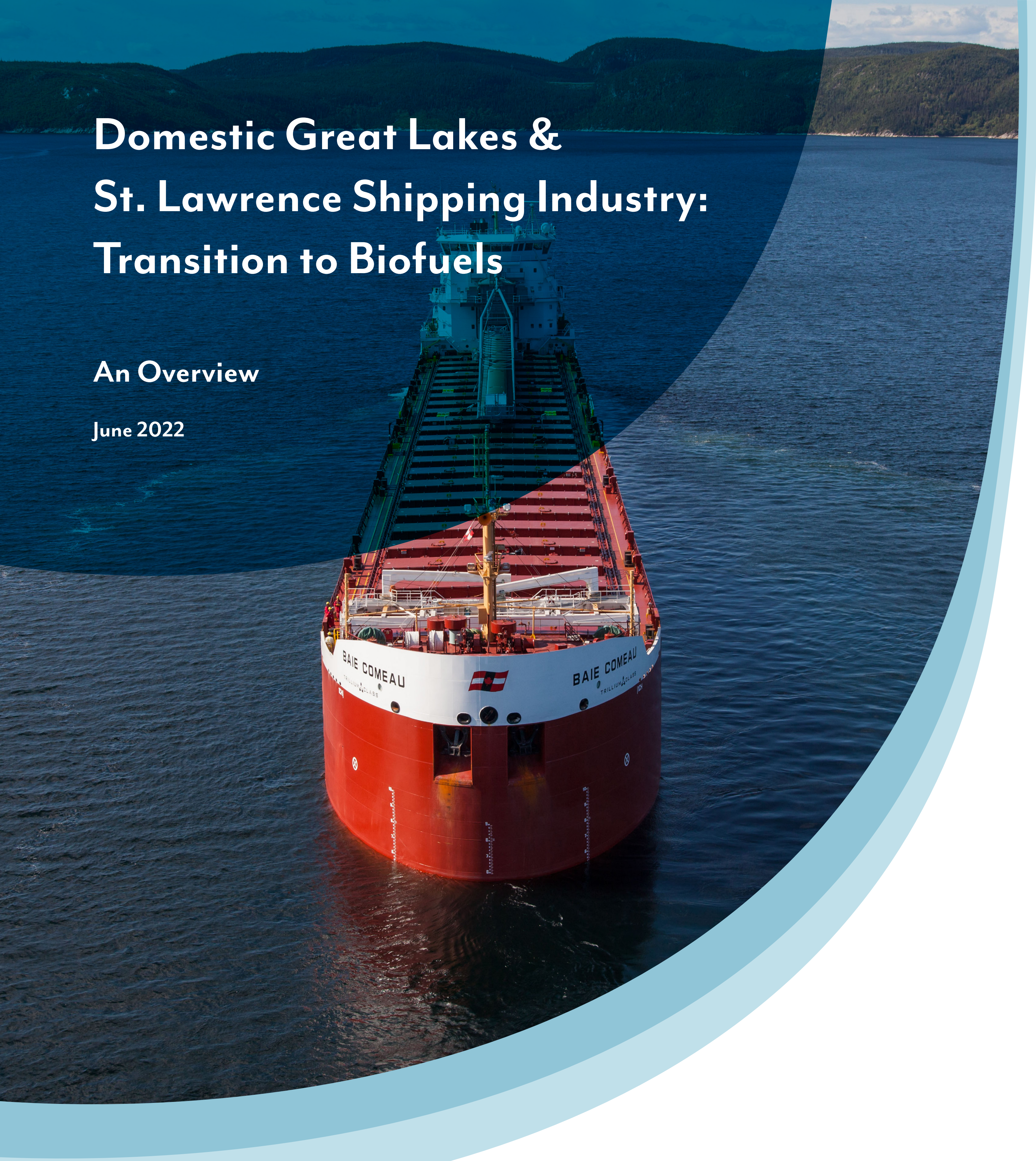

Domestic Great Lakes & St. Lawrence Shipping Industry: Transition to Biofuels

An Overview

June 2022

INNOVATION MARITIME
INSTITUT MARITIME DU QUÉBEC

GREAT LAKES
ST. LAWRENCE
GOVERNORS
& PREMIERS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES


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1. EXECUTIVE SUMMARY

An important step toward reducing carbon emissions from transportation is to get cargo onto the water. In no other mode of transport is the ratio of cargo carried to GHG emissions as good as in shipping. GHG emissions reduction can be further improved by using second-generation biofuels (drop-in fuels). The energy content of these biofuels is a very important issue and the biggest hurdles to introducing their use is biofuels' higher cost and the need for supply security.

To reduce the GHG emissions of the fleet operating in the Great Lakes St. Lawrence maritime system (GLS), switching from fossil fuels to biofuels is a possible answer. Given that the GLS fleet comprises freshwater and saltwater vessels, drop-in fuels are the most promising solution. We have identified three fuels that meet GLS ecosystem requirements: biodiesel, renewable diesel and Fischer-Tropsch diesel. Biodiesel has a lower energy content than renewable diesel and Fischer-Tropsch diesel and performs worse at low temperatures, a problem that can be solved by using heated fuel systems, like for heavy fuel oil. However, biodiesel is less expensive than renewable diesel due to additional costs incurred for upgrading renewable diesel pre-fuel in a refinery. Unlike renewable diesel and Fischer-Tropsch diesel, biodiesel is already available in large volumes and a distribution infrastructure exists. Renewable diesel is also commercialized but volumes are still small. This is expected to change by 2026 and renewable diesel production volumes should increase significantly. If the entire GLS fleet were to switch over to 60%-or-so biofuels by 2030, the Canadian (40%) and US (50%) GHG emissions reduction targets could be achieved. If the entire fleet could be supplied with Fischer-Tropsch diesel, emissions could be reduced by up to 90% (near carbon neutrality) compared to 2019. Biofuel's disadvantage as a drop-in fuel is its relatively higher price and lack of supply security.

If all measures promised by the Canadian and US governments and industry biofuel-related commitments are enacted, supply security would be guaranteed for the entire GLS fleet from 2026 on. However, it seems unlikely that the significant 300% price difference between biofuels and fossil fuels could be offset by increased supply alone. If a carbon tax were to be considered as a solution, our analysis shows that it would have to be $400-500 US/mt CO_2e to equalize fossil fuel and biofuel price levels at the time this report was written. Coordinated action between governments and industry would clearly be needed to help overcome these problems. To do so, we recommend:

1. Provide early adopter benefits
2. Align Canadian and US policy initiatives
3. Funds raised through carbon taxes, carbon credits or similar initiatives should be reinvested in decarbonization projects
4. Promote supply infrastructure
5. Implement subsidies to expand and/or converting refineries
6. Recognize biofuels as marine fuels
7. Continue and expand industry pilot projects to test biofuels in real-world settings
8. Undertake more research projects on the issue of supply security
9. Research projects to identify the special needs of the different maritime services (tugs, cargo, distributor, etc.) in terms of biofuel switchover options
10. Research new refining catalysts to enhance the biofuel production rate, to lower the final price
11. Research regulatory processes of the Scandinavian countries which are much faster to implement innovation in the maritime sector.

2. INTRODUCTION

Recent years have been marked by growing awareness and concern about climate change caused by the emission of greenhouse gases (GHGs) and other pollutants of human origin. The Paris Agreement and stricter shipping regulations adopted by the International Maritime Organization (IMO) reflect worldwide commitments to fight climate change. IMO-imposed restrictions led to a 0.5% reduction in marine fuels' sulfur content in 2020 and a cap on nitrogen oxides (NO_x) in emission control areas (ECA). [1][2] Major upcoming IMO regulations are aimed at reducing GHG emissions by at least 40% by 2030 and 70% by 2050.

However, IMO regulations do not apply to the entire Great Lakes St. Lawrence Seaway System (GLS), which is divided into two parts: the freshwater Great Lakes and the partially saltwater St. Lawrence River, which constitutes an IMO emission control area downriver from Montreal. All ships navigating this ECA must comply with the stricter NO_x emission standards and the IMO-imposed 0.1% cap on fuel SO_x content. [1] The Great Lakes situation is unique as the Lakes constitute an inland waterway system divided by the Canada-US border, with Canadian and US regulations and initiatives differing.

Despite these dissimilarities, governments, industry and stakeholders in both Canada and the US are seeking solutions to reduce the marine sector's environmental footprint. However, other contextual elements must be taken into account when evaluating potential GHG solutions.

The US domestic fleet has been subject to the *Jones Act* or *Merchant Marine Act* since 1920. [3][4] This legislation requires ships operating on the Great Lakes to be built in US shipyards which are somewhat more costly by international standards. Further, many US vessels operating on the Great Lakes are too wide to transit through the locks to enter the St. Lawrence and therefore operate only in freshwater and have relatively long service lives. As a result, the US domestic fleet has a significantly higher average vessel age: 40 years is not uncommon. For this reason, existing ships may have limitations in terms of altering engines, onboard machinery or fuels. In contrast to freshwater ships, saltwater vessels' average life expectancy is 25 years, resulting in a higher renewal rate. Of course, there is more flexibility with new vessels in terms of design, engine type, machinery and fuel types.

Potential solutions must take this difference in fleet structure and renewal dynamics into account, despite the pollution-reduction measures already implemented, to further reduce GHGs in order to achieve Canadian and US climate targets. Solutions must improve environmental footprints, be economically viable and apply to as many ships as possible regardless of the model and year of construction for both the Canadian and US fleets.

Second-generation biofuels: a possible solution?

One way to address the goal of reducing GHG emissions in the GLS is to use second-generation biofuels. Over their whole life cycle, these biofuels show GHG-reduction potential of up to 90%. Fossil-fuel alternatives must be "drop-in" fuels, i.e. fuels that can be used in existing ship engines with minor or no modifications, a criterion met by certain biofuels. However, a marine-industry switchover to biofuels requires acceptable biofuel volumes, infrastructures, biofuel prices and biofuel availability for the shipping sector.

