloud Pt °C
January	1st Half	-23	-25	-25	-30	-29	-35	-34	-38
	2nd Half	-22	-25	-24	-30	-29	-34	-34	-38
February	1st Half	-20	-22	-22	-28	-26	-32	-34	-36
	2nd Half	-18	-21	-21	-27	-23	-30	-29	-36
March	1st Half	-18	-19	-18	-23	-22	-28	-28	-34
	2nd Half	-12	-12	-13	-16	-16	-22	-21	-29
April	1st Half	-7	-6	-7	-8	-10	-16	-14	-23
	2nd Half	-3	-1	-3	-5	-5	-9	-8	-16
May	1st Half	-1	-1	-1	-3	-1	-4	-4	-9
	2nd Half	-1	-1	-1	-1	-1	-2	-2	-5
June	1st Half	-1	-1	-1	-1	-1	-1	-1	-2
	2nd Half	-1	-1	-1	-1	-1	-1	-1	-1
July	1st Half	-1	-1	-1	-1	-1	-1	-1	-1
	2nd Half	-1	-1	-1	-1	-1	-1	-1	-1
August	1st Half	-1	-1	-1	-1	-1	-1	-1	-1
	2nd Half	-1	-1	-1	-1	-1	-1	-2	-1
September	1st Half	-1	-1	-1	-3	-1	-3	-4	-5
	2nd Half	-2	-2	-2	-6	-4	-6	-8	-10
October	1st Half	-6	-6	-7	-9	-10	-15	-16	-20
	2nd Half	-9	-10	-10	-15	-14	-20	-22	-27
November	1st Half	-16	-19	-17	-23	-22	-28	-29	-33
	2nd Half	-18	-22	-19	-26	-26	-32	-32	-37
December	1st Half	-23	-25	-25	-29	-29	-35	-34	-38
	2nd Half	-23	-25	-25	-30	-29	-35	-34	-38

Appendix F: OEM Warranty Approvals for City of Toronto On-Road Vehicles

Table F-1: City of Toronto Fleet Services On-Road Vehicle List

#	Year	Make	Model	Category Class	Category Description	OEM Blend Approved
24	2008	AUTOCAR	EXPEDITOR	CLASS8	CLASS 8 PACKER - AUTOMATED	B20
1	2006	BLUE BIRD	VISION	CLASS4/5	CLASS 4/5 BUS	B5
3	2009 - 2010	CHEVROLET	2500HD	CLASS2	PICK UP - 3/4 TON STD OR EXT CAB 4X4	B5
1	2009	CHEVROLET	EXPRESS 2500	CLASS2	CLASS 2/3 VAN - CARGO 200 SERIES	B5
3	2005	CHEVROLET	SILVERADO	CLASS3	CLASS 2/3 TRUCK DUMP - CREW CAB	B5
1	2001	CHEVROLET	3500	CLASS4/5	CLASS 4/5 TRUCK - UTILITY	B5
2	2002	CHEVROLET	C3500 HD	CLASS4/5	CLASS 4/5 TRUCK - FLATBED	B5
30	2005 - 2007	CHEVROLET	C5500	CLASS4/5	CLASS 4/5 BUS	B5
14	2009	DODGE	2500	CLASS2	PICK UP - 3/4 TON STD OR EXT CAB 4X4	B20
11	2007	DODGE	RAM 2500	CLASS2	PICK UP - 3/4 TON STD OR EXT CAB 4X2	B20
94	2011 - 2015	DODGE	RAM 2500	CLASS2	PICK UP - 3/4 TON STD OR EXT CAB 4X2	B20
9	2005 - 2006	DODGE	RAM 3500	CLASS2	PICK UP - 1 TON STD OR EXT CAB 4X2	B5
42	2007 - 2010	DODGE	RAM 3500	CLASS2	PICK UP - 1 TON STD OR EXT CAB 4X2	B20

37	2011 - 2016	DODGE	RAM 3500	CLASS2	PICK UP - 1 TON STD OR EXT CAB 4X2	B20
26	2004 - 2009	DODGE	SPRINTER2500	CLASS2	CLASS 2/3 VAN - CARGO 200 SERIES	B5
6	2008 - 2009	DODGE	SPRINTER3500	CLASS2	CLASS 2/3 VAN - CARGO 300 SERIES	B5
3	2008	DODGE	4500	CLASS4/5	CLASS 4/5 TRUCK - FLATBED	B5
1	2012	DODGE	4500	CLASS4/5	CLASS 4/5 TRUCK - FLATBED	B20
2	2008	DODGE	RAM 4500	CLASS4/5	CLASS 4/5 TRUCK - FLATBED	B20
30	2011 - 2015	DODGE	RAM 4500	CLASS4/5	CLASS 4/5 TRUCK - FLATBED	B20
315						
58	2002 - 2010	FORD	F250	CLASS2	PICK UP - 3/4 TON STD OR EXT CAB 4X2	B5
120	2011 - 2017	FORD	F250	CLASS2	PICK UP - 3/4 TON STD OR EXT CAB 4X4	B20
8	2001 - 2010	FORD	E350	CLASS2	CLASS 2/3 VAN - CARGO 300 SERIES	B5
32	2002 - 2010	FORD	F350	CLASS2	PICK UP - 1 TON STD OR EXT CAB 4X4	B5
33	2015 - 2016	FORD	F350	CLASS2	PICK UP - 1 TON CREW CAB 4X4	B20
1	2015	FORD	TRANSIT 350	CLASS2	CLASS 2/3 VAN - CARGO 300 SERIES	B20
2	2012	FORD	F350 S. DUTY	CLASS3	CLASS 2/3 TRUCK - UTILITY	B20
1	2006	FORD	CLUB WAGON	CLASS3	CLASS 2/3 MINI BUS	B5
1	1995	FORD	CLUB WAGON		BUS	B5
1	1993	FORD			TRUCK-DUMP TRUCK	B5
3	2004 - 2006	FORD	F350	CLASS3	CLASS 2/3 TRUCK DUMP - CREW CAB	B5

13	2000 - 2010	FORD	F350	CLASS3	CLASS 2/3 TRUCK DUMP - CREW CAB	B5
14	2003 - 2010	FORD	F350	CLASS3	CLASS 2/3 TRUCK - UTILITY	B5
1	1990	FORD	F350		TRUCK-DUMP WITH 8 YEAR LIFE	B5
7	2001 - 2008	FORD	E450	CLASS4/5	CLASS 4/5 VAN - CUBE	B5
2	2006	FORD	E450		BUS	B5
7	2002	FORD	E450 S. DUTY	CLASS4/5	CLASS 4/5 VAN - CUBE	B5
6	2005 - 2009	FORD	F450	CLASS4/5	CLASS 4/5 TRUCK - UTILITY	B5
1	2005	FORD	F450	CLASS4/5	CLASS 4/5 PACKER - SIDE LOADING	B5
41	2002 - 2009	FORD	F450	CLASS4/5	CLASS 4/5 TRUCK DUMP - SINGLE AXLE	B5
19	2011 - 2017	FORD	F450	CLASS4/5	CLASS 4/5 TRUCK - UTILITY	B20
75	2011 - 2017	FORD	F450	CLASS4/5	CLASS 4/5 TRUCK DUMP - SINGLE AXLE	B20
1	2008	FORD	F550	CLASS4/5	CLASS 4/5 VAN - CUBE	B5
4	2004 - 2008	FORD	F550	CLASS4/5	CLASS 4/5 TRUCK - FLATBED	B5
36	2004 - 2010	FORD	F550	CLASS4/5	CLASS 4/5 TRUCK - UTILITY	B5
9	2007 - 2010	FORD	F550	CLASS4/5	CLASS 4/5 PACKER - SIDE LOADING	B5
4	2003 - 2007	FORD	F550	CLASS4/5	CLASS 4/5 TRUCK DUMP - SINGLE AXLE	B5
34	2011 - 2017	FORD	F550	CLASS4/5	CLASS 4/5 TRUCK - UTILITY	B20
7	2011 - 2015	FORD	F550	CLASS4/5	CLASS 4/5 PACKER - SIDE LOADING	B20
2	2003 - 2010	FORD	F650	CLASS4/5	CLASS 4/5 TRUCK - FLATBED	B5

15	2001 - 2010	FORD	F650	CLASS6/7	CLASS 6/7 TRUCK DUMP - SINGLE AXLE	B5
2	2006	FORD	F650	CLASS6/7	CLASS 6/7 TRUCK - UTILITY	B5
1	2012	FORD	F650	CLASS6/7	CLASS 6/7 TRUCK DUMP - SINGLE AXLE	B20
1	2017	FORD	F650	CLASS6/7	CLASS 6/7 VAN - CUBE	B20
2	1991	FORD	L8000	CLASS8	CLASS 8 TRUCK - SEWER	B5
564						
15	2006 - 2007	FREIGHTLNR	FC80	ST_CLEAN	STREET SWEEPER	
1	2002	FREIGHTLNR	MT45	CLASS4/5	CLASS 4/5 VAN - CUBE	B20
1	2016	FREIGHTLNR	MT55	CLASS4/5	CLASS 4/5 BUS	B20
1	2012	FREIGHTLNR	CHASIS	CLASS6/7	CLASS 6/7 BUS	B20
1	2015	FREIGHTLNR	M2 106	CLASS4/5	CLASS 4/5 VAN - CUBE	B20
3	2016	FREIGHTLNR	M2 106	CLASS6/7	CLASS 6/7 VAN - CUBE	B20
2	2010	FREIGHTLNR	M2 106	CLASS6/7	CLASS 6/7 TRUCK DUMP - SINGLE AXLE	B20
2	2016	FREIGHTLNR	M2 106	CLASS6/7	CLASS 6/7 TRUCK DUMP - SINGLE AXLE	B20
2	2017	FREIGHTLNR	M2 106	CLASS6/7	CLASS 6/7 TRUCK - UTILITY	B20
1	2016	FREIGHTLNR	M2 106	CLASS6/7	CLASS 6/7 TRUCK - FLATBED	B20
2	2003	FREIGHTLNR	FL70	CLASS6/7	CLASS 6/7 TRUCK DUMP - SINGLE AXLE	B20
1	1995	FREIGHTLNR	FL80	CLASS8	CLASS 8 TRUCK - TRACTOR	B5
1	2001	FREIGHTLNR	FL80		PACKER-REAR LOADING	B20

