Domestic Great Lakes & St. Lawrence Shipping Industry: Transition to Biofuels – Transit Cost Analysis

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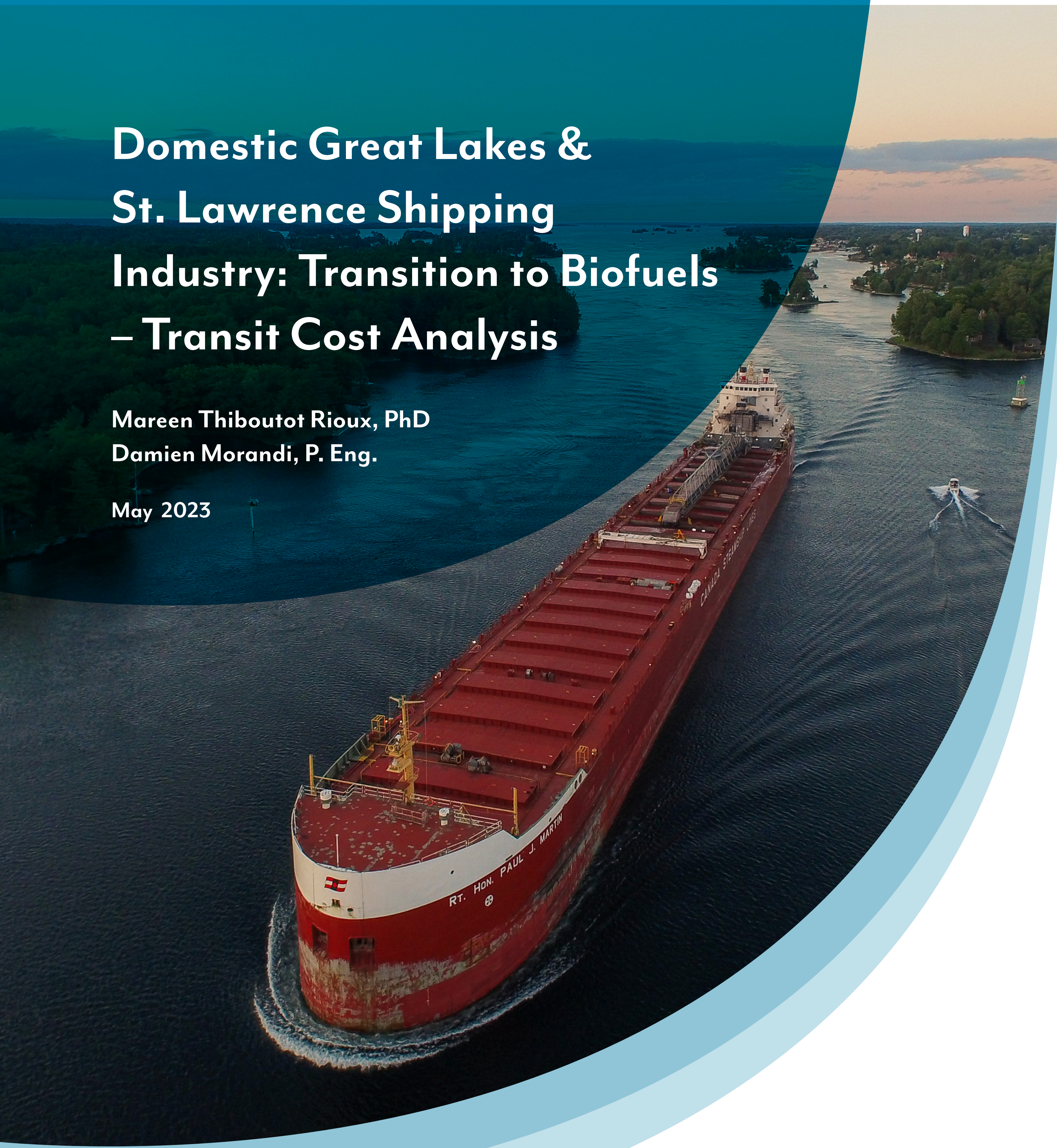

INNOVATION MARITIME
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GREAT LAKES ST. LAWRENCE GOVERNORS & PREMIERS

EXECUTIVE SUMMARY

In order to reduce overall fuel use and greenhouse gas (GHG) emissions, getting cargo onto the water is essential. Shipping offers the best cargo-to-emissions ratio compared to other transportation methods, and the use of drop-in biofuels provides an opportunity to reduce the maritime sector's GHG emissions and achieve government-mandated emission reduction targets and more. The price differential between biofuels (e.g., biodiesel) and fossil diesel (e.g., MGO) is approximately 28% (2022 values), making biofuels' use economically unappealing. In this study conducted by Innovation Maritime (IMAR), we analyzed five transits on the Great Lakes and St. Lawrence Seaway (GL&SLS) to assess the impact of using biodiesel (B100 and B75) on the overall voyage cost. To do this, we developed a *Financial transit cost evaluation model* to examine the additional cost incurred by using biodiesel and also explored three policy measures to mitigate the impact of this cost on overall voyage costs: an energy content-based fuel tax, carbon trading (cap-and-trade or CAT) systems (Québec-California and European Union) and a carbon tax (Sweden).

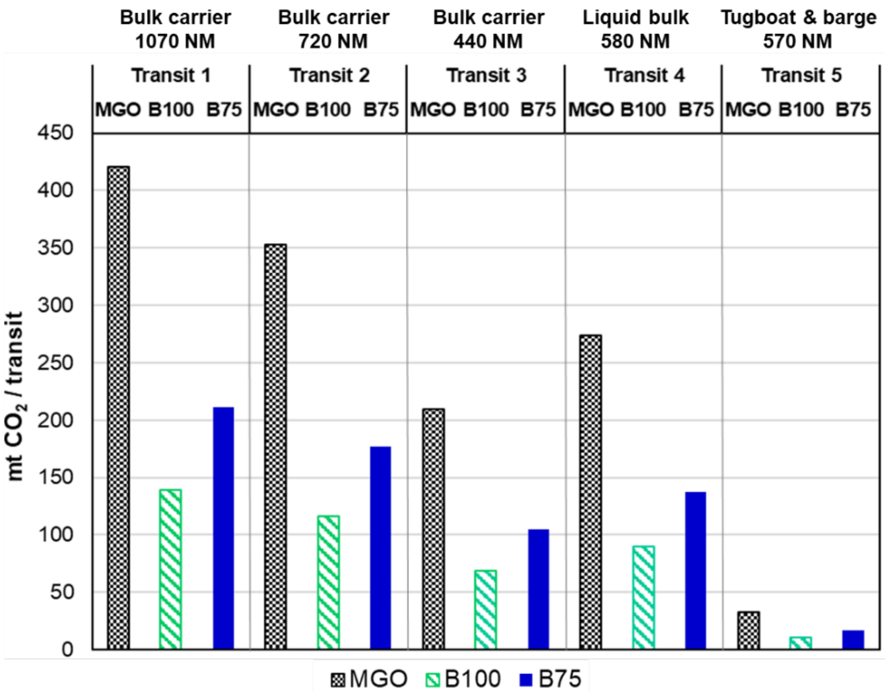


Figure 1 Emission distributions among the transits and the GHG reduction using B100 and B75

The selection of ship types for analysis was based on their respective contribution to GHG emissions in the GL&SLS shipping sector. In Canada, bulk carriers (solid bulk) and chemical tankers (liquid bulk) account for 83% of GHG emissions, while in the US, bulk carriers (solid bulk) and tugboats & barges (liquid bulk) account for 95% of GHG emissions. The use of B100 results in a 67% emissions reduction and an 11.5%-17.2% price increase per metric ton of cargo. Alternatively, B75 biofuel, which contains 25% fossil diesel or MGO, achieves a 50% emissions reduction and an 8.4%-12.5% price increase per metric ton of cargo, depending on the specific transit. The reference year for the study is 2022.

Table 1 - Fuel costs' share (%) in overall voyage costs for five transits, 2022

	Ship type	Distance (NM)	Fuel costs (MGO)
Transit 1	Bulk carrier	1 070	32.4%
Transit 2	Bulk carrier	720	31.5%
Transit 3	Bulk carrier	440	23.9%
Transit 4	Liquid bulk carrier	580	29.7%
Transit 5	Tugboat & barge - liquid	570	35.6%

To evaluate the impact of policy measures on overall voyage costs, we integrated them into the *Financial transit cost evaluation model*, using the values of fossil fuel marine gas oil (MGO) (2022) as a reference. The analysis revealed that a fuel tax based on energy content had minimal influence on overall voyage costs (Figure 2). However, the implementation of a carbon trading system, where credits earned through the use of biodiesel could be traded, significantly reduced overall voyage costs. The higher the price of the credits to be traded – European Union Emissions Trading System (EU-ETS) credit costs are higher than CAT Québec-California's for example– the lower the price difference on overall voyage costs of using B75 or B100. Additionally, a carbon tax based on the

Swedish model substantially increased the price of fossil fuel (MGO) (2022). As shown in Figure 1 (carbon tax values for transits 1 to 4), this tax resulted in an increase of less than 3% in the overall voyage costs for B100 and 1% below the reference level for B75 (2022 values). However, it should be noted that these findings may not be applicable to all ship types. For transit 5, which involved a tugboat and barge, biodiesel remained economically unattractive despite the implementation of the three aforementioned policy measures.