The purpose of this study is to evaluate biofuel availability for a switchover of GLS shipping and to assess the potential gains of using biofuels within an environmental carbon-emissions reduction strategy.

3. CURRENT CANADIAN AND US BIOFUEL PRODUCTION – LITERATURE REVIEW

Biofuel is a generic term for all fuels made from primary biomass/organic waste or extracted from biomass produced by micro-organisms. Traditionally, biofuels are classified into three generations: first, second and third. This study will focus exclusively on second-generation biofuels, which are produced from biomass waste: plant residues, animal fats, used cooking oils (UCOs) or lignocellulosic residues, mostly from forestry and paper mills. Second-generation biofuels are particularly attractive as a marine biofuel based on GHG-reduction potential, technical maturity and raw material availability.

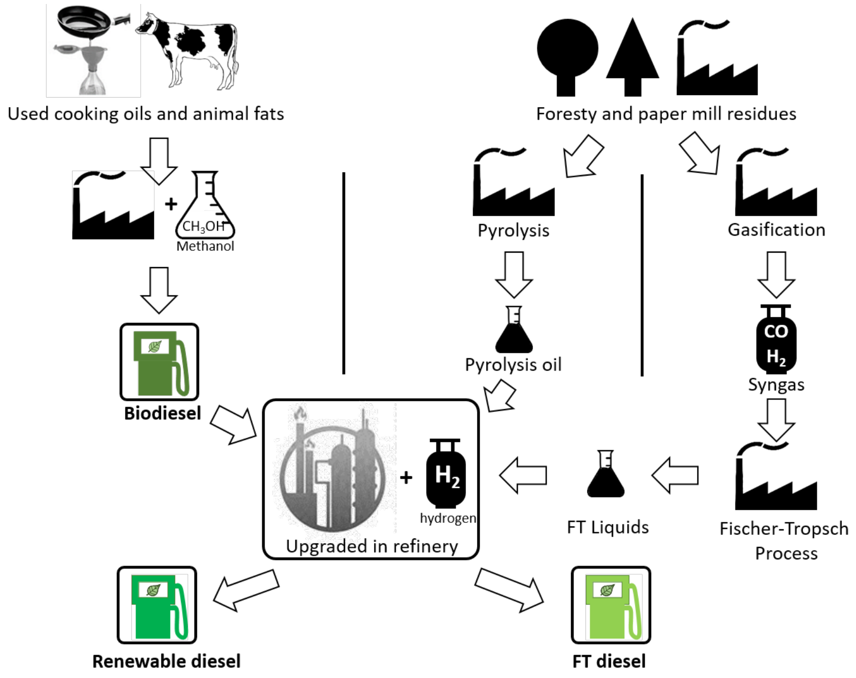
3.1. BIOFUEL TYPES CONSIDERED IN THIS STUDY AND THEIR SYNTHESIS PATHWAYS

A great many biofuels, biofuel feedstocks, synthesis and production pathways are intertwined (See Appendix A). Note that the term "biodiesel" is reserved for a specific type of fuel: fatty acid methyl esters, similar to fossil diesel but containing oxygen. Other types of alternative diesels can be classified as renewable diesel: hydrotreated vegetable oil or green diesel, sometimes known as hydroprocessed esters and fatty acids. In contrast to biodiesel, renewable diesel does not contain oxygen, has the same molecules as fossil diesel and can be used as is in a ships' combustion system. A third, renewable diesel-equivalent alternative is Fisher-Tropsch diesel. [5][6] Whereas biodiesel and renewable diesel are already available commercially, Fischer-Tropsch diesel is not yet available in large quantities although the Fischer-Tropsch process is a well-known technology developed in the 1920s.

These biofuel types are considered alternatives to existing fuels like heavy fuel oil and marine gas oil and can be used as drop-in fuels, i.e. requiring minor or no changes to existing ship diesel engines or to the fuel supply chain. Drop-in biofuels can be used as pure biofuel or blended with fossil fuels in various ratios. The main difference between biodiesel vis-a-vis renewable diesel and diesel produced by using the Fischer-Tropsch process is that they do not contain oxygen. The oxygen content of biodiesel is the reason for its lower energy content and poorer performance at low temperatures.

Figure 1 is a highly simplified diagram of biofuel production processes illustrating the different feedstock and processing pathways that ultimately define the resulting fuel's properties and end price. Used cooking oils and unusable slaughter waste (animal fats) can be processed to obtain biodiesel. Biodiesel's energy content is lower than fossil diesel's, i.e. more biodiesel is needed to travel the same distance. To overcome this, biodiesel can be upgraded through refining, by adding hydrogen to achieve renewable diesel with the same energy content as fossil diesel.

Figure 1: Examples of pathways for producing drop-in biofuels



Data source: Innovation Maritime

Forestry and paper mill residues (lignocellulosic feedstock) must be processed differently from oils and fats. Currently, the two possible synthesis routes are pyrolysis and gasification. In the pyrolysis process, the resulting pyrolysis oil must be refined for more extensive use in marine engines. After refining, its energy content and property profile is the same as fossil diesel and it can be described as "renewable diesel." The second synthesis pathway for forestry and paper mill residues is gasification with subsequent synthesis of liquids using the Fischer-Tropsch process. The liquids are intermediates and, like pyrolysis oil, must be refined for more extensive use in marine engines. By in-refinery upgrading, a fossil diesel property profile can be achieved. The resulting fuel is called Fischer-Tropsch diesel, indicating that synthesis was performed using this process. Where pricing is concerned, every step adds costs, especially hydrogen-based refining. However, forestry and paper mill residues are less expensive feedstocks than used cooking oils or animal fats.

3.2 RAW MATERIALS FOR BIOFUEL PRODUCTION

Biofuel properties reflect the production process and feedstocks used. Different feedstocks result in fuels with slightly different characteristics.

Fats, oils and greases are a potential feedstock. They are energy-dense and their supply chain is well established and commercialized in the road transport sector. However, fats, oils and grease are more expensive than lignocellulosic feedstock and resources like used cooking oils, are decentralized and, unlike crude oil deposits, are not available in large reservoirs. Further, available used cooking oil volumes and price depend on external factors like cooking oil consumption in the food industry.

Lignocellulosic feedstock is available from wheat straw, corn stover or forest and paper mill residues. Its main advantage is that the raw material is abundant. Québec biomass alone has an energy potential of 326 petajoules (PJ) with the main share of 254 PJ stored in forest biomass. Based on energy content, this would be sufficient to cover the Port of Montreal's fuel consumption for 517 years (reference year = 2020). [7] The downside, however, is that lignocellulosic raw material provides significantly less energy than fats, oils and greases, meaning it always requires refining (Figure 1) to boost its energy content. Furthermore, transportation is an issue: either resources must be transported long distances to be processed in urban centers or production facilities must be built close to the feedstock (e.g. forest) and the resulting final fuel must then be transported. Both have a negative impact on the GHG balance, albeit less in the latter case.

3.3 ASSESSMENT OF BIOFUEL PRODUCTION IN THE US AND CANADA

3.3.1 Canadian biofuel production

In early 2022, we found six operational biodiesel plants in Canada for a total production capacity of 685 MLPY/181 MGPY (millions of liters/gallons per year). For second-generation biodiesel alone, this represents 255 MLPY (67 MGPY): this corresponds to 37% of total Canadian biodiesel production in 2021 and 50% of GLS annual fuel consumption.[1] We were unable to identify any Canadian production of renewable biodiesel .[2]

See Appendix E for detailed information on Canadian biofuel production and production volumes.

3.3.2 US biofuel production

In early 2022, the US' many biodiesel plants accounted for a total biodiesel production capacity of 9905 MLPY (2617 MGPY), with second-generation biodiesel production capacity totaling 4754 MLPY (1256 MGPY). Data collection was challenging since some producers state that they use "multifeedstock" for fuel production. It is unclear whether this means that different plant species are used (canola, soy, corn, etc.), which could correspond to first-generation biodiesel, or whether a mixture of different sources (used cooking oils, animal fats, canola, soy, etc.) is used. If we consider producers that gave clear indications, i.e. other than "multifeedstock", and use second-generation feedstock, 535 MLPY (141 MGPY) of biodiesel are available and could support approximately 105% of the GLS fleet (Canadian- and US-flagged vessels).

US renewable diesel production is 4932 MLPY (1303 MGPY). Of this total, 2555 MLPY (657 MGPY) can definitely be termed second-generation and could cover 501% of GLS fuel consumption.

See Appendix E for a complete list of US biofuel producers.

3.4 SUMMARY OF BIOFUEL PRODUCTION

From the range of biofuels available, biodiesel, renewable diesel and Fischer-Tropsch diesel were selected for further consideration, since all three alternatives can be used as drop-in fuels. The production processes and feedstock used influence the subsequent fuel properties. Fats, oils and greases are energy-rich and requires few improvement steps, but feedstock is decentralized and its price is subject to external market influences. Lignocellulosic feedstock is low in energy and always requires refining but the raw material can be obtained from forestry residues which are abundant, centralized and less subject to price fluctuations.

The US is one of the world's largest biodiesel and renewable diesel producers. Canadian biodiesel production capacity is significantly lower than US capacity, however Canadian consumers benefit from this since the two markets are intertwined. US second-generation biofuel production alone could meet the needs of the GLS fleet. Of course, the volumes described above cannot be easily made available to the marine sector, given that they are already being used in land-based transportation. Possible avenues for freeing up these volumes for use by the marine sector are discussed in Section 3.3.

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[1] Fuel consumption data based on reference [14].

[2] Pyrolysis oil is produced but would have to be refined to become renewable biodiesel.