2	2003	FREIGHTLNR	FL80	CLASS8	CLASS 8 TRUCK - SEWER	B20
1	2003	FREIGHTLNR	FL80	CLASS8	CLASS 8 TRUCK DUMP - TANDEM AXLE	B20
17	2011 - 2017	FREIGHTLNR	CASCADIA 125	CLASS8	CLASS 8 TRUCK - TRACTOR	B5
9	2010	FREIGHTLNR	FLD120	CLASS8	CLASS 8 TRUCK - TRACTOR	B20
9	2005 - 2009	FREIGHTLNR	FLD120SD	CLASS8	CLASS 8 TRUCK - TRACTOR	B20
11	2007	FREIGHTLNR	FLD12064SDT	CLASS8	CLASS 8 TRUCK - TRACTOR	B20
1	2004	FREIGHTLNR	M2 106	CLASS8	PACKER-REAR LOADING	B20
5	2009	FREIGHTLNR	M2 106	CLASS8	CLASS 8 PACKER - SIDE LOADING	B20
2	2010 - 2011	FREIGHTLNR	M2 106	CLASS8	CLASS 8 TRUCK - FLATBED	B20
1	2010	FREIGHTLNR	M2 106	CLASS8	CLASS 8 TRUCK - SEWER	B20
1	2010	FREIGHTLNR	M2 106	CLASS8	CLASS 8 PACKER - REAR LOADING	B20
2	2006	FREIGHTLNR	M2 106	CLASS8	CLASS 8 PACKER - SIDE LOADING	B20
6	2012 - 2013	FREIGHTLNR	M2 106	CLASS8	CLASS 8 TRUCK-FLATBED	B20
9	2011	FREIGHTLNR	M2 106	CLASS8	CLASS 8 TRUCK DUMP - SINGLE AXLE	B20
16	2011 - 2017	FREIGHTLNR	M2 106	CLASS8	CLASS 8 TRUCK DUMP - TANDEM AXLE	B20
1	2013	FREIGHTLNR	M2 108SD	CLASS8	CLASS 8 TRUCK - FLATBED WITH CRANE	B20
15	2013 - 2015	FREIGHTLNR	M2 108SD	CLASS8	CLASS 8 TRUCK DUMP - TANDEM AXLE	B20
2	2009 - 2010	FREIGHTLNR	M2112	CLASS8	CLASS 8 TRUCK - SEWER	B20
20	2010	FREIGHTLNR	M2112	CLASS8	CLASS 8 PACKER - SIDE LOADING	B20

163						
7	2007	GMC	SIERRA 3500	CLASS2	PICK UP - 1 TON CREW CAB 4X2	B5
3	2007 - 2009	GMC	SAVANA	CLASS2	CLASS 2/3 VAN - CARGO 200 SERIES	B5
1	2005	GMC	2500HD	CLASS2	PICK UP - 3/4 TON STD OR EXT CAB 4X2	B5
1	1991	GMC	3500	CLASS3	CLASS 2/3 TRUCK DUMP - CREW CAB	B5
5	2007	GMC	SIERRA 3500	CLASS4/5	CLASS 4/5 TRUCK DUMP - SINGLE AXLE	B5
1	2009	GMC	T7500	CLASS6/7	CLASS 6/7 VAN - CUBE	B5
1	2004	GMC	C6500	CLASS6/7	CLASS 6/7 TRUCK - FLATBED	B5
1	2004	GMC	TC6E042	CLASS6/7	CLASS 6/7 TRUCK - FLATBED	B5
7	2002 - 2009	GMC	TC7E042	CLASS6/7	CLASS 6/7 TRUCK DUMP - SINGLE AXLE	B5
3	2008	GMC	TSR	CLASS6/7	CLASS 6/7 TRUCK - FLATBED	B5
1	1995	GMC	WX64T	CLASS8	CLASS 8 TRUCK - SEWER	B5
5	2008	GMC	C8500	CLASS8	CLASS 8 TRUCK DUMP - SINGLE AXLE	B5
1	2009	GMC	TC8C64	CLASS8	CLASS 8 TRUCK DUMP - TANDEM AXLE	B5
2	2007	GMC	550	CLASS8	CLASS 8 TRUCK-FLATBED	B5
39						
6	2008 - 2010	HINO	185	CLASS4/5	CLASS 4/5 VAN - CUBE	B5
6						
4	2013	INTERNATIONAL	TERRA STAR	CLASS4/5	CLASS 4/5 VAN - CUBE	B5

19	2011 - 2018	INTERNATIONAL	4300	CLASS6/7	CLASS 6/7 VAN - CUBE	B5
2	2005	INTERNATIONAL	4200	CLASS6/7	CLASS 6/7 TRUCK DUMP - SINGLE AXLE	B5
23	2010 - 2013	INTERNATIONAL	4300	CLASS6/7	CLASS 6/7 TRUCK DUMP - SINGLE AXLE	B20
1	2006	INTERNATIONAL	4200	CLASS6/7	CLASS 6/7 TRUCK - FLATBED	B5
1	2005	INTERNATIONAL	4300	CLASS6/7	CLASS 6/7 TRUCK DUMP - AERIAL	B5
15	2010	INTERNATIONAL	4300	CLASS6/7	CLASS 6/7 TRUCK - UTILITY	B20
27	2010	INTERNATIONAL	4300	CLASS6/7	CLASS 6/7 PACKER - SIDE LOADING	B20
1	2013	INTERNATIONAL	4300	CLASS6/7	CLASS 6/7 TRUCK - SEWER	B20
2	2016	INTERNATIONAL	4400	CLASS6/7	CLASS 6/7 TRUCK DUMP - SINGLE AXLE	B5
1	1996	INTERNATIONAL	4700	CLASS6/7	CLASS 6/7 TRUCK DUMP - SINGLE AXLE	B5
2	2001	INTERNATIONAL	4700	CLASS6/7	CLASS 6/7 TRUCK DUMP - SINGLE AXLE	B5
1	2001	INTERNATIONAL	4700	CLASS6/7	CLASS 6/7 TRUCK - FLATBED	B5
1	1991	INTERNATIONAL	5 TON	CLASS8	CLASS 8 TRUCK - SEWER	B5
1	2005	INTERNATIONAL	4200	CLASS8	CLASS 8 TRUCK - FLATBED	B5
8	2007	INTERNATIONAL	4200	CLASS8	CLASS 8 TRUCK DUMP - AERIAL	B5
3	2011 - 2016	INTERNATIONAL	4300	CLASS8	CLASS 8 BUS	B20
2	2008	INTERNATIONAL	4300	CLASS8	CLASS 8 TRUCK - FLATBED	B20
5	2008	INTERNATIONAL	4300	CLASS8	CLASS 8 TRUCK DUMP - AERIAL	B20
5	2008 - 2014	INTERNATIONAL	4300	CLASS8	CLASS 8 TRUCK - FLATBED	B20

3	2009	INTERNATIONAL	4300	CLASS8	CLASS 8 TRUCK - HYBRID AERIAL	B20
4	2009 - 2010	INTERNATIONAL	4400	CLASS8	CLASS 8 TRUCK DUMP - AERIAL	B20
10	2001	INTERNATIONAL	4700	CLASS8	CLASS 8 TRUCK DUMP - SINGLE AXLE	B5
3	2011	INTERNATIONAL	7400	CLASS8	CLASS 8 TRUCK DUMP - SINGLE AXLE	B20
2	2016	INTERNATIONAL	7400	CLASS8	CLASS 8 TRUCK DUMP - TANDEM AXLE	B20
2	2017	INTERNATIONAL	7400	CLASS8	CLASS 8 TRUCK - FLATBED	B20
9	2011 - 2017	INTERNATIONAL	7500	CLASS8	CLASS 8 TRUCK DUMP - TANDEM AXLE	B20
1	2010	INTERNATIONAL	7600	CLASS8	CLASS 8 TRUCK - FLATBED	B5
1	2011	INTERNATIONAL	7600	CLASS8	CLASS 8 TRUCK DUMP - TANDEM AXLE	B20
8	2010 - 2015	INTERNATIONAL	7600	CLASS8	CLASS 8 TRUCK - SEWER	B5
2	2012	INTERNATIONAL	WORKSTA 7300	CLASS8	CLASS 8 TRUCK - HYBRID AERIAL	B20
7	2013	INTERNATIONAL	WORKSTA 7300	CLASS8	CLASS 8 TRUCK DUMP - SINGLE AXLE	B20
2	2014	INTERNATIONAL	WORKSTA 7300	CLASS8	CLASS 8 TRUCK DUMP - AERIAL	B20
2	2017	INTERNATIONAL	WORKSTA 7600	CLASS8	CLASS 8 TRUCK DUMP - TANDEM AXLE	B20
1	2009	INTERNATIONAL	DURASTAR4300	CLASS8	CLASS 8 TRUCK - FLATBED	B20
181						
4	2014	ISUZU	NRR	CLASS4/5	CLASS 4/5 PACKER - SIDE LOADING	B20
7	2014 - 2015	ISUZU	NRR	CLASS4/5	CLASS 4/5 PACKER - REAR LOADING	B20
1	2011	ISUZU	NRR	CLASS4/5	CLASS 4/5 TRUCK - SEWER	B20

12						
1	1992	MACK	600		TRUCK WITH CRANE ATTACHMENT	B5
4	2008	MACK	600	CLASS8	CLASS 8 PACKER - AUTOMATED SIDE LOADING	B5
5	2012 - 2015	MACK	GU813	CLASS8	CLASS 8 TRUCK - FLATBED TILT AND LOAD	B20
51	2012 - 2015	MACK	LEU613	CLASS8	CLASS 8 PACKER - AUTOMATED SIDE LOADING	B20
14	2015	MACK	MRU 613	CLASS8	CLASS 8 PACKER - REAR LOADING	B20
75						
8	2006	MERCEDES	SMART	CLASS1	PASSENGER SUBCOMPACT	B5
12	2011 - 2013	MERCEDES	SPRINTER2500	CLASS2	CLASS 2/3 VAN - CARGO 200 SERIES	B5
6	2011	MERCEDES	SPRINTER3500	CLASS2	CLASS 2/3 VAN - CARGO 300 SERIES	B5
3	2011	MERCEDES	SPRINTER3500	CLASS3	CLASS 2/3 VAN - CUBE 300 SERIES	B5
29						
1	2002	PETERBILT	330	CLASS6/7	CLASS 6/7 TRUCK DUMP - SINGLE AXLE	B20
1	2010	PETERBILT	320	CLASS8	CLASS 8 PACKER - SIDE LOADING	B20
2	2004	PETERBILT	330	CLASS8	CLASS 8 TRUCK DUMP - TANDEM AXLE	B20
4						
13	2007 - 2008	STERLING	BULLET	CLASS4/5	CLASS 4/5 TRUCK DUMP - SINGLE AXLE	B5
7	2009	STERLING	ACTERRA	CLASS6/7	CLASS 6/7 PACKER - REAR LOADING	B5
2	2004	STERLING	ACTERRA	CLASS6/7	CLASS 6/7 TRUCK DUMP - AERIAL	B5