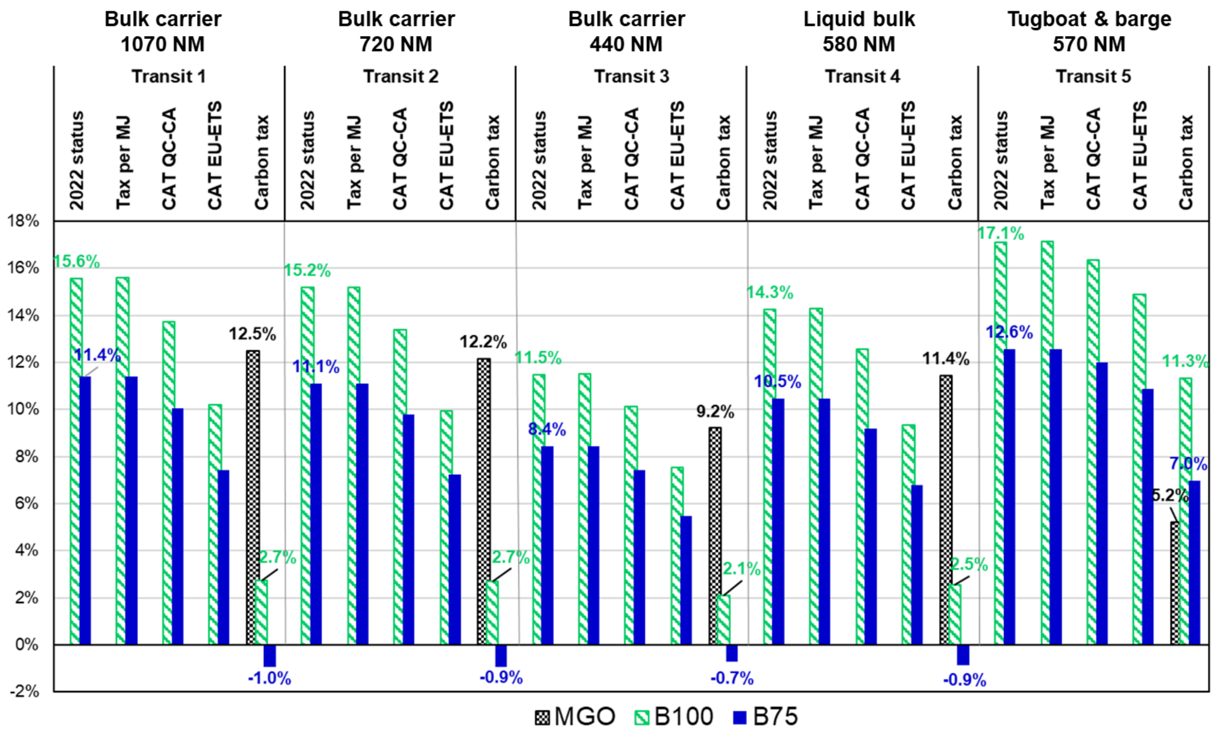


Figure 2 - Impact of political measures on overall voyage costs for MGO vs. B100 and B75 (2022)

Furthermore, the study examined the pioneering role of Scandinavian countries in reducing shipping-generated GHG emissions (Appendix C).

Based on our findings and the outcome of our research, IMAR would make the following recommendations:

1. It is crucial to allocate support funds for the production of biodiesel, renewable diesel and Fischer-Tropsch diesel.
2. Governments should lead by example, using biodiesel for state-owned vessels.
3. Considering vessel type and operating profile for biodiesel adoption; alternative propulsion types (e.g. electric) may be better for some classes (e.g., tugboats).
4. Proactive decision-making by governments can accelerate the transition to low-GHG-emission alternatives.
5. Tax credits, grants and subsidies can incentivize biodiesel production. Subsidizing the price difference between biodiesel and fossil diesel (MGO) can enhance environmental benefits while maintaining competitiveness.
6. Funding for biofuel technology advancements and feedstock exploration is necessary.
7. Investments in storage, transportation and bunkering facilities for biodiesel-powered ships are essential.
8. Establishing favorable regulatory frameworks with clear rules for biofuel use in ships can encourage wider adoption.
9. Alignment of Canadian and US policies prevents division and transition disparities.
10. Educational efforts should provide targeted information for stakeholders and decision-makers in different sectors.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

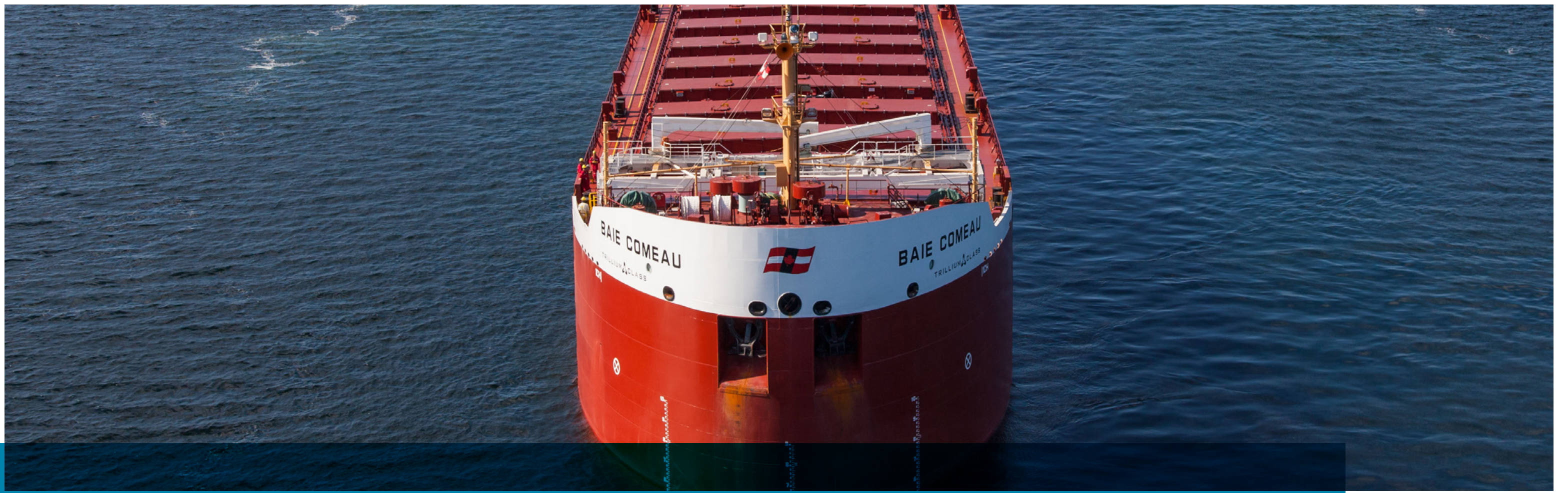
LIST OF ABBREVIATIONS

B100	100% biodiesel
B75	75% biodiesel–25% fossil diesel blend
CAT	Cap and trade
CAT QC-Cal.	Québec–California cap and trade system
CFR	Clean Fuel Regulations
CI	Carbon intensity
CII	Carbon intensity indicator
CTF	Cleaner Transportation Fuels regulation
DNV	Det Norske Veritas
EPS	Emissions Performance Standards
ERC	Emissions reduction credit
EU-ETS	European Union Emissions Trading System (cap and trade system)
gCO2e	Gram carbon dioxide equivalent (in MJ)
GHG	Greenhouse gas or gases
GL&SLS	Great Lakes and St. Lawrence Seaway
GT	Gross tonnage
HFO	Heavy Fuel Oil
ICCT	International Council of Clean Transportation
IFO	Intermediate fuel oil
IMAR	Innovation maritime
LCA	Life cycle analysis
MGO	Marine Gas Oil
MJ	mega Joule
mt	metric ton
MtCO2e	Metric tons of CO2 equivalent
NM	nautical mile
RD	Renewable diesel
RFR	Renewable Fuels Regulations
RFS	Renewable Fuel Standard
RIN	Renewable Identification Number
RLF	Regulation respecting the integration of low-carbon-intensity fuel content into gasoline and diesel fuel

INTRODUCTION

In response to the urgent need to reduce greenhouse gas (GHG) emissions and combat climate change, Canada and the United States have set climate targets and the shipping sector is looking for alternative fuels. Drop-in fuels, which include biodiesel, renewable diesel (RD) and Fischer-Tropsch diesel, are a promising alternative which can be seamlessly integrated into existing marine diesel engines without requiring technical modifications. In the study "*Domestic Great Lakes and St. Lawrence Shipping Industry: Transition to Biofuels - An Overview*", [1] conducted for the Great Lakes St. Lawrence Governors & Premiers and published in 2022, Innovation Maritime (IMAR) investigated whether these fuels are potentially suitable for a fossil-to-renewable fuels switchover and to what extent such a switchover would affect GHG emissions. Our results showed positive answers to both questions. We found that the required volumes may be available by 2026 and that switching to biodiesel (RD or Fischer-Tropsch diesel) would contribute to the crucial need for reducing GHG emissions.

However, an important question remained regarding the economic implications of adopting these biofuels, which are considerably more expensive. Specifically, this study seeks to quantify the impact of biofuels on overall voyage costs and, consequently, on the price of transported cargo. To quantify the economic impact, IMAR developed a *Financial transit cost evaluation model* using real-world data and various references. The results of the different cost scenarios are presented in the initial section of the report. The study also examined the influence of policy measures such as a carbon tax, on overall voyage costs, which is explored in the second part of this study. Additionally, the study investigated other measures that the US and Canadian governments could implement to accelerate the adoption and usage of biofuels as marine fuel. The study concludes with recommendations on measures to speed up a transition to low-GHG-emissions alternatives for Great Lakes and St. Lawrence River shipping.



TRANSITS ON THE GREAT LAKES AND ST. LAWRENCE SEAWAY

This section calculates overall voyage costs for five different transits (transportation of cargo from the departure port to the destination port) that differ as to route, ship type and transit costs. The data used for the financial evaluation are based on actual anonymized values, the literature and publicly available sources.