4. BIOFUEL PRODUCTION GROWTH PREDICTIONS - LITERATURE REVIEW

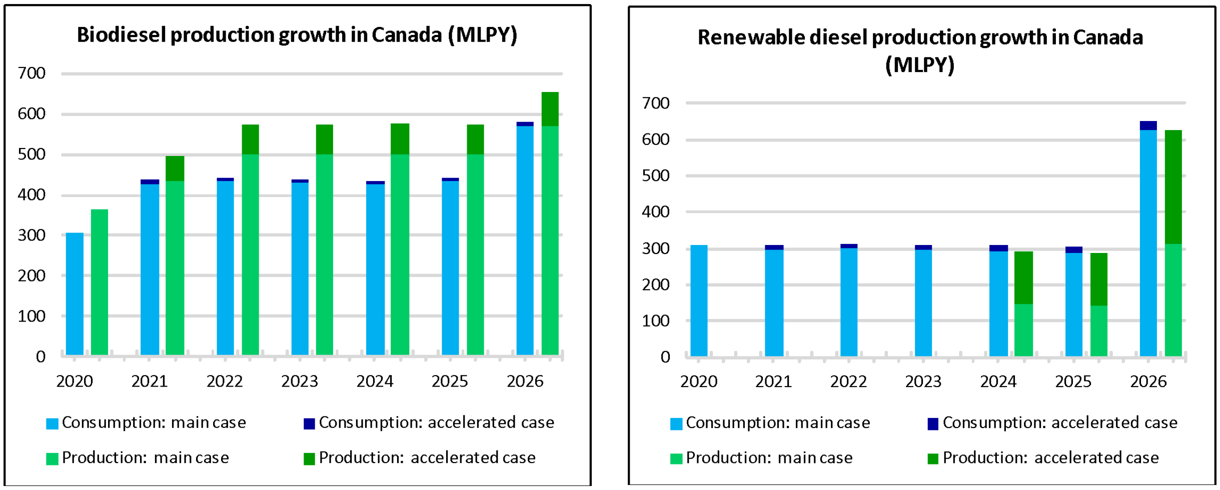
Recent literature on biofuel production growth prediction models is sparse. Much of the literature is no longer applicable since pre-2020 forecasts could not foresee the impact of the COVID-19 crisis on the global economy. The following discussion is based on the International Energy Agency (IEA) report "Renewables 2021: Analysis and forecast to 2026". [8]

4.1 LITERATURE REVIEW PREDICTIONS – CANADA

Figure 2's left-hand histogram presents the IEA report's biodiesel consumption (blue bars) and production (green bars) growth predictions for Canada. The lighter-colored areas represent conservative growth (main case) and the darker-colored areas correspond to best-case growth (accelerated case), which takes government incentives and industry biofuel-related commitments into account. Unfortunately, the IEA report does not specify the generations of biofuels considered. Based on the volumes indicated (in MLPY), we assume they were first- and second-generation biofuels. In future, the share of second-generation biodiesel is expected to increase since the majority of new production projects fall into this category.

Canadian biodiesel production volumes increased from 2020 to 2022 in both the main and accelerated cases. After that, they remain constant in both scenarios. In 2026, a further increase in production volume is predicted, bringing production capacity to 655 MLPY (173 MGPY), an increase of 55% (main case) and 78% (accelerated case) from the initial 2020 values. The trend for projected biodiesel consumption is similar. However, biodiesel production volumes always exceed biodiesel consumption volumes.

Figure 2: Canadian biodiesel and renewable diesel production growth (MLPY)



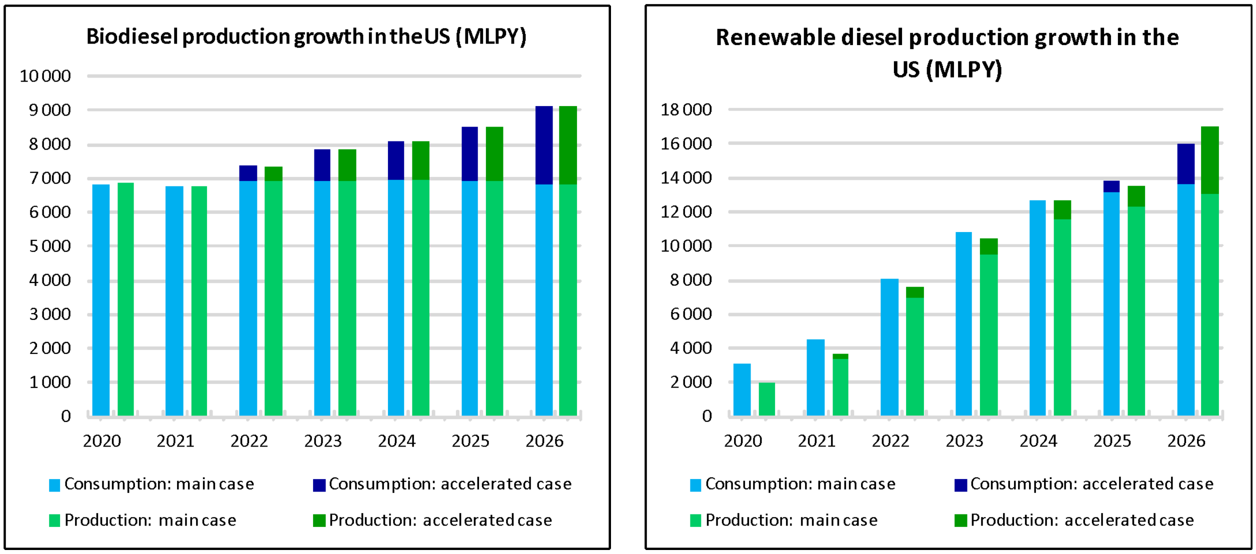
The green bars represent predicted production and the blue bars represent predicted fuel consumption. The darker-colored areas represent predictions that include government incentives and industry biofuel-related commitments. Data source: IEA report [9]

The initial renewable diesel situation (Figure 2's right-hand histogram) differs completely from its biodiesel counterpart. As mentioned earlier, we found no renewable diesel production facilities in Canada. In 2020, Canadian renewable diesel consumption was completely covered by imports, about 83% from the US. [10] According to predictions, this situation will not change before 2024 when Canadian renewable diesel production is slated to start. Imperial Oil Ltd. plans to build a renewable diesel unit at its refinery near Edmonton and production is scheduled to begin in 2024. [11] Covenant Energy Ltd. plans to produce renewable jet diesel in Saskatchewan beginning in 2024. [12] This explains the surge in production volume. Canadian production (accelerated case) could thus almost cover Canadian consumption which means that less renewable diesel would have to be imported than in 2020. The Canadian market's self-sufficiency trend continues in 2025 and 2026. Production volumes are expected to virtually double in 2026 compared to 2025, reaching 313 MLPY (83 MGPY) in the main case and 627 MLPY (166 MGPY) in the accelerated case. Consumption could also more than double due to increased supply. However, Canada would be self-sufficient only in the accelerated case. In the main case, demand would be approximately twice as high as the volumes produced.

4.2 LITERATURE REVIEW PREDICTIONS - US

Figure 3's left-hand histogram presents the IEA report's biodiesel consumption (blue bars) and production (green bars) growth predictions for the US. The lighter-colored areas represent conservative growth (main case) and the darker-colored areas correspond to best-case growth (accelerated case), which takes government incentives and industry biofuel-related commitments into account. For biodiesel, main case production and consumption levels will remain stable for the next five years, both at about 6900 MLPY (1823 MGPY). This means that the US biodiesel market could be self-sufficient with production able to meet demand. In the accelerated case, both biodiesel consumption and production volumes increase at the same rate, posting an annual average of 6.1% (between 2022 and 2026), and the final best-case production volume shows growth potential of 33.6% compared to 2020.

Figure 3: US biodiesel and renewable diesel production growth (MLPY)



The green bars represent predicted production and the blue bars represent predicted fuel consumption. The darker-colored areas represent predictions that include government incentives and industry biofuel-related commitments. Data source: IEA report [9]

Predicted US renewable diesel production growth is shown in the right-hand histogram. In contrast to biodiesel production growth, renewable diesel production is predicted to increase annually in both the main and accelerated cases. From 2020 to 2026, increases of 546% (main) and 742% (accelerated) are expected due to US government policies leading to demand tripling and hence the need for larger production volumes. [8] Due to its enormous growth potential, renewable diesel is expected to exceed biodiesel volumes by mid-2022. Main case renewable diesel production volume would exceed accelerated case biodiesel production volume by 43%. However, renewable diesel demand would increase at the same rate as production capacity. Only in the accelerated case, beginning in 2026, would US production be able to meet US demand. If the main scenario occurs, the volume shortfall will have to be covered by imports. This enormous predicted growth is based on expansion of existing plants and construction of new ones, e.g. the Green Diamond facilities, which expect to reach a production capacity of 4315 MLPY (1140 MGPY) by late 2023, a volume that would cover 827% of 2019 GLS needs. [13]

4.3 GREAT LAKES - ST. LAWRENCE SEAWAY CONSIDERATIONS

This section presents calculations for biofuel consumption in the GLS to determine whether biofuel supply could be sufficient to cover the needs of the entire GLS fleet. These calculations are based on 2019 fuel consumption data from reference [14] and compared to the 2026 IEA forecast. In 2019, the consumption of liquid fossil fuels by the fleet was approximately 509 MLPY[3] (134 MGPY). As mentioned in Section 2.4, the biofuel volumes theoretically considered sufficient do not guarantee supply security for the entire GLS fleet given that the lion's share of these volumes is used to meet GHG emission mandates in the land-based transport sector.