18	2004 - 2008	STERLING	ACTERRA	CLASS6/7	CLASS 6/7 TRUCK DUMP - SINGLE AXLE	B5
4	2006 - 2008	STERLING	ACTERRA	CLASS6/7	CLASS 6/7 TRUCK - FLATBED	B5
1	2003	STERLING	ACTERR M8500	CLASS6/7	CLASS 6/7 TRUCK DUMP - AERIAL	B5
2	2007	STERLING	LT8513	CLASS6/7	CLASS 6/7 TRUCK - SEWER	B5
3	2003 - 2004	STERLING	LT9513	CLASS6/7	CLASS 6/7 TRUCK - SEWER	B5
1	2003	STERLING	ACTERR M8500	CLASS8	PACKER-REAR LOADING	B5
4	2003	STERLING	ACTERR M8500	CLASS8	CLASS 8 TRUCK DUMP - TANDEM AXLE	B5
5	2004	STERLING	ACTERR M8500	CLASS8	CLASS 8 TRUCK - FLATBED	B5
3	2004 - 2009	STERLING	ACTERRA	CLASS8	CLASS 8 TRUCK-FLATBED	B5
26	2004 - 2009	STERLING	ACTERRA	CLASS8	CLASS 8 TRUCK DUMP - TANDEM AXLE	B5
7	2007 - 2009	STERLING	ACTERRA	CLASS8	CLASS 8 TRUCK DUMP - SINGLE AXLE	B5
44	2004 - 2008	STERLING	ACTERRA	CLASS8	CLASS 8 PACKER - REAR LOADING	B5
1	2008	STERLING	ACTERRA	CLASS8	CLASS 8 PACKER - SIDE LOADING	B5
4	2006 - 2008	STERLING	LT7500	CLASS8	CLASS 8 TRUCK DUMP - TANDEM AXLE	B5
26	2002 - 2007	STERLING	LT7501	CLASS8	CLASS 8 TRUCK DUMP - TANDEM AXLE	B5
1	2008	STERLING	LT7501	CLASS8	CLASS 8 TRUCK DUMP - AERIAL	B5
1	2004	STERLING	LT8513	CLASS8	CLASS 8 TRUCK - FLATBED	B5
1	2003	STERLING	M8500	CLASS8	CLASS 8 PACKER - REAR LOADING	B5
174						

2	2001 - 2006	THOMAS BUS	090	CLASS4/5	CLASS 4/5 BUS	B5

Appendix G: Summary of OEM On-Road B20 Blend Approval Statements

This section includes a list of some of the B20 OEM warranty statements. The list is not exhaustive but includes those found in the public domain.

Fiat Chrysler Automobiles (FCA) OEM Warranty Statement

Formerly known as Chrysler, FCA supports B20 for use in the Dodge Ram for 2007 and newer in approved U.S. Government and commercial fleets and B5 for all other diesel vehicle applications. [17]

Commentary

From a strictly parts and materials compatibility standpoint, there were not special vehicles produced for U.S. Government or commercial fleets. The models produced were the same in Canada and the U.S. for the various models. The U.S. military and in particular, the U.S. Navy procured B20. Thus, the warranty statements were in some cases based on knowledgeable users and not simply whether parts were compatible or not.

Ford OEM Warranty Statement

Ford products built up to 2010 are compatible with B5. The 2011 and newer models are warranted to B20. [18]

Freightliner OEM Warranty Statement

Freightliner truck models equipped with Cummins engines are approved for use with B20 biodiesel blends. Freightliner truck models equipped with Detroit Diesel engine models DD13, DD15, DD16 are approved for B5 biodiesel blends.[19] Biodiesel blends must meet the specifications listed in the Detroit Diesel Biodiesel Policy.[20]

Commentary

Some models of M2 106 currently come with Cummins or Detroit Diesel engines. The vintage would indicate that the engines are likely Cummins but awaiting confirmation from City of Toronto.

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[17] NBB web site http://biodiesel.org/using-biodiesel/oem-information/oem-statement-summary-chart
[18] ibid
[19] ibid
[20] https://ddcsn-ddc.freightliner.com/cps/rde/xbcr/ddcsn/Detroit_Bio_Fuel_Position_Statement.pdf

Hino Trucks OEM Warranty Statement

Hino Trucks' complete product line of class 4 and 5 cab over, and class 6 and 7 conventional trucks are approved to use up to B20biodiesel.[21]

International/Navistar OEM Warranty Statement

Navistar unconditionally warrants use of biodiesel blends up to and including **B5** blends meeting the ASTM standard. Use of **B6-B20** blends in International MaxxForce Diesel Engines 2007-up is at the discretion of the customer/operator provided the biodiesel blended meets the ASTM standards.[22] Navistar International Corporation is a holding company whose subsidiaries and affiliates produce International® brand commercial and military trucks, MaxxForce brand diesel engines, IC Bus™ brand school and commercial buses.

Commentary

Navistar announced that as of Sept. 27, 2012 that it dropped its MaxxForce 15-liter heavy-duty diesel engine in favor of the Cummins ISX15, which will appear in ProStar+ tractors by the end of 2012.[23] Navistar has also seen billions of dollars in financial losses in the last half decade stemming from warranty issues related to the MaxxForce engine line.[24] Hence there is question as to the degree that biodiesel blends and warranty with MaxxForce may be moot.

Isuzu OEM Warranty Statement

Isuzu warrants 2011 and newer model year N-series diesel model trucks.[25] Isuzu also has a link for statements regarding up to B20 biodiesel blends.[26]

Mack OEM Warranty Statement

Mack states that the use of biodiesel up to B20 in and of itself will not affect the manufacturer's mechanical warranty and engine and emissions system related components provided ASTM specifications are met. There is also has a B20 statement on a Mack web link.[27]

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[21] http://biodiesel.org/using-biodiesel/oem-information/oem-statement-summary-chart
[22] ibid
[23] https://www.overdriveonline.com/navistar-discontinues-maxxforce-15-drops-ict-terminology/
[24] https://www.hardworkingtrucks.com/navistar-loses-31m-lawsuit-against-its-maxxforce-engines
[25] http://biodiesel.org/using-biodiesel/oem-information/oem-statement-summary-chart
[26]http://biodiesel.org/docs/oem-statements/2011-and-2012-model-year-isuzu-n-series-warranty-for-bio-diesel.pdf?sfvrsn=0
[27] http://biodiesel.org/docs/oem-statements/mack-b20-warranty-statement.png?sfvrsn=0

Merecedes-Benz OEM Warranty Statement

Mercedes-Benz approves the use of B5 provided it meets ASTM D6751 specification. For use of biodiesel blends above B5, Mercedes includes a brochure for guidance on use. Mercedes does not exclude use of up to B20 but includes a link that includes cautions for continued use of B20 blends.[28]

Commentary

It is noteworthy that the link for the Mercedes brochure is from Illinois where there were issues with biodiesel and biodiesel blend quality.

Peterbilt OEM Warranty Statement

All model years are approved for B20.[29]

Sterling OEM Warranty Statement

There is no Sterling on the NBB web site.[30]

Commentary

Sterling Trucks Corporation (commonly designated Sterling) is a former American truck manufacturer of Class 5-8 trucks. Taking on its name from a defunct American truck manufacturer, Sterling was formed in 1997 as Freightliner acquired the rights to the heavy-truck product lines of Ford Motor Company. Sterling built class 8 tractors, as well as a range of medium and heavy-duty cab/chassis vehicles. With bodies added by third-party upfitters/body builders, these cab/chassis vehicles were used for freight distribution as well as heavy vocational uses, such as construction, snow plowing and refuse collection. From 1997 to 2009, Sterling produced several lines of trucks. Within Daimler-Benz, the Sterling product range was slotted between the Freightliner and Western Star product lines. Through much of its existence, the Sterling product range served as continuation of the second-generation Ford Louisville/AeroMax conventional product line. Acterra - used a Ford LNT 9000 body. On October 14, 2008, Daimler Trucks North America announced a plan to discontinue the Sterling product line in an effort to consolidate its North American truck manufacturing operations under the Freightliner and Western Star brands. The company stopped taking orders for new trucks in January 2009, the St. Thomas manufacturing plant closed in March 2009, and the Portland, Oregon, plant was

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[28] http://biodiesel.org/docs/default-source/oem-statements/illinois-mb-biodiesel-brochure.pdf?sfvrsn=2
[29] http://biodiesel.org/docs/default-source/ffs-basics/oem-support-summary.pdf?sfvrsn=22

[30] http://biodiesel.org/using-biodiesel/oem-information/oem-statement-summary-chart

closed in June 2010. Thus, arguably the considerations relative to warranty with Sterling trucks and biodiesel blends are not relevant.