DESCRIPTION OF TRANSIT MODEL

The goal of this section is to assess how 2022 biodiesel prices affect overall voyage costs and thus the price of cargo carried. This study presents a financial evaluation for B75 and B100. As our above-mentioned 2022 study [1] showed, a blend containing at least 75% biodiesel could be used to achieve the climate goal of 50% GHG reduction by 2030 for shipping on the Great Lakes and St. Lawrence. In 2022, the average price of biodiesel was US$1527/mt (CAN$1985/mt) [2] and the average price of MGO was US$1196/mt (CAN$1556/mt). [3] The price of B75 was calculated using average MGO and B100 prices, resulting in US$1444/mt (CAN$1877/mt). On average, B100 was 28% more expensive than MGO and B75 was 21% more expensive in 2022.

We wanted to know how the overall voyage costs would reflect these higher fuel costs. Which ship types would be most affected and how much higher would the cost be? Would transit length matter?

To answer these questions, IMAR created a *Financial transit cost evaluation model* that determines the impact of different cost factors on the overall voyage costs. These cost factors include but are not limited to:

- Fuel costs
- Fees
- Piloting costs
- Maintenance

In total, more than 100 different cost items were entered into the *Financial transit cost evaluation model*.

FIVE TRANSITS SELECTED

Five actual transits were selected to accurately assess the cost increases associated with a switchover to B75 and B100. To maintain confidentiality, we have omitted the names of vessels, ports of departure and ports of destinations.

To determine five representative transits, we utilized the INNAV and AIS databases to map all St. Lawrence-Great Lakes axis ship movements and determine port duos regularly visited by the desired ship types. Overall 2022 traffic on the GL&SLS is shown in Appendix A. We selected vessel types based on an *International Council on Clean Transportation* (ICCT) study that presents the proportion of CO_2 emissions generated by the Canadian and US fleets on the GL&SLS by vessel type. [4] As shown in Figure 3, bulk carriers are responsible for most CO_2 emissions in Canada (61%), followed by chemical tankers (15%) and oil tankers (7%). Together, these vessel classes account for 83% of Canada's GL&SLS emissions. A similar picture emerges for the US fleet, where bulk carriers also represent the largest emissions share (77%), followed by service tugs (18%). Together, these two classes account for 95% of US emissions.

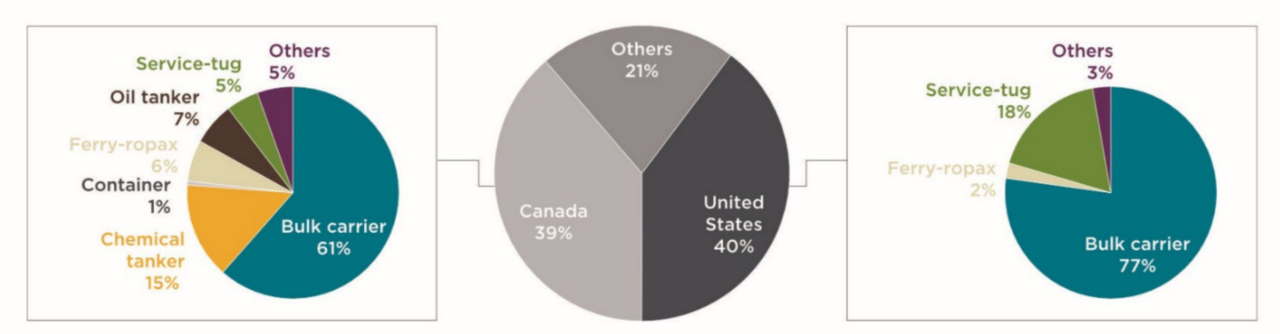


Figure 3 - Proportion of Canadian and US fleet-generated CO_2 emissions on the Great Lakes and Saint Lawrence Seaway by vessel type Source: ICCT [4]

Based on this emissions distribution for the domestic GL&SLS fleet, the following transits were selected:

- Transit 1: A bulk carrier on the Great Lakes, from a Canadian port to another Canadian port
- Transit 2: A bulk carrier on the Great Lakes, from a US port to another US port
- Transit 3: A bulk carrier between the Great Lakes and St. Lawrence River, from a Canadian port to another Canadian port
- Transit 4: A liquid bulk carrier (chemical tanker) on the Great Lakes, from a Canadian port to another Canadian port
- Transit 5: A tugboat & barge on the Great Lakes, from a US port to another US port.

COST INCREASE (2022 PRICES)

The results of the *Financial transit cost evaluation model* are presented in Table 2. The table shows the total share of fuel costs on the overall voyage costs as well as the distance traveled in nautical miles (NM).

Table 2 - Fuel costs' share (%) in overall voyage costs for five transits, 2022

	Ship type	Distance (NM)	Fuel costs (MGO)
Transit 1	Bulk carrier	1 070	32.4%
Transit 2	Bulk carrier	720	31.5%
Transit 3	Bulk carrier	440	23.9%
Transit 4	Liquid bulk carrier	580	29.7%
Transit 5	Tugboat & barge - liquid	570	35.6%

The model also revealed that several critical factors have a significant impact on costs including ship type, ports frequented and distance traveled. While numerous factors come into play, we observed an unsurprising correlation between transit length and fuel cost. When looking at the bulk carrier class, we can observe that the share of fuel costs decreases from Transit 1 to Transit 3 as the distance traveled becomes shorter. However, it is important to note that distance alone does not determine the fuel costs' share of total cost. For example, Transit 4 and Transit 5 both covered roughly the same number of nautical miles but despite the similar distances, there is a 5.9% difference in fuel costs between the two transits. This discrepancy can be attributed to differences in operating profile and route, which account for the higher fuel cost share in one transit compared to the other. Higher fuel consumption of the tugboat and barge compared to the liquid bulk carriers is not responsible for this cost difference. The interplay of transit costs (e.g., pilots) and operating costs (e.g., maintenance) exhibits greater variation than fuel costs alone.

Given that fuel costs' share in overall voyage costs varies from 23.9% to 35.6%, the choice of fuel and its price undoubtedly impacts the overall voyage costs as depicted in Table 3.

Table 3 - Cost variation in overall voyage costs for B100 or B75 vs. MGO

	Ship type	Distance (NM)	Cost variation MGO vs. B100 (with MGO being the lower value)	Cost variation MGO vs. B75 (with MGO being the lower value)	GHG emissions variation MGO vs. B100 (with B100 being the lower value)	GHG emissions variation MGO vs. B75 (with B75 being the lower value)
Transit 1	Bulk carrier	1 070	15.6%	11.4%	-67%	-50%
Transit 2	Bulk carrier	720	15.2%	11.1%		
Transit 3	Bulk carrier	440	11.5%	8.4%		
Transit 4	Liquid bulk carrier	580	14.3%	10.4%		
Transit 5	Tugboat & barge - liquid	570	17.2%	12.5%		

For all transits, the overall voyage costs per ton of cargo is higher for B100 (11.5%-17.2%) and B75 (8.4%- 12.5%) compared to MGO. Due to the B75 blend's 25% content of lower-priced MGO, its impact on increasing overall voyage costs is lower than B100's.

These price variations clearly indicate that increases in overall voyage costs do not directly mirror biodiesel's higher prices, which are 28% higher than MGO for B100 and 21% higher for B75 (see Section 2.1). Using the fuel prices of Section 2.1 in the *Financial transit cost evaluation model* showed that increases in overall voyage costs of 8.4%-12.5% for B75 and 11.5%-17.2% for B100 can be expected. Price markups may even be single-digit figures (e.g. Transit 3, B75). As a result, policy measures aimed at subsidizing the full market price differential do not necessarily need to match the 28% range for B100 or 21% range for B75 to make the use of biodiesel financially viable. To assess the impact of different policies on overall voyage costs, IMAR's *Financial transit cost evaluation model* was expanded to integrate various policy measures. We discuss the results in detail in Section 4 and an overview of different cost mitigation strategies in Section 3.

GHG REDUCTION (2022 EMISSIONS)

The choice of fuel has a direct impact on GHG emissions. In comparison to MGO, the use of B100 can lead to a GHG emission reduction of approximately 67%, while B75 can achieve a reduction of 50%. These figures are based on the full life cycle assessment of the fuels. [1] Table 3 shows the results of the *Financial transit cost evaluation model* calculations using B100 and B75 blends, with all other variables remaining the same. It should be noted that the calculations account for the fact that a larger volume of biodiesel is required to cover the same travel distance.

Figure 4 shows the emission values in metric tons of CO_2 per transit, which align with the findings of the ICCT study. Comparing transit 4 and 5, which cover approximately the same distance, it is evident that the emissions of the bulk carrier are significantly higher than those of the tug with barge. However, this does not necessarily mean that bulk carriers have a greater negative environmental impact. Considering the engine size and the associated higher fuel consumption, more CO_2 is inevitably emitted. However, bulk carriers also have the largest cargo capacity on the GL&SLS, which drastically improves the GHG balance per ton of cargo. As transit distance increases, fuel consumption and CO_2 emissions also increase (Transit 3 < Transit 2 < Transit 1).