Since overall GLS marine-related fuel consumption is not expected to change drastically in the coming years, we used the 2019 consumption for our calculations. If the accelerated case forecast for 2026 is accurate, excess biofuel production in 2026 will equal 4% of combined Canadian and US biofuel (biodiesel and renewable diesel) production. GLS demand would use half of this total combined production volume, leaving a 2% surplus that is unallocated. The accelerated case predictions thus lead us to conclude that 100% of the

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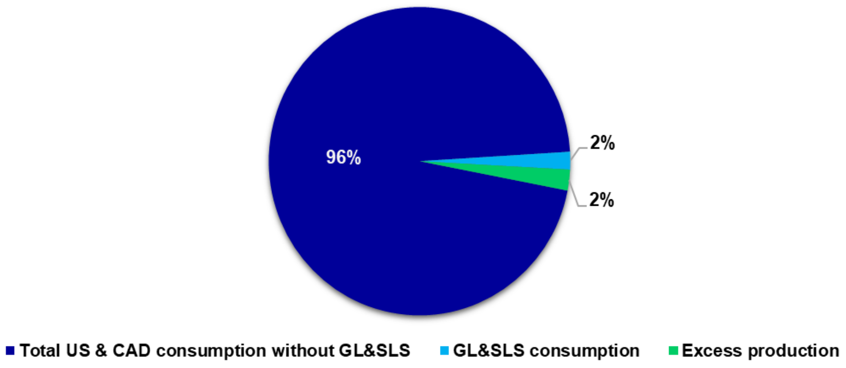
[3] This amount corresponds to approximately 510,000 mt/year for all ships operating in the GL&SLS including non-Canadian- and non-US-flagged ships. Consumption by Canadian- and US-flagged ships was approximately 407 MLPY (107 MGPY) or 400,000 mt.

GLS fleet could switch to biofuels, whose supply would be guaranteed.

Figure 4: Total predicted US and CDN biofuel production surplus for 2026 including additional GLS consumption (2019 values)



Calculations use data from Figure 2 and Figure 3, taking additional GLS consumption (509 MLPY) in 2019 into account. The 2019 values are compared to the 2026 accelerated case predictions. Data source: Innovation Maritime

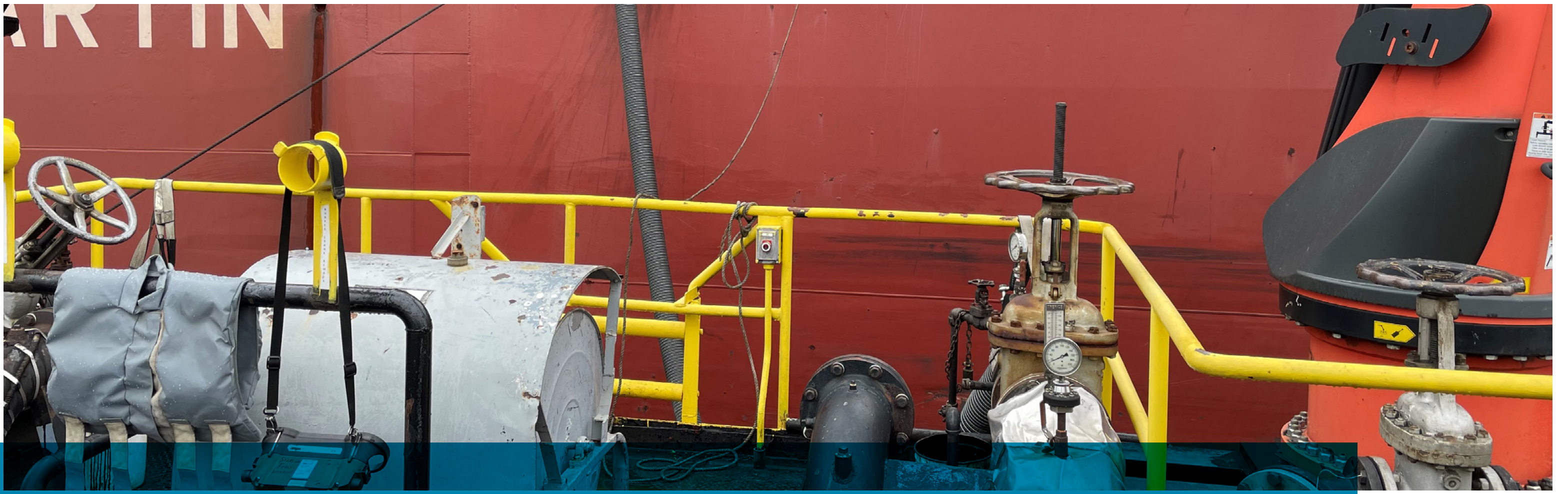
4.4. GOVERNMENT SUPPORT

Longstanding, successful US government support programs to expand biodiesel and renewable production capacity have made the US one of the world's top biofuel producers. The US and Canadian fuel markets are closely linked which is an advantage for Canadian consumers who can benefit from well-developed infrastructure. The difference in production volumes is significant for biodiesel and even more dramatic for renewable diesel. Canadian renewable diesel production is expected to be available in 2024 but will be modest compared to expected US 2026 production. About two-thirds of US renewable production growth is driven by policy initiatives such as the *Renewable Fuel Standard*, blender tax credits and *California's Low Carbon Fuel Standard* credits. [9][15]

In Canada, the *Clean Fuel Regulations* embedded in the Canadian *Clean Fuel Standard,* part of Canada's climate plan, will be introduced in 2022 with financial support from the *Clean Fuels Fund*. This fund aims to accelerate Canadian non-fossil-fuel and biofuel production, establish a supply chain for the biomass needed and introduce codes and standards such as tax incentives for biofuel producers. [16] Canada's forests represent vast, as-yet-unexploited energy potential. This lignocellulosic feedstock could make a major contribution to Canada's energy transition as it could be used to produce both renewable diesel and Fischer-Tropsch diesel (Figure 1).

4.5 SUMMARY

Biofuel production capacity is predicted to increase in both Canada and the US in coming years. The US already has a well-developed biofuel infrastructure whose production capacity is significantly higher than Canada's. In 2026, it might be possible to use biofuels to meet total GLS fleet demand and post a production surplus that is as yet unallocated. Fischer-Tropsch diesel has not been included in projections because historical data is not yet available. Both Fischer-Tropsch diesel and renewable diesel can be produced from lignocellulosic waste which is abundant, centralized and cheaper than fats, oils and greases. However, both of these diesel alternatives entail refining which turns the pre-fuels into fuels that are identical to fossil diesel and have the same energy content.



5. OVERALL ASSESSMENT OF BIOFUEL GHG EMISSIONS

To understand alternative fuels' effects on GHG emissions, we must perform a life cycle analysis on each fuel type. The analysis calculates the amount of energy needed and GHGs produced during all of a fuel's life steps: raw material production, addition of chemicals (e.g. hydrogen), transport for further processing in a refinery, upgrading and transport to consumers (in this case, ports). Life cycle analysis values are often expressed in gram CO_2 equivalents per energy unit (gCO_2e/MJ). This functional unit was introduced to be able to compare life cycle analyses, given that CO_2 is a GHG but so is methane, for instance. The lower the life cycle analysis value, the fewer the GHGs emitted.

When looking at life cycle analyses, we must pay very close attention to what is being considered. Analyses can be divided into three groups:

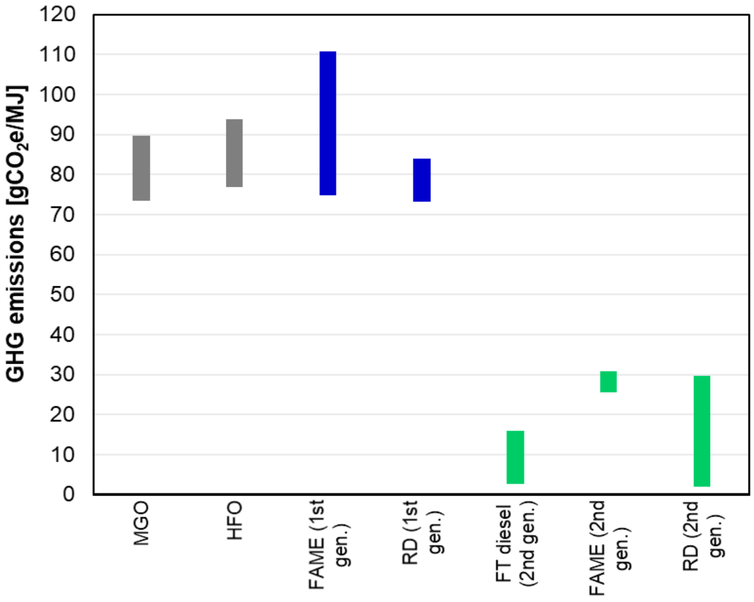
1. Consider fuel production to tank/filling station
2. Consider only the GHG emitted during combustion
3. Comprehensive analyses that include all stages, i.e. cultivation, transport, combustion.

Our discussions here are based on comprehensive analyses: from the very first step of the life cycle to the very last one, i.e. combustion in a marine diesel engine, often referred to as well-to-propeller. Note that the IMO considers only life cycle analyses that deal solely with fuel combustion (Group 2 above) although this is expected to change soon.

To further complicate things, several models exist for calculating life cycle analyses which in turn are used to determine GHG emission, therefore potentially resulting in differing emission values. A study prepared for the IEA Bioenergy Task 39 [17] calculated the GHG impacts of used cooking oil-based renewable diesel using different life cycle analysis models. Calculations using one model resulted in GHG emissions of 21 gCO_2e/MJ while another resulted in emission of 3 gCO_2e/MJ for the same fuel, using the same feedstock in the same production context.

Like petrochemical fuel combustion, biodiesel, renewable diesel and Fischer-Tropsch diesel combustion releases CO_2. Biofuel GHG emissions are reduced elsewhere because biofuel feedstock is organic matter which binds CO_2 from the atmosphere during its lifetime. When biofuel is burned, only this CO_2 is returned to the atmosphere unlike petrochemical fuels which, when burned, add to atmospheric CO_2.

Figure 5: GHG emissions distribution by fuel type



Data source: Innovation Maritime

Figure 5 presents the results of our literature review. Marine gas oil (MGO) and heavy fuel oil (HFO) are included for reference. All fuels' GHG emission values are scattered because different references give different values. The blue bars show why a switch to first-generation biofuels is clearly not a useful alternative. Due to the indirect land use change penalty, first-generation biodiesel performs poorly compared to second-generation biodiesel. According to some calculations, the use of Fischer-Tropsch diesel and renewable diesel could even achieve near carbon neutrality. Biodiesel does not perform as well, but its GHG emissions reduction potential is approximately 60%.