Appendix H: OEM Warranty Approvals for City of Toronto Off-Road Vehicles

Table H-1: City of Toronto Fleet Services Off-Road Vehicle List

#	Year	Make	Model	Category Class	Category Description	OEM Blend Approved
1	1996	ATLAS	XAS 90 DD	ATTACH	VEHICLE MOUNTED - COMPRESSOR	
16	2002 - 2003	ATLAS	XAS96JD	ATTACH	APPARATUS-COMPRESSOR 70-80 HP	
1	1996	BEAVER	935BC	ATTACH	APPARATUS - BRUSH CHIPPER	
2	2016	BOBCAT	5600G	FA/GROUNDS	UTILITY CARTS - GREATER THAN 30 HP	
1	2010	BOBCAT	S205	CONSTRUCT	LOADER - SKIDSTEER	
1	1996	BOMBARDIER	PLUSME	WINTERMAIN	SNOW GROOMER	
1	1993	BOMBARDIER	SW48DA	WINTERMAIN	SIDEWALK SNOW PLOWS	
2	1987 - 1989	CASE	385	FA/GROUNDS	TRACTOR <35 HP	B5
6	2006 - 2008	CASE	430	CONSTRUCT	LOADER - SKIDSTEER	B5
2	1990	CASE	495	FA/GROUNDS	TRACTOR 46 HP TO 55 HP	B5
6	2013 - 2015	CASE	1021F XR	CONSTRUCT	LOADER ARTICULATED >180 HP	B20
3	1991 - 1996	CASE	1845C	CONSTRUCT	LOADER - SKIDSTEER	B5
1	2008	CASE	221E	CONSTRUCT	LOADER - ATRICULATED	B20
1	2015	CASE	321F	CONSTRUCT	LOADER ARTICULATED <100 HP	B20

1	2008	CASE	327B	CONSTRUCT	ARTICULATED ROCK TRUCK	B20
3	2003	CASE	40XT	CONSTRUCT	LOADER - SKIDSTEER	B5
2	2001 - 2002	CASE	521D	CONSTRUCT	LOADER ARTICULATED 101 HP - 140 HP	B5
2	2010	CASE	521E	CONSTRUCT	LOADER ARTICULATED 101 HP - 140 HP	B20
3	2016 - 2017	CASE	521F	CONSTRUCT	LOADER ARTICULATED 101 HP - 140 HP	B20
2	2005	CASE	570MXT	CONSTRUCT	TRACKLESS (ARTICULATED TRACTOR)	B5
18	2004 - 2009	CASE	580SM	CONSTRUCT	LOADER - BACKHOE	B5
20	2011 - 2017	CASE	580SN	CONSTRUCT	LOADER - BACKHOE	B20
1	1996	CASE	621B	CONSTRUCT	LOADER ARTICULATED 101 HP - 140 HP	B5
1	1992	CASE	621ZF	CONSTRUCT	LOADER ARTICULATED 101 HP - 140 HP	B5
16	2008 - 2012	CASE	721E	CONSTRUCT	LOADER ARTICULATED 141 HP - 180 HP	B20
2	2015 - 2016	CASE	821F	CONSTRUCT	LOADER ARTICULATED >180 HP	B20
1	2004	CASE	CX225	CONSTRUCT	LOADER - CRAWLER	B5
1	2007	CASE	CX75	CONSTRUCT	LOADER - CRAWLER	B5
3	2007	CASE	DV201	ATTACH	APPARATUS - ASPHALT ROLLER	B5
1	2012	CAT	100	ATTACH	APPARATUS - GENERATOR	B20
1	1999	CAT	301.5	CONSTRUCT	MINI EXCAVATORS	B5
1	1998	CAT	416	CONSTRUCT	LOADER - BACKHOE	B5
1	2008	CAT	973C	CONSTRUCT	LOADER - CRAWLER	B5

4	2012 - 2015	CAT	973D	CONSTRUCT	LOADER - CRAWLER	B20
1	1994	CAT	D4	CONSTRUCT	TRACKLESS (ARTICULATED TRACTOR)	B5
1	2015	CAT	D4K2 XL	CONSTRUCT	LOADER - CRAWLER	B20
1	2008	CAT	D6N	CONSTRUCT	LOADER - CRAWLER	B5
1	1991	CAT	V50DSA	CONSTRUCT	FORKLIFTS	B5
1	1986	CHAMPION	STATIONARY	ATTACH	VEHICLE MOUNTED - COMPRESSOR	
6	1997	CUSHMAN	UTV MAX	FA/GROUNDS	UTILITY CARTS - UNDER 30 HP	
2	1985 - 1987	D-B-H	RF82TA	ATTACH	APPARATUS - THAWING MACHINE	
1	2005	ELGIN	PELICAN	ST_CLEAN	STREET SWEEPER - 4 CUBIC YARD	
2	1985	ELGIN	SWEEPER	ST_CLEAN	STREET SWEEPER - 4 CUBIC YARD	
1	1992	FERRIS	PROCUT 61	FA/GROUNDS	MOWER 21 TO 35 HP	
2	1989 - 1993	FLYGT	GENERATOR	ATTACH	VEHICLE MOUNTED - GENERATOR	
1	1989	FORD	345C	CONSTRUCT	TRACKLESS (ARTICULATED TRACTOR)	B5
1	1993	FORD	CU5PW2	FA/GROUNDS	TRACTOR <35 HP	B5
5	1990	FORD	3910	FA/GROUNDS	TRACTOR 36 HP TO 45 HP	B5
25	2008	GMC	T7F042	ST_CLEAN	STREET SWEEPER - 6 CUBIC YARD	B5
9	2007 - 2008	GMC	W5500	ST_CLEAN	STREET SWEEPER - 4 CUBIC YARD	B5
1	1996	GEHL	SL5625S	CONSTRUCT	LOADER - SKIDSTEER	
1	1998	GHIBLI	5030GG	ATTACH	APPARATUS - POWER WASHER	

1	2000	GHIBLI	PH6030DG0E	ATTACH	APPARATUS - POWER WASHER	
17	2003 - 2011	GIANT VAC	SM8000	ATTACH	APPARATUS - LEAF LOADER	
4	2011	GLOBAL	GPC 46 HT	ATTACH	APPARATUS - WATER PUMP	
4	2005 - 2009	GODWIN	CD100M	ATTACH	VEHICLE MOUNTED - WATER PUMP	
1	2002	GORMAN	84A2-3029D	ATTACH	APPARATUS - WATER PUMP	
1	1995	GRADALL	XL5200	CONSTRUCT	MINI EXCAVATORS	
1	1992	GRAVELY	47366	FA/GROUNDS	MOWER LESS THAN 10 HP	
1	1993	GRAVELY	47366	FA/GROUNDS	TRACTOR (UNDER 59 HP)	
7	2007 - 2008	HAKO	CM1200	ST_CLEAN	SIDEWALK SWEEPER	
2	2015 - 2016	HELI	CPCD25-KU11G	CONSTRUCT	FORKLIFTS	
1	2015	HOLDER	X-30	ST_CLEAN	SIDEWALK SWEEPER	
1	1983	INGERSOLL	F3-6L912/W	ATTACH	APPARATUS - COMPRESSOR	
6	2004 - 2010	INGERSOLL	185CFM	ATTACH	APPARATUS-COMPRESSOR- 60 HP	
1	1991	INGERSOLL	P 185WJD	ATTACH	APPARATUS-COMPRESSOR- 60 HP	
25	2000 - 2007	INGERSOLL	P185WJD	ATTACH	APPARATUS-COMPRESSOR- 60 HP	
1	2013	INGERSOLL	P260	ATTACH	APPARATUS-COMPRESSOR 70-80 HP	
1	2013	INGERSOLL	P375	ATTACH	APPARATUS-COMPRESSOR 140 HP	
1	2010	ISUZU	NRR	ST_CLEAN	STREET SWEEPER - 4 CUBIC YARD	B20
1	2014	JACOBSEN	AR722T	FA/GROUNDS	MOWER 51 TO 60 HP	

3	2016 - 2017	JACOBSEN	HR600	FA/GROUNDS	MOWER 36 TO 50 HP	
1	2005	JACOBSEN	HR6010	FA/GROUNDS	MOWER 51 TO 60 HP	
10	2016 - 2017	JACOBSEN	HR800	FA/GROUNDS	MOWER 61 TO 80 HP	
1	1999	JACOBSEN	HR9016	FA/GROUNDS	MOWER GREATER THAN 81 HP	
10	2015	JACOBSEN	HR9016	FA/GROUNDS	MOWER 61 TO 80 HP	
7	2014	JACOBSEN	LF550	FA/GROUNDS	MOWER 36 TO 50 HP	
1	2015	JACOBSEN	MOWER	FA/GROUNDS	MOWER 61 TO 80 HP	
4	2011	JACOBSEN	R-311	FA/GROUNDS	MOWER 36 TO 50 HP	
1	2003	JCB	190	CONSTRUCT	LOADER - SKIDSTEER	
1	1997	JCB	215	CONSTRUCT	LOADER - BACKHOE	
11	2007	JCB	3CX 14FT	CONSTRUCT	LOADER - BACKHOE	
1	2002	JCB	409B	CONSTRUCT	LOADER ARTICULATED <100 HP	
3	2000	JOHN DEERE	250	CONSTRUCT	LOADER - SKIDSTEER	B20
2	2004	JOHN DEERE	317	CONSTRUCT	LOADER - SKIDSTEER	B20
1	1992	JOHN DEERE	540	CONSTRUCT	LOADER ARTICULATED 101 HP - 140 HP	B5
2	2006	JOHN DEERE	997	FA/GROUNDS	MOWER 21 TO 35 HP	B20
26	2001 - 2010	JOHN DEERE	1445	FA/GROUNDS	MOWER 21 TO 35 HP	B20
1	2015	JOHN DEERE	2500	FA/GROUNDS	MOWER 21 TO 35 HP	B20
1	2005	JOHN DEERE	3420	CONSTRUCT	LOADER ARTICULATED 101 HP - 140 HP	B20

3	2008 - 2012	JOHN DEERE	3520	FA/GROUNDS	TRACTOR 36 HP TO 45 HP	B20
7	2007 - 2010	JOHN DEERE	3720	FA/GROUNDS	TRACTOR <35 HP	B20
2	2010	JOHN DEERE	4520	FA/GROUNDS	TRACTOR 56 HP TO 65 HP	B20
3	2012	JOHN DEERE	4720	FA/GROUNDS	TRACTOR 56 HP TO 65 HP	B20
1	2012	JOHN DEERE	5093	FA/GROUNDS	TRACTOR 76 HP TO 85 HP	B20
1	2000	JOHN DEERE	5210	FA/GROUNDS	TRACTOR 36 HP TO 45 HP	B20
10	2008	JOHN DEERE	5325	FA/GROUNDS	TRACTOR 66 HP TO 75 HP	B20
5	2007	JOHN DEERE	5425	FA/GROUNDS	TRACTOR 76 HP TO 85 HP	B20
3	2013 - 2014	JOHN DEERE	7400	FA/GROUNDS	MOWER 21 TO 35 HP	B20
28	2005 - 2014	JOHN DEERE	1445 II	FA/GROUNDS	MOWER 21 TO 35 HP	B20
3	2003 - 2014	JOHN DEERE	1600T	FA/GROUNDS	MOWER 51 TO 60 HP	B20
2	2015	JOHN DEERE	318E	CONSTRUCT	LOADER - SKIDSTEER	B20
1	2016	JOHN DEERE	318G	CONSTRUCT	LOADER - SKIDSTEER	B20
1	2009	JOHN DEERE	5075M	FA/GROUNDS	TRACTOR 66 HP TO 75 HP	B20
3	2010	JOHN DEERE	5085M	FA/GROUNDS	TRACTOR 76 HP TO 85 HP	B20
10	2001 - 2012	JOHN DEERE	6X4 GATOR	FA/GROUNDS	UTILITY CARTS - UNDER 30 HP	B20
2	2000	JOHN DEERE	F1145	FA/GROUNDS	MOWER 21 TO 35 HP	B20
1	1993	JOHN DEERE	F935	FA/GROUNDS	MOWER 21 TO 35 HP	B5
11	2013	JOHN DEERE	GATOR 4X4	FA/GROUNDS	UTILITY CARTS - UNDER 30 HP	B20