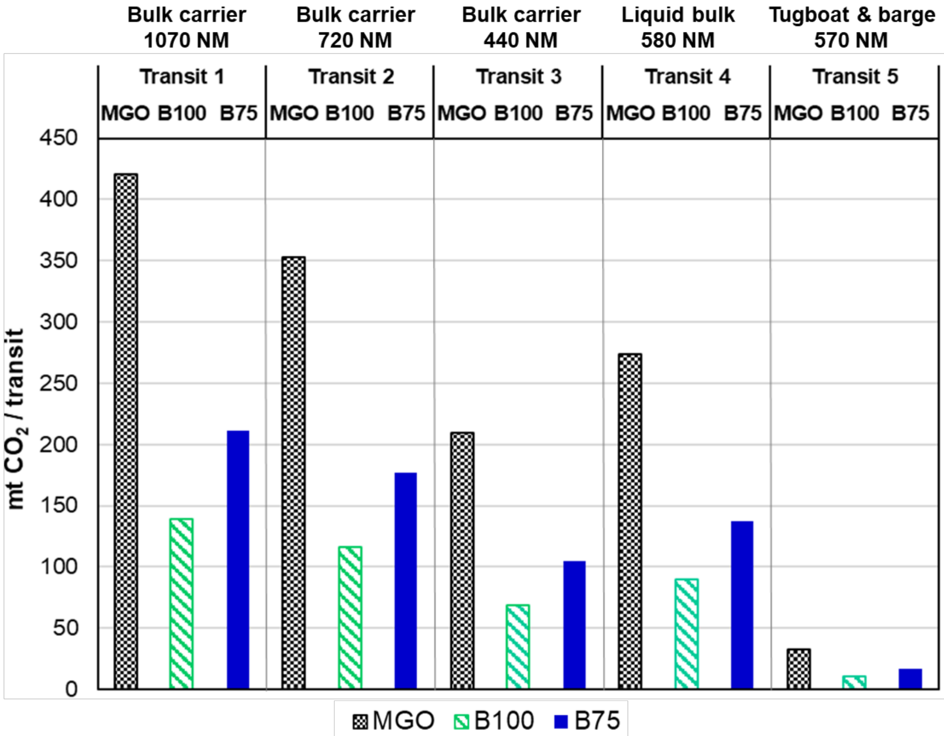


Figure 4 - Emission distributions among the transits and the GHG reduction using B100 and B75

CO_2 REDUCTION STRATEGIES AND FUEL PRICING

This section explores different strategies available to governments for implementing specific climate goals in the industry. We begin by presenting basic strategies for changing consumption and emission habits in society and industry. Subsequently, we will discuss the measures implemented in Canada and the US. Additionally, we will delve into the European Union's approach as it is in the process of incorporating shipping into its abatement program and boasts an extensive interconnected regulatory framework. The *European Union Emissions Trading System* (EU-ETS) is also discussed. Although the *International Maritime Organization* (IMO) has no direct influence on national GHG reduction regulations governing the Canadian and US domestic fleets, since 2023, new IMO requirements have affected all ships departing the GL&SLS for international waters. Therefore, we will provide a brief overview of relevant IMO abatement strategies.

The public policies to reduce emissions mentioned below do not apply to the maritime sector or to recognized marine fuels like heavy fuel oil (HFO), intermediate fuel oil (IFO) or marine gas oil (MGO). These fuels are exempt from fuel standards in both Canada and the US, which is a policy decision rather than a technical one. Furthermore, marine fuels are also exempt from the blend rates specified in the respective fuel regulations, apart for the Ontario's CTF blending regulations.

DESCRIPTION OF PUBLIC POLICIES TO REDUCE EMISSIONS [5]

Governments have several policy options to encourage emissions reductions, with the main initiatives being as follows:

Market-based incentives and trading systems: Emitters can earn *emissions reduction credits* (ERC) by keeping their emissions below a given threshold (e.g., a limit of grams of CO_2 per distance traveled) specific to them or their industry sector. The biggest drawback to this measure is that there is no overall emissions cap. If more parties join these incentives or systems, total emissions may increase even if individual emitters stay below the threshold. To address this, a capped allowance system known as *cap and trade* (CAT) can be implemented, where a sector's total emissions are subject to an upper limit or "cap" Emissions allowances are then distributed among the members of the sector and unused allowances can be auctioned to others

Taxes and fees: Monetary charges (fees or taxes) per unit of pollutant emissions (e.g., gCO_2e) seek to reduce emissions as a whole. These measures penalize those who exceed the limits but do not guarantee lower emissions.

Pollution control subsidies: Unlike taxes and fees, subsidies (e.g., favorable tax treatment or low-interest loans) are provided to reward emitters who successfully reduce their emissions.

Voluntary action: Government programs that allow emitters to voluntarily participate enable policymakers to test new approaches and initiatives. Participating parties gain a public relations advantage over non-participating parties.

Information disclosure: By requiring emitters to disclose their emissions levels, governments aim to encourage cleaner practices. Disclosure can influence public perception positively or negatively and can allow affected parties to become part of the policy-making process by providing decision-makers with real data.

Regulatory measures: Implementing blend rates that include biofuels in the fossil fuel pool can lower emissions. Regulatory measures have the advantage of equally affecting both producers and consumers in terms of cost and emissions. Blend rates may, but need not, be combined with a CAT system.

EXAMPLES OF PUBLIC POLICIES TO REDUCE EMISSIONS

The following provides an overview of public policies to reduce emissions and potential policies that could be employed by different countries. For the later discussion, cap and trade, carbon tax and fuel tax per unit of energy are relevant. For more detailed information, please refer to Appendix A.

In Canada, public policies to reduce emissionsinclude the *Clean Fuel Regulations* which replaced the *Renewable Fuel Regulations*. The *Clean Fuel Regulations* implemented a carbon intensity (CI)-based approach with a CAT. The blend rate reduction starts at 3.5 gCO_2e/MJ in 2023 and increases annually to reach 14 gCO_2e/MJ in 2030. Ontario and Québec have their own regulations such as the *Cleaner Transportation Fuels* regulation in Ontario [6] and the *Regulation respecting the integration of low-carbon-intensity fuel content into gasoline and diesel fuel* in Québec which includes a CAT market with the state of California. [7], [8] Carbon taxes are imposed on large emitters under the *Greenhouse Gas Pollution Pricing Act*, with prices increasing from CAN$65/ton CO_2 in 2023 to CAN$170/ton CO_2 in 2030. [9]

In the United States, the *Renewable Fuel Standard* program mandates a minimum percentage of renewable fuel in transportation fuel. *Renewable Identification Numbers* are used to monitor renewable content. [10] Different states bordering the Great Lakes like Minnesota, Indiana, and Pennsylvania have their own fuel mandates and blend rates. [11]–[13] *Renewable Identification Numbers* can be traded and their prices are determined by market factors. [14]

Taxation practices based on volume such as per liter or gallon indirectly penalize alternative fuels with lower energy content. This affects biodiesel users who need to burn more fuel to travel the same distance as fossil diesel users. [15] Taxation based on unit of energy (e.g., tax/MJ) is a way to mitigate these issues. [16]

In Europe, the Emission Trading System has been in place since 2005 covering EU nations and some additional countries. [17] The system establishes permit prices and has expanded to include industries like intra-European air traffic, chemical and aluminum sectors. [18] It is highly likely that ships traveling to Europe will be required to participate in the Emission Trading System starting from 2024 onwards. [19]

The International Maritime Organization (IMO) aims to reduce ship-generated GHG emissions to net-zero by 2050, with checkpoints in 2030 and 2040 and has implemented measures like the Energy Efficiency Existing Ship Index and Carbon Intensity Indicator. [20]

INTEGRATING PUBLIC POLICIES TO REDUCE EMISSIONS INTO THE *FINANCIAL TRANSIT COST EVALUATION MODEL*

This section reports on the impacts on each transit scenario of including the following three public policies to reduce emissions in the *Financial transit cost evaluation model*:

- energy content-based fuel tax
- carbon cap and trade system
- carbon tax.

We performed calculations for B100 and B75 blends. Renewable diesel or Fischer-Tropsch diesel, evaluated in IMAR's 2022 study [1], are very promising alternatives for reducing GHG emissions, but were not yet sufficiently available in 2022 to be included in the model. Biodiesel is already available on the Great Lakes and is used by 16 vessels on the GL&SLS. [21]

Before examining the impact of the three public policies to reduce emissions, we will present the details of the economic assumptions used to evaluate their performance (Section 4.1).

COST EVALUATION OF PUBLIC POLICIES TO REDUCE EMISSIONS

The **ENERGY CONTENT-BASED FUEL TAX** described in Section 3.2 and Appendix B, is a tax levied per liter (or per unit weight) which penalizes all fuels with less energy content than the same amount of fossil fuel. We will look at how a tax levied per mega Joule (MJ) affects transit costs. Calculations use an energy content of 37 MJ/L for diesel and 33 MJ/L for biodiesel. It is difficult to determine the taxes levied on marine fuel, as they depend on the flag state, country of refueling, province or state and fuel type. To make calculations possible, we used the average of the excise tax levied in Canada and the US which is US$0.04/L of diesel. [22]

CAT SYSTEMS do not currently include maritime emitters so no prices for CAT permits and credits are available. Calculation of the impact on transit costs was based on Québec and Californian CAT data. Québec is both a member of the GL&SLS region and shares the auction market with California so a US perspective is included. The US also has an emissions-based credit trading system in the form of RINs. However, quotas are determined based on many factors and not exclusively by the government. Our second calculation for CAT systems will be performed according to the EU-ETS system. On one hand, the credit prices are higher, on the other, the EU will be the first to include shipping in a CAT system. We used MGO emissions for the different transits. Emissions limits (cap) help drive emissions saved and can be used as credits (trade). These credits can then be used as offsets to generate revenue on the fictional carbon market, thereby reducing overall voyage costs. For this study, the credits were fixed at the mean 2022 credit price:

- Québec-California CAT system (CAT QC-Cal.): US$27/mt CO_2e (CAN$32/mt CO_2e)
- European Union CAT system (CAT EU-ETS): US$80/mt CO_2e (CAN$105/mt CO_2e)

When considering integration of a **CARBON TAX,** we must distinguish between two types of carbon taxes:

a. Pure CO_2 tax which refers to the amount and type of fuel burned,
b. Tax or fine on emissions in a CAT system that exceed the allocated emission quota.

Variant **a** has been levied in Sweden since 1990 in the amount of €118 (US$125; CAN$164[1]) per metric ton of fossil fuel burned in 2022. Companies participating in the EU-ETS are exempt from this tax [25] as are renewable fuels including biodiesel. [26] To determine the impact of a pure carbon tax, voyage costs were calculated using Sweden's carbon tax. Variant **b** applies, for example, to the CAT system under the CFR and RFL.