5.1 GHG ASSESSMENT SUMMARY

To determine GHG emissions, the literature review-based life cycle analysis data that we used considered the whole life cycle and referred specifically to the marine sector. Analysis of this data shows that GHG emissions for alternative fuels vary substantially since different assumptions and models were used for the individual calculations. As Figure 5 shows, second-generation biofuels have the highest GHG reduction potential.

For calculations to be accurate for a given fleet, the combustion profile of each individual ship must be used in addition to the life cycle analysis of the biofuel that the ship owner wants to use.

Biofuel use can lead to significant GHG savings, most optimistically even near carbon neutrality. A detailed look at GHG emissions is presented below.

6. GHG EMISSIONS AND SWITCHOVER SCENARIOS TO-SECOND-GENERATION BIOFUELS

In the first part of this report, we discussed potentially interesting fuels, described their overall properties, and touched on Canadian and US predicted production growth and production volumes currently available. Now, we will take a closer look at GHG emissions and our fuel price literature review, explain carbon pricing scenarios and consider their usefulness as a decision-making support.

6.1 GLS GHG EMISSIONS

The GLS GHG emissions estimates used here are based primarily on a study by the International Council on Clean Transportation [14] for GLS fuel consumption and the gCO_2e emission values based on our literature review. In 2019, GLS liquid fuel consumption for the Canadian- and US-flagged GLS fleet, which comprises 80% of all vessels operating on the GLS, was 399,849 mt (338,640 mt = Marine Gas Oil and 61,200 mt = Heavy Fuel Oil).

Based on these consumption figures, we will now look at the impact of a switchover from fossil fuels to second-generation biofuels and the associated GLS GHG emissions savings.

We will consider four switchover scenarios in terms of gCO_2e:

1) 100% switchover (all fossil fuels are replaced by second-generation biofuels);

2) 75% switchover;

3) 50% switchover; and

4) 25% switchover.

A 50% switchover, for example, can mean either of the following:

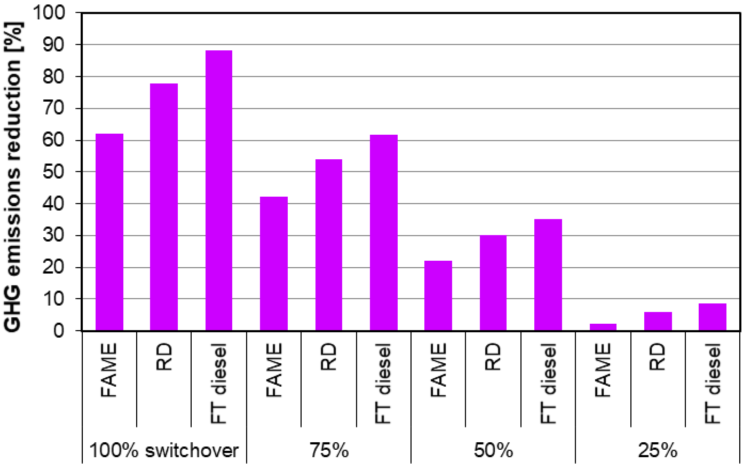
- 50% of the fleet switches to 100% biofuel, or
- 100% of the fleet uses a 50-50 biofuel/fossil fuel blend.

6.2 GLS GHG EMISSIONS DATA FOR THE FOUR SWITCHOVER SCENARIOS

To see how using second-generation biofuels (drop-in fuels) affects GLS fleet emissions, we used the emissions data averages from the literature review findings (Appendix B).

If 100% of the GLS fleet (Canadian- and US-flagged vessels) used the second-generation biofuels described in this report, the GHG savings could be a 60-90% improvement over the 2019 figures thereby achieving the 70% savings climate target set for 2050. Even a nearly carbon neutral future seems possible, assuming the whole fleet could use Fischer-Tropsch diesel (See Figure 6). A 25% switchover to biofuels, however, could not achieve the 40% savings climate target set for 2030. If the 2030 climate target is to be achieved through the use of second-generation biofuels (drop-in fuels) alone, more than half of the GLS fleet would have to switch over to them. GHG emissions savings from the use of biodiesel would be lower than renewable diesel or Fischer-Tropsch diesel-related savings due to biodiesel's lower energy content and the need to consume more biodiesel to cover the same distance. Nevertheless, savings of 60% are sufficient to achieve the 2030 climate goal. The 20-30% savings gap compared to renewable diesel or Fischer-Tropsch diesel is somewhat offset by the fact that the biodiesel infrastructure is well established, biodiesel is less expensive than renewable diesel and biodiesel production capacity is already high.

Figure 6: GHG emissions reduction from GLS fleet 25-100% switchover to second-generation biofuels, compared to 2019 emissions using Marine Gas Oil and Heavy Fuel Oil



Data source: Innovation Maritime

6.3 GHG EMISSIONS SUMMARY

The four fuel switchover scenarios (25-50-75-100%) were used to assess the impact on GLS greenhouse gas emissions of using second-generation biofuels (drop-in fuels).

Our GHG switchover analysis shows that these biofuels offer high potential for bringing the shipping sector to a low-carbon future. However, since biofuel life cycle analysis reflects specific factors (feedstock, factory's energy source, transport, engine performance, etc.), a comprehensive in-situ analysis would be needed for more accurate assessment.

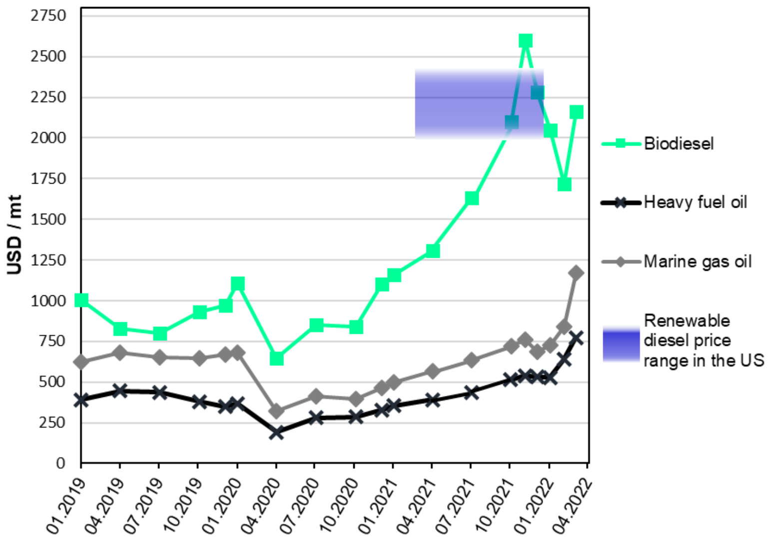
7. ECONOMIC ANALYSIS OF BIOFUELS

This section contains an analysis of the growth in biodiesel prices compared to marine gas oil and heavy fuel oil prices, since zero-to-limited data on renewable diesel or Fischer-Tropsch diesel prices were available. Prices are shown in US$/mt. [18] [19]

7.1 BIOFUEL PRICE GROWTH

Biodiesel is more expensive than marine gas oil, which, in turn, is more expensive than heavy fuel oil. All three of these fuels show the same price trend, although biodiesel is always higher.

Figure 7: Fuel price growth - January 2019 to March 2022



Data source: [18][19]

Beginning in 2020, fuel prices for these three fuel categories dropped due to lower consumption caused by the COVID-19 crisis. By fall 2020, prices had increased to pre-COVID levels and continued to rise. The price of biodiesel peaked in October 2021 at $2600 US/mt (marine gas oil = $760 US/mt and heavy fuel oil = $540 US/mt). After this peak, the price of biodiesel fell to $1720 US/mt, whereas the price of fossil fuels did not decline as much. With the onset of the Russo-Ukrainian war, fuel prices began to rise again. In March 2022, all fuel prices had doubled from their January 2019 levels to $2160 US/mt for biodiesel, $1170 US/mt for marine gas oil and $770 US/mt for heavy fuel oil.

For renewable diesel, we were able to identify only one reference which gives US prices between July and December 2021 (Figure 7), [20] as $2000-$2400 US/mt. Generally, the price of renewable diesel is higher than that of biodiesel, due to the additional processing and refining required (See Figure 1) to upgrade the pre-fuels to high-quality renewable diesel.

Fischer-Tropsch diesel is not yet in full commercial production so no historical pricing data is available. In 2019, four Fischer-Tropsch diesel gasification plants were operational in North America (pilot, demonstration (2) and first-of-its-kind plants). [21] The literature shows prices ranging from $688 US/mt to $2838 US/mt. [22] [5]

7.2 FACTORS INFLUENCING SECOND-GENERATION BIOFUEL PRICES

The context of COVID-19 and the Russo-Ukrainian war makes it very difficult to predict biofuel prices and we were unable to find data enabling us to make price forecasts. Consequently, instead of predicting price growth, we are providing an overview of factors that influence biofuel prices.

Global fuel markets (fossil fuels and biofuels) are intertwined--especially Canadian and US fossil fuel markets which are highly interconnected because they share the pipeline network for importing, exporting and reimporting. Fossil fuel prices are based on the price of crude oil which is set in the global marketplace but varies with transport costs and crude oil quality. [23]

Figure 7 shows that biodiesel price growth resembles that of marine gas oil and heavy fuel oil, albeit with a higher starting point and subsequent higher values. This seems illogical because biodiesel is not crude oil-based but made from organic raw materials. One would expect biofuel prices to depend mainly on the price of the respective feedstocks used to make them. Feedstock price plays a role, of course, but is not the driving force for pricing. Since biodiesel is a relatively new product compared to fossil fuels, in the early days of trading, its price was pegged to the price of heating oil, a petroleum product like marine gas oil. This explains the similar biodiesel and marine gas oil price growth trends. This approach is now being questioned and efforts are being made to trade biodiesel as an independent commodity completely separate from fossil fuel prices.

