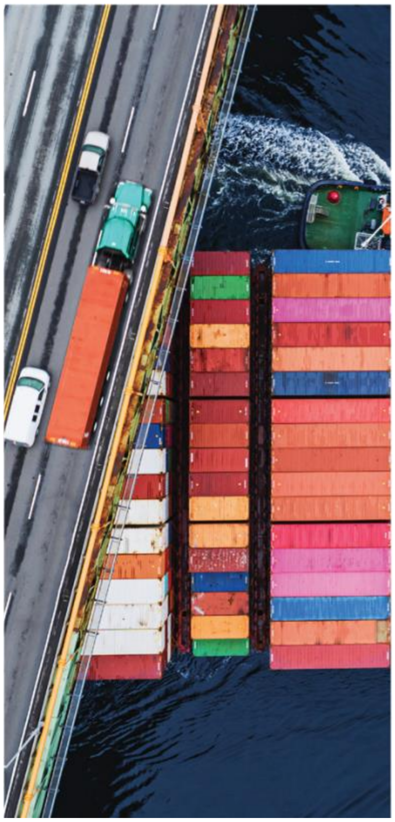
The Impact of

Ship Emission Fees on Mode Shift Potential

in the United States



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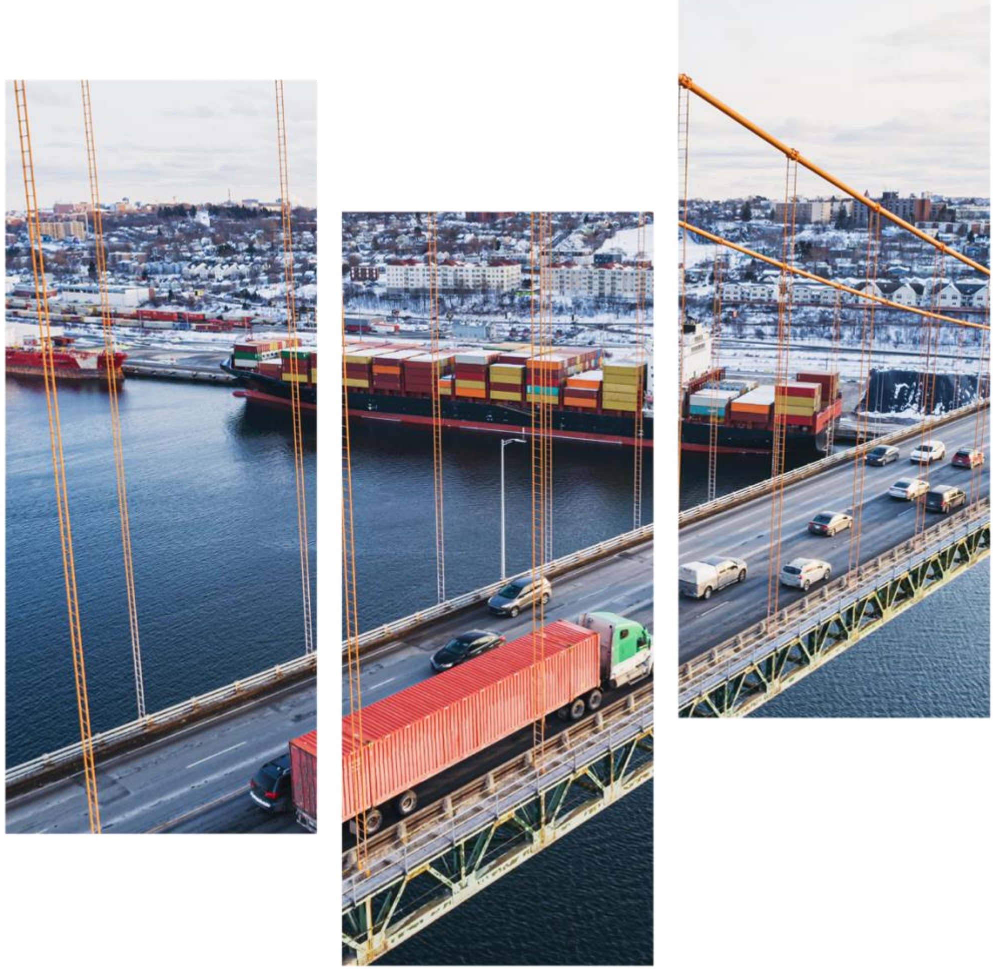
Contents

List of Abbreviations and Acronyms

IMPAA Report Abbreviations List

Abbreviation	Name/Phrase
A	Alternate
ATRI	American Transportation Research Institute
B	Baseline
BEA	Business Economic Area
CAA	Clean Air Act
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide-equivalent
CSA	Clean Shipping Act of 2023
ECA	Emission control area
EERA	Energy and Environmental Research Associates, LLC
EEZ	Exclusive Economic Zone
EF	Emission factors
EPA	Environmental Protection Agency
g	Grams
g/MJ	Grams per megajoules
gCO2e/MJ	Grams of carbon dioxide equivalent per megajoule
GHG	Greenhouse gas
GIFT	Geospatial Intermodal Freight Transportation
GREEN-T	Global Routing Energy and Emissions Network for Transportation
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Technologies
GRT	Gross register tonnage
HFO	Heavy fuel oil
IMO	International Maritime Organization
IMPAA	International Maritime Pollution Accountability Act
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram

Abbreviation	Name/Phrase
km	Kilometers
kWh	Kilowatt-hour
lbs	Pound
MDO	Marine diesel oil
MGO	Marine gas oil
mi	Miles
MJ	Megajoules
MJ/kg	Megajoules per kilogram
MJ/t-km	Megajoules per ton-kilometer
MT	Metric tons
N_2O	Nitrous oxide
NM	Nautical miles
NO_x	Nitrogen oxide
OD	Origin-destination
PM	Particulate matter
$PM_{2.5}$	Fine particulate matter
PUWS	Public Use Waybill Sample
RFS	Renewable Fuel Standard
SO_2	Sulfur dioxide
SO_x	Sulfur oxide
STCC	Standard Transportation Commodity Code
TEU	Twenty-foot equivalent unit
tn	Short ton
U.S.	United States
USACE	U.S. Army Corps of Engineers
USD/FEU	U.S. dollar per forty-foot equivalent unit
USD/kg	U.S. dollar per kilogram
USD/mile	U.S. dollar per mile
USD/t-km	U.S. dollars per ton-kilometer
USD/ton-mile	U.S. dollar per ton-mile
VLSFO	Very low sulfur fuel oil
WtW	Well-to-wake



Executive Summary

Governments and international agencies are establishing progressive climate goals to guide a global transition to net-zero by 2050.

To meet these goals, these organizations are implementing a series of progressively stricter regulations to transition industries to cleaner practices while minimizing economic disruption.

The maritime industry, in particular, faces significant challenges to align with these targets due to the industry's reliance on fossil fuels and the large-scale pollution generated by shipping activities. Emitting an estimated one billion metric tons of greenhouse gasses (GHG) each year,[1] the shipping industry's large emissions footprint exacerbates already worsening climate warming. Moreover, the industry primarily relies on low-grade conventional fuels, such as heavy fuel oil (HFO) and marine gas oil (MGO), which result in sizable emissions of particulate matter (PM), sulfur, and nitrogen oxides (SO_X and NO_X), heavily contributing to air pollution in port communities and coastal regions.

[1] 1 gigaton of CO_2 equivalent emissions = 1 billion metric tons: https://sciencebasedtargets.org/resources/files/SBTi-Maritime-Guidance.pdf

At the national level, the United States (U.S.). is assessing policies aimed at accelerating the adoption of alternative fuels and more sustainable practices in maritime shipping to reduce the industry's environmental and public health impact.[2,3] This includes the consideration of economic measures, such as carbon and pollutant pricing mechanisms, to make the use of unsustainable conventional fuels and practices more expensive and encourage investments in cleaner alternatives.

One proposed policy, the International Maritime Pollution Accountability Act (IMPAA),[4] would impose carbon dioxide-equivalent[5] (CO_2e) fees for all freight ultimately bound for U.S. import, along with air pollutant fees applied to criteria pollution emissions (nitrogen oxides, sulfur dioxide, and fine particulate matter) within the U.S. exclusive economic zone (EEZ). The CO_2e fees would apply to the entire voyage; whereas fees for criteria pollutants would only apply to the voyage segment within the U.S. EEZ.

Under IMPAA, importers of U.S.-bound cargo would be responsible for reporting CO_2e emissions and for paying fees based on the fuel consumption of the voyage, regardless of where importers offload. If cargo is offloaded at a foreign port and then transported into the U.S. by land or air, the fees would be adjusted according to the share of cargo bound for U.S. import and considering any emissions fees paid during the same journey, to avoid double charging. Avoiding U.S. waters would only exempt shipments from criteria air pollutant fees, not from CO_2e fees (See Policy Interpretations).

Using a geospatial model, this study assesses the economic and logistical implications of IMPAA on shipping routes, particularly focusing on potential unintended consequences where shippers seek to bypass fees or reduce their time within the U.S. EEZ by shifting cargo to alternative ports. This "loophole" could result in cargo moving via less efficient land-based transport modes, such as trucks and trains, in response to the increased costs and thus could undermine the emission reduction goals of IMPAA. Transportation mode shifts are most feasible for containerized cargo, which can be easily transferred between ships, rail, and trucks for intermodal transportation.

The findings indicate that, for the majority of routes, the potential for transportation mode shift is low, as most established routes remain economically and environmentally favorable despite the additional IMPAA fees. A few specific routes show some potential for mode shifting due to lower costs or emissions from alternative rail or road segments; however, the estimated IMPAA fees were not a determining factor for those specific routes. The findings suggest that the proposed fees introduced by IMPAA are likely not sufficient to induce a mode shift, or shifts to alternative fuels.

[2] See the "Zero-Emission Vessel Innovation Fund" encouraged by the Congressional Committee on Transportation and Infrastructure to be considered within the Maritime Administration to provide $500 million in financing for pilot projects, demonstration projects, and research into zero-emissions marine vessels and the retrofitting of existing vessels: https://www.congress.gov/118/chrg/CHRG-118hhrg52632/CHRG-118hhrg52632.pdf

[3] See federal development of the "U.S. Maritime Decarbonization Action Plan" to establish economic and policy levers to promote the investment and adoption of vessel decarbonization fuels, energies, and technologies: https://www.transportation.gov/sites/dot.gov/files/2023-12/MAP_Preview_Final.pdf

[4] https://www.padilla.senate.gov/wp-content/uploads/IMPA-Act-2023.pdf

[5] According to the IMO's greenhouse gas studies, the primary GHGs considered when calculating CO_2e for shipping emissions are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

Introduction & Purpose

Ships are considered to be the most efficient mode of freight transport due to their ability to transport large volumes of containers simultaneously over long distances. Transporting the same amount of cargo by truck or train would require many separate units and would result in higher emissions per unit of freight.[6] However, the maritime shipping industry relies on an aging fleet that consumes large quantities of fossil fuels, contributing to approximately 3% of global GHG emissions.[7] To address this, the industry has set ambitious targets to reach net-zero emissions by 2050, with the International Maritime Organization (IMO) aiming for 5-10% of the global fleet's fuel to be low-GHG alternatives by 2030.[8]

To support these goals, governments around the world are implementing policies to encourage the adoption of alternative fuels in the shipping sector. Among these tools are carbon taxes and polluter-pays schemes, which impose financial penalties on high-emission activities in an effort to push the industry towards cleaner alternatives. This study leverages a geospatial modeling approach to assess how proposed environmental policies in the U.S., specifically cost-increasing measures, could impact transportation costs and influence shippers to reconfigure their logistics strategies—potentially shifting cargo to less efficient transport modes.

The Global Routing Energy and Emissions Network for Transportation[9] (GREEN-T) geospatial model is capable of evaluating the energy, emissions, and costs associated with transportation routes with intermodal connections (i.e. water, rail, road). Routes can be adjusted based on constraints such as time, cost, emissions, cargo types, route preferences, and ship characteristics (e.g. size, engine, fuel). Under this study, GREEN-T was utilized to determine the price and emissions delta for shifts in origin-destination (OD) routes to avoid proposed fees on GHG and criteria pollutant emissions.

Focusing on containerized cargoes, this study establishes base case (route costs without IMPAA fees) freight rates for 24 shipping routes to and from the continental U.S.. The rates account for the current fuel and technology prices for each transportation mode, considering current regulatory measures such as global sulfur caps and emission control areas. These base case routes include a mix of waterborne, rail, and road transportation, as cargo must be moved from its production site to a coastal departure port and then from the arrival port to its final destination.

An offline version of the GREEN-T model was applied and adjusted to evaluate how changes in fees under proposed policies could influence shippers to switch away from these routes. The evaluation considers shifts in various types of waterborne transport, including short-sea, coastwise, trans-oceanic, inland, and Jones Act-compliant[10] routes. The findings unveil routes and ports vulnerable to mode shifts, particularly those routes and ports that allow vessels to bypass IMPAA fee areas. This information will uncover how economic responses that alter freight routing decisions could undermine the emissions reduction goals of these policies, enabling decision-makers and stakeholders to account for these potential impacts and to develop strategies to mitigate unintended outcomes.

[6] https://climate.mit.edu/explainers/freight-transportation

[7] https://unctad.org/system/files/official-document/rmt2023_en.pdf

[8] https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx

[9] GREEN-T is under development by Energy and Environmental Research Associates, LLC for the U.S. Maritime Administration and it will soon be available at https://www.eera.io/work

[10] U.S. law (46 U.S.C. § 55102) that mandates goods transported between U.S. ports must be carrier by vessels that are U.S. built, owned, crewed and operated: https://www.maritime.dot.gov/ports/domestic-shipping/domestic-shipping

Background

As a signatory to the Paris Agreement[11] and in line with IMO targets and its own climate goals[12], the U.S. government is working to decarbonize the shipping industry by advancing domestic policies that promote cleaner fuels, electrification, and energy efficiency improvements in ports and vessels. Strategies include market-based measures such as the Inflation Reduction Act[13] and the Bipartisan Infrastructure Law[14], which provide substantial funding[15,16] to support sustainable research and development in the alternative fuels and maritime sectors. Furthermore, fees and carbon pricing mechanisms are being considered to penalize high-emission operations to align the shipping sector with national and international climate goals.