PUBLIC POLICIES TO REDUCE EMISSIONS AND THEIR IMPACT ON TRANSIT COST SCENARIOS

We integrated the three above-mentioned public policies to reduce emissions into the five transit cost scenarios defined in Section 2. Figure 5 shows the impact of the use of biodiesel in combination with different policy measures. Because overall voyage costs using MGO is used as a reference, there are black bars in the diagram only when considering the carbon tax. While taxation per unit of energy and a CAT system refer to a difference in base value (MGO) and thus do not affect coverall voyage costs in the case of fossil fuel, the carbon tax refers directly to the quantity and type of fuel burned. This increases the transit costs for MGO use compared to the 2022 base value.

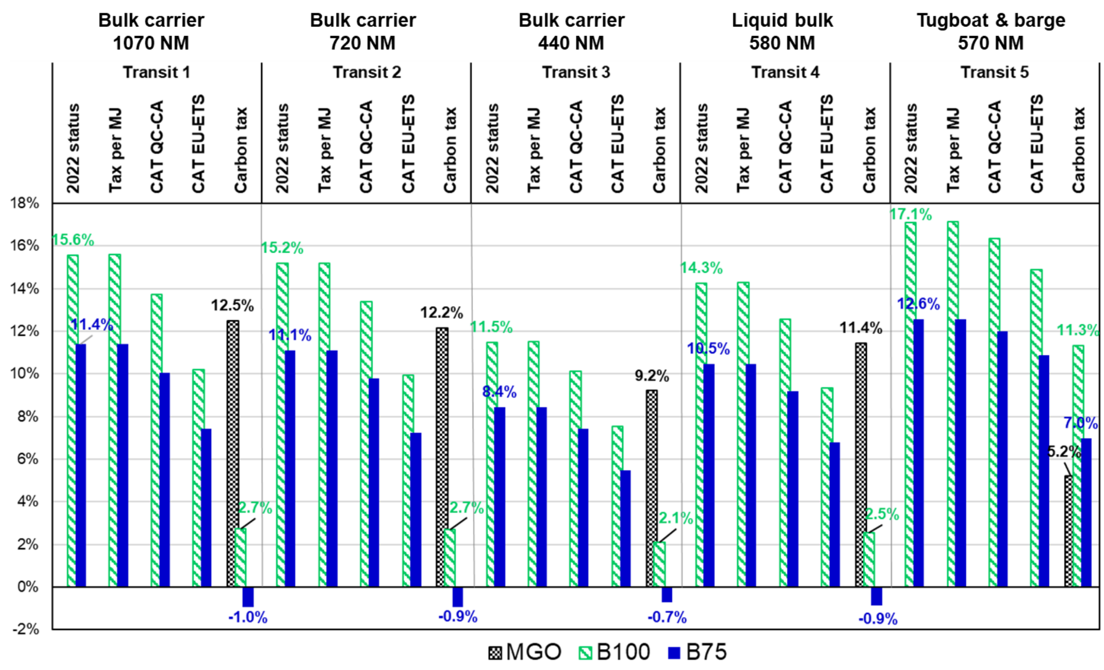


Figure 5 – Impact of policy measures on cargo prices for MGO vs. B100 and B75

1 Average 2022 exchange rates were Euro-US$1.06 [23] and Euro-CAN$ 1.4 [24]

The first public policies to reduce emissions --taxation of fuels based on energy content-- has minimal impact on overall voyage costs. Although a more detailed analysis considering all taxes imposed (not just the excise tax) might reveal some impact in the future, it is expected to remain relatively small due to the “small” fuel quantities used per voyage. Implementing a CAT system in the shipping sector, by contrast, leads to significant cost reductions, especially when the price of traded credits is high (CAT QC-Cal. < CAT EU-ETS). The CAT calculations are based on 2022 credit prices (see Appendix B). Over time, the available credits in a CAT decrease, driving up future prices all other things being equal. This should allow biodiesel-generated credits to be sold at a higher profit, resulting in a decrease in the incremental cost per ton of cargo each year

The most impactful policy measure is integrating a carbon tax based on the Swedish model (US$125/mt of fuel burned), which significantly impacts the cost profile. Since the carbon tax is only applied to fossil fuels, overall voyage costs increase by 5.2%-12.5% when using MGO, making biodiesel comparatively much cheaper. Using B75, transit costs for Transits 1 to 4 would actually decrease approximately 1% below the 2022 reference level. Although carbon taxes must be paid on the 25% MGO content in the B75 blend, the price difference between biodiesel and MGO in 2022 means that the cheaper MGO could more than offset this tax. This applies to the bulk carrier class (solid and liquid), which accounts for about 66% of the total GHG emissions of the US and Canadian domestic fleets operating on the GL&SLS.

However, the price-reducing effect of a CAT is much smaller for Transit 5. Not even the drastic measure of a carbon tax is able to make the use of biodiesel attractive for the “tugboat & barge.” Due to different cost distributions and the highest proportion of fuel costs in overall voyage costs of all transits considered, the use of B100 and B75 is not financially appealing. Even with a carbon tax similar to the Swedish model, the use of MGO remains more economically viable.

SCANDINAVIAN COUNTRIES' SUCCESS

Policy measures have the potential to make biodiesel competitive and influence the emissions behavior of service providers and industry. This can be seen in the examples of Norway and Sweden, two Scandinavian countries that have made significant advancements in the maritime sector and the adoption of clean technologies.

In Norway, the marine industry is one of the country's most important sectors and has fostered innovation and collaboration through specialization and regional centralization. This has created a culture of innovation and exchange involving ship owners, national shipyards, maritime equipment suppliers, maritime services, engine manufacturers, R&D institutions and public agencies. The key innovation catalyst was the Norwegian government's 2015 decision to lower emissions in the country's ferry network, consisting of some 120 ships that crisscross the country's many fjords. The responsibility for these ferries lies with the authorities, who award 10-year contracts to private companies through a competitive call-for-tender process. To meet the government's new emissions requirements, only companies able to demonstrate reduced GHG emissions win these contracts, with all-electric ferries being the most attractive. [27] Additionally, the *Norwegian Maritime Authority* has been proactively involved in developing and regulating low-GHG alternatives since before 2000. [28]

In Sweden, a similar trend is emerging regarding the use of methanol as an alternative fuel with close cross-sector collaboration between *DNV* (class society), R&D institutions and the *Swedish Marine Administration*. This collaboration has been so promising that *Methanex*[2] has signed up as a partner for a methanol fuel project. [29], [30] In addition, the Swedish government is an early adopter of innovations for its state-owned vessels. [31] For further examples of Scandinavia's pioneering role, see Appendix C.

2 Methanex, the world's largest methanol producer, is a Canadian company.

FURTHER MEASURES TO STRENGTHEN THE TRANSITION TO BIODIESEL

Transitioning to biofuels requires more than just measures to address the overall voyage cost differential between biodiesel and traditional fuel. It is also important to focus on other measures that improve biofuel infrastructure and promote widespread availability of these fuels. Our previous study demonstrated that, starting in 2026, there would be enough biofuel supply to fuel the entire Great Lakes and St. Lawrence fleet. To make this future a reality, governments can provide support through the following measures:

Financial Incentives: Governments can offer biofuel producers tax credits, grants and subsidies. These incentives help offset the higher production costs associated with biofuels compared to conventional fuels, encouraging investment and increased production.

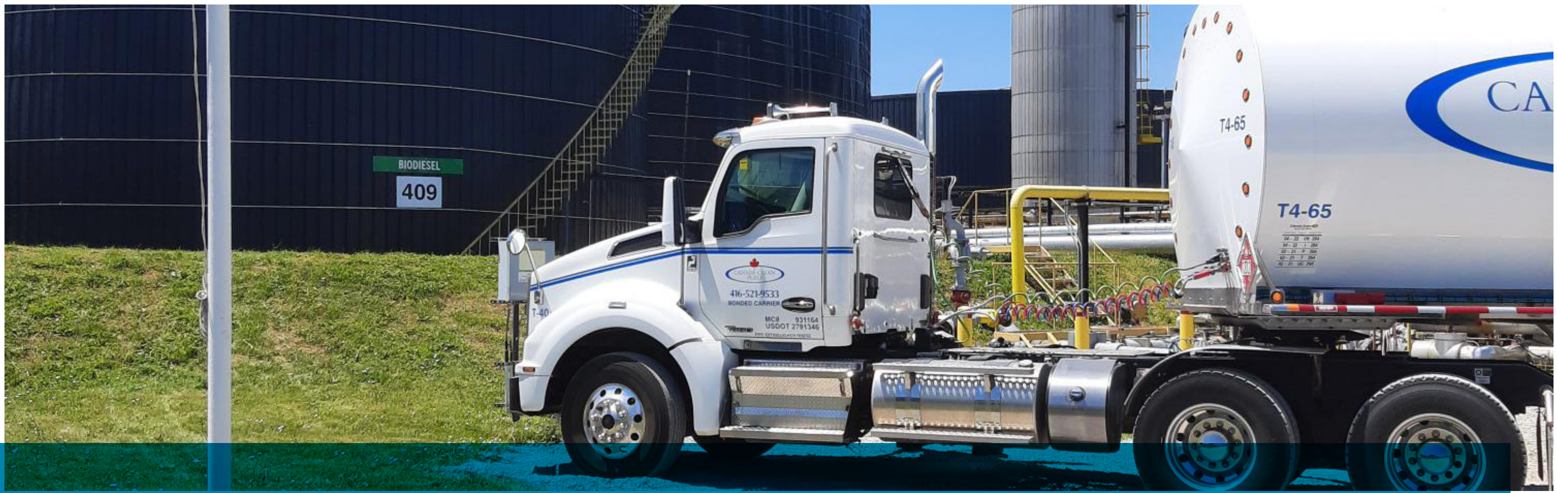
Research and Development Funding: Governments can allocate funding to advance biofuel production technologies, improve efficiency and explore new input feedstocks. This support promotes innovation within the sector and the development of more sustainable and cost-effective biofuel solutions.