The North American renewable diesel pricing situation is somewhat different. We were unable to find reliable historical data. Our research and discussions with members of the biofuel industry lead us to believe that the price of renewable diesel in North America is set primarily by the Californian market. Because of the high blend rates under *California's Low Carbon Fuel Standard*, California must import significant volumes of renewable diesel to meet its own requirements. Because California pays the highest prices, most of the renewable diesel is sold there and, as a result, Californian prices become the US norm.

As discussed in Section 3.1, to date, no Fischer-Tropsch diesel price peg has been determined. As more production facilities start up and Fischer-Tropsch diesel volumes increase, a trading base will emerge.

Generally speaking, biofuel prices depend on many factors, each of which could be positively affected by government incentives, government support for technical innovation and industry biofuel-related commitments. The lower the price, the more interesting the biofuel alternative becomes for commercial use. We tried to identify factors affecting biofuel prices (See Appendix C). Production costs and feedstock prices are the main factors determining final fuel prices. If a fuel requires refining to achieve the desired property profile, the cost of refining also contributes significantly to determining the final fuel price. Refining uses hydrogen which is expensive and subject to its own price fluctuations. In the medium term, it seems that biofuel prices could be reduced only by governmental incentivization initiatives.

8. CARBON PRICING SCENARIOS

One way for governments to influence biofuels' competitiveness vis-à-vis fossil fuels is through a carbon tax. Canada introduced a federal carbon tax in 2019 ($40 US/mt CO_2e in spring 2022 and $170 US/mt CO_2e by 2030). In the US, the carbon tax is controversial and currently not levied. Can a carbon tax really make biofuels competitive? If so, how high would the tax need to be? Based on February 2022 fossil fuel (marine gas oil and heavy fuel oil) and biofuel prices (See Section 6.1 and Figure 7), the tax would have to be $400-500 US/mt CO_2e to equalize fossil fuel and biofuel prices (See Appendix D). It seems unlikely that a carbon tax of this magnitude will be implemented. For comparison purposes, Sweden's carbon tax was approximately $125 US/mt CO_2e in 2021. Even such a high tax could not close the fossil fuel/biofuel price gap in North America. Furthermore, other far-reaching measures would have to be considered to increase the price of fossil fuels, lower the price of biofuels or a combination of both.

A further incentive to encourage biofuel use is by introducing carbon credits as the US has done. These carbon credits make imported US biodiesel cheaper which is why almost all biodiesel used in Canada comes from the US. The lower price benefits Canadian importers like Canadian Clean Fuels. Conversely, Canadian biodiesel producers benefit from the higher US biofuel price due to high blend rates, e.g. under the Low Carbon Fuel Standard. Introducing carbon credits as an incentive is conceivable in Canada. However, doing so might not necessarily benefit the marine sector since other industries could buy up available biofuel volumes so as to benefit from the credits.

9. RECOMMENDATIONS

In sum, if all measures promised by the Canadian and US governments and industry biofuel-related commitments are enacted, supply security would be guaranteed for the entire GLS fleet from 2026 on. However, it seems unlikely that the current 300% price difference between biofuels and fossil fuels could be offset by increased supply alone. Measures such as a carbon tax that could bridge this gap are unlikely to be at a rate sufficient to equalize fossil fuel and biofuel price levels at the time this report was written. Coordinated action between governments and industry would clearly be needed to help overcome these problems and encourage greater use of biofuels. We therefore recommend:

1. The transition to second-generation biofuels requires investment so incentives should be created to provide early adopter benefits. Such incentives could include special tax savings for early adopters, carbon credits and/or subsidies for any

technical conversion needed. Easy access to subsidies and a transparent tax and credit policy are critical. Complicated applications and review procedures, non-transparent taxation and complex regulations slow down the switchover to low carbon alternative fuels.

2. Aligning Canadian and US policy initiatives would be desirable since supporting widely differing policies could divide the currently interwoven GLS economic area and create transition winners and losers.
3. To eliminate reluctance and increase biofuels' overall acceptance, funds raised through carbon taxes, carbon credits or similar initiatives should be reinvested in decarbonization projects.
4. The supply infrastructure (fuel producers, importers and distributors) must also be promoted. For example, transporting pre-fuels from production site to refinery requires equipment-related investments.
5. To increase second-generation biofuel (drop-in fuel) volumes, subsidies must be available for expanding and/or converting existing refineries or moving forward the construction of new ones. Refineries are important for improving fuels and upgrading pre-fuels to achieve fossil diesel-equivalent energy content. This is true for renewable diesel and Fischer-Tropsch diesel which can be produced from various second-generation resources and refined to achieve nearly the same property profile as marine gas oil. Such drop-in fuels at acceptable price levels should eliminate many stakeholders' reservations since they can barely be distinguished from fossil diesel.
6. An issue that governments should address as soon as possible is to recognize biodiesel, renewable diesel and Fischer-Tropsch diesel as marine fuels. Doing so would eliminate significant uncertainty for all stakeholders.
7. Continue and expand industry pilot projects to test biofuels in real-world settings
8. Research institutions can help bridge the gap between producers and consumers (shipowners) through projects as intermediaries. Thus, the issue of security of supply can be addressed.
9. More educational work should be done to provide stakeholders with more information to facilitate decisions on biofuels-such as through webinars and studies that address the specific needs of the individual GLS sectors. For example, the needs of tugboats are different from those of large cargo ships.
10. With regard to the refining process, the focus should also be on catalyst manufacturers. Novel catalysts used in biofuel refining have the potential to increase production rates, reduce by-products and thus make production more efficient and the fuel price more favorable. [24]an assessment of technical approaches being developed and an overview of anticipated challenges in large scale commercialization of so called “drop-in” biofuels. For the purposes of this report, “drop-in” biofuels are defined as “liquid bio-hydrocarbons that are functionally equivalent to petroleum fuels and are fully compatible with existing petroleum infrastructure”. The global petroleum industry is expected to require increasing amounts of hydrogen in the coming years to upgrade crude oil feedstocks of declining quality (i.e., increasingly heavier and more sour
11. It should be investigated as to why some countries are more successful in converting their fleets to alternative fuels than others. Especially with regard to bureaucratic hurdles, the approach of the Scandinavian countries should be examined more closely. There, innovations are integrated much more quickly from the conception and prototype phase into everyday maritime life. [25]

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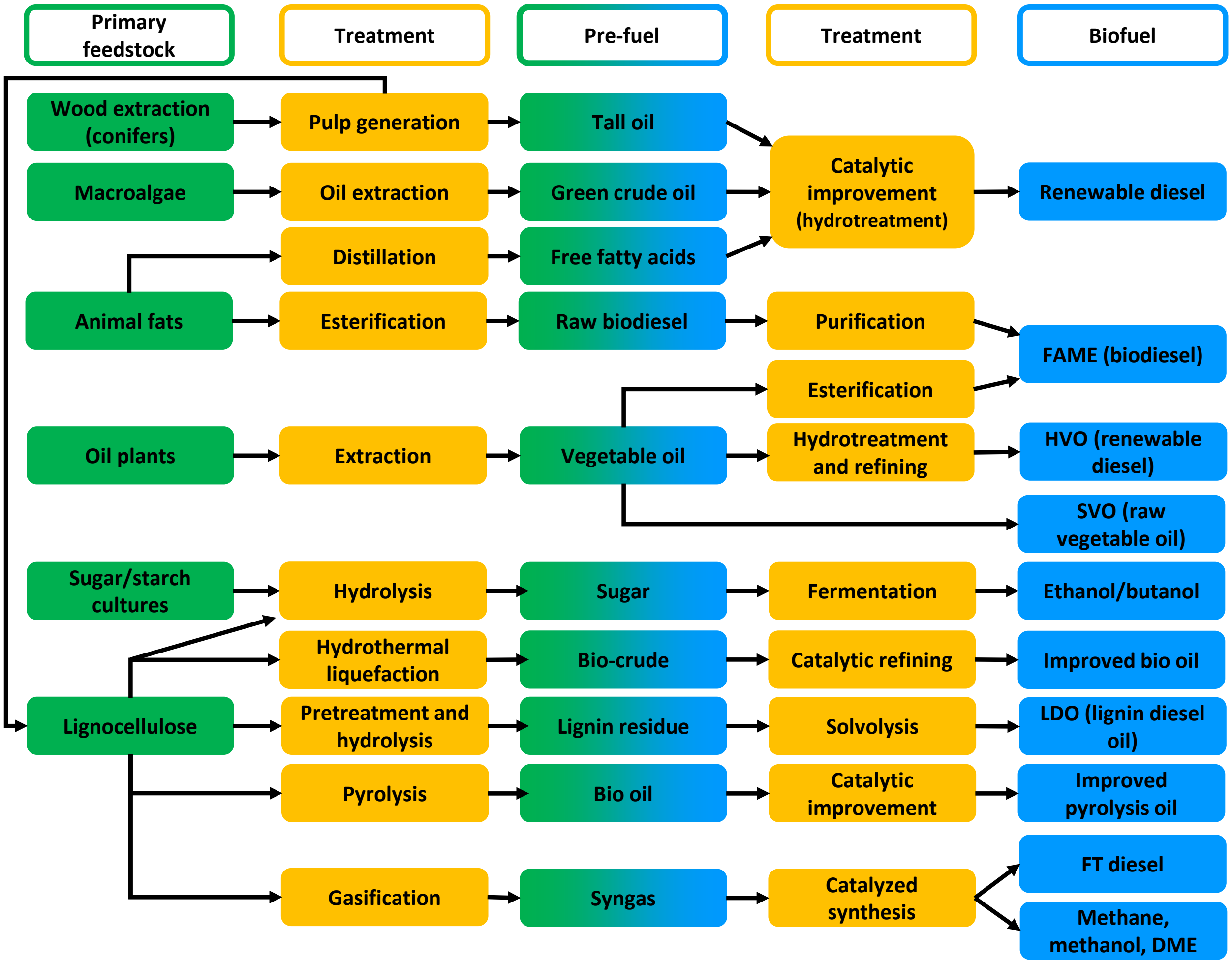
APPENDICES

APPENDIX A

Overview of feedstock, production methods and resulting biofuels. Pathways are often intertwined.