2	2005 - 2012	JOHN DEERE	GATOR HPX	FA/GROUNDS	UTILITY CARTS - UNDER 30 HP	B20
1	2004	JOHN DEERE	GATOR4X2	FA/GROUNDS	UTILITY CARTS - UNDER 30 HP	B20
3	2005	JOHN DEERE	HPX GATOR	FA/GROUNDS	UTILITY CARTS - UNDER 30 HP	B20
8	2015 - 2016	JOHN DEERE	JD3046	FA/GROUNDS	TRACTOR 46 HP TO 55 HP	B20
3	2015	JOHN DEERE	JD5085E	FA/GROUNDS	TRACTOR 76 HP TO 85 HP	B20
7	2008	JOHN DEERE	TH 6X4	FA/GROUNDS	UTILITY CARTS - UNDER 30 HP	B20
1	2001	JOHNSTON	3000	ST_CLEAN	STREET SWEEPER - 6 CUBIC YARD	
1	2004	KOHLER	.	ATTACH	APPARATUS - POWER WASHER	
1	1981	KOHLER	ZOROZJO1	ATTACH	APPARATUS - GENERATOR	
1	2013	KUBOTA	BX2670	FA/GROUNDS	TRACTOR <35 HP	B20
4	2002 - 2005	KUBOTA	F3060	FA/GROUNDS	MOWER 21 TO 35 HP	B20
14	2011 - 2013	KUBOTA	F3080	FA/GROUNDS	MOWER 21 TO 35 HP	B20
35	2006 - 2009	KUBOTA	F3680	FA/GROUNDS	MOWER 36 TO 50 HP	B20
14	2003 - 2006	KUBOTA	L3430HSTC	FA/GROUNDS	TRACTOR <35 HP	B20
5	2007	KUBOTA	L3540HSTC	FA/GROUNDS	TRACTOR 36 HP TO 45 HP	B20
2	2007	KUBOTA	L4240HSTC	FA/GROUNDS	TRACTOR <35 HP	B20
4	2010 - 2013	KUBOTA	L4240HSTC	FA/GROUNDS	TRACTOR 36 HP TO 45 HP	B20
2	2006	KUBOTA	L4330	FA/GROUNDS	TRACTOR <35 HP	B20
3	2003	KUBOTA	L4630GST	FA/GROUNDS	TRACTOR 46 HP TO 55 HP	B20

18	2005	KUBOTA	L4630GSTC	FA/GROUNDS	TRACTOR 46 HP TO 55 HP	B20
1	2002	KUBOTA	L48	FA/GROUNDS	TRACTOR 46 HP TO 55 HP	B20
2	2005	KUBOTA	L48	CONSTRUCT	LOADER - BACKHOE	B20
8	2010 - 2011	KUBOTA	L5240HSTC	FA/GROUNDS	TRACTOR 46 HP TO 55 HP	B20
3	1996 - 1998	KUBOTA	M4700F	FA/GROUNDS	TRACTOR 46 HP TO 55 HP	B20
1	2003	KUBOTA	M4900DTC	FA/GROUNDS	TRACTOR 46 HP TO 55 HP	B20
5	2011 - 2013	KUBOTA	M6040DTHSC	FA/GROUNDS	TRACTOR 56 HP TO 65 HP	B20
3	2014	KUBOTA	M7060 DHCC	FA/GROUNDS	TRACTOR 66 HP TO 75 HP	B20
1	2001	KUBOTA	M8200 DTC	FA/GROUNDS	TRACTOR 76 HP TO 85 HP	B20
11	2010 - 2014	KUBOTA	RTV1100	FA/GROUNDS	UTILITY CARTS - UNDER 30 HP	B20
	2015	KUBOTA	RTV1140	FA/GROUNDS	UTILITY CARTS - UNDER 30 HP	B20
52	2006 - 2012	KUBOTA	RTV900	FA/GROUNDS	UTILITY CARTS - UNDER 30 HP	B20
2	2016	KUBOTA	SVL90-2HFC	CONSTRUCT	LOADER - SKIDSTEER	B20
1	2005	KUBOTA	ZD21	FA/GROUNDS	MOWER 21 TO 35 HP	B20
1	2007	KUBOTA	ZD331	FA/GROUNDS	MOWER 21 TO 35 HP	B20
1	2007	KUT KWIK	SSM35-72D	FA/GROUNDS	MOWER 21 TO 35 HP	
1	1994	LEROI	0175DJE	ATTACH	APPARATUS-COMPRESSOR- 60 HP	
1	2003	LIEBHERR	LR632	CONSTRUCT	LOADER - CRAWLER	
5	1994 - 2001	MADVAC	101D	ST_CLEAN	LITTER VACUUM	

27	2008 - 2015	MADVAC	LN50	ST_CLEAN	LITTER VACUUM	
1	2015	MAGNUM	MMG25	ATTACH	APPARATUS - GENERATOR	
1	2008	MAGNUM PRO	MMG150	ATTACH	APPARATUS - GENERATOR	
2	1997	MARATHON	HMT3000	ATTACH	VEHICLE MOUNTED - ASPHALT ROLLER	
15	2004	MARATHON	HMT4000DT	ATTACH	VEHICLE MOUNTED - ASPHALT ROLLER	
1	1991	MASSEY FER	231	FA/GROUNDS	TRACTOR 36 HP TO 45 HP	
2	2014	MASSEY FER	1749	FA/GROUNDS	TRACTOR 36 HP TO 45 HP	
1	1996	MORBARK	10	ATTACH	APPARATUS - BRUSH CHIPPER	
1	1999	NATIONAL	HT-7	FA/GROUNDS	MOWER 11 TO 20 HP	
2	2010	NEW HOLLAN	BOOMER 3045	FA/GROUNDS	TRACTOR 36 HP TO 45 HP	B20
1	2011	NEW HOLLAN	BOOMER 4055	FA/GROUNDS	TRACTOR 46 HP TO 55 HP	B20
5	2001 - 2003	NEW HOLLAN	LB90	CONSTRUCT	TRACKLESS (ARTICULATED TRACTOR)	B20
1	2001	NEW HOLLAN	LS170	CONSTRUCT	LOADER - SKIDSTEER	B20
3	2004	NEW HOLLAN	LW130B	CONSTRUCT	LOADER ARTICULATED 101 HP - 140 HP	B20
13	2002 - 2003	NEW HOLLAN	LW170	CONSTRUCT	LOADER ARTICULATED 141 HP - 180 HP	B20
3	2004	NEW HOLLAN	LW170B	CONSTRUCT	LOADER ARTICULATED >180 HP	B20
1	1996	NEW HOLLAN	SKID STEER	CONSTRUCT	LOADER - SKIDSTEER	B5
5	2002	NEW HOLLAN	TN55D	FA/GROUNDS	TRACTOR 46 HP TO 55 HP	B20
2	2002 - 2003	NEW HOLLAN	TN70D	FA/GROUNDS	TRACTOR 66 HP TO 75 HP	B20

1	2009	NEW HOLLAN	W50BTC	CONSTRUCT	LOADER ARTICULATED <100 HP	B20
1	2015	NORMAN	65E	CONSTRUCT	MINI EXCAVATORS	
1	2011	OMEGA LIFT	2430-8	CONSTRUCT	FORKLIFT,SCISSOR LIFT,ETC.	
1	2013	ONAN	25DSKCA240V	ATTACH	APPARATUS - GENERATOR	
1	2003	PISTEN BUL	200	WINTERMAIN	SNOW GROOMER	
37	2015 - 2016	POLARIS	BRUTUS	OFF-ROAD	GATOR	
	2009	PRINOTH	BR-350	WINTERMAIN	SNOW GROOMER	
12	2000 - 2010	R.P.M. TEC	LM220	WINTERMAIN	SNOW BLOWERS	
4	2005 - 2007	RAYCO	RG50	ATTACH	APPARATUS - STUMP CUTTER	
2	2004	SDMO	JS60UC	ATTACH	APPARATUS - GENERATOR	
1	1991	SOMERS	DMT50C-1	ATTACH	APPARATUS - GENERATOR	
2	2001	SRECO FLEX	HTL/H LOADER	ATTACH	APPARATUS - SEWER BUCKET	
5	2001 - 2003	SRECO FLEX	PI/H PULL-IN	ATTACH	APPARATUS - SEWER BUCKET	
1	2012	SULLAIR	185DPQ -CAT	ATTACH	VEHICLE MOUNTED - COMPRESSOR	
1	1991	SUPER PAC	420	ATTACH	VEHICLE MOUNTED - ASPHALT ROLLER	
2	2003	T&T POWER	50MDK-ART	ATTACH	APPARATUS - GENERATOR	
4	2010	TENCO MANU	TCS202LMP	WINTERMAIN	SNOW BLOWERS	
1	2008	TENNANT	6100	FA/GROUNDS	FLOOR SCRUBBER	
1	2008	TENNANT	6200	FA/GROUNDS	FLOOR SCRUBBER	