Infrastructure Investment: In addition to increasing biofuel production, investment is needed to expand the associated infrastructure. This includes expanding storage and transportation facilities in addition to establishing bunkering sites (or bunkering vessels) for biofuel-powered ships. Robust infrastructure is crucial for a reliable supply chain and a necessary precondition for the widespread adoption of biofuels. Currently, biodiesel can only be refueled in Windsor, Ontario, limiting the fuel's use for ships that cannot refuel there.

Partnership Development: Governments can foster partnerships between industry stakeholders, research institutions and State/Federal government agencies to drive collaboration and knowledge-sharing within the sector thereby accelerating the technological transition.

Regulation: Establishing favorable regulatory frameworks is an essential part of promoting biofuel use within the regional maritime transportation system. Exploring how examples of existing regulation from around the globe (CAT, carbon taxes) might impact biofuel use and production in the Great Lakes St. Lawrence region is just one part. Clear regulations for the use of B100 (100% biodiesel) in ships and streamlining the permit process to ensure stable regulations would provide market certainty and encourage wider biofuel adoption.

By implementing supportive measures, governments would help foster an environment that encourages biofuel production, increases infrastructure development and accelerate the overall transition to a more resilient, sustainable and low-carbon future for the Great Lakes St. Lawrence maritime transportation system.



CONCLUSIONS AND RECOMMENDATIONS

IMAR's 2022 study [1] showed that if all political and industry promises are kept, enough biofuel could well be available to supply the domestic fleet on the GL&SLS. However, the significant price difference between biofuels and fossil fuels at refueling stations acts as a barrier to the use of biodiesel from an economic standpoint. To further analyze the cost factors impacting cargo prices, IMAR conducted a detailed analysis and found that, even without policy measures, the difference in fuel costs is relativized by overall voyage costs and other operating expenses. Instead of the expected 28% higher overall voyage cost that might be expected for B100, the price per ton of cargo increases from 11.2%-17.2% depending on a transit's operating profile. With a slightly cheaper B75 blend, the overall voyage cost for a ton of cargo increases by 8.4%-12.5%. However, when considering public policies aimed at reducing GHG emissions (such as a tax per unit of energy content; CAT system - Québec-California or European Union-, carbon tax), the use of biodiesel becomes more economically attractive. In fact, using B75 could be even more advantageous than using MGO under some scenarios. These findings demonstrate that transitioning to biodiesel can be ecologically beneficial and economically feasible. Governments can play a crucial role in accelerating this transition.

Nevertheless, the operating profile and vessel type are significant factors in the decision to switch to biodiesel. While it may be interesting for bulk carriers, the switchover to biodiesel may be less appealing for tugboats and barges. Therefore, companies that do not benefit as much from policy initiatives on biodiesel transition should be assisted in evaluating other alternative fuels or alternative propulsion systems that are suitable for their specific needs.

The fact that the increase in overall voyage costs when using biodiesel is less than the fuels' price differential provides an opportunity for policymakers to partially ameliorate the biodiesel-MGO price differential in order to promote environmental benefits while maintaining the competitiveness of marine carriers. Based on the findings of this current study, we can update and provide more detailed recommendations and statements [1] compared to our previous report:

1. Support funds for expanding biodiesel, renewable diesel and Fischer-Tropsch diesel production should continue to be made available. B75 demonstrates that a combination of biofuel and fossil fuels is the most attractive option in the near future. By taking advantage of the reduced carbon intensity of the bio component, a higher percentage of fossil fuels can be incorporated into the blend
2. Where possible, governments should lead by example by fuelling their own vessels with biodiesel (renewable diesel or Fischer-Tropsch diesel), showcasing their commitment to sustainable fuels.

3. Converting the bulk carrier fleet to biodiesel/biodiesel blends is a reasonable approach both from an ecological and economic perspective. However, the suitability of biodiesel may vary depending on vessel type and operating profile. Therefore, a thorough evaluation of different vessel classes should be conducted to determine the most suitable propulsion types such as electric, hybrid or methanol for each class.
4. Proactive approaches by the government, as demonstrated by Sweden and Norway, can accelerate the transition to low-GHG-emission alternatives. By making decisions ahead of IMO requirements and fostering collaborations between industry stakeholders, research institutions, class societies and government agencies, governments can facilitate technological advancements and knowledge sharing.
5. Governments can offer tax credits, grants and subsidies to biodiesel producers to offset higher production costs, encourage investment and increase biodiesel production.
6. Funding should be allocated to advance biofuel production technologies, improve efficiency and explore new feedstock in order to promote innovation and cost-effectiveness.
7. Investments in expanding and adapting storage, transportation facilities and bunkering sites for biodiesel-powered ships are crucial to ensure a reliable supply chain and widespread adoption since routes and operating profiles differ by cargo and ship type.
8. Establishing favorable regulatory frameworks are essential, including clear regulations for the use of high-blend or pure biofuels in ships, ensures market stability and encourages wider adoption of biofuels. In particular, recognizing biodiesel, renewable diesel and Fischer-Tropsch diesel as marine fuels would eliminate significant uncertainty for all stakeholders.
9. Aligning Canadian and US policy initiatives would be desirable, and supporting harmonized policies avoids dividing the interconnected GL&SLS economic area.
10. More educational efforts should be done to provide stakeholders and decision-makers with comprehensive information to facilitate decisions on biofuels. Webinars and studies that address the specific needs of the individual GL&SLS sectors can facilitate informed decision-making. Recognizing the distinct requirements of tugboats versus large cargo ships is an important consideration, as confirmed by this study.

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REFERENCES

[1] Innovation Maritime, "Domestic Great Lakes & St. Lawrence Shipping Industry: Transition to Biofuels," The Great Lakes St. Lawrence Governors & Premiers; Innovation Maritime, Jun. 2022. [Online]. Available: https://gsgp.org/projects/maritime/maritime-news/biofuels-report-released-gsgp-innovation-maritime/

[2] U.S. Bioenergy Statistics, "U.S. Bioenergy Statistics - Table 17. Biodiesel and diesel prices." https://www.ers.usda.gov/data-products/u-s-bioenergy-statistics/ (accessed Mar. 17, 2023).

[3] Ship & Bunker, "Ship & Bunker - Americas Average." https://shipandbunker.com/prices/av/region/av-am-americas-average#MGO

[4] Z. Meng and B. Comer, "Great Lakes-St. Lawrence Seaway ship emissions inventory, 2019," ICCT, no. March, 2022.

[5] Environmental Protection Agency, "Economic Incentives." Aug. 2022. Accessed: Mar. 01, 2023. [Online]. Available: https://www.epa.gov/environmental-economics/economic-incentives#permit

[6] Government of Ontario, O. Reg. 663/20: Cleaner Transportation Fuels: Renewable Content Requirements for Gasoline and Diesel Fuels. 2020. [Online]. Available: https://www.ontario.ca/laws/regulation/r20663

[7] Government of Québec, "Auction Proceeds Allocated to the Electrification and Climate Change Fund," Mar. 02, 2023. https://www.environnement.gouv.qc.ca/changements/carbone/revenus-en.htm

[8] Government of Québec, "The Carbon Market, a Green Economy Growth Tool!," Mar. 02, 2023. https://www.environnement.gouv.qc.ca/changementsclimatiques/marche-carbon

[9] Government of Canada, Clean Fuel Regulations, vol. 156. 2022.

[10] U.S. Department of Energy, "Renewable Fuel Standard," Mar. 02, 2023. https://afdc.energy.gov/laws/RFS#:~:text=The%20Renewable%20Fuel%20Standard%20(RFS,Act%20of%202007%20(EISA).

[11] The Weights and Measures Division and of the Minnesota Department of Commerce, "B20 Mandate Requirements." Mar. 02, 2023. [Online]. Available: https://mn.gov/commerce-stat/pdfs/b20.pdf

[12] U.S. Department of Energy, "Indiana - Special Fuel Tax Exemption," Mar. 03, 2023. https://afdc.energy.gov/laws/11804

[13] Pennsylvania Department of Agriculture, "Weights and Measures Annual Report 2008." Mar. 2009. [Online]. Available: https://www.agriculture.pa.gov/consumer_protection/weights_measures/Documents/Weights%20and%20Measures%20Annual%20Report%202008.pdf

[14] U.S. Department of Energy, "Renewable Identification Numbers," Mar. 02, 2023. https://afdc.energy.gov/laws/RIN.html

[15] Innovation Maritime; Technopole maritime du Québec, "Les carburants alternatifs dans le transport maritime au Québec," vol. 2022, 2021.

[16] Navius Research, "Biofuels in Canada 2020 Tracking biofuel consumption, feedstocks and avoided greenhouse gas emissions About Navius Research," 2020.

[17] Trading Economics, "EU Carbon Permits - 2023 Data - 2005-2022 Historical - 2024 Forecast - Price - Quote." https://tradingeconomics.com/commodity/carbon (accessed Mar. 03, 2023).

[18] Deutsche Emissionshandelsstelle im Umweltbundesamt, "Factsheet: Emissionshandel im Luftverkehr," 2021, [Online]. Available: https://www.dehst.de/SharedDocs/downloads/DE/publikationen/Factsheet_LV.pdf?__blob=publicationFile&v=2

[19] DNV, "EU ETS: Preliminary agreement to include shipping in the EU's Emission Trading System from 2024." https://www.dnv.com/news/eu-ets-preliminary-agreement-to-include-shipping-in-the-eu-s-emission-trading-system-from-2024-238068 (accessed Mar. 03, 2023).

[20] IMO, "EEXI and CII - ship carbon intensity and rating system." https://www.imo.org/en/MediaCentre/HotTopics/Pages/EEXI-CII-FAQ.aspx (accessed Mar. 03, 2023).