Data source: Innovation Maritime

APPENDIX B

Table 1 data is based on our life cycle analysis literature review findings (See Section 5). Marine gas oil and heavy fuel oil data are shown for comparative purposes.

Table 1: GHG emissions data

GHG emissions [gCO$_2$e/MJ]	Min. value	Max. value	**Average**
Marine gas oil	74	90	**85**
Heavy fuel oil	77	94	**87**
Fischer-Tropsch diesel (2nd gen. biofuel)	3	16	**9**
Biodiesel (2nd gen. biofuel)	26	31	**28**
Renewable diesel (2nd gen. biofuel)	2	30	**16**

Data source: LCA literature review Innovation Maritime

APPENDIX C

Table 2: Factors affecting biofuel (drop-in fuel) prices

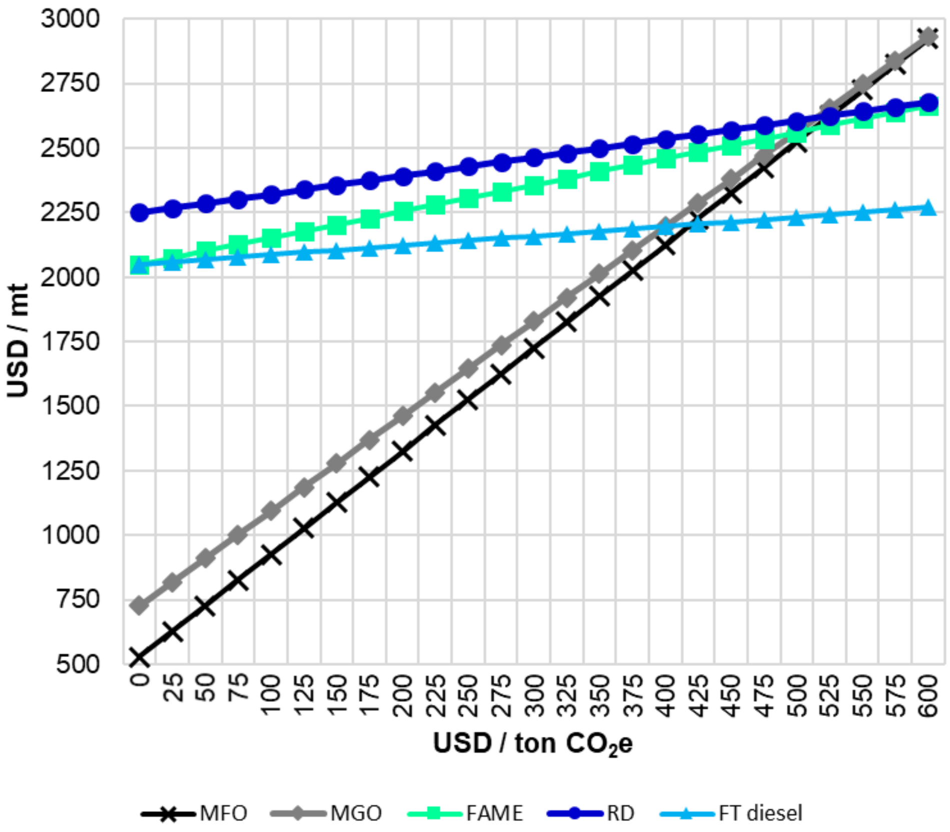
Factor	Relevance for fuel			Comments	Reference
	FAME	RD	FT Diesel		
Fats, oils and greases feedstock price	x	x		Yellow fat, oils, grease	[26]
Forestry residue feedstock price		x	x	Fuel via gasification or pyrolysis	[26] [24]
Pretreatment	x	x	x	Feedstock cleaning, drying	[24]
Production	x	x	x	Transesterification, pyrolysis, gasification	[24] [27]
Hydrotreatment		x		Additional energy; H_2	[28]
Hydrocracking		x	x	Additional energy; H_2	[28]
Fischer-Tropsch process			x	Additional energy	[28]
Methanol price	x			Green / grey methanol	[29][30]
Hydrogen price		x	x	Green / grey H_2	[31]
Transportation	x	x	x	Different costs for pipeline, ship, train, road	[32]
Feedstock quality	x	x	x	High energy content	[26]
Government incentives	x	x	x	e.g. RIN credits, carbon tax	[15]
Pegged to heating oil price	x			Efforts underway to make FAME a commodity	

Data source: Innovation Maritime

APPENDIX D

Calculations for the carbon tax amount that would equalize North American fossil fuel and second-generation biofuel prices. The point where the straight lines intersect is where the fuel price is the same.

Table 3: Effect of a potential carbon tax on fuel prices (US/mt CO_2e) (February 2022 prices[4])



The point where the straight lines intersect is where the fuel price is the same.

Data source: Innovation Maritime

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[4] The literature shows prices ranging from $688 US/mt to $2838 US/mt. So we set the price for FT diesel to the same price as FAME. This seemed realistic to us, as the lignocellulosic feedstock is cheaper than fats, oils and greases, but Fischer-Tropsch diesel is costlier to produce due to refining.

APPENDIX E

List of Canadian biodiesel and renewable diesel producers and production volumes 2021

Company name	Location	State	Fuel type	Feedstock	Production capacity (MLPY)	Production capacity (MGPY)
Archer Daniels Midland Co. - Lloydminster	Lloydminster	AB	Biodiesel	Canola	265	70
Canary Biofuels Inc.	Lethbridge	AB	Biodiesel	Second-generation	151.4	40
Innoltek	Saint-Jean-sur-Richelieu	QC	Biodiesel	animal fats, recycled cooking oil	18.9	5
Verbio Diesel Canada	Welland, Ontario	ON	Biodiesel	Canola and soybean oil	170.3	45
World Energy - Hamilton	Hamilton, Ontario	ON	Biodiesel	Animal fats, recycled cooking oil	68.1	18
Consolidated Biofuels Ltd.	Delta, British Columbia	BC	Biodiesel	Used cooking oil	11.4	3
Bioénergie AE Côte-Nord Canada*	Port-Cartier/Saint-Léonard, Québec	QC	Pyrolysis oil	Forestry residue	40	11

* Factory started pyrolysis oil production in 2022. This oil would have to be refined for use as RD.

Data source: Innovation Maritime

List of US biodiesel and renewable diesel producers and production volumes 2021

Company name	Location	State	Fuel type	Feedstock	Production capacity (MLPY)	Production capacity (MGPY)
RBF Port Neches LLC	Port Neches/Houston	Texas	Biodiesel	Multifeedstock	681.4	180.0
REG Grays Harbor LLC	Hoquiam	Washington	Biodiesel	Low FFA	378.5	100.0
World Energy Houston	Galena Park/Houston	Texas	Biodiesel	Multifeedstock	340.7	90.0
Archer Daniels Midland Co. - Velva	Velva	North Dakota	Biodiesel	Canola oil	321.8	85.0
World Energy Natchez	Natchez	Mississippi	Biodiesel	Vegetable oil	272.5	72.0
Cincinnati Renewable Fuels LLC	Cincinnati	Ohio	Biodiesel	Soy oil	265.0	70.0
REG Seneca LLC	Seneca	Illinois	Biodiesel	High and low FFA	227.1	60.0
Ag Processing Inc. - Algona	Algona	Iowa	Biodiesel	Soy oil	227.1	60.0
Ag Processing Inc. - Sergeant Bluff	Sergeant Bluff	Iowa	Biodiesel	Soy oil	227.1	60.0
Cargill Inc. - Wichita	Wichita	Kansas	Biodiesel	Soy oil	227.1	60.0
FutureFuel Chemical Company	Batesville	Arkansas	Biodiesel	Multifeedstock	223.3	59.0
Calgren Renewable Fuels LLC	Pixley	California	Biodiesel	Corn/sorghum	213.9	56.5
Cargill Inc. - Iowa Falls	Iowa Falls	Iowa	Biodiesel	Soy oil	212.0	56.0
Paseo Cargill Energy LLC	Kansas City	Missouri	Biodiesel	Soy oil	212.0	56.0
Deerfield Energy LLC	Deerfield	Missouri	Biodiesel	Soy oil	189.3	50.0
Mid-America Biofuels	Mexico	Missouri	Biodiesel	Soy oil	189.3	50.0
Duonix LLC (Marathon)	Beatrice	Nebraska	Biodiesel	Multifeedstock	189.3	50.0
Hero BX - Erie	Erie	Pennsylvania	Biodiesel	Multifeedstock	189.3	50.0
REG Danville LLC	Danville	Illinois	Biodiesel	High and low FFA	170.3	45.0