IMPAA[17,18] is a proposed U.S. regulation aimed at reducing emissions from ships importing freight to U.S. destinations by imposing fees on GHGs and other air pollutants. IMPAA proposes a fee of $150 per metric ton of CO_2e (assumed to include carbon dioxide [CO_2], methane [CH_4], and nitrous oxide [N_2O] emissions) for the entire voyage of ships transporting goods to the U.S., even if the cargo is offloaded in another country and then enters the U.S. by land or air. For voyages calling within the U.S. EEZ[19], which extends up to 200 nautical miles (nm) from the U.S. coastline, IMPAA would impose fees based on the amounts of nitrogen oxides (NO_X), sulfur dioxide (SO_2), and fine particulate matter ($PM_{2.5}$) emitted from fuel consumption.[20]

By charging pollution fees for maritime shipping, IMPAA intends to incentivize the adoption of low or zero-GHG alternative fuels and technologies by increasing the cost of conventional operations. To avoid higher costs associated with these emissions, some shippers may invest in adopting these alternative fuels and technologies that reduce their emissions. However, this policy could have unintended consequences. For instance, shippers might divert cargo to ports outside the U.S., such as Mexico or Canada, to escape the fees on criteria pollutants. Consequently, they may rely on less efficient land-based transportation, such as trucks and trains, to complete the freight's journey to its final destination.

Given these potential shifts, this report aims to assess the economic and logistical impacts of IMPAA on freight transportation networks. By evaluating the potential for mode shifts and route diversions, this work aims to inform strategies that align the maritime sector and broader freight operations with climate targets, while minimizing unintended environmental and economic consequences.

[11] https://unfccc.int/process-and-meetings/the-paris-agreement

[12] https://bidenwhitehouse.archives.gov/climate/

[13] https://bidenwhitehouse.archives.gov/cleanenergy/inflation-reduction-act-guidebook/

[14] https://bidenwhitehouse.archives.gov/build/guidebook/

[15] Nearly $394 billion has been allocated to climate and clean energy initiatives under the Inflation Reduction Act: https://www.mckinsey.com/industries/public-sector/our-insights/the-inflation-reduction-act-heres-whats-in-it

[16] Nearly $75 billion has been allocated for various clean energy and power projects under the Bipartisan Infrastructure Act. See pp. 151-154 for an overview: https://bidenwhitehouse.archives.gov/wp-content/uploads/2022/05/BUILDING-A-BETTER-AMERICA-V2.pdf

[17] https://www.congress.gov/bill/118th-congress/senate-bill/1920

[18] https://www.padilla.senate.gov/wp-content/uploads/IMPA-Act-2023.pdf

[19] https://oceanexplorer.noaa.gov/facts/useez.html

[20] These fees are calculated in pounds of pollutants emitted per unit mass of fuel burned.

Policy Interpretations

Under IMPAA, the CO_2e emissions fee is based on the total amount of fuel consumed across a ship's freight voyage, from origin to destination. If cargo is offloaded at a foreign port, such as in Canada or Mexico, and then transported into the U.S. by another mode of transportation, the importer remains responsible for the CO_2e fee for the portion of freight destined for U.S. markets. However, fees for criteria pollutants (NO_X, SO_2, $PM_{2.5}$) only apply to the portion of the voyage that takes place within the U.S. EEZ. Therefore, rerouting a voyage to a foreign port would only allow an importer to avoid the criteria pollutant fees associated with its U.S.-bound freight, but would not exempt an importer from the CO_2e voyage fees based on the entire distance traveled.

IMPAA SEC. 3(11)	"The term **"ultimately bound for the United States"**, with respect to cargo or freight, includes—all cargo or freight that is offloaded in the United States by a vessel making a covered voyage; and all cargo or freight that is—initially offloaded at an intermediate [i.e. foreign] port; and subsequently transported to the United States by sea, land, or air."
IMPAA SEC. 5(c)	"The term "qualified importing voyage" means a voyage made using a vessel [for which] the primary purpose of which is transporting cargo or freight; and that, at a foreign port of call, offloads cargo or freight that is **ultimately intended to be transported to the United States by sea, land, or air**." "The amount of the **fee shall be prorated** for the share (by mass) of the cargo or freight on the vessel making the qualified importing voyage that is ultimately bound for the United States that is being imported by the importer."[21]

IMPAA includes a flexible fee structure to avoid double charging ship operators. It sets a maximum charge of $150/MT-$CO_2e$, but the legislation would sunset if IMO adopts a higher global fee.[22] If IMO introduces a levy less than $150/MT-$CO_2e$, or no levy at all, IMPAA's fee would either cover the difference up to $150/MT-$CO_2e$ or apply in full.

The CO_2e and criteria pollutant emissions profiles, used to calculate a ship's freight fee, take into account the entire life cycle of the fuel(s). The specific life cycle emissions values for each fuel have not yet been detailed in the policy, but the policy directs the U.S. Environmental Protection Agency (EPA) to develop a life cycle emissions profile for each fuel, represented as the emissions per mass combusted. Additionally, under IMPAA the EPA Administrator will develop a life cycle emissions profile for the criteria pollutants for each fuel used in maritime shipping.

[21] https://www.padilla.senate.gov/wp-content/uploads/IMPA-Act-2023.pdf

[22] IMO discussions on an emissions pricing mechanism have been ongoing since its initial GHG strategy, but discussions have gained significant traction recently, with more countries and stakeholders advocating for it: https://www.bloomberg.com/news/articles/2024-03-22/world-s-first-global-c02-charge-inches-closer-at-london-meetings

IMPAA SEC. 5(a)	"Not later than January 1, 2024*, the [EPA] Administrator shall develop a **lifecycle** carbon dioxide equivalent (CO_2e) emissions profile for each fuel used in maritime shipping to express the emissions from the combustion of that fuel in carbon dioxide-equivalent per unit mass combusted."
IMPAA SEC. 6(a)	"Not later than January 1, 2024*, the [EPA] Administrator shall develop a **lifecycle** emissions profile for each fuel used in maritime shipping to express the emissions from the combustion of that fuel of each of nitrogen oxides, sulfur dioxide, and fine particulate matter ($PM_{2.5}$) per unit mass combusted."[23]

*Note that because IMPAA has not yet been passed into law, the necessary coordination for assessing the life cycle emissions profiles for each fuel type has been delayed, which means that the target date would be updated.

In this report, we interpret this IMPAA language to mean that well-to-wake (WtW), or the full lifecycle of greenhouse gas emissions, of each fuel should be considered when developing these profiles, though the fees will be calculated based on fuel consumed in transit. In practical terms, the fee would be based on the total mass of each fuel type consumed during the voyage, multiplied by the fuel's emissions per unit mass (derived from WtW emissions), and then further multiplied by the set fee per the emissions type.

$$\textit{IMPAA Fee} = (\textit{Mass of Fuel Consumed}) \times (\textit{Emissions per Unit Mass}) \times (\textit{Set Fee})$$

Mass of Fuel Consumed	calculated using the vessel's fuel(s) consumption across the entire voyage for CO_2e, but only the fuel(s) consumed in the U.S. EEZ for the criteria pollutants
Emissions per Unit Mass	emissions profiles to be developed by the EPA at a later date
Set Fee	outlined below, summarized from the IMPAA policy

SET FEES–

CO_2e CO_2, CH_4, N_2O*	$150.00 per metric ton
NO_X	$6.30 per pound
SO_2	$18.00 per pound
$PM_{2.5}$	$38.90 per pound

*Note that IMPAA does not specify which GHGs will be considered within its CO_2e value. In the absence of explicit guidance in IMPAA, it is reasonable to assume that the CO_2e value should cover at least the three major GHGs (CO_2, CH_4, and N_2O), consistent with the Intergovernmental Panel on Climate Change (IPCC) and other standard practices.[24]

[23] https://www.padilla.senate.gov/wp-content/uploads/IMPA-Act-2023.pdf

[24] The EPA considers the GWP estimates presented in the most recent IPCC scientific assessment to reflect the state of the science: https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

IMPAA SEC. 5(2)(A)	"…shall be the total sum of, for each type of fuel consumed during the covered voyage, the product obtained by multiplying the **total mass of the fuel consumed during the covered voyage**; the carbon dioxide-equivalent emissions of the fuel, expressed in metric tons per unit mass of fuel consumed, as determined under subsection (a); and $150."
IMPAA SEC. 6(2)(A)	"…shall be the total sum of, for each type of fuel consumed during the covered voyage—the product obtained by multiplying—the **total mass of the fuel consumed during the covered voyage within the exclusive economic zone**; the quantity of [criteria pollutant] emitted by the consumption of the fuel, expressed in pounds per unit mass of fuel consumed, as determined under subsection (a); and [*see set fee table*]."[25]

The Clean Shipping Act of 2023 (CSA) was introduced in Congress to reduce emissions from ships (>400 gross tonnage) in U.S. waters by setting limits on the GHG intensity of marine fuels. The standards would gradually tighten to 2040, aiming for ships to adopt zero-emission fuels and technologies to achieve 100% emissions reductions. Additionally, the CSA sets requirements to eliminate emissions from all vessels at-berth or at anchorage in U.S. waters by 2030.[26] CSA explicitly supports a WtW approach to close emissions loopholes, for example, for fuels such as liquefied natural gas and gray hydrogen. The CSA defines "lifecycle [*sic*] greenhouse gas emissions" in reference to the Clean Air Act's (CAA) explication.

CSA SEC. 212A(d)(6)	"The term '**lifecycle** greenhouse gas emissions' has the meaning given such term in section 211(o) [of the Clean Air Act]."[27]

The CAA includes direct as well as indirect emissions, encompassing all stages of the fuel lifecycle from feedstock generation to distribution to end-use, with values adjusted based on the most recent global warming potential measurement.[28] The CAA has been amended to reflect more recent U.S. energy and environmental regulations, and its emissions definitions were updated with consideration of the evolving science.

CAA SEC. 211(o)(1)(H) amended	Defines the term "**lifecycle** greenhouse gas emissions" to mean "the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes), as determined by the [EPA] Administrator, related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential."[29,30]

[25] https://www.padilla.senate.gov/wp-content/uploads/IMPA-Act-2023.pdf

[26] https://www.congress.gov/bill/118th-congress/house-bill/4024/text

[27] https://www.congress.gov/118/bills/hr4024/BILLS-118hr4024ih.pdf

[28] The EPA considers the GWP estimates presented in the most recent IPCC scientific assessment to reflect the state of the science: https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

[29] Congress provided the definition of "lifecycle greenhouse-gas emissions" in CAA section 211(o)(1)(H) for the purpose of the RFS program, and it is within that context that the EPA has interpreted and applied this term: https://home.treasury.gov/system/files/136/45V-NPRM-EPA-letter.pdf

[30] https://www.irs.gov/pub/irs-drop/n-24-06.pdf

The Renewable Fuel Standard (RFS) program, established under the CAA and administered by the EPA, requires consideration of a fuel's full life cycle. This ensures renewable fuels like biodiesel, ethanol, biogas, and so forth are evaluated with their land use changes, feedstock carbon offsets, and other factors in mind to provide a more accurate assessment of their sustainability.

Government agencies, including the Internal Revenue Service and the U.S. Department of the Treasury have provided guidance for the RFS that highlights how the EPA has determined the only methodology meeting the life cycle analysis and modeling requirements of the CAA is the methodology under the RFS. However, federal agencies collaborated on the 2024 release of the Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) model,[31] ensuring that GREET 2024 would meet the necessary requirements for a life cycle assessment.

IRS Notice 2024-6 SEC. 5	"As relevant to § 40B(e)(2), the only current methodology that [EPA] has determined satisfies the CAA § 211(o)(1)(H) criteria is the methodology, modeling, and analysis the EPA developed in 2010 for the RFS program and applied in subsequent RFS rulemakings."
IRS Notice 2024-6 SEC. 6	"The DOE is collaborating with other federal agencies to develop the §40B(e)(2) GREET model to calculate the emissions reduction percentage under § 40B(e)(2). The collaborating agencies anticipate that the § 40B(e)(2) GREET model will be available in early 2024, and will satisfy the statutory requirements of § 40B(e)(2)."[32]

These interpretations support the use of GREET emission values for marine fuels for calculating the potential IMPAA fees in our geospatial model assessment. Energy and Environmental Research Associates, LLC (EERA) has applied WtW life cycle emission factors from GREET 2024 of 92.1670 grams of carbon dioxide equivalent per megajoule (gCO2e/MJ) for MDO (marine diesel oil) and 95.4017 gCO2e/MJ for HFO in its calculations of IMPAA fees (Table 1).

Table 1: Comparison of Fuel Specific Life Cycle Emission Factors

	Well-to-Wake Emission Factors (g-CO_2e/MJ)			
	HFO (2.7% S)	**HFO (0.5% S)**	**MDO (0.5% S)**	**MDO (0.1% S)**
GREET 2024	94.2	95.4	91.9	92.2
ISO 14083:2023 North America	94.3	95.5	92.0	–
IMO 3rd & 4th GHG Studies[33]	83.3	–	79.3	–

[31] https://www.energy.gov/eere/greet

[32] https://www.irs.gov/pub/irs-drop/n-24-06.pdf

[33] IMO emission factor values are converted from grams emission per grams fuel.

Model Inputs

EERA built the GREEN-T model upon the current best practices and standards for GHG and air pollutant emissions through open-source tools and data. GREEN-T supports a variety of users, including shipping and logistics companies seeking to identify and evaluate transportation routes with the lowest energy use and carbon intensity, as well as users looking to calculate their Scope 3[34] supply chain emissions.

GREEN-T is a new model, developed for the U.S. Maritime Administration, built on concepts initially developed for the Geospatial Intermodal Freight Transportation (GIFT) network model and for its online companion, WebGIFT.[35] GREEN-T is built according to GHG emissions and carbon accounting principles across the supply chain under the ISO 14083:2023[36] and EN 16258:2012[37] standards.

The GREEN-T model integrates global data on roads, railways, and waterways, linking these transport networks at ports and intermodal connections. The model calculates emissions based on energy use, compares alternative and conventional fuels using fuel-specific emission factors, and can provide GHG emissions for the full well-to-wake life cycle . The model has been developed with input from industry stakeholders through beta-testing focus groups. The following sections detail the project-specific inputs to the GREEN-T model.

Transportation Cost Data

To support the GREEN-T model, project-specific transportation cost data were gathered through a literature review and a collection of publicly available sources on fuel and other mode-specific operational costs to provide updated cost parameters. These data, which consider the total costs associated with each transportation mode, will inform the modeling of mode shift potential in response to IMPAA regulations.

Road—Truck

The American Transportation Research Institute (ATRI) released its report "An Analysis of the Operational Costs of Trucking: 2024 Update" in June 2024.[38] This report includes detailed cost data from industry surveys and provides a comprehensive and up-to-date view of the trucking industry. The data sample covers nearly 151,000 truck-tractors, 400,000 trailers, and more than 11.97 billion vehicle miles traveled. The average national costs per mile for trucking in 2023 was $2.27, up from $2.25 per mile in 2022 and $1.86 per mile in 2021. Average vehicle-based costs per mile are displayed in Table 2 below.

EERA applied a freight rate of 0.1411 U.S. dollars per ton-kilometer (USD/t-km) for road transportation, derived from the national average in ATRI's 2023 trucking cost data. This rate was calculated by converting miles to kilometers and assuming an average truck payload of 10 metric tons (MT) (see Geospatial Modeling).

34 Indirect GHG emissions that occur from upstream and downstream activities in the company's supply chain operations, product use, and waste disposal.

35 https://www.youtube.com/@theGIFTmodel

36 https://www.iso.org/standard/78864.html

37 https://www.en-standard.eu/din-en-16258-methodology-for-calculation-and-declaration-of-energy-consumption-and-ghg-emissions-of-transport-services-freight-and-passengers/

38 https://truckingresearch.org/wp-content/uploads/2024/06/ATRI-Operational-Cost-of-Trucking-06-2024.pdf

Table 2: 2023 ATRI Truck Transportation Costs Per Mile

(USD/mile)	National	Midwest	Northeast	Southeast	Southwest	West
Fuel	0.553	0.532	0.542	0.538	0.547	0.604
Lease/purchase	0.360	0.385	0.420	0.364	0.302	0.331
Repair/maintenance	0.202	0.206	0.215	0.190	0.182	0.201
Insurance	0.099	0.083	0.092	0.104	0.097	0.105
Permits/licenses	0.009	0.006	0.009	0.006	0.007	0.006
Tires	0.046	0.044	0.050	0.050	0.046	0.042
Tolls	0.034	0.037	0.059	0.028	0.025	0.018
Driver Wages	0.779	0.735	0.850	0.788	0.798	0.733
Driver Benefits	0.188	0.166	0.198	0.206	0.195	0.170
Total	**2.270**	**2.194**	**2.435**	**2.274**	**2.199**	**2.210**

While more truck fleets are starting to include at least one alternative fuel vehicle (12.8% in 2023, up from 8.2% in 2022 and 7% in 2021), the actual percentage of trucks using alternative fuels is still quite low (4.39% in 2023, up from 3.4% in 2022 and 2.7% in 2021). Most of these alternative fuel trucks are operated by a small number of large carriers, indicating that widespread adoption across the industry is still limited. Due to the minimal adoption of alternative fuels across the trucking industry, diesel fuel use was exclusively modeled for road-based transportation.

Table 3 provides an overview of average rates for North American freight brokerage in May 2024.[39] Contracted rates are pre-negotiated and fixed for a set period, covering multiple shipments over time. In contrast, spot rates are the current market rate for a one-time shipment, influenced by supply and demand conditions, and thus more subject to market fluctuations.

Table 3: North American Trucking Freight Costs Per Mile – May 2024

Freight Type	Contracted Rates (USD/mile)	Spot Rates (USD/mile)
Trailer, dry goods, non-temp controlled	2.44	2.02
Reefer, climate controlled	2.81	2.42
Flatbed, exposed irregular load	3.13	2.53

[39] https://www.dat.com/trendlines

Rail

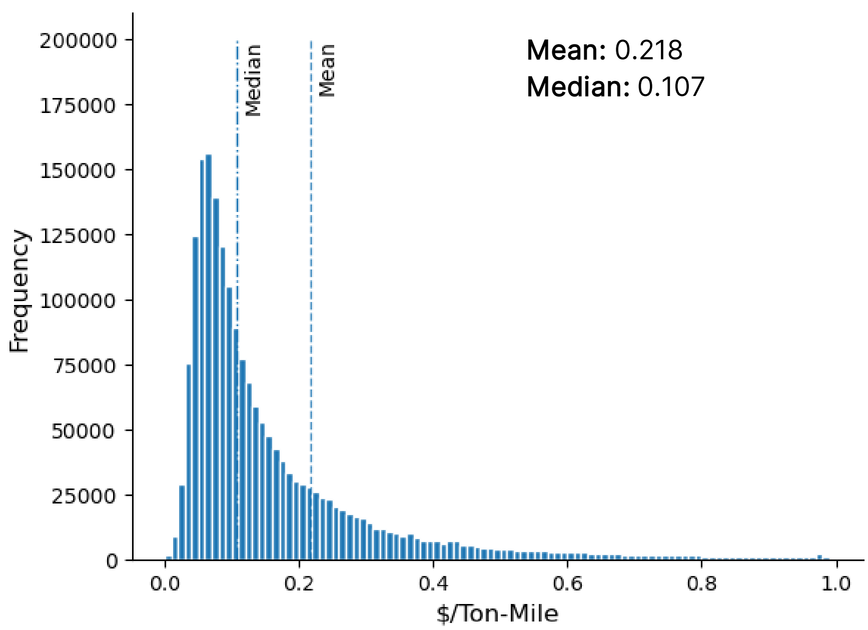
Rail data are available in the Publicly Available Waybill Sample from the Surface Transportation Board.[40] The Public Use Waybill Summary data contain waybill records from more than 2.1 million rail movements in 2022 that are statistically representative of national and regional freight movements by rail.

These data include detailed information on the costs of moving goods by train, including information on commodities, tonnages, origins and destination regions, hazardous cargoes, intermodal shifts, container counts, and other factors. Data are structured in terms of tonnage, total revenue, and rail distances between U.S. Business Economic Area (BEA) regions, enabling calculation of revenue per tonne-mile freight rates for use in this mode shift analysis.

Considering all waybills (Figure 1), the overall mean cost per ton-mile is $0.218, and the median is $0.107. The cost per ton-mile data inclusive of all waybills are highly and positively skewed to the right (skewness=2690.6, p < 0.0). This skewness suggests that there are relatively few instances of exceptionally high costs per ton-mile compared to the majority of the observations.

Figure 1: 2024 Distribution of Cost per Ton-Mile for Rail Freight

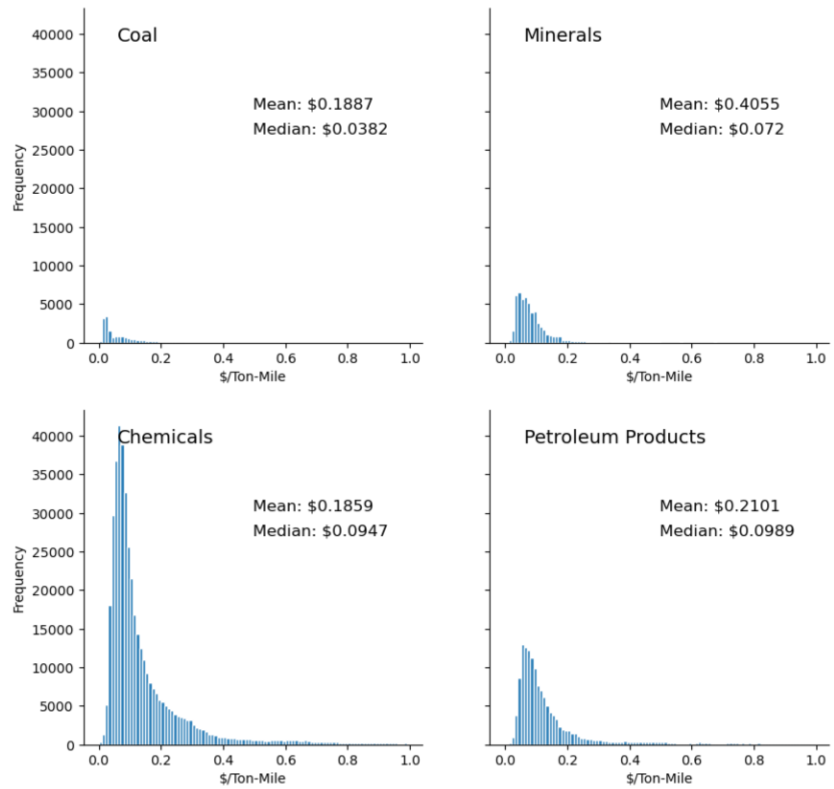
Frequency refers to the number of waybill observations



As shown in Figure 2 and Table A1, the mean and median costs vary by commodity, with median costs for the four commodities shown varying from $0.0382/ton-mile up to $0.0989/ton-mile. Given the skewness of the data, unusually high values can affect the mean, and thus median costs by commodity can be the most representative statistic. Commodities are listed by the first two digits of the Standard Transportation Commodity Code (STCC2) in Appendix Table A1.

[40] https://www.stb.gov/reports-data/waybill/

Figure 2: 2024 Waybill Cost per Ton-Mile for Selected Rail Freight



Coal (STCC11) is the least expensive commodity to move via rail at a median cost of $0.0382 per ton-mile; transportation equipment (STCC37), as noted in Table A1, is the most expensive at $0.2721 per ton-mile.

While there is a broad range in observed freight rates, EERA applied a freight rate of 0.0679 USD/t-km for rail transportation, which was calculated using the median data for "freight all kinds, mixed shipments" from the Public Use Waybill Sample (PUWS) commodity data and converting miles to kilometers (see Geospatial Modeling).

Water

Waterborne transportation costs were estimated using published 2024 freight rates from Drewry and Freightos, considering shipping routes to/from the U.S. East and West Coasts and China.[41,42] EERA applied a freight rate of 0.0238 USD/t-km for waterborne transportation (see Geospatial Modeling).

Rates were initially reported in USD per forty-foot equivalent unit (USD/FEU), which represents the volume of a 40-foot long shipping container; the rates were then converted to USD/t-km by calculating the nautical mile (NM) distances between the Port of Shanghai/from the Port of New York and from the Port of Los Angeles (U.S. NYC – CN SGH and U.S. LAX – CN SGH), representing each U.S. coast. Nautical miles were then converted to kilometers, and FEU was converted to metric tons, assuming 22 MT/FEU.

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[41] https://www.drewry.co.uk/supply-chain-advisors/supply-chain-expertise/world-container-index-assessed-by-drewry

[42] https://www.freightos.com/freight-resources/container-shipping-cost-calculator-free-tool/

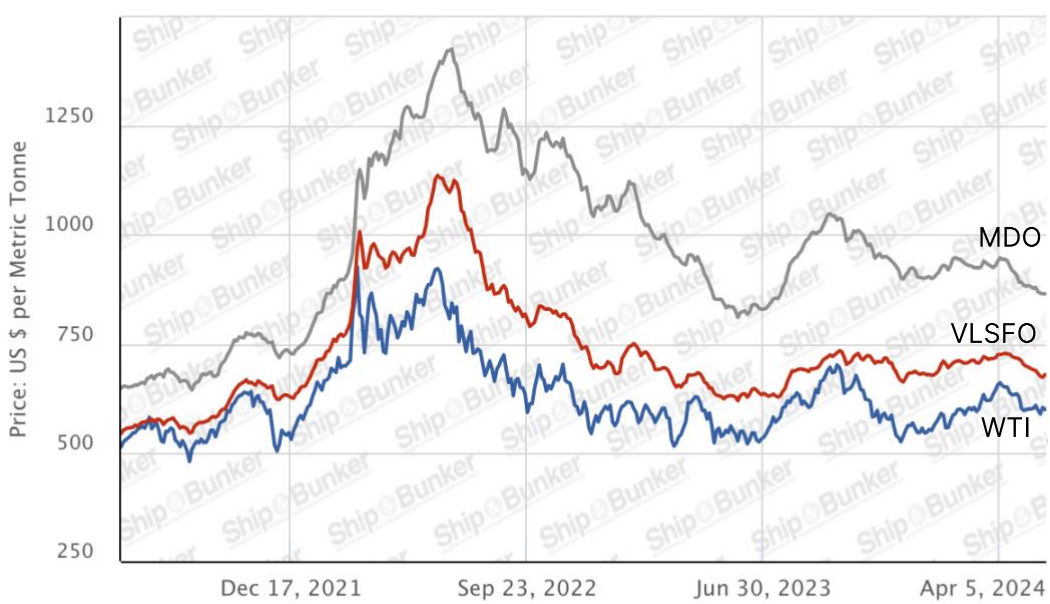
Although literature sources estimate weights between 10-25 MT/TEU (twenty-foot equivalent unit), EERA based these calculations on a value of 11 MT/TEU, considering only the average weight of mixed cargo and not including the container itself.[43] This value was doubled to 22 MT/FEU to align with FEU cargo capacity. Using only the cargo tonnage, excluding the container's weight, ensures consistency with how rail and road freight rates were reported, based solely on goods. This approach aligns ship calculations with the other transportation modes.

Table 5: 2024 Waterborne Freight Rates

	Source	USD/FEU-NM	USD/t-km
US NYC – CN SGH	Drewry	0.5231	0.0128
	Freightos	0.8624	0.0212
US LAX – CN SGH	Drewry	1.1079	0.0272
	Freightos	1.3882	0.0341
Average Rate			**0.0238**

Global average prices of fuel used by ships,[44] MGO and very low sulphur fuel oil (VLSFO) (bunker prices) (Figure 3), show significant price volatility over the past three years with MGO reaching a high of $1,427/MT in June 2022. Marine fuel prices are correlated with the WTI crude oil and Brent crude oil spot prices, because of their role as feedstocks for marine diesel fuels.

Figure 3: Time series data showing VLSFO and MGO global average bunker price, and WTI spot price



[43] https://worldcraftlogistics.com/what-is-teu-in-shipping
[44] https://shipandbunker.com/prices/av/global/av-glb-global-average-bunker-price#MGO

Origin & Destination Pairs

The candidate origin-destination (OD) route pairs, used to evaluate the mode shift potential, were established through observed ship entrances and clearances data[45] from the U.S. Army Corps of Engineers (USACE). The most recent data are from 2022, and include voyage details for 77,784 entrances and clearances, including port of entry (“PORT_NAME”), vessel name ('VESSNAME'), origin port ('WHERE_PORT'), and vessel tonnage ('NRT', 'GRT').

The IMPAA applies to imports to the U.S.,[46] therefore we focused on the subset of foreign cargoes.[47] While mode shift is possible for a majority of cargoes, it is most likely for containerized cargo,[48] which may be easily transferred intermodally between waterborne, rail, and truck carriers. Liquid bulk cargoes often require transport via pipeline due to the large volumes moved, limiting the potential for mode shift. Break-bulk cargoes (such as heavy machinery) often operate on the tramp market, calling at ports aligned with their clients cargo needs, again limiting a mode shift potential. Other modes, such as RO-ROs (cargo ships designed to carry cars and other rolling cargo) and reefers (refrigerated cargo ships), require specialized infrastructure at their ports of call and may not readily shift routes.

This OD analysis focuses on containerized cargoes. After filtering the USACE entrances and clearances data, we found 8,275 entrances to U.S. ports from containerships originating from foreign ports in 2022. Those entrances form the basis for the results presented in this report.

Table 6 shows the top 20 origin-destination pairs for foreign containerized imports to the U.S. in 2022, ordered by vessel gross register tonnage (GRT). (Note that origin port names are preserved from the original data, which may contain alternative spellings.) OD pairs are ordered by the sum total GRT. Vessel tonnage is the best available proxy in the USACE data for vessel installed power, and therefore for fuel consumption available in the USACE data. We also include the count of voyages recorded.

The typical vessel size varies significantly by route, with Houston-Tampico, Mexico vessels being on the order of 66,000 GRT on average, while vessels on the New York – Busan, KOR route are almost twice as large, averaging around 123,000 GRT. This analysis focuses on vessels 10,000 GT or larger that are covered under the proposed IMPAA act.

[45] https://ndclibrary.sec.usace.army.mil/resource/bc1a09db-0d03-43f5-be18-cba194075d9f
[46] 'TYPEDOC' == 0
[47] 'WHERE_IND' == “F”
[48] ‘CONTAINER’ == “C”

Table 6: Top 20 Origin-Destination Pairs for Foreign Containerized Imports to the U.S. in 2022

U.S. Port	Foreign Port	Foreign Country	Number of Calls	Sum GRT
Port of Houston Authority of Harris County, TX	Tampico	Mexico	225	14,986,057
Port Authority of New York and New Jersey, NY & NJ	Pusan[49]	South Korea	106	13,039,815
Port of Long Beach, CA	Pusan	South Korea	142	12,418,431
Port Authority of New York and New Jersey, NY & NJ	Algeciras	Spain	198	11,925,266
Port Authority of New York and New Jersey, NY & NJ	Halifax, NS	Canada	133	11,762,298
Port of Los Angeles, CA	Yantian	China	138	11,362,640
Port of Los Angeles, CA	Pusan	South Korea	111	9,890,219
Port of Long Beach, CA	Yantian	China	71	9,747,001
Port Authority of New York and New Jersey, NY & NJ	Singapore	Singapore	68	7,778,690
Port of Long Beach, CA	Ning Bo[50]	China	72	7,531,277
Port of Los Angeles, CA	Ning Bo	China	104	7,305,897
Port of Long Beach, CA	Shanghai	China	123	7,115,735
Port of Seattle, WA	Pusan	South Korea	69	7,088,788
Port of Los Angeles, CA	Amoy	China	53	7,041,290
Mobile, AL	Pusan	South Korea	91	6,825,312
Port of Houston Authority of Harris County, TX	Pusan	South Korea	87	6,636,000
Port of Savannah, GA	Colon	Panama	55	6,492,673
Port of Long Beach, CA	Kao Hsiung[51]	China Taiwan	57	6,262,549
Port Authority of New York and New Jersey, NY & NJ	Colon	Panama	44	5,798,618
Port of Savannah, GA	Manzanillo	Panama	60	5,520,984

The working subset of USACE data includes entrances at 44 ports in the U.S. These ports are described geographically in the following sections. We omit destination ports in the U.S. territories (e.g. Puerto Rico and the U.S. Virgin Islands), Hawaii, and Alaska, because the potential for mode shift in those locations is limited as there are no viable land-based alternatives to maritime trade.

The following sections present tables showing the top three OD pairs for each port, ordered by the sum of vessel GRT calling on those routes. Routes shown in **Bold** are identified candidate OD pairs, with discussion of the criteria for route selection following in the summary table.

In the USACE dataset, “other [country] ports” refers to all ports in that country that are not classified as primary or principal ports, grouping smaller or less significant ports together under a single category. These groupings were not selected for the OD pairs.

[49] Alternate spelling for Busan, South Korea

[50] Alternate spelling for Ningbo, China

[51] Alternate spelling for Kaohsiung, Taiwan

East Coast

Table 7: Top OD Pair routes for East Coast ports, based on vessel GRT

East Coast Destination Port	Foreign Origin Port	Country	n Calls	Sum GRT
Baltimore, MD	**Halifax, NS**	**Canada**	**13**	**1,120,328**
	Colon	Panama	6	784,697
	Freeport, Grand Bahama I	Bahamas	7	541,811
Jacksonville, FL	Freeport, Grand Bahama I	Bahamas	26	840,072
	Manzanillo	Mexico	5	301,329
	Other Chinese Ports	China	3	81,524
Philadelphia Regional Port Authority, PA	**Cartagena**	**Colombia**	**46**	**1,727,125**
	Cork	Ireland	39	1,398,960
	Bahia de Moin	Costa Rica	28	1,016,045
Port Authority of New York and New Jersey, NY & NJ	**Pusan**	**South Korea**	**106**	**13,039,815**
	Algeciras	**Spain**	**198**	**11,925,266**
	Halifax, NS	Canada	133	11,762,298
Port Everglades, FL	Freeport, Grand Bahama I	Bahamas	46	2,761,006
	Halifax, NS	Canada	34	1,881,811
	Quatema	Guatemala	84	1,824,102
Port of Boston, MA	**Le Havre**	**France**	**13**	**564,842**
	Halifax, NS	Canada	9	510,345
	Sines	Portugal	7	340,940
Port of Charleston, SC	**Colon**	**Panama**	**26**	**3,456,525**
	Freeport, Grand Bahama I	Bahamas	44	3,228,073
	London	United Kingdom	41	3,098,739
Port of Palm Beach District, FL	**Halifax, NS**	**Canada**	**43**	**654,245**
	St. Maarten	Neth Antilles	26	395,590
	Philipsburgh	Neth Antilles	16	243,440
Port of Savannah, GA	Colon	Panama	55	6,492,673
	Manzanillo	Panama	60	5,520,984
	Cristobal	Panama	36	3,297,213
Port of Virginia, VA	Le Havre	France	33	2,353,795
	Pusan	South Korea	20	2,311,753
	Bremerhaven	Germany	44	2,301,089
Portland, ME	Reykjavik	Iceland	3	30,331
	Halifax, NS	Canada	2	21,930
	Other Iceland Ports	Iceland	1	10,119
Port Miami, FL	Freeport, Grand Bahama I	Bahamas	39	3,238,073
	Rio Haina	Dominican Republic	62	1,123,626
	Manzanillo	Panama	50	975,723

South Jersey Port Corporation, NJ	Santo Tomas de Castilla	Guatemala	45	962,595
	Other Guatemala Caribbean Ports	Guatemala	4	85,564
	Savu	Fiji	2	54,102
Wilmington, DE	**Puerto Castilla**	**Honduras**	**37**	**1,175,823**
	Puerto Cortes	Honduras	33	1,086,022
	Quatema	Guatemala	14	461,195
Wilmington, NC	Quatema	Guatemala	2	36,960
	Puerto Cortes	Honduras	1	22,914

West Coast

Table 8: Top OD Pair routes for West Coast ports, based on vessel GRT

West Coast Destination Port	Foreign Origin Port	Country	n Calls	Sum GRT
Clallam County Port District, WA	Yokohama	Japan	1	26,374
Oxnard Harbor District, CA	**Lazaro Cardenas**	**Mexico**	**37**	**984,647**
	Puerto Quetzal	Guatemala	31	679,663
	Tampico	Mexico	29	661,342
Port of Everett, WA	Yokohama	Japan	15	391,820
	Tokyo	Japan	3	78,826
Port of Long Beach, CA	**Pusan**	**South Korea**	**142**	**12,418,431**
	Yantian	China	71	9,747,001
	Ning Bo	China	72	7,531,277
Port of Los Angeles, CA	**Yantian**	**China**	**138**	**11,362,640**
	Pusan	South Korea	111	9,890,219
	Ning Bo	China	104	7,305,897
Port of Oakland, CA	Shanghai	China	31	1,570,046
	Pusan	South Korea	11	938,753
	Vancouver, BC	**Canada**	**14**	**807,860**
Port of Portland, OR	Pusan	South Korea	9	533,364
	Vancouver, BC	Canada	5	242,464
	Prince Rupert, BC	Canada	1	95,681
Port of Seattle, WA	Pusan	South Korea	69	7,088,788
	Vancouver, BC	Canada	82	5,350,064
	Kao Hsiung	China Taiwan	15	947,062
San Diego Unified Port District, CA	**Puerto Quetzal**	**Guatemala**	**48**	**1,241,914**
	Other Guatemala WC Ports	Guatemala	1	26,046
	Other Costa Rica Caribbean Ports	Costa Rica	1	25,669
San Francisco Port Commission, CA	Other Panama WC Ports	Panama	1	116,295
Tacoma, WA	**Yantian**	**China**	**51**	**4,901,696**
	Vancouver, BC	Canada	33	3,177,043
	Pusan	South Korea	24	2,340,715

Gulf Coast

Table 9: Top OD Pair routes for Gulf Coast ports, based on vessel GRT

Gulf Coast Destination Port	Foreign Origin Port	Country	n Calls	Sum GRT
Galveston, TX	Veracruz	Mexico	1	22,801
Manatee County Port Authority, FL	**Bahia de Moin**	**Costa Rica**	**30**	**641,730**
	Tuxpan	Mexico	7	121,520
	Coatzacoalcos	Mexico	3	52,080
Mobile, AL	**Pusan**	**South Korea**	**91**	**6,825,312**
	Tampico	Mexico	7	527,173
	Veracruz	Mexico	4	307,806
Port Freeport, TX	Puerto Castilla	Honduras	47	1,358,206
	Quatema	Guatemala	31	710,334
	Other Honduras Ports	Honduras	5	144,490
Port of Gulfport, MS	Quatema	Guatemala	15	347,855
	Puerto Castilla	Honduras	2	57,796
Port of Houston Authority of Harris County, TX	**Tampico**	**Mexico**	**225**	**14,986,057**
	Pusan	South Korea	87	6,636,000
	Freeport, Grand Bahama I	**Bahamas**	**48**	**3,757,289**
Port of New Orleans, LA	**Tampico**	**Mexico**	**36**	**2,724,501**
	Kingston	Jamaica	17	610,841
	Veracruz	Mexico	3	264,281
Tampa Port Authority, FL	Yantian	China	1	41,482
	Quatema	Guatemala	1	28,898

Great Lakes

Container shipping intercontinentally via the Great Lakes is limited. We have identified the Port of Cleveland, Ohio and a route to Europe as an example route.

Summary Table

The summary table, Table 10, identifies 24 candidate OD pairs for further study. We have identified the selection criteria for these pairs, including a selection of routes that test the impact of the proposed IMPAA fees on coastwise transits with landside alternatives of different lengths on the East Coast (e.g. Halifax, NS → Baltimore and Halifax, NS → Palm Beach) and West Coast (e.g. Vancouver, BC → Port of Los Angeles and Vancouver, BC → Port of Oakland). We also select routes to test the potential for shifts to land bridge alternatives, such as Busan, South Korea → New York and New Jersey, which may shift from transiting the Pacific and then the Panama Canal en route to New York to instead calling at West Coast ports and then moving cargo via rail and truck. We have also selected routes where there may be potential under the IMPAA to reduce the length of transit in U.S. waters, calling at U.S. ports that limit the water distance (e.g. Cartagena → Philadelphia may shift to calling at a more southern port) or at nearby ports in Canada or Mexico (e.g. Freeport, Bahamas → Houston, TX) to reduce EEZ criteria pollutant emissions and therefore lower exposure to IMPAA fees.

Table 10: Summary of top OD Pair routes for U.S. ports and their selection criteria

Region	Destination Port	Origin Port	Selection Criteria
East Coast	Baltimore, MD	Halifax, NS	Coastwise route. Road and rail alternatives.
	Philadelphia, PA	Cartagena	Caribbean origin, long distance traveled in U.S. waters, potential to shift to southern U.S. ports to limit emissions in EEZ.
	New York and New Jersey, NY & NJ	Pusan	Long Atlantic or Pacific route with Panama Canal transit and long distance in U.S. waters. Explores west coast land bridge potential.
		Algeciras	Trans-Atlantic route, explores potential to shift to Canadian ports.
	Port of Boston, MA	Le Havre	Trans-Atlantic route, explores potential to shift to Canadian ports. Cargo terminates at **Albany, NY**.
	Port of Charleston, SC	Colon	Caribbean origin, long distance traveled in U.S. waters, potential to shift to southern/Gulf port.
	Port of Palm Beach District, FL	Halifax, NS	Coastwise route. Road and rail alternatives.
	Port of Savannah, GA	Bremerhaven	Trans-Atlantic route, explores potential to shift to Canadian ports
	Wilmington, DE	Puerto Castilla	Caribbean origin, long distance traveled in U.S. waters, potential to shift to southern ports.
West Coast	Oxnard Harbor District, CA	Lazaro Cardenas	Coastwise route. Road and rail alternatives.
	Port of Long Beach, CA	Pusan	Long Pacific route. For inland destinations, may shift to northern U.S. or Canadian ports then overland to final destination. Cargo terminates in **San Bernardino, CA**.
	Port of Los Angeles, CA	Yantian	Long Pacific route. For inland destinations, may shift to northern ports. Cargo terminates at **Las Vegas, NV**.
		Vancouver, BC	Coastwise route. Road and rail alternatives.

	Port of Oakland, CA	Vancouver, BC	Coastwise route. Road and rail alternatives.
		Kao Hsiung	Long Pacific route. For inland destinations, may shift to northern ports. Cargo terminates in **Denver, CO**.
	San Diego Unified Port District, CA	Puerto Quetzal	Longer coastwise route. Road alternatives and potential shift to Mexican ports. Cargo terminates in **San Bernardino, CA**.
	Tacoma, WA	Yantian	Long Pacific route. Potential shift to Canadian ports.
Gulf Coast	Manatee County Port Authority, FL	Bahia de Moin	Caribbean origin with potential to shift to alternate Florida ports depending on end point. Cargo terminates in **Columbia, SC**.
	Mobile, AL	Pusan	Long route with canal transit and long distance in U.S. waters. Explores west coast land bridge potential. Cargo terminates in **Birmingham, AL**.
	Port of Gulfport, MS	Puerto Cortes	Potential for shift to Florida ports, then to road and rail alternatives. Cargo terminates in **Jackson, MS**.
	Port of Houston	Tampico	Coastwise route. Road and rail alternatives.
		Freeport	Potential for shift to Florida ports, then to road and rail alternatives.
	Port of New Orleans, LA	Tampico	Coastwise route. Road and rail alternatives.
Great Lakes	Cleveland-Cuyahoga County, OH	Antwerp	Long Atlantic route with Great Lakes transit. Potential to shift to East Coast ports and then overland.

Geospatial Modeling

This section describes the results of geospatial modeling using EERA's GREEN-T network model.[52] GREEN-T includes multimodal transport options, including rail, truck, and waterways, allowing the estimation of energy consumption, route distance, and emissions, by transport mode.

Routes were selected to include a variety of coastal routes, Pacific and Atlantic transoceanic routes, and coastal and inland locations in the U.S. Some routes are identified with origins and destinations at coastal ports, while other routes explore a mode shift to final destinations that are far inland.

Fuel Assumptions

- VLSFO outside of the U.S. emission control area (ECA)
- MDO inside the U.S. ECA
- Diesel on Rail
- Diesel on Road
- Calculations assume movement of 10,000 MT of cargo, equivalent to around 910 twenty-foot equivalent units (TEUs).

[52] GREEN-T is not publicly available at the time of writing.

Conversions

1 pound (lbs)	0.45359237 kilogram (kg)
1 kilowatt-hour (kWh)	3.6 megajoules (MJ)
1 metric ton (MT)	1000 kilograms (kg)
1 short ton (tn)	907.185 kilograms (kg)
1 kilogram (kg)	1000 grams (g)
1 mile (mi)	1.60934 kilometers (km)
1 nautical mile (nm)	1.852 kilometers (km)
1 twenty-foot equivalent unit (TEU)	11 metric tons (MT)[53]

The effective IMPAA fee may be calculated including all pollutants, assuming MDO fuel use and the emission factors laid out in the conversions above. By multiplying the energy content emission factors by the energy content of the fuel and the proposed IMPAA fees for criteria and GHG emissions, we estimate the sum of IMPAA fees on GHGs for the whole voyage and criteria pollutant emissions inside the U.S. EEZ.

The model estimates PM emissions using IMO's reported PM values rather than explicitly adjusting for $PM_{2.5}$. IMO methodology suggests estimating $PM_{2.5}$ as 92% of PM10, while EPA methodology places $PM_{2.5}$ between 92% and 97% of total PM depending on the fuel. Given this relatively narrow range and the inherent variability of PM emissions, especially their sensitivity to low engine load, this approach remains appropriate for a screening-level analysis. Low-load conditions can result in increased PM emissions by up to 25%, but adjusting for this level of detail is beyond the scope of the model.

Table 11: Model input values for water, road, and rail energy modes, including emission factors (EF) , fuel energy content, freight rates, and proposed IMPAA fees

	Water	Road	Rail
Mode-specific energy efficiency (MJ/t-km)	0.123	1.300	0.199
Assumption Notes	*Average of routes to the U.S. not including Africa*	*Average of North American EF values*	*U.S. Bureau of Transportation Statistics*
Fuel Energy Content (MJ/kg)	39.5 VLSFO 42.6 MDO	45.5 Diesel	

[53] https://worldcraftlogistics.com/what-is-teu-in-shipping

<table>
<tr><th></th><th>Water</th><th>Road</th><th>Rail</th></tr>
<tr><td>Emission factors (g/MJ)</td><td></td><td></td><td></td></tr>
<tr><td>CO_2</td><td>78.84
VLSFO</td><td colspan="2"></td></tr>
<tr><td></td><td>75.26
MDO</td><td colspan="2">75.258
Diesel</td></tr>
<tr><td>CH_4</td><td>0.00
VLSFO</td><td colspan="2"></td></tr>
<tr><td></td><td>0.00
MDO</td><td colspan="2">0.001
Diesel</td></tr>
<tr><td>N_2O</td><td>0.00
VLSFO</td><td colspan="2"></td></tr>
<tr><td></td><td>0.00
MDO</td><td colspan="2">0.004
Diesel</td></tr>
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Diesel</td></tr>
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<tr><td></td><td>0.04
MDO</td><td colspan="2">0.065
Diesel</td></tr>
<tr><td>PM</td><td>0.18
VLSFO</td><td colspan="2"></td></tr>
<tr><td></td><td>0.02
MDO</td><td colspan="2">0.023
Diesel</td></tr>
<tr><td>Assumption Notes</td><td colspan="3">$CO_2e = CO_2 + CH_4 + N_2O$
Using GWP conversions of *28.9 for CH_4 and *273 for N_2O</td></tr>
<tr><td></td><td>OGV values calculated from IMO GHG Studies</td><td colspan="2">Road and rail values calculated from port emissions inventories guided by EPA</td></tr>
<tr><td>Proposed IMPAA fees (USD/kg-emitted)</td><td></td><td></td><td></td></tr>
<tr><td>CO_2</td><td>0.15</td><td>–</td><td>–</td></tr>
<tr><td>NO_X</td><td>13.89</td><td>–</td><td>–</td></tr>
<tr><td>SO_2</td><td>39.58</td><td>–</td><td>–</td></tr>
<tr><td>PM</td><td>85.76</td><td>–</td><td>–</td></tr>
<tr><td>Freight rates (USD/t-km)</td><td>0.0238</td><td>0.1411</td><td>0.0679</td></tr>
<tr><td>Sources</td><td>Freightos and Drewry for
US NYC – CN SGH
US LAX – CN SGH</td><td>ATRI 2024</td><td>PUWS waybill commodity data median freight all kinds, mixed shipments</td></tr>
</table>

Results

This section presents an analysis of emissions and cost differences modeled across the 24 selected OD pairs. The subsections that follow provide detailed information regarding the energy, emissions, and cost variation for each OD route under multiple scenarios. Each OD pair was first evaluated for its base case route, reflecting typical conditions. Subsequently, each OD pair was assessed for potential shifts in route and/or transport mode due to the changes in waterborne transport costs from the adoption of alternative fuels and the introduction of emissions pricing under the proposed IMPAA regulations.

Results were analyzed to identify if and where price increases—driven by mode shift costs and IMPAA emission fees for CO_2e, NO_X, SO_2, and $PM_{2.5}$—could create economic pressure that incentivizes a shift from marine routes to other land-based alternatives, such as rail or truck.

The results can be used to provide decision-makers and stakeholders with insights into whether IMPAA and/or other emissions regulations, by increasing the cost of waterborne transport into the U.S., could inadvertently lead to higher freight emissions by shifting cargo to less efficient land-based modes. Additionally, these results can help to assess the potential for economic diversions along more cost-efficient routes through Canada or Mexico, decreasing domestic handling activity for the U.S. economy when bypassing U.S. ports. The original routes and alternate ports studies are shown in Table 12.

Table 12: Baseline and alternate routes selected for model

Route	Origin-Destination	Baseline U.S. Port	Alt. Port
1	Baltimore, MD – Halifax, NS	Baltimore, MD	-
2	Philadelphia, PA – Cartagena, Colombia	Philadelphia, PA	Palm Beach, Florida
3	New York, NY – Busan, Korea	New York, NY	Los Angeles, CA
4	New York, NY – Algeciras, Spain	New York, NY	Halifax, NS
5	Albany, NY – Le Havre, France	Boston, MA	Halifax, NS
6	Charleston, SC – Colon, Panama	Charleston, SC	Port Manatee, FL
7	Palm Beach, FL – Halifax, NS	Palm Beach, FL	-
8	Savannah GA – Bremerhaven, Germany	Savannah, GA	Halifax, NS
9	Wilmington, DE – Puerto Castilla, Honduras	Wilmington, DE	Palm Beach, FL
10	Oxnard, CA – Lazara Cardenas, Mexico	Oxnard, CA	-
11	San Bernardino, CA – Busan, Korea	Long Beach, CA	San Diego, CA
12	Las Vegas, NV – Yantian, China	Long Beach, CA	Vancouver, BC
13	San Bernardino, CA – Vancouver, BC	Los Angeles, CA	-
14	Oakland, CA – Vancouver BC	Oakland, CA	-
15	Denver, CO – Kaohsiung, Taiwan	Oakland, CA	Tacoma, WA
16	San Bernardino, CA – Puerto Quetzal, Guatemala	San Diego, CA	Rosarito, Mexico
17	Tacoma, WA – Yantian, China	Tacoma, WA	Vancouver, BC
18	Columbia, SC – Bahia de Moin, Costa Rica	Port Manatee, FL	Palm Beach, FL
19	Birmingham, AL – Busan, Korea	Mobile, AL	Los Angeles, CA
20	Jackson, MS – Puerto Cortes, Honduras	Gulfport, MS	Port Everglades, FL
21	Houston, TX – Tampico, Mexico	Houston, TX	-
22	Houston, TX – Freeport, Bahamas	Houston, TX	Palm Beach, FL
23	New Orleans – Tampico, Mexico	New Orleans, LA	-
24	Cleveland, OH – Antwerp, Belgium	Cleveland, OH	New York, NY

See later pages in this report for visual mapping of these baseline and alternate routes.

Figure 4: Map of the baseline OD pair routes, numbered by route.

Figure 5: Map of the alternate OD pair routes, numbered by route.

Figure 4 and Figure 5 display a global overview of the baseline and alternate OD pair routes modeled. Figure 6 and Figure 7 provide a more detailed view, zooming in on the continental U.S. to highlight the extensions of transportation by land.

Figure 6: Continental view of U.S. and nearby OD locations for the baseline, numbered by route.

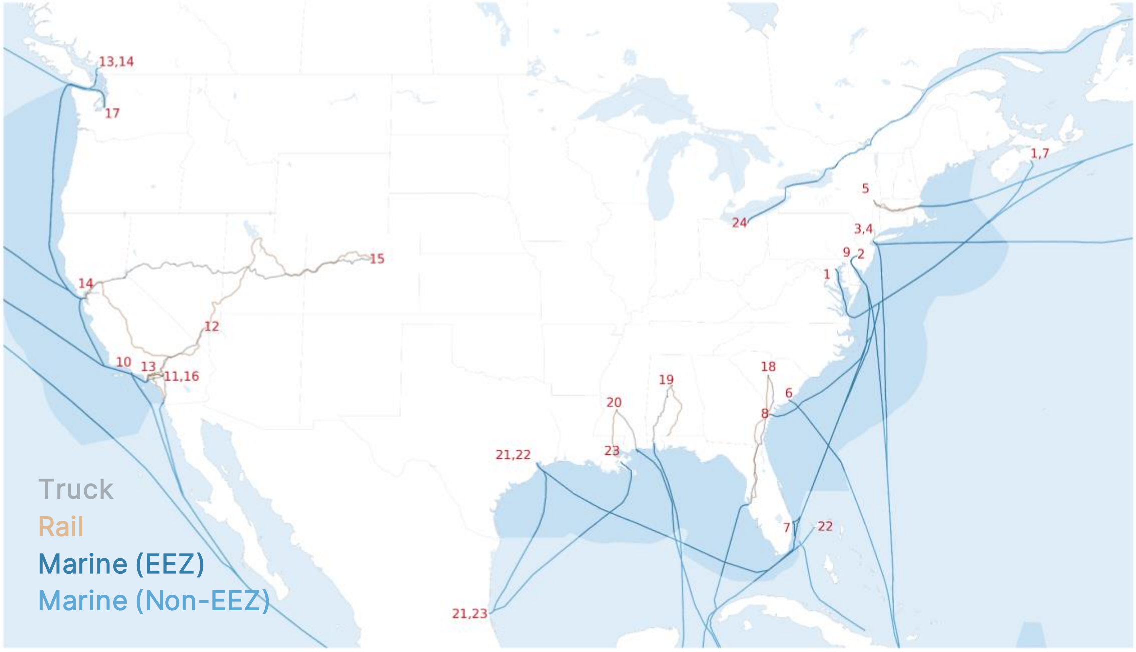
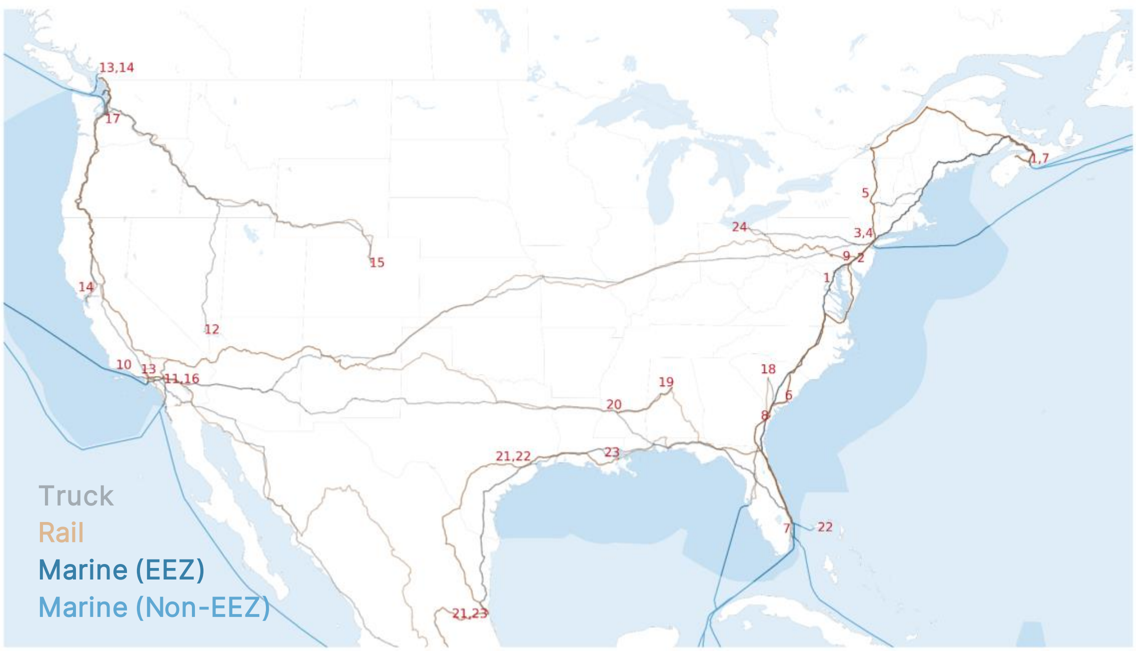


Figure 7: Continental view of U.S. and nearby OD locations for the alternate, numbered by route.

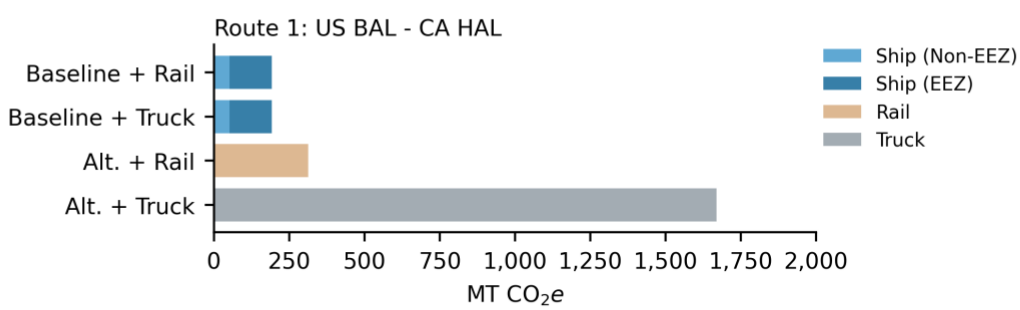


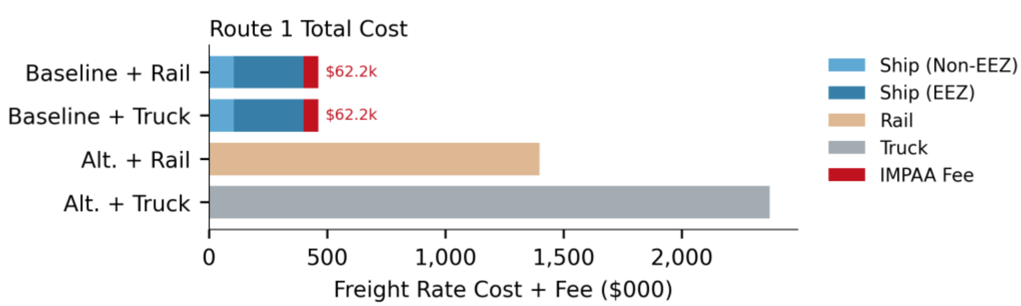
Route 1: Baltimore, MD and Halifax, Nova Scotia

Baseline route: Water from Halifax to Baltimore
Alternate route: All land, via truck or rail from Halifax to Baltimore

Emissions	Emissions from all-land truck/rail alternatives are much higher than from the all-water route.
Freight Rate + IMPAA Fee	Costs from all-land truck and rail alternatives are much higher than the all-water route. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 15.6%.
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
1	Baseline + Rail	Ship (EEZ)	1,240	1,524,000	140.5	2.01	0.06	0.04
	Baseline + Rail	Ship (Non-EEZ)	440	539,500	51.5	1.04	0.61	0.10
	Baseline + Truck	Ship (EEZ)	1,240	1,524,000	140.5	2.01	0.06	0.04
	Baseline + Truck	Ship (Non-EEZ)	440	539,500	51.5	1.04	0.61	0.10
	Alt. + Rail	Rail	2,060	4,096,900	312.9	7.94	0.27	0.09
	Alt. + Truck	Truck	1,680	21,849,500	1,668.9	42.32	1.42	0.50



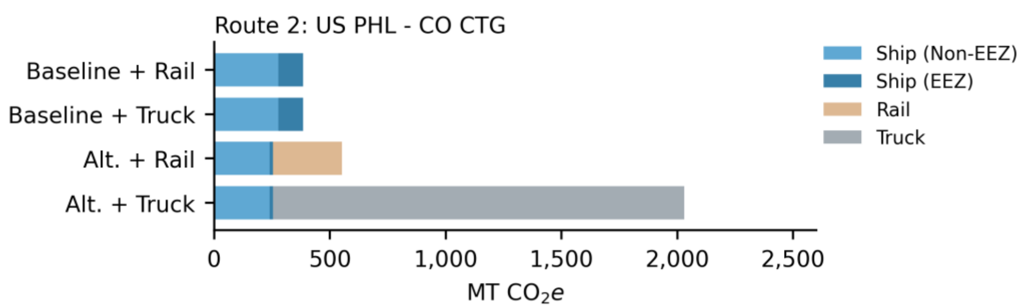


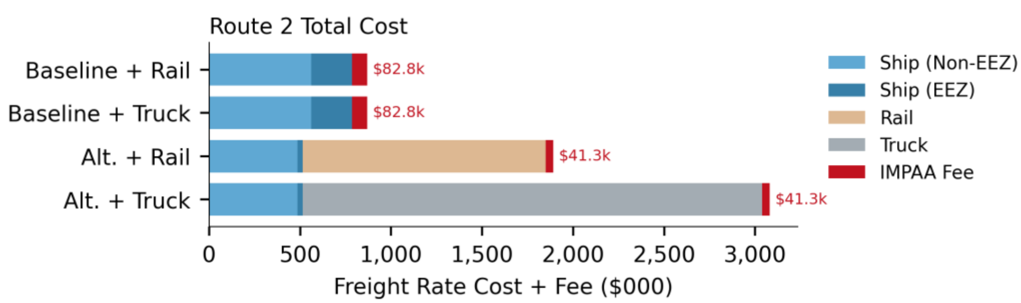
Route 2: Philadelphia, PA – Cartagena, Colombia

Baseline route: Ship from Cartagena, Colombia to Philadelphia, PA
Alternate route: Ship from Cartagena, Colombia to Palm Beach, FL, then overland to Philadelphia, PA

Emissions	Emissions from a mode shifted route with truck/rail alternatives are much higher than from the all-water route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives are much higher than the all-water route. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 10.5% and would increase alternate route costs by around 1.3% (truck) to 2.23% (rail).
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
2	Baseline + Rail	Ship (EEZ)	940	1,157,200	106.7	1.53	0.05	0.03
	Baseline + Rail	Ship (Non-EEZ)	2,360	2,899,500	276.6	5.57	3.28	0.51
	Baseline + Truck	Ship (EEZ)	940	1,157,200	106.7	1.53	0.05	0.03
	Baseline + Truck	Ship (Non-EEZ)	2,360	2,899,500	276.6	5.57	3.28	0.51
	Alt. + Rail	Rail	1,970	3,912,700	298.8	7.58	0.25	0.09
	Alt. + Rail	Ship (EEZ)	120	148,700	13.7	0.20	0.01	0.00
	Alt. + Rail	Ship (Non-EEZ)	2,040	2,512,600	239.7	4.83	2.84	0.44
	Alt. + Truck	Ship (EEZ)	120	148,700	13.7	0.20	0.01	0.00
	Alt. + Truck	Ship (Non-EEZ)	2,040	2,512,600	239.7	4.83	2.84	0.44
	Alt. + Truck	Truck	1,790	23,252,900	1,776.1	45.04	1.51	0.53



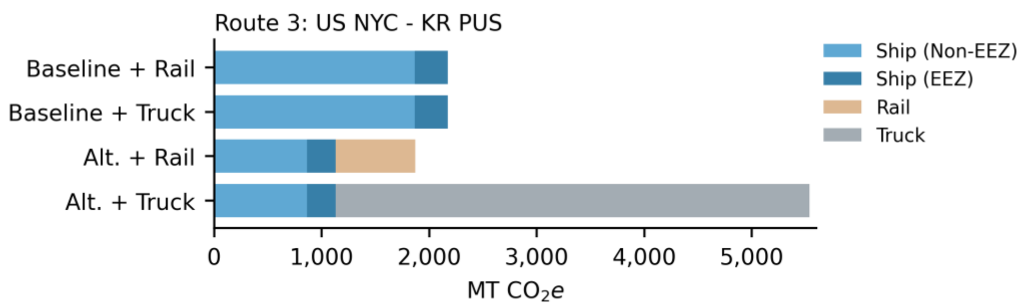


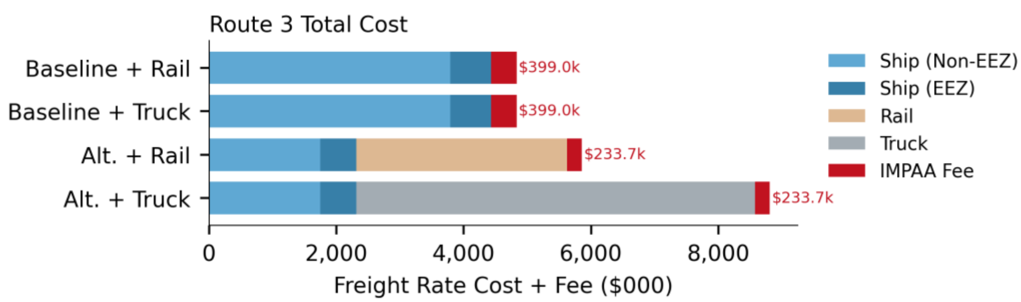
Route 3: New York, NY – Busan, Korea

Baseline route: Ship from Busan, Korea to New York, NY via the Panama Canal
Alternate route: Ship from Busan, Korea to Los Angeles, then overland to New York, NY

Emissions	Emissions from land-bridge routes with rail alternatives are lower than from the all-water route. Truck emissions are much higher than all-water routes.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives are higher than the all-water route. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 9% and would increase alternate route costs by around 2.7% (truck) to 4.2% (rail).
Mode Shift Potential	LOW
Comments	Lower total GHG emissions may be realized by utilizing the land bridge from the U.S. West Coast to East Coast with rail.

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
3	Baseline + Rail	Ship (EEZ)	2,710	3,329,700	306.9	4.40	0.13	0.08
	Baseline + Rail	Ship (Non-EEZ)	15,910	19,568,400	1,866.9	37.60	22.11	3.45
	Baseline + Truck	Ship (EEZ)	2,710	3,329,700	306.9	4.40	0.13	0.08
	Baseline + Truck	Ship (Non-EEZ)	15,910	19,568,400	1,866.9	37.60	22.11	3.45
	Alt. + Rail	Rail	4,870	9,695,000	740.5	18.78	0.63	0.22
	Alt. + Rail	Ship (EEZ)	2,380	2,928,200	269.9	3.87	0.12	0.07
	Alt. + Rail	Ship (Non-EEZ)	7,340	9,023,200	860.8	17.34	10.20	1.59
	Alt. + Truck	Ship (EEZ)	2,380	2,928,200	269.9	3.87	0.12	0.07
	Alt. + Truck	Ship (Non-EEZ)	7,340	9,023,200	860.8	17.34	10.20	1.59
	Alt. + Truck	Truck	4,440	57,685,400	4,406.0	111.74	3.75	1.33





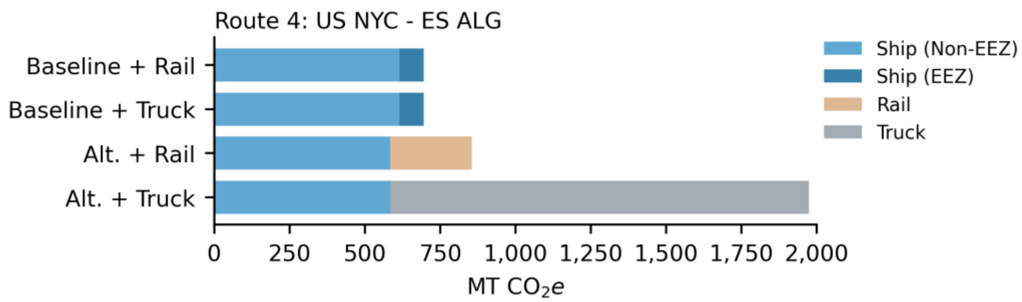
Route 4: New York, NY – Algeciras, Spain

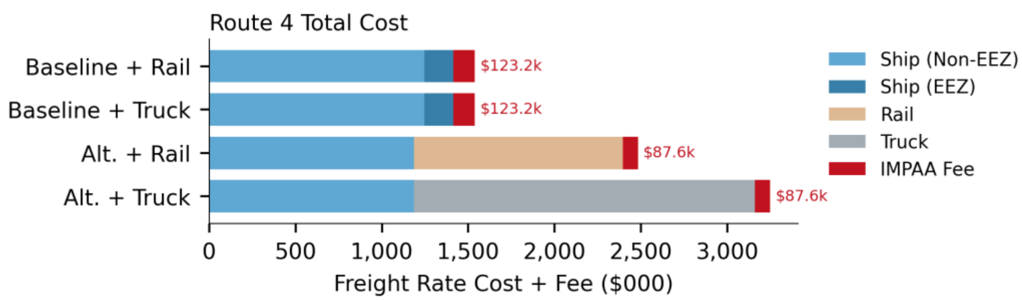
Baseline route: Ship from Algeciras, Spain to New York, NY

Alternate route: Ship from Algeciras, Spain to Halifax, Nova Scotia, then overland to New York, NY

Emissions	Emissions from a mode shifted route with truck/rail alternatives are higher than from the all-water route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives are much higher than the all-water route. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 8.7% and would increase alternate route costs by around 2.8% (truck) to 3.7% (rail).
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
4	Baseline + Rail	Ship (EEZ)	710	870,200	80.2	1.15	0.03	0.02
	Baseline + Rail	Ship (Non-EEZ)	5,230	6,438,800	614.3	12.37	7.28	1.13
	Baseline + Truck	Ship (EEZ)	710	870,200	80.2	1.15	0.03	0.02
	Baseline + Truck	Ship (Non-EEZ)	5,230	6,438,800	614.3	12.37	7.28	1.13
	Alt. + Rail	Rail	1,780	3,543,500	270.7	6.86	0.23	0.08
	Alt. + Rail	Ship (Non-EEZ)	4,980	6,124,800	584.3	11.77	6.92	1.08
	Alt. + Truck	Ship (Non-EEZ)	4,980	6,124,800	584.3	11.77	6.92	1.08
	Alt. + Truck	Truck	1,400	18,194,800	1,389.7	35.24	1.18	0.42



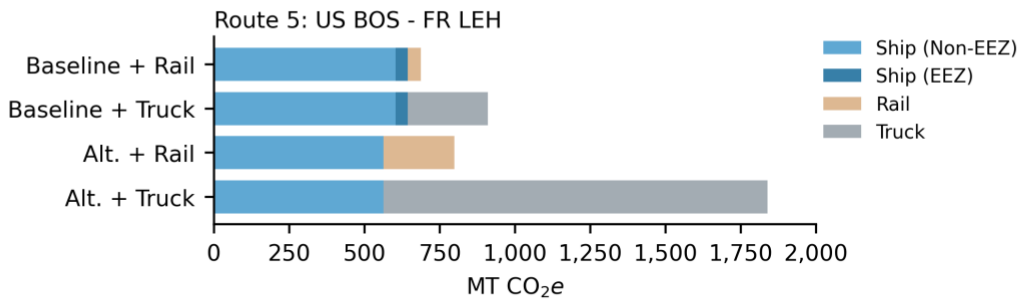


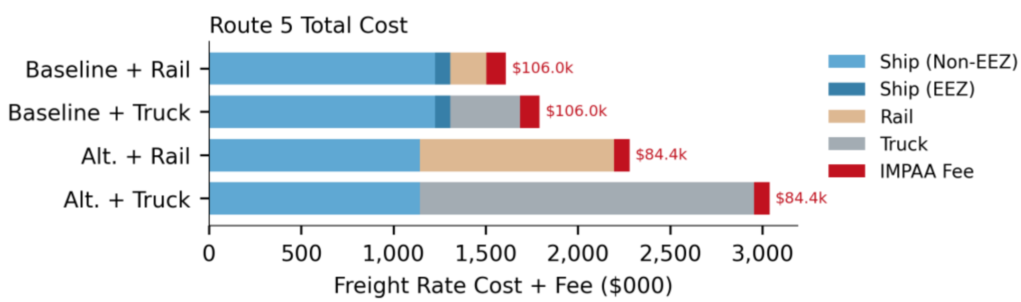
Route 5: Albany, NY – Le Havre, France

Baseline route: Ship from Le Havre, France to Boston, MA, then overland to Albany NY
Alternate route: Ship from Le Havre, France to Halifax, Nova Scotia, then overland to Albany NY

Emissions	Emissions from a mode shifted route with rail alternatives are slightly higher, while emissions from road alternatives are significantly higher than the baseline route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives are much higher than the baseline route. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 6.3 to 7% and would increase alternate route costs by around 2.9% (truck) to 3.9% (rail).
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
5	Baseline + Rail	Rail	290	572,100	43.7	1.11	0.04	0.01
	Baseline + Rail	Ship (EEZ)	350	432,500	39.9	0.57	0.02	0.01
	Baseline + Rail	Ship (Non-EEZ)	5,140	6,324,800	603.4	12.15	7.15	1.11
	Baseline + Truck	Ship (EEZ)	350	432,500	39.9	0.57	0.02	0.01
	Baseline + Truck	Ship (Non-EEZ)	5,140	6,324,800	603.4	12.15	7.15	1.11
	Baseline + Truck	Truck	270	3,481,200	265.9	6.74	0.23	0.08
	Alt. + Rail	Rail	1,550	3,085,900	235.7	5.98	0.20	0.07
	Alt. + Rail	Ship (Non-EEZ)	4,800	5,898,900	562.8	11.33	6.67	1.04
	Alt. + Truck	Ship (Non-EEZ)	4,800	5,898,900	562.8	11.33	6.67	1.04
	Alt. + Truck	Truck	1,280	16,701,200	1,275.6	32.35	1.09	0.38



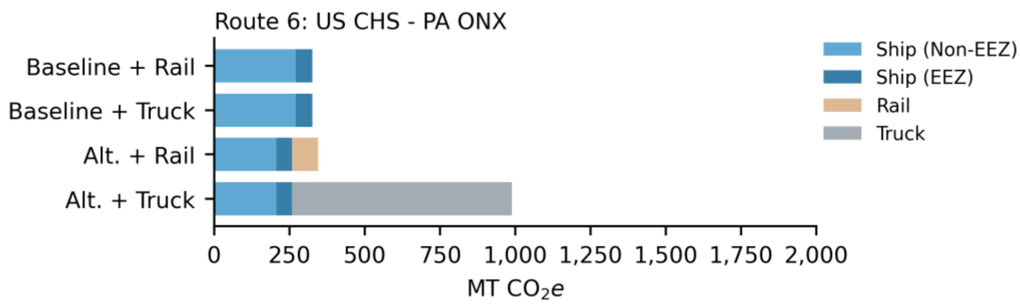


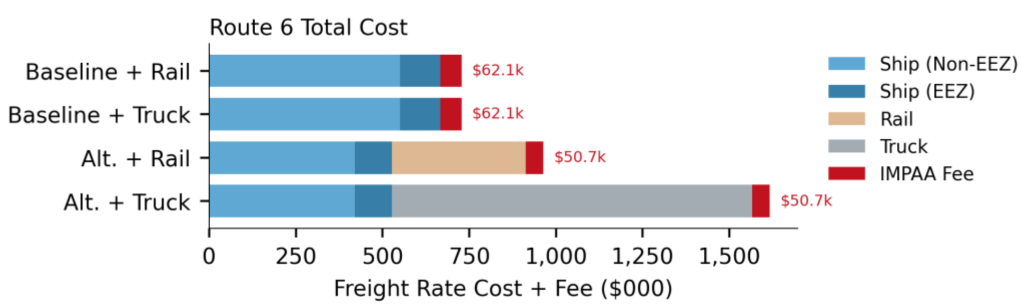
Route 6: Charleston, SC – Colon, Panama

Baseline route: Ship from Colon, Panama to Charleston, SC
Alternate route: Ship from Colon, Panama to Port Manatee, FL then overland to Charleston, SC

Emissions	Emissions from a mode shifted route with rail alternatives are comparable to the baseline all-water route, while emissions from road alternatives are significantly higher.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives are much higher than the baseline route. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 9.3% and would increase alternate route costs by around 3.2% (truck) to 5.6% (rail).
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
6	Baseline + Rail	Ship (EEZ)	490	601,100	55.4	0.79	0.02	0.01
	Baseline + Rail	Ship (Non-EEZ)	2,310	2,839,900	270.9	5.46	3.21	0.50
	Baseline + Truck	Ship (EEZ)	490	601,100	55.4	0.79	0.02	0.01
	Baseline + Truck	Ship (Non-EEZ)	2,310	2,839,900	270.9	5.46	3.21	0.50
	Alt. + Rail	Rail	570	1,132,100	86.5	2.19	0.07	0.03
	Alt. + Rail	Ship (EEZ)	450	550,000	50.7	0.73	0.02	0.01
	Alt. + Rail	Ship (Non-EEZ)	1,770	2,171,700	207.2	4.17	2.45	0.38
	Alt. + Truck	Ship (EEZ)	450	550,000	50.7	0.73	0.02	0.01
	Alt. + Truck	Ship (Non-EEZ)	1,770	2,171,700	207.2	4.17	2.45	0.38
	Alt. + Truck	Truck	740	9,571,200	731.0	18.54	0.62	0.22



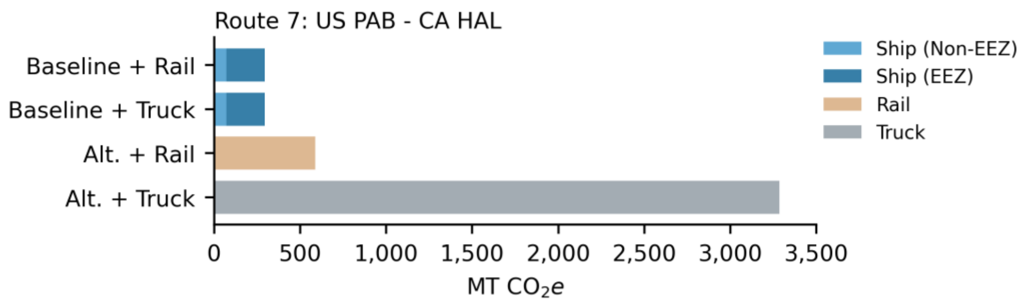


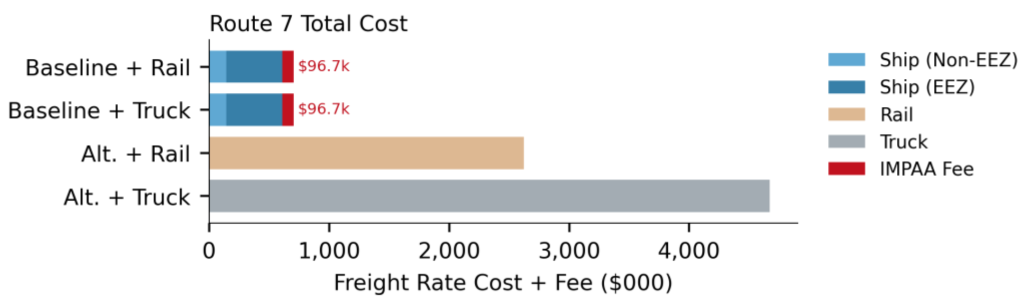
Route 7: Palm Beach, FL – Halifax, Nova Scotia

Baseline route: Ship from Halifax, Nova Scotia to Palm Beach, FL
Alternate route: overland from Halifax, Nova Scotia to Palm Beach, FL

Emissions	Emissions from a mode shifted route with rail and truck alternatives are much higher than from the all-water route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives are much higher than the baseline routes. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 15.9%.
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
7	Baseline + Rail	Ship (EEZ)	1,960	2,413,800	222.5	3.19	0.10	0.06
	Baseline + Rail	Ship (Non-EEZ)	600	732,900	69.9	1.41	0.83	0.13
	Baseline + Truck	Ship (EEZ)	1,960	2,413,800	222.5	3.19	0.10	0.06
	Baseline + Truck	Ship (Non-EEZ)	600	732,900	69.9	1.41	0.83	0.13
	Alt. + Rail	Rail	3,860	7,689,900	587.4	14.90	0.50	0.18
	Alt. + Truck	Truck	3,310	43,030,500	3,286.7	83.35	2.80	0.99



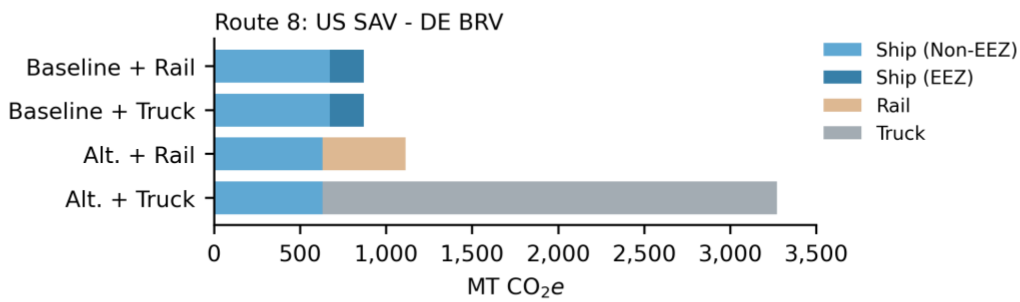


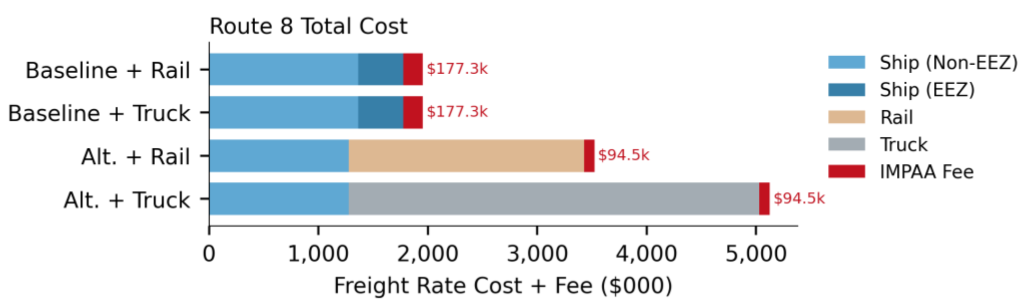
Route 8: Savannah, GA – Bremerhaven, Germany

Baseline route: Ship from Bremerhaven, Germany to Savannah, GA
Alternate route: Ship from Bremerhaven, Germany to Halifax, Nova Scotia, then overland to Savannah, GA

Emissions	Emissions from a mode shifted route with rail and truck alternatives are much higher than from the all-water route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives are much higher than the baseline routes. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 10.0% and would increase alternate route costs by around 1.9% (truck) to 2.8% (rail).
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
8	Baseline + Rail	Ship (EEZ)	1,740	2,144,600	197.7	2.83	0.08	0.05
	Baseline + Rail	Ship (Non-EEZ)	5,720	7,037,900	671.4	13.52	7.95	1.24
	Baseline + Truck	Ship (EEZ)	1,740	2,144,600	197.7	2.83	0.08	0.05
	Baseline + Truck	Ship (Non-EEZ)	5,720	7,037,900	671.4	13.52	7.95	1.24
	Alt. + Rail	Rail	3,170	6,302,500	481.4	12.21	0.41	0.14
	Alt. + Rail	Ship (Non-EEZ)	5,370	6,602,000	629.8	12.69	7.46	1.16
	Alt. + Truck	Ship (Non-EEZ)	5,370	6,602,000	629.8	12.69	7.46	1.16
	Alt. + Truck	Truck	2,660	34,571,900	2,640.6	66.97	2.25	0.80



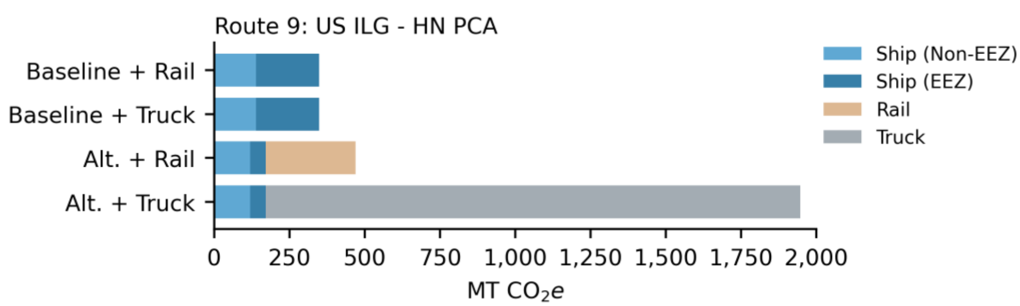


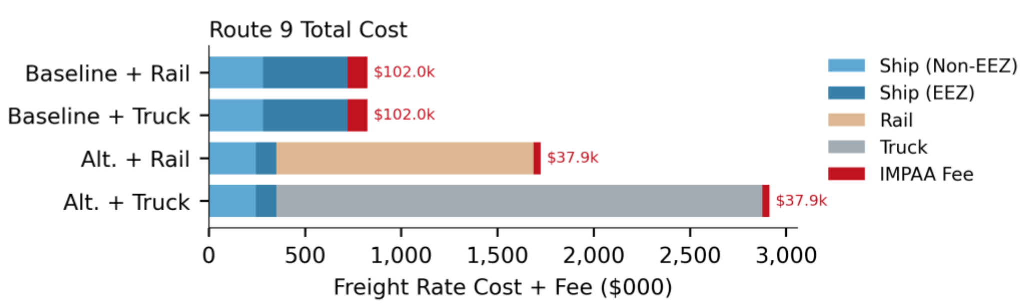
Route 9: Wilmington, DE – Puerto Castilla, Honduras

Baseline route: Ship from Puerto Castilla, Honduras to Wilmington, DE
Alternate route: Ship from Puerto Castilla, Honduras to Palm Beach, FL, then overland to Wilmington, DE

Emissions	Emissions from a mode shifted route with rail and truck alternatives are higher than from the all-water route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives are much higher than the baseline routes. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 14.1% and would increase alternate route costs by around 1.3% (truck) to 2.2% (rail).
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
9	Baseline + Rail	Ship (EEZ)	1,850	2,271,200	209.3	3.00	0.09	0.05
	Baseline + Rail	Ship (Non-EEZ)	1,180	1,455,600	138.9	2.80	1.64	0.26
	Baseline + Truck	Ship (EEZ)	1,850	2,271,200	209.3	3.00	0.09	0.05
	Baseline + Truck	Ship (Non-EEZ)	1,180	1,455,600	138.9	2.80	1.64	0.26
	Alt. + Rail	Rail	1,970	3,912,700	298.8	7.58	0.25	0.09
	Alt. + Rail	Ship (EEZ)	450	558,000	51.4	0.74	0.02	0.01
	Alt. + Rail	Ship (Non-EEZ)	1,020	1,256,000	119.8	2.41	1.42	0.22
	Alt. + Truck	Ship (EEZ)	450	558,000	51.4	0.74	0.02	0.01
	Alt. + Truck	Ship (Non-EEZ)	1,020	1,256,000	119.8	2.41	1.42	0.22
	Alt. + Truck	Truck	1,790	23,252,900	1,776.1	45.04	1.51	0.53



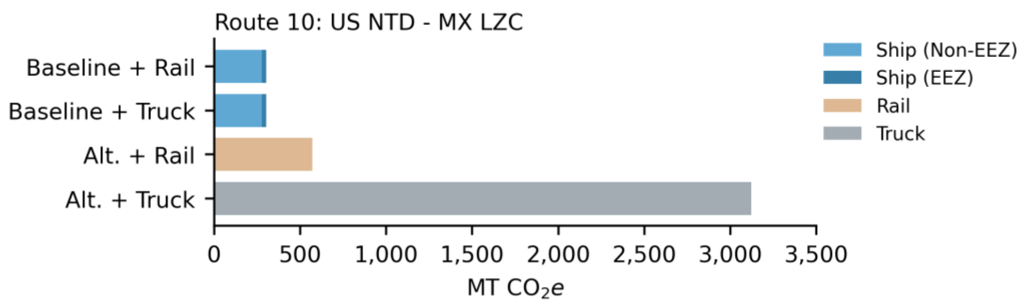


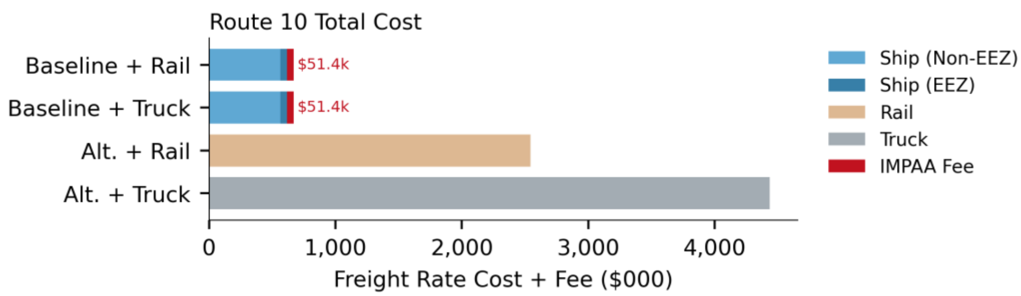
Route 10: Oxnard, CA – Lazara Cardenas, Mexico

Baseline route: Ship from Lazara Cardena, Mexico to Oxnard, CA
Alternate route: overland from Lazara Cardena, Mexico to Oxnard, CA

Emissions	Emissions from a mode shifted route with rail and truck alternatives are higher than from the all-water route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives are much higher than the baseline routes. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 8.3%.
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
10	Baseline + Rail	Ship (EEZ)	220	273,700	25.2	0.36	0.01	0.01
	Baseline + Rail	Ship (Non-EEZ)	2,360	2,908,600	277.5	5.59	3.29	0.51
	Baseline + Truck	Ship (EEZ)	220	273,700	25.2	0.36	0.01	0.01
	Baseline + Truck	Ship (Non-EEZ)	2,360	2,908,600	277.5	5.59	3.29	0.51
	Alt. + Rail	Rail	3,750	7,456,100	569.5	14.44	0.48	0.17
	Alt. + Truck	Truck	3,140	40,867,100	3,121.4	79.16	2.66	0.94



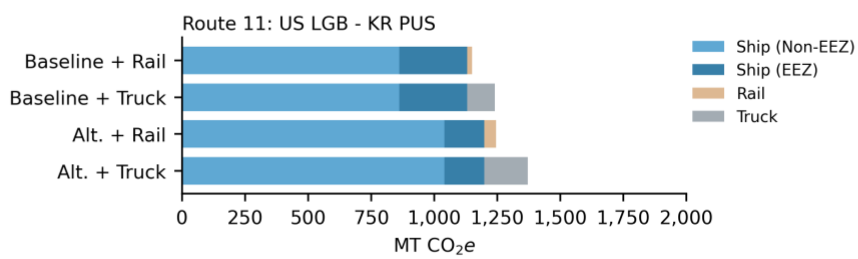


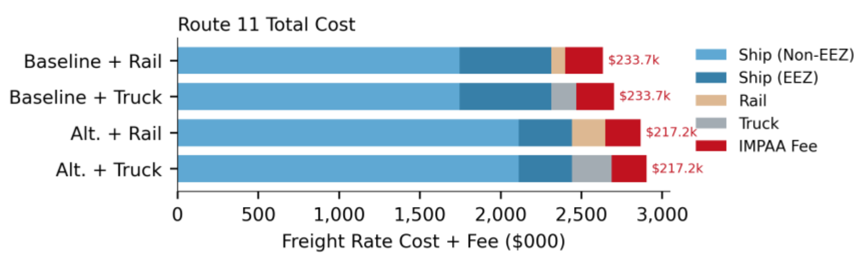
Route 11: San Bernardino, CA – Busan, South Korea

Baseline route: Ship from Busan South Korea to Long Beach, CA, then overland to San Bernardino
Alternate route: Ship from Busan South Korea to San Diego, CA, then overland to San Bernardino

Emissions	Emissions from a mode shifted route with rail and truck alternatives are slightly higher than from the baseline route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives exceed the baseline route costs, though minimally. The IMPAA fee does not affect the route diversion. The proposed IMPAA fee would increase baseline route costs by around 9.5-9.7% and would increase alternate route costs by around 8.1% (truck) to 8.2% (rail).
Mode Shift Potential	LOW
Comments	Cost differentials are not high. Favorable rates or treatment at mode shift ports may induce a shift.

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
11	Baseline + Rail	Rail	130	254,000	19.4	0.49	0.02	0.01
	Baseline + Rail	Ship (EEZ)	2,380	2,927,500	269.8	3.86	0.12	0.07
	Baseline + Rail	Ship (Non-EEZ)	7,340	9,023,200	860.8	17.34	10.20	1.59
	Baseline + Truck	Ship (EEZ)	2,380	2,927,500	269.8	3.86	0.12	0.07
	Baseline + Truck	Ship (Non-EEZ)	7,340	9,023,200	860.8	17.34	10.20	1.59
	Baseline + Truck	Truck	110	1,427,800	109.1	2.77	0.09	0.03
	Alt. + Rail	Rail	310	607,100	46.4	1.18	0.04	0.01
	Alt. + Rail	Ship (EEZ)	1,390	1,710,000	157.6	2.26	0.07	0.04
	Alt. + Rail	Ship (Non-EEZ)	8,870	10,907,000	1,040.5	20.96	12.32	1.92
	Alt. + Truck	Ship (EEZ)	1,390	1,710,000	157.6	2.26	0.07	0.04
	Alt. + Truck	Ship (Non-EEZ)	8,870	10,907,000	1,040.5	20.96	12.32	1.92
	Alt. + Truck	Truck	170	2,254,300	172.2	4.37	0.15	0.05



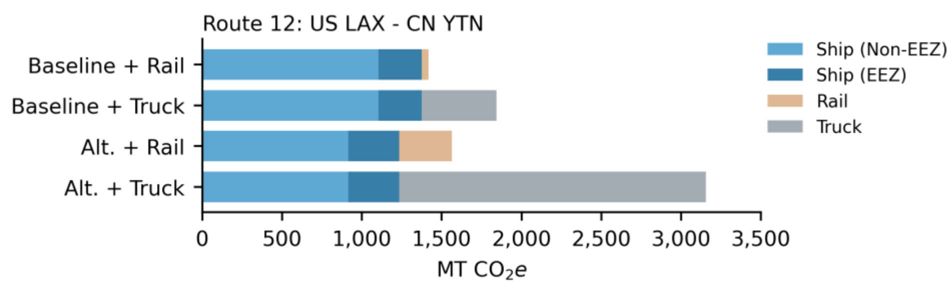