[21] Waterways Journal, Inc, Greenwood's Guide to the Great Lakes Shipping 2022. Harbor House Publisher, 2022. [Online]. Available: https://seawayreview.com/greenwoods-guide/

[22] Canada Revenue Agency, "Current Rates of Excise Taxes." Jan. 2023. Accessed: Mar. 01, 2023. [Online]. Available: https://www.canada.ca/en/revenue-agency/services/forms-publications/publications/currate/current-rates-excise-taxes.html

[23] "Euro to US Dollar Spot Exchange Rates for 2023." https://www.exchangerates.org.uk/EUR-USD-spot-exchange-rates-history-2023.html (accessed May 15, 2023).

[24] "Annual exchange rates - Bank of Canada." https://www.bankofcanada.ca/rates/exchange/annual-average-exchange-rates/ (accessed May 15, 2023).

[25] Government of Sweden, "Sweden's carbon tax." https://www.government.se/government-policy/swedens-carbon-tax/swedens-carbon-tax/ (accessed Mar. 06, 2023).

[26] H. Hammar and S. Åkerfeldt, "CO_2 Taxation in Sweden - 20 Years of Experience and Looking Ahead," 2011.

[27] M. M. Bugge, A. D. Andersen, and M. Steen, "The role of regional innovation systems in mission-oriented innovation policy: exploring the problem-solution space in electrification of maritime transport," Eur. Plan. Stud., vol. 30, no. 11, pp. 2312–2333, Nov. 2022, doi: 10.1080/09654313.2021.1988907.

[28] S. Diserudal Mildal - Norwegian Maritime Administration, "Why is Norway so advanced when it comes to alternative ship propulsion?," Feb. 06, 2023.

[29] Stena Line, "Methanol – a marine fuel for the future." 2017. [Online]. Available: https://brintbranchen.dk/wp-content/uploads/2017/10/Erik-Lewenhaupt_Stenaline.pdf

[30] Waterfront Shipping, "Shipping Industry To Welcome New, Lower Emission, Methanol Dual-Fuel Vessels," Nov. 30, 2020. https://www.waterfront-shipping.com/news/2020/11/shipping-industry-welcome-new-lower-emission-methanol-dual-fuel-vessels (accessed Jun. 19, 2023).

[31] offshore-energy, "World's 1st methanol-powered pilot boat launched." https://www.offshore-energy.biz/worlds-1st-methanol-powered-pilot-boat-launched/ (accessed Mar. 08, 2023).

[32] Marine Cadastre Canada, "Access AIS Tool." https://marinecadastre.gov/accessais/

[33] Government of Ontario, "Technical Guideline: Cleaner Transportation Fuels. 2023 v 2.0." [Online]. Available: https://prod-environmental-registry.s3.amazonaws.com/2023-04/Technical%20Guideline%20- %20Cleaner%20Transportation%20Fuels%20-%20Version%202.0.pdf

[34] Government of Québec, Regulation respecting the integration of low-carbon-intensity fuel content into gasoline and diesel fuel, vol. 153. 2021.

[35] E. Danielson, "Report Name: Biofuels Annual - Canada," Unites States Dep. Agric. Foreign Agric. Serv., p. 11, 2020.

[36] Government of Canada, Greenhouse Gas Pollution Pricing Act. 2018.

[37] Governments of Canada, Output-Based Pricing System Regulations: SOR/2019-266. [Online]. Available: https://canadagazette.gc.ca/rp-pr/p2/2019/2019-07-10/html/sor-dors266-eng.html

[38] Government of Ontario, "O. Reg. 241/19: Emissions Performance Standards Regulation."

[39] Navius Research, "Biofuels in Canada 2022." Oct. 27, 2022.

[40] Adam Schubert, "EPA Issues Proposed RFS Standards for 2023-2025 plus Requirements for eRINs," Mar. 02, 2023.

[41] U.S. Energy Information Administration, "Pennsylvania Biodiesel Production Capacity," Petroleum & Other Liquids, Mar. 03, 2023. https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=m_epoobd_8bdpc_spa_mmgl&f=a

[42] American Petroleum Institute, "Regional Gasoline Motor Fuel Taxes," Jan. 2022.

[43] European Council, "Fit for 55 - The EU's plan for a green transition - Consilium," 2023. https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/ (accessed Mar. 03, 2023).

[44] DNV, "EEXI – Energy Efficiency Existing Ship Index." https://www.dnv.com/maritime/insights/topics/eexi/index.html#:~:text=The%20Energy%20Efficiency%20eXisting%20ship,in%202023%20at%20the%20latest.

[45] IMO, "Energy Efficiency Measures." https://www.gard.no/web/articles?documentId=34536140 (accessed Mar. 03, 2023).

[46] Ship Technology, "Viking Lady Offshore Supply Vessel," 2010. https://www.ship-technology.com/projects/viking-lady/ (accessed Mar. 08, 2023).

[47] Ship Technology, "Ampere Electric-Powered Ferry - Ship Technology." https://www.ship-technology.com/projects/norled-zerocat-electric-powered-ferry/ (accessed Mar. 07, 2023).

[48] Riviera, "World's first hydrogen ferry set for sea trials," 2022. https://www.rivieramm.com/news-content-hub/news-content-hub/worlds-first-hydrogen-ferry-set-for-sea-trials-73501 (accessed Mar. 08, 2023).

APPENDICES

TRAFFIC ON THE GREAT LAKES AND ST. LAWRENCE SEAWAY IN 2019

Representation of AIS data for traffic on the GL&SLS in 2019.

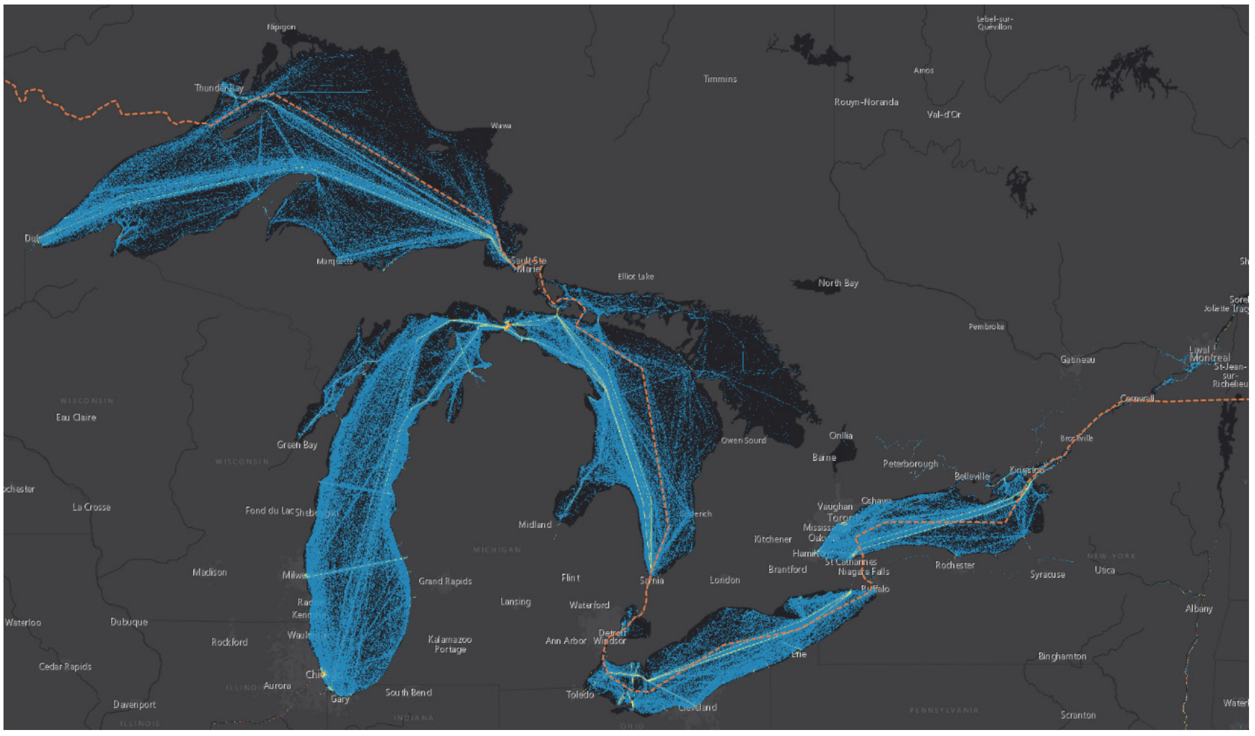

Figure 1 - Main transit routes on the Great Lakes and St. Lawrence Seaway - AIS 2019. [32]

EXAMPLES OF PUBLIC POLICIES TO REDUCE EMISSIONS

Examples of public policies to reduce emissions in Canada

Canada's *Clean Fuel Regulations* (CFR) have been in force since July 2022, replacing the *Renewable Fuel Regulations*. The CFR affects all primary fuel suppliers (fuel producers and importers). The CFR represents a carbon intensity (CI)-based approach and include a CAT system that takes effect in 2023. CI-based means that the CI is included in calculating the required blend rate (2% by volume). The reduction in 2023 is 3.5 gCO_2e/MJ. It increases annually to reach 14 gCO_2e/MJ in 2030. Because different renewable fuels have varying emissions levels, the government provides software that calculates a fuel's complete life cycle CI which is then used to determine the final blend rate. [9]

Since 2018, a carbon tax has been levied under the *Greenhouse Gas Pollution Pricing Act*. Some provinces have their own standards, which the CFR does not supersede if their requirements exceed those of the CFR. However, provincial regulations apply exclusively to primary suppliers such as fuel producers and fuel importers.

In Ontario, the *Cleaner Transportation Fuels regulation* has been in effect since 2020 and requires a 4% renewable content blend rate for diesel subject to the weighted average Carbon Intensity (CI) of the biofuel, which must be at least 70% below the reference CI for diesel fuel. [33] The blend rate can be lower if the renewable content's emissions are lower than the threshold.