Owensboro Grain Biodiesel LLC	Owensboro	Kentucky	Biodiesel	Soy oil	170.3	45.0
World Energy Harrisburg	Camp Hill	Pennsylvania	Biodiesel	Multifeedstock	170.3	45.0
Western Iowa Energy LLC	Wall Lake	Iowa	Biodiesel	Multifeedstock	170.3	45.0
Seaboard Energy Oklahoma LLC	Guymon	Oklahoma	Biodiesel	Animal fats	170.3	45.0
Agron Bioenergy	Watsonville	California	Biodiesel	Multifeedstock	170.3	45.0
Incobrasa Industries Ltd.	Gilman	Illinois	Biodiesel	Soy oil	166.6	44.0
American GreenFuels LLC	New Haven	Connecticut	Biodiesel	Used cooking oil Animal fats	151.4	40.0
Bioenergy Development Group LLC	Memphis	Tennessee	Biodiesel	Multifeedstock	151.4	40.0
Solfuels USA LLC	Helena	Arkansas	Biodiesel	Multifeedstock	151.4	40.0
GC Lipids	Chattanooga	Tennessee	Biodiesel	Multifeedstock	151.4	40.0
GEB3	Warrenville	South Carolina	Biodiesel	Multifeedstock	151.4	40.0
World Energy Estill	Estill	South Carolina	Biodiesel	Multifeedstock	151.4	40.0
Crimson Renewable Energy LP	Bakersfield	California	Biodiesel	Multifeedstock	136.3	36.0
REG Houston LLC	Seabrook	Texas	Biodiesel	Low FFA	132.5	35.0
Western Dubuque Biodiesel LLC	Farley	Iowa	Biodiesel	Soy oil/tallow/canola/refined corn oil/refined WCO	119.0	31.0
Iowa Renewable Energy LLC	Washington	Iowa	Biodiesel	Multifeedstock	113.6	30.0
REG Newton LLC	Newton	Iowa	Biodiesel	High and low FFA	113.6	30.0
REG Mason City LLC	Mason City	Iowa	Biodiesel	High and low FFA	113.6	30.0
REG Ralston LLC	Ralston	Iowa	Biodiesel	Low FFA	113.6	30.0
REG Albert Lea LLC	Albert Lea	Minnesota	Biodiesel	High and low FFA	113.6	30.0
Seaboard Energy Missouri LLC	St. Joseph	Missouri	Biodiesel	Corn oil/animal fats/waste/vegetable oil/FOG	113.6	30.0
Ag Processing Inc. - St. Joseph	St. Joseph	Missouri	Biodiesel	Soy oil	113.6	30.0
Minnesota Soybean Processors	Brewster	Minnesota	Biodiesel	Soy oil	113.6	30.0
Fuel Bio One LLC	Elizabeth	New Jersey	Biodiesel	Multifeedstock	94.6	25.0
Community Fuels	Stockton	California	Biodiesel	Multifeedstock	85.2	22.5
Stepan Co. - Joliet	Joliet	Illinois	Biodiesel	Soy oil	79.5	21.0
REG Madison LLC	DeForest	Wisconsin	Biodiesel	High and low FFA	75.7	20.0
Express Grain Oil Mill	Greenwood	Mississippi	Biodiesel	Soy oil	75.7	20.0
Scott Petroleum Corp.	Greenville	Mississippi	Biodiesel	Multifeedstock	75.7	20.0
Hero BX - Moundville	Moundville	Alabama	Biodiesel	Multifeedstock	75.7	20.0
World Energy Rome at US Biofuels Inc.	Rome	Georgia	Biodiesel	Multifeedstock	68.1	18.0
Rio Valley Biofuels LLC	El Paso	Texas	Biodiesel	Multifeedstock	64.4	17.0
SeQuential	Salem	Oregon	Biodiesel	Used cooking oil	64.4	17.0

W2Fuel - Adrian	Adrian	Michigan	Biodiesel	Soy oil	56.8	15.0
Delek Renewables - Crossett	Crossett	Arkansas	Biodiesel	Multifeedstock	56.8	15.0
REG New Boston LLC	New Boston	Texas	Biodiesel	High and low FFA	56.8	15.0
Delek Renewables - Cleburne	Cleburne	Texas	Biodiesel	Multifeedstock	45.4	12.0
New Leaf Biofuel LLC	San Diego	California	Biodiesel	Yellow grease	45.4	12.0
Imperial Western Products Inc.	Coachella	California	Biodiesel	Multifeedstock	39.7	10.5
Hero BX - Clinton	Clinton	Iowa	Biodiesel	Soy oil/corn oil/ animal fats	37.9	10.0
W2Fuel - Crawfordsville	Crawfordsville	Iowa	Biodiesel	Soy ol	37.9	10.0
Lakeview Biodiesel LLC	Moberly	Missouri	Biodiesel	Multifeedstock	37.9	10.0
General Biodiesel Northwest	Seattle	Washington	Biodiesel	Multifeedstock	37.9	10.0
Genuine Bio-Fuel Inc.	Indiantown	Florida	Biodiesel	Waste vegetable oil/ tallow	34.8	9.2
Newport Biodiesel Inc.	Newport	Rhode Island	Biodiesel	Yellow grease	30.3	8.0
Delek Renewables - New Albany	New Albany	Mississippi	Biodiesel	Soy oil	28.4	7.5
SME Dublin LLC	East Dublin	Georgia	Biodiesel	Brown grease	28.4	7.5
Green Biofuels Miami LLC	Miami	Florida	Biodiesel	Used cooking oil	26.5	7.0
White Mountain Biodiesel LLC	North Haverhill	New Hampshire	Biodiesel	Multifeedstock	24.6	6.5
Integrity Biofuels LLC	Morristown	Indiana	Biodiesel	Multifeedstock	24.3	6.4
Pacific Biodiesel	Keaau	Hawaii	Biodiesel	Multifeedstock	20.8	5.5
BioVantage Fuels LLC	Belvidere	Illinois	Biodiesel	Soy oil/used cooking oil/corn oil	18.9	5.0
CHS Patriot Fuels Biodiesel LLC	Annawan	Illinois	Biodiesel	Distillers corn oil	18.9	5.0
Walsh BioFuels LLC	Mauston	Wisconsin	Biodiesel	Distillers corn oil	18.9	5.0
Natural Biodiesel Plant LLC	Hayti	Missouri	Biodiesel	Multifeedstock	18.9	5.0
Virginia Biodiesel Refinery LLC	West Point	Virginia	Biodiesel	Used cooking oil/ poultry grease/ soy oil	18.9	5.0
Triangle Biofuels Industries Inc.	Wilson	North Carolina	Biodiesel	Multifeedstock	18.9	5.0
Southeast Biodiesel LLC	North Charleston	South Carolina	Biodiesel	Multifeedstock (primarily used cooking oil)	18.9	5.0
Buster Biofuels	Escondido	California	Biodiesel	Used cooking oil	18.9	5.0
SJV Biodiesel LLC	Pixley	California	Biodiesel	Distillers corn oil	18.9	5.0
Blue Ridge Biofuels LLC	Newton	North Carolina	Biodiesel	Used cooking oil	15.1	4.0
Reco Biodiesel LLC	Richmond	Virginia	Biodiesel	Used cooking oil	13.6	3.6
GeoGreen Biofuels Inc.	Vernon	California	Biodiesel	Used cooking oil	11.4	3.0
Adkins Energy Biodiesel	Lena	Illinois	Biodiesel	Distillers corn oil	9.5	2.5
Griffin Industries Inc.	Butler	Kentucky	Biodiesel	Used cooking oil	7.6	2.0

Sullens Biodiesel LLC	Morrison	Tennessee	Biodiesel	Used Cooking oil	7.6	2.0
Down to Earth Energy LLC	Monroe	Georgia	Biodiesel	Multifeedstock	7.6	2.0
Northeast Biodiesel LLC	Greenfield	Massachusetts	Biodiesel	Yellow grease	6.6	1.8
Maine Standard Biofuels	Portland	Maine	Biodiesel	Yellow grease	5.7	1.5
Mason Biodiesel LLC	Westerly	Rhode Island	Biodiesel	Multifeedstock	4.5	1.2
Cape Cod Biofuels	Sandwich	Massachusetts	Biodiesel	Used cooking oil	4.5	1.2
GTBE Production	Houston	Texas	Biodiesel	Waste glycerin/palm waste	4.5	1.2
Mid America Agri Products - Wheatland LLC	Madrid	Nebraska	Biodiesel	Distillers corn oil	3.8	1.0
Simple Fuels Biodiesel	Chilcoot	California	Biodiesel	Yellow grease	3.8	1.0
Thumb BioEnergy LLC	Sandusky	Michigan	Biodiesel	Used cooking oil	2.8	0.8
Green Energy Biofuel	Winnsboro	South Carolina	Biodiesel	Multifeedstock	1.1	0.3
Eberle Biodiesel	Liverpool	Texas	Biodiesel	Waste vegetable oil	1.1	0.3
Alaska Green Waste Solutions Inc.	Anchorage	Alaska	Biodiesel	Used cooking oil	1.1	0.3
Omaha Biofuels Coop	Omaha	Nebraska	Biodiesel	Waste vegetable oil	0.9	0.3
Enviro-Brite Solutions Inc.	Oscoda	Michigan	Biodiesel	Waste vegetable oil	0.6	0.2
Kelley Green Biofuel	Goshen	Kentucky	Biodiesel	Waste vegetable oil	0.4	0.1
Loyola University Chicago	Chicago	Illinois	Biodiesel	Used cooking oil	0.4	0.1
Ever Cat Fuels LLC	Isanti	Minnesota	Biodiesel	Multifeedstock	11.4	3.0
Marathon Petroleum - Martinez Refinery***	Martinez	California	Renewable diesel	Multifeedstock	2786.1	736.0
Phillips 66 - Rodeo***	Rodeo	California	Renewable diesel	Multifeedstock	2574.1	680.0
Diamond Green Diesel - Norco*	Norco	Louisiana	Renewable diesel	Animal fats/used cooking oil	2555.2	675.0
Diamond Green Diesel - Port Arthur***	Port Arthur	Texas	Renewable diesel	Multifeedstock	1514.2	400.0
REG Geismar LLC*	Geismar	Louisiana	Renewable diesel	Multifeedstock	1287.0	340.0
World Energy - Paramount*	Paramount	California	Renewable diesel	Multifeedstock	1135.6	300.0
Alon Bakersfield Refinery	Bakersfield	California	Renewable diesel	Multifeedstock	870.6	230.0
Marathon Petroleum - Dickinson Refinery	Dickinson	North Dakota	Renewable diesel	Soy oil	696.5	184.0
HollyFrontier Corp. - Artesia**	Artesia	New Mexico	Renewable diesel	Multifeedstock	416.4	110.0
Ryze Renewables Las Vegas LLC	Las Vegas	Nevada	Renewable diesel	Multifeedstock	378.5	100.0

HollyFrontier Corp. - Cheyenne**	Cheyenne	Wyoming	Renewable diesel	Multifeedstock	340.7	90.0
East Kansas Agri-Energy LLC - Renewable diesel facility	Garnett	Kansas	Renewable diesel	Distillers corn oil	15.1	4.0

* Under construction

** Under expansion

*** Proposed

Data source: Innovation Maritime

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