1	2003	TENNANT	6550	FA/GROUNDS	FLOOR SCRUBBER	
1	2006	TENNANT	8410	FA/GROUNDS	FLOOR SCRUBBER	
40	2006 - 2015	TENNANT	ATLV 4300	ST_CLEAN	LITTER VACUUM	
1	2008	TENNANT	M30	FA/GROUNDS	FLOOR SCRUBBER	
3	2008 - 2013	TEREX	RL-4000	ATTACH	APPARATUS - LIGHT TOWER	
1	2004	TEREX	TX-860	CONSTRUCT	LOADER - BACKHOE	
1	2001	THOMAS	175	CONSTRUCT	LOADER - SKIDSTEER	B20
1	1988	THOMAS	T-133	CONSTRUCT	LOADER - SKIDSTEER	B5
26	2009 - 2014	TORO	5910	FA/GROUNDS	MOWER GREATER THAN 81 HP	B20
1	1993	TORO	7205	FA/GROUNDS	UTILITY CARTS - UNDER 30 HP	
18	2012 - 2016	TORO	7210	FA/GROUNDS	MOWER 21 TO 35 HP	B20
2	2007	TORO	3100D	FA/GROUNDS	MOWER 11 TO 20 HP	B5
2	2008	TORO	3100D	FA/GROUNDS	MOWER 21 TO 35 HP	B20
1	1994	TORO	325-D	FA/GROUNDS	MOWER 21 TO 35 HP	B5
56	2015 - 2017	TORO	3280D	FA/GROUNDS	MOWER 21 TO 35 HP	B20
1	2007	TORO	3500D	FA/GROUNDS	MOWER 21 TO 35 HP	B5
3	2007	TORO	4000D	FA/GROUNDS	MOWER 36 TO 50 HP	B5
1	2009	TORO	4000D	FA/GROUNDS	MOWER 36 TO 50 HP	B20
7	2012 - 2013	TORO	4010D	FA/GROUNDS	MOWER 51 TO 60 HP	B20

1	2003	TORO	4500D	FA/GROUNDS	MOWER 51 TO 60 HP	B5
1	2013	TORO	4500D	FA/GROUNDS	MOWER 51 TO 60 HP	B20
1	2006	TORO	4700D	FA/GROUNDS	MOWER 51 TO 60 HP	B5
1	2011	TORO	4700D	FA/GROUNDS	MOWER 51 TO 60 HP	B20
1	2005	TORO	5500D	FA/GROUNDS	MOWER 21 TO 35 HP	B5
1	1995	TORO	580D	FA/GROUNDS	MOWER 61 TO 80 HP	
17	2005 - 2007	TORO	580D	FA/GROUNDS	MOWER 61 TO 80 HP	B5
9	2008	TORO	580D	FA/GROUNDS	MOWER 61 TO 80 HP	B20
2	2011	TORO	DINGO TX 525	CONSTRUCT	LOADER - COMPACT UTILITY	B20
4	2017	TORO	HDX	FA/GROUNDS	UTILITY CARTS - UNDER 30 HP	B20
1	2012	TRACKLESS	MT6	CONSTRUCT	TRACKLESS (ARTICULATED TRACTOR)	
1	2007	TRACKLESS	MTV	CONSTRUCT	TRACKLESS (ARTICULATED TRACTOR)	
2	2008 - 2009	TRAMS INTE	6000	FA/GROUNDS	TRAM VEHICLE	
1	1982	TRECAN	.	WINTERMAIN	SNOW BLOWERS	
1	2004	TRECAN	350-PD	WINTERMAIN	MELTERS	
1	2011	TUG - MR10	MR-10	FA/GROUNDS	TRACTOR - AIR TOW	
1	2002	VAC-TRON	PMD800SDTE	ATTACH	VAC ALL ATTACHMENT-10 YEAR LIFE	
6	2015 - 2017	VENTRAC	4500Y	FA/GROUNDS	TRACTOR <35 HP	
41	2005 - 2014	VERMEER	BC1000XL	ATTACH	APPARATUS - BRUSH CHIPPER	

2	2003	VERMEER	BC1230A	ATTACH	APPARATUS - BRUSH CHIPPER	
4	2002	VERMEER	BC1250A	ATTACH	APPARATUS - BRUSH CHIPPER	
12	2008 - 2012	VERMEER	BC1500XL	ATTACH	APPARATUS - BRUSH CHIPPER	
4	2014	VERMEER	S800TX	CONSTRUCT	LOADER - SKIDSTEER	
2	2000	VERMEER	SC752	ATTACH	APPARATUS - BRUSH CHIPPER	
2	2002	VERMEER	SC752	ATTACH	APPARATUS - STUMP CUTTER	
1	2007	VERMEER	SC802	ATTACH	APPARATUS - STUMP CUTTER	
1	2008	VERMEER	SC852	ATTACH	APPARATUS - STUMP CUTTER	
2	2000	VOHL	DV-4000-C275	WINTERMAIN	SIDEWALK SNOW PLOWS	
1	2008	VOLVO	E360CL	FA/GROUNDS	MISC GROUNDS EQUIPMENT	
1	2001	VOLVO	EC460	CONSTRUCT	MINI EXCAVATORS	
1	2003	VOLVO	EC55	CONSTRUCT	MINI EXCAVATORS	
12	2004 - 2010	VOLVO	L150E	CONSTRUCT	LOADER ARTICULATED >180 HP	
4	2011	VOLVO	L150G	CONSTRUCT	LOADER ARTICULATED >180 HP	
6	2003	WACKER	LTC4L	ATTACH	APPARATUS - LIGHT TOWER	
1	2012	WACKER	WL50	CONSTRUCT	LOADER ARTICULATED <100 HP	

Appendix I: Summary of OEM Off-Road B20 Blend Approval Statements

This section includes a list of some of the B20 approval statement for off-road vehicles. The list is not exhaustive but includes those found in the public domain.

Case Construction Equipment

Case approves more than 90% of equipment for B20 depending on the model and the remainder is approved for B5.

Caterpillar

Caterpillar is approved for B20 for Tier III and Tier IV engines with after treatment devices and approves B5 for Tier II stage or earlier engines.

John Deere

All John Deere engines can use biodiesel blends. B5 blends are preferred, but concentrations up to 20 percent (B20) can be used providing the biodiesel used in the fuel blend meets ASTM specifications.

John Deere engines without exhaust filters can operate on biodiesel blends below and above B20 (up to 100 percent biodiesel). For these engines, John Deere-approved fuel conditioners containing detergent/dispersant additives are required when using biodiesel blends of B20 or higher and recommended when using lower biodiesel blends. John Deere engines with exhaust filters should not use biodiesel blends above B20.

Kubota

Kubota approves the use of B20 biodiesel fuel as a blend component that meets ASTM specifications. The Kubota Warranty, as specified in the Owner's Warranty Information Guide, only covers defects in product materials and workmanship for Kubota approved products. Accordingly, any problems that may arise due to the use of poor quality fuels that fail to meet the above requirements, whether biodiesel or mineral oil based, are not covered by the Kubota Warranty.

New Holland

New Holland supports the use of B100 biodiesel in all equipment with New Holland-manufactured diesel engines, including electronic injection engines with common rail technology. Biodiesel must meet the approved ASTM D6751 standard.

Toro

Toro equipment B20 approved includes 2008 Model Year (or newer) - All diesel-powered Toro Reelmaster, Groundsmaster, Greensmaster, Workman, Multi Pro and Z Master product families and 2009 Model Year - All diesel-powered Toro® Dingo® compact utility loaders.

Appendix J: Additional Results and Scenarios Analyses for Biodiesel and HDRD GHG Emissions

Additional results: GHG emissions in units of g CO_2e/L

The tables below present life cycle GHG emission results for the base scenarios in units of g CO_2e/L. Table J-1 presents results for biodiesel, corresponding to the same scenario as Table 7-1, but with different units (g CO_2e/L instead of g CO_2e/MJ).

Table J-2 presents results for HDRD, corresponding to the same scenario as Table 7-2 but with different units (g CO_2e/L instead of g CO_2e/MJ).

Table J-1: GHG emission results for biodiesel blends for base case scenarios. Data presented in g CO_2e/L fuel (petroleum diesel reference value is 3552 g CO_2e/L).

	B5	B10	B20
Canola	3385	3217	2881
Soybean	3419	3285	3019
Yellow grease	3385	3218	2883
Tallow	3361	3171	2789

Table J-2: GHG emission results for HDRD blends for base case scenarios. Data presented in g CO2e/L fuel (petroleum diesel reference value is 3552 g CO_2e/L).

	R5	R10	R20
Canola	3390	3228	2905
Soybean	3432	3311	3071
Yellow grease	3398	3245	2938
Tallow	3368	3185	2819

Updated life cycle data

The base case scenarios shown in Section 7 were assessed by updating data for key parameters such as agronomic yields, fertilizer inputs, energy for farming, crushing, pre-treatment, and biodiesel process energy inputs. Historical data for canola and soybean grain yields were obtained from Statistics Canada[31,32]. A five-year weighted average (based on production) of canola yield from three regions (Alberta, Manitoba, and Saskatchewan) was calculated for the period from 2013 to 2017. Similarly, a five-year average soybean yield from Ontario was calculated for the period from 2013 to 2017. Agronomic inputs for canola and soybean were obtained from the Canola Council of Canada survey and from OMAFRA[33]. Inventory data for the commercial biodiesel production process was based on the recent survey by the National Biodiesel Board in 2016[34].

Life cycle emissions for canola biodiesel range from a low of 5.6 g CO_2e/MJ biodiesel (GHGenius default values) to a high of 8.5 g CO_2e/MJ biodiesel (updated data). This slight increase in emissions is mainly due to a higher nitrogen input (from 87 to 107 N/ha) and higher inputs in the updated data for the pretreatment and biodiesel production process like electricity, natural gas and methanol (Figure J-1). Canola HDRD followed a similar trend and resulted in a range of 8.5 to 11.5 g CO_2e/MJ biodiesel (Figure J-2).

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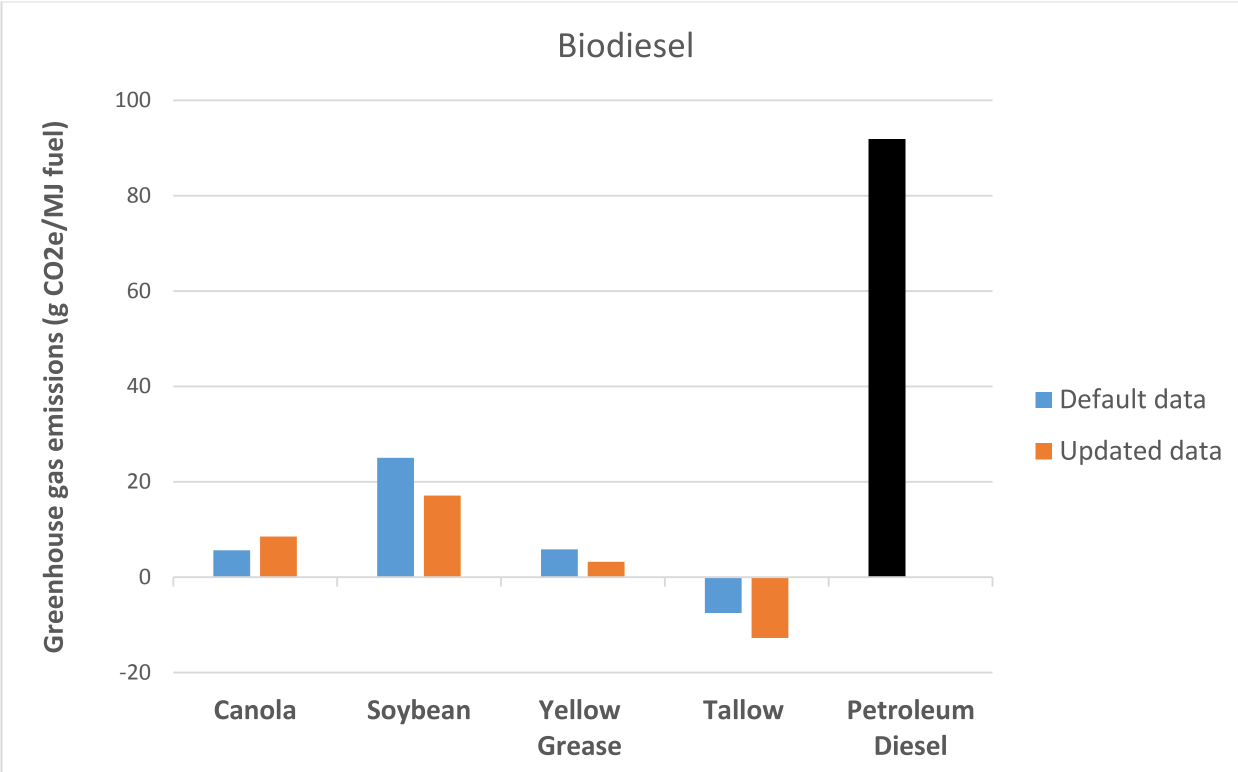
[31] Statistics Canada. CANSIM Table 001-0071: Estimated areas, yield and production of principal field crops by Small Area Data Regions, in metric and imperial units annual n.d. http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=10071.

[32] OMAFRA. Soybean Production in Ontario 2017. http://www.omafra.gov.on.ca/english/crops/field/soybeans.html.

[33] Canola Council of Canada. Development of Aggregated Regional GHG Emission Values for Canola Production in Canada. 2013.

[34] Chen R, Qin Z, Han J, Wang M, Taheripour F, Tyner W, et al. Life cycle energy and greenhouse gas emission effects of biodiesel in the United States with induced land use change impacts. Bioresour Technol 2018;251:249–58.

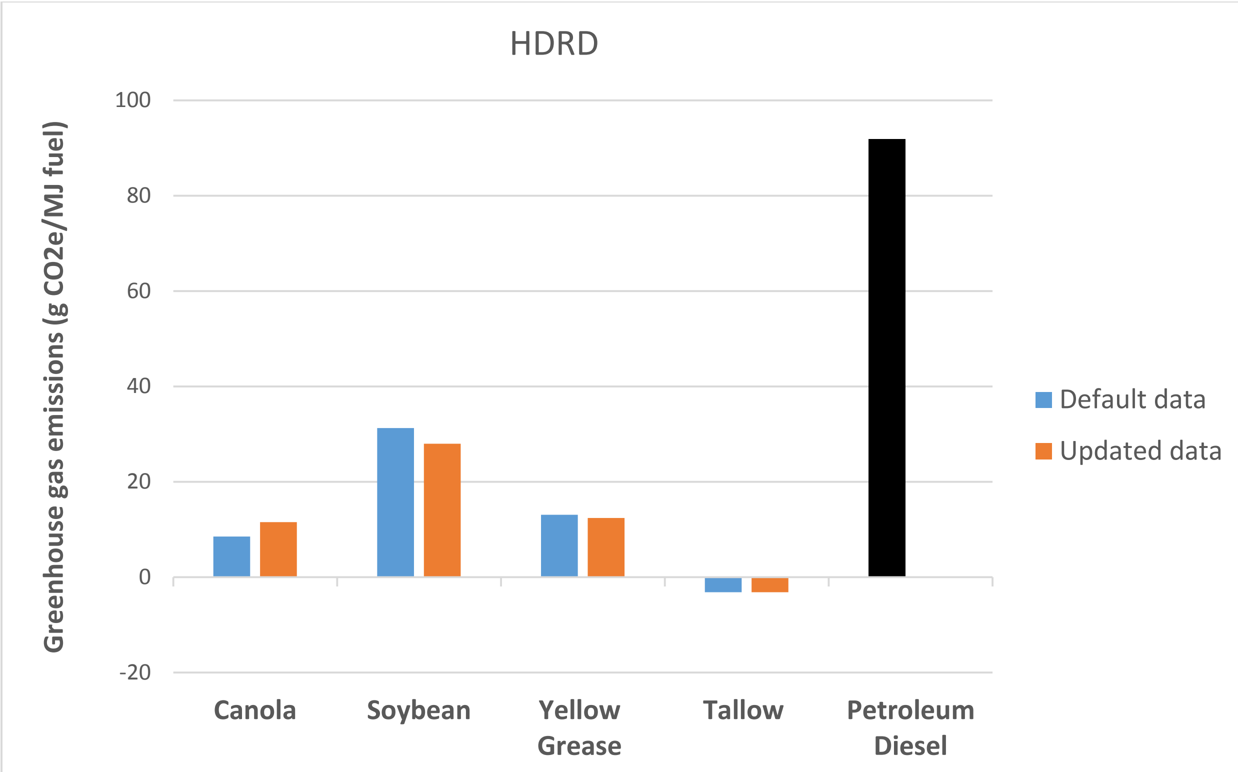


**Reference petroleum-derived diesel for base case scenarios based on GHGenius 4.03a as per Ontario Greener Diesel Mandate*

Figure J-1: GHG emissions for canola, soybean, yellow grease, and tallow neat Biodiesel with updated data.

Life cycle emissions for Soybean biodiesel range from a low of 17.1g CO_2e/MJ biodiesel (updated data) to a high of 24.9 g CO_2e/MJ biodiesel (GHGenius default values). The decrease in emission could be mainly explained by a much lower energy input in the updated data from the NBB 2016 survey compared to the GHGenius default values for the crushing and pretreatment of soybean (Figure J-1). Soybean HDRD followed a similar trend and resulted in a range of 28 to 31.3 g CO_2e/MJ biodiesel (Figure J-2).

Yellow grease was evaluated with updated data concerning the pretreatment step. In a low energy input process the yellow grease is heated to liquefy it and then the water is separated from the oil. Less energy is required than the conventional process where the water is evaporated. Life cycle emissions for Yellow grease biodiesel range from a low of 3.2g CO_2e/MJ biodiesel (low energy pretreatment input) to a high of 5.8 g CO_2e/MJ biodiesel (Figure J-1).



**Reference petroleum-derived diesel for base case scenarios based on GHGenius 4.03a as per Ontario Greener Diesel Mandate*

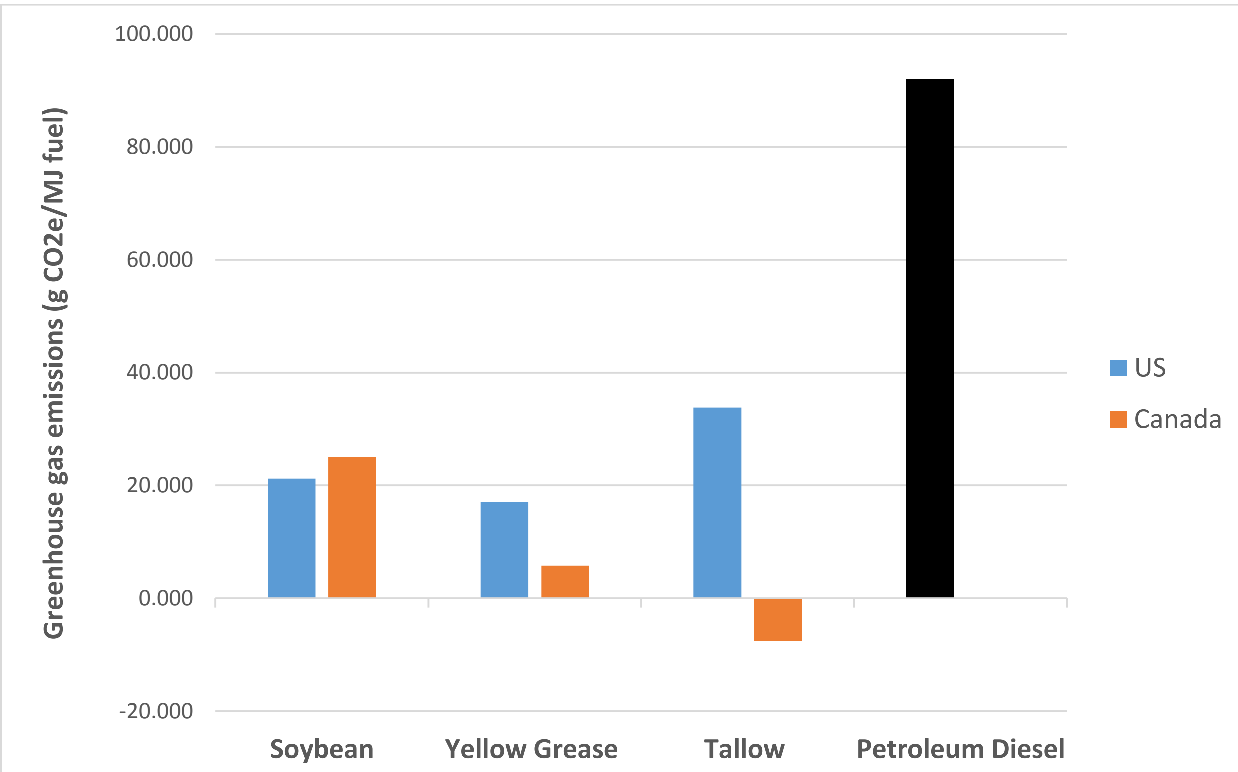
Figure J-2: GHG emissions for canola, soybean, yellow grease, and tallow neat HDRD with updated data.

Life cycle emissions for tallow range from a low of -12.8 g CO_2e/MJ biodiesel (updated data) to a high of -7.5 g CO_2e/MJ biodiesel (GHGenius default values). The decrease in emission could be mainly explained by a much lower energy input in the updated data from the NBB 2016 survey compared to the GHGenius default values for biodiesel conversion process. Even with the updated data for biodiesel and HDRD, the GHG emissions are still below those of petroleum diesel (91.9 g CO_2e/MJ).

Analysis of imported biodiesel from the US

A point of uncertainty is the origin of the supply of the bio-based fuels. We modeled the GHG emissions of biodiesel produced in central US from soybean, yellow grease and tallow. Note that the major production of biodiesel in the US comes from soybeans. Canola is very little grown in the US, consequently it was not modeled in this section.

The GHG intensities for soybean, yellow grease, and tallow as neat biodiesel (B100) for the base case scenarios in Canada and US are presented in Figure J-3. Life cycle emissions for the base case scenarios in Canada are 24.9 g CO_2e/MJ for soybean, 5.8 g CO_2e/MJ for yellow grease, and -7.5 g CO_2e/MJ for tallow. Life cycle emissions in the US was lower for soybean (19 g CO_2e/MJ biodiesel) and higher for yellow grease (17 g CO_2e/MJ) and tallow (34 g CO_2e/MJ) compared to Canada. For the three feedstocks, the fuel production stage was more GHG intensive in US compared to Canada, due to differences in the electricity mix. The fuel distribution stage was also higher in the US compared to Canada. These two factors explain the higher GHG emissions for yellow grease and tallow biodiesel in the US. However, GHG emissions from Soybean biodiesel were lower in the US and this could be explained by a soil carbon credit in central-US, counteracting the GHG intensities of the fuel production and fuel distribution stages. The GHG emissions from biodiesel produced in the US are still below petroleum diesel (91.9 g CO_2e/MJ). Similar trends were obtained for HDRD produced in the US.



**Reference petroleum-derived diesel for base case scenarios based on GHGenius 4.03a as per Ontario Greener Diesel Mandate*

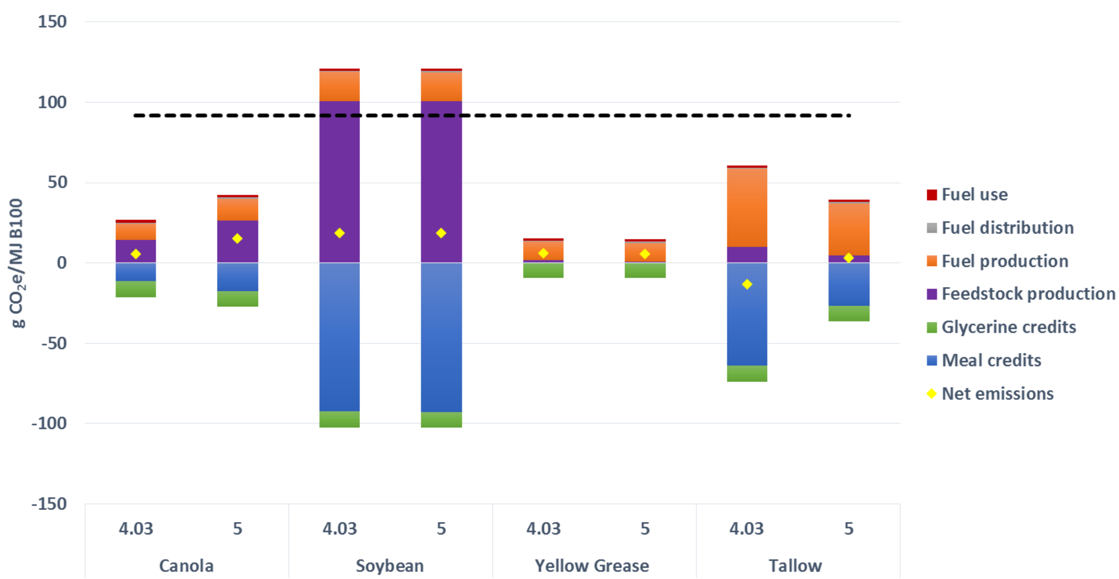
Figure J-3: Comparison between biodiesel production in Canada and US.

GHGenius Model Update

The Ontario Greener Diesel Regulation has based all emissions calculations on GHGenius version 4.03a since its introduction in 2014. In July of 2018, an updated model was released as GHGenius version 5.0 that supersedes version 4.03a, which is no longer available in the public domain. Both biodiesel and

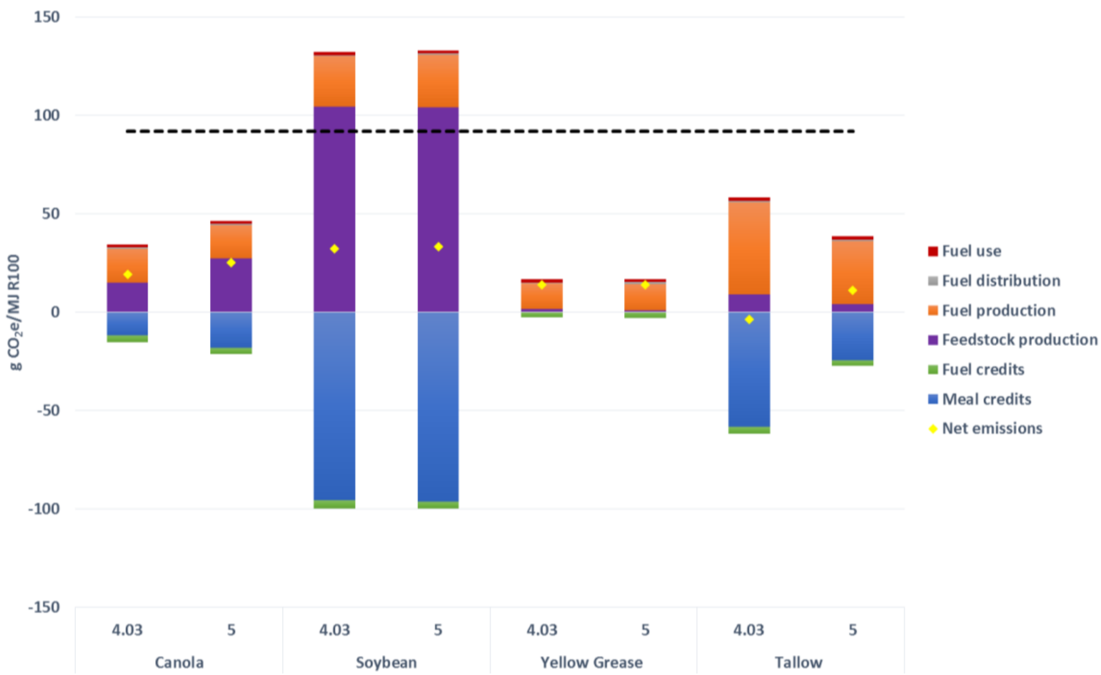
HDRD pathways were examined in the updated model to determine the impact of the changes. The results of the biodiesel and HDRD pathways are driven by the data changes in the biomass production stage where new model parameters are used. This can be seen in Figure J-4 for biodiesel and Figure J-5 for HDRD.

Biodiesel and HDRD from Soybean and Yellow grease generated similar results between the two versions. In contrast, biodiesel and HDRD from Canola resulted in higher GHG emissions in the new version (Version 4.03a: 5.6 g CO_2e/MJ biodiesel and 8.5 g CO_2e/MJ HDRD; version 5.0a: 15.4 g CO_2e/MJ biodiesel and 25.2 g CO_2e/MJ HDRD). The differences in values for Canola biodiesel and HDRD in version 5.0a are explained by lower SOC credits, higher harvest yield, higher direct N-N2O on-site emissions, higher crushing yield (less seed for the same amount of oil with less meal). Tallow also resulted in higher GHG emissions in the new version for biodiesel and HDRD (Version 4.03a: -7.5 g CO_2e/MJ biodiesel and -3.1 g CO_2e/MJ HDRD; version 5.0a: 3.2 g CO_2e/MJ biodiesel and 11.2 g CO_2e/MJ HDRD). The changes for tallow are explained by lower rendering energy and lower bone meal yield in the new version. Despite the slightly higher GHG results for bio-based diesels in GHGenius version 5.0a, the values are still below petroleum diesel (91.9 g CO_2e/MJ).



**Reference petroleum-derived diesel for base case scenarios based on GHGenius 4.03a as per Ontario Greener Diesel Mandate*

Figure J-4: Comparison of biodiesel pathway results between GHGenius version 4.03a and 5.0a



**Reference petroleum-derived diesel for base case scenarios based on GHGenius 4.03a as per Ontario Greener Diesel Mandate*

Figure J-5: Comparison of HDRD pathway results between GHGenius version 4.03a and 5.0a

Appendix K: Prices summary for the Financial Analysis

Table K-1 shows the prices used for the assessments. When data was available a 5-year historical average was used for the prices.

Table K-1: Summary of prices (CAD)

Summary of major prices		
	CAD	Comments
Canola oil price	$1.0 /kg	5 years average (2013-2018) Source: Canola Council
Soybean oil price	$1.05 /kg	5 years average (2013-2018) Source: Index Mundi. Primary source: ISTA Mielke GmbH, Oil World; US Department of Agriculture; World Bank.
Yellow grease price	$0.66 /kg	Price 2017 Source: USDA gov
Wholesale diesel price	$ 0.74/Liter	5 years average Source: Natural Res. Can.
Biodiesel price	$1.08/Liter $1.09/liter	Price dec 2017 Source: OPIS Average biodiesel price from 2009 to 2018
Crude glycerin price	$0.18 /kg	Source: Glycerin market report (oleoline)
Refined glycerin (99.5% pure) price	$0.86 /kg	Source: Glycerin market report (oleoline)
HDRD price	$0.99-1.1 / liter	Assumptions

Capital construction cost estimates

The capital construction cost estimates used in the financial analysis for the different cases are shown in Table K-2.

Table K-2 Capital Cost estimates (CAD)

	Biodiesel 60 MMLY crude glycerin	Biodiesel 60 MMLY, refined glycerin	Biodiesel 140 MMLY, crude glycerin	HDRD 189 MMLY
Total engineering and construction cost	$ 50,333,141	$57,502,027	$63,756,892	$ 155,544,318
Total estimated project cost	$ 63,927,467	$73,047,112	$96,712,709	$ 191,848,830

The decision to sell refined glycerin adds capital cost for distillation and refining. The HDRD facility requires more expensive equipment than the biodiesel facility.