Québec has its *Regulation respecting the integration of low-carbon-intensity fuel content into gasoline and diesel fuel* which requires a 3% blend rate for diesel as of 2023 and 10% as of 2030. As in Ontario, this rate is CI-based and assumes an average CI of 45.7 gCO_2e/MJ for the renewable content. [34] [35]

Under the *Greenhouse Gas Pollution Pricing Act,* Canada's Output-Based Pricing System imposes a tax on CO_2 emitted. As of 2023, one metric ton of CO_2 will cost CAN$65, which will rise to CAN$170 by 2030 as defined in the *Output-Based Pricing System*. If a facility's emissions are below its emissions limit, the credits generated can be traded with participants who have exceeded their threshold. Compliance for 2023 emissions year will be in 2024. [36] [37]

Ontario's Emissions Performance Standards (EPS) program was fully implemented in 2022, replacing the costlier federal Output-Based Pricing System that was in place in Ontario from 2019 to 2021. In specified industries, facilities with annual CO_2e emissions equal to or greater than 50 000 tonnes must register, those that emit at least 10 000 tonnes may opt-in. [38]

Québec has had its own CAT system since 2013. It, too, requires large emitters (≥ 25,000 mt CO_2e) to comply with the emission thresholds set for them by the government and tightened annually. Auctions are held four times a year. Since 2014, Québec's CO_2 market has been linked to California's. Credits can be traded among the participating parties. In late 2022, the price per credit unit was US$27/mt CO_2e (CAN$32/mt CO_2e). This price will rise every year by 5% plus inflation. [7] [8]

Table 4 – Blend rates and carbon pricing policies in Canada, Ontario and Québec

Region	2022 blend rate [vol%]	2030 blend rate 2030 [vol%]	Carbon pricing			Regulations
			Program	US$/mt$CO_2e$ 2023	US$/mt$CO_2e$ 2030	
Canada	2	22[3]	Cap and trade	48	125	CFR [9]
Ontario	4	4[4] [33]	Cap and trade	37	125	EPS [38]
Québec	3	10	Cap and trade	27	35[5]	RLF [34]

Examples of public policies to reduce emissions in the United States

The US *Renewable Fuel Standard* program (2005) requires that transportation fuel contain a minimum percentage of renewable fuel. To control this, *Renewable Identification Numbers* (RIN) were introduced to monitor the renewable content of transportation fuel. [10] For 2022, the final RIN volume was 36 billion gallons (136 billion liters). The volume for bio-based diesel (RIN category D4) was equivalent to 2.8 billion gallons (10.6 billion liters) or 2.33% of the total RIN volume. The *Environmental Protection Agency* sets the RINs and blend rates to be complied with annually. No data is yet available for 2030. For 2025, 2.95% blend rates are proposed for biomass-based diesel. [38] These bio-based diesels must have a GHG LCA reduction rate of 50%. RINs can be traded following the same logic as the CAT examples. However, RIN prices are based on market factors, typically of other commodities and not necessarily government decisions. [14]

3 Carbon intensity corrected: The 22% blend rate corresponds to a reduction of 14 gCO_2e/MJ as required by the CFR by 2030. For example, for diesel with 93 gCO_2e/MJ[9], emissions must be reduced to 79 gCO_2e/MJ. Based on a complete LCA value of 30 gCO_2e/MJ for biodiesel [1], the blend rate is 22%. The blend rate depends on the emissions value of the renewable content.

4 Based on CI.

5 Only the annual 5% price increase was taken into account. The future value is likely to be higher due to inflation.

Of the eight Great Lakes states, some (Minnesota, Indiana and Pennsylvania) also have their own fuel mandates, blend rates and tax exemptions. In Minnesota, road diesel must contain at least 5% biodiesel between October and March, 10% from April 1 to 15, and 20% between April 15 and September 30. [11] In Indiana, "biodiesel [and] blended biodiesel [...] used to power an internal combustion engine [...] is exempt from state gross retail tax." [12] Pennsylvania set a minimum blend percentage in its fuel mandate for July 2008 that is tied to in-state biodiesel production. Under the Renewable Fuel Standard, diesel must contain at least 2% biodiesel. Once in-state biodiesel production in Pennsylvania reaches 100 million gallons over three months, the blend rate must be increased to 5% biodiesel and then to 20% biodiesel once production reaches 400 million gallons over three months. [13] In 2020, Pennsylvania's in-state production was 90 million gallons. [41]

Table 5 - Blend rates and carbon pricing policies in the US, Minnesota, Indiana and Pennsylvania

Region	2022 blend rate [vol%]	2030 blend rate [vol%]	Carbon pricing		Regulations
			Program	D4 US$/RIN 2022	
US	2	n.a.	RIN	0.51 – 2.08	RFS
Minnesota	5 -20[6]	5-20[6]	RIN	0.51 – 2.08	RFS & [11]
Indiana	2	As per RFS	RIN & exemption for biodiesel constitute gross retail tax	0.51 – 2.08	RFS & [12]
Pennsylvania	2[7]	2[7]	RIN	0.51 – 2.08	RFS & [13]

Taxation by volume, penalizing alternative fuels

Taxes that authorities levy on fuels influence the price and thus attractiveness of a fuel and indirectly affect purchasing behavior and, consequently, emissions. It is common practice to levy taxes per unit of volume (e.g., liter, gallon). Volume-based taxes indirectly penalize biodiesel users instead of rewarding them. As indicated elsewhere, biodiesel's energy content (33.3 MJ/L) is lower than MGO's (36.6 MJ/L). [15] This means more biodiesel must be burned to travel the same distance as fossil diesel: 1162 L of biodiesel and 1117 L of B75 contain about as much energy as 1000 L of fossil diesel. Since both biodiesel and fossil diesel are taxed per liter, biodiesel consumers are at a financial disadvantage. To simplify, considering only federal fuel taxes in our example, biodiesel consumers in the US pay US$12 more for biodiesel and US$10 more for B75 (federal excise tax US$0.0645/L or US$0.244 cents/gallon) [42] and, in Canada, they pay US$6 more for biodiesel and US$5 more for B75 (federal excise tax US$0.4/L or US$0.15/gallon) [22] to travel the same distance as fossil diesel users. This tax disadvantage holds for all alternative fuels with less energy content per liter than fossil equivalents. The additional costs incurred seem negligible, but, in addition to excise taxes, there are provincial, sales and carbon taxes, all of which also relate to volume. A 2020 study by Navius Research stated: "In 2020, [...] "surtaxes" [...] paid on biofuels amounted to an extra 31%/yr, or roughly $339 million (2020 CAD), relative to the tax that would have been paid if taxes were assessed equally on a "per unit of energy" basis instead of a "volumetric" basis [...]". [16] The only way to mitigate such "surtaxes" is through taxation per unit of energy (e.g., tax/MJ).

Examples of public policies to reduce emissions in Europe

Europe has had a CAT system*, the Emission Trading System* (ETS), since 2005. All 27 EU nations, Iceland, Norway and Liechtenstein are members. Permit prices started at about €20 (US$24[8]) in 2005, peaked at €107 (US$114[8]) in February 2023, and were €97 (US$107[8]) in March 2023. [17] Previously, participation was mandatory only for industry, power plants and large heat generators. In

6 Seasonal

7 Depends on PA's in-state production capacity over 3 months = 90 million gallons in 2020 [41].

8 Average Euro-to-US$ exchange rate was 1.18 for 2005 and 1.07 for February and March 2023 [23].

2012, intra-European air traffic was integrated. Since 2013, chemical and aluminum industries have also been largely covered by the EU ETS. [18] With the "Fit for 55" program, various legislative proposals were made to align energy and climate policy instruments with the new climate target of reducing emissions by at least 55% from 1990 levels by 2030. [43]

To come closer to achieving this goal, as of 2024, ships exceeding a gross tonnage (GT) of 5000 traveling to Europe will have to participate in the ETS. Over time, smaller cargo and offshore vessels (400-5000 GT) will also be integrated. Ships that fail to meet requirements for two consecutive periods may be denied entry to Europe. Companies that do not manage to comply with the regulation can pay a fine of €100/mtCO_2e (US$107/mt$CO_2$e[8]).

The European Parliament and Council of the European Union have yet to officially adopt their directive to this effect, but including shipping in the ETS has been endorsed by both institutions. [19]

Examples of IMO policies to reduce emissions

The International Maritime Organization (IMO) has no power over the carbon policies of individual countries, but it does have an influence on ships that sail in international waters. The IMO aims to bring ship-generated GHG emissions to net-zero from 2008 levels by 2050. All GL&SLS vessels that also operate internationally must comply with measures such as the *Energy Efficiency Existing Ship Index* (EEXI), *Energy Efficiency Design Index* and *Carbon intensity indicator* (CII). We will not go into the details here, interested readers are referred to references [44] and [45]. The EEXI calculates the CII, an initiative to quantify GHG emissions, which has been in effect since January 2023. [20] Every year, CII requirements become stricter, meaning that a ship that does not continuously become more efficient is no longer compliant over time. Uncompliant vessels must develop an action plan, submit it to the relevant authorities and implement it. Failure to do so may result in fines.

SCANDINAVIAN LOW-EMISSIONS SHIPPING PROJECTS

- First hybrid offshore vessel, *Viking Lady* with LNG/Liquid fuel cell propulsion (Norway 2009) [46]
- First methanol ship, *Stena Germanica* (2015 Sweden) [29]
- First all-electric ferry, *MV Ampere* (2015 Norway) [47]
- First liquid hydrogen ferry, *Hydra* (2021 Norway) [48]
- Norway's significant participation in creating the IMO's *International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels* (*IGF Code*), which regulates the use of LNG as a fuel.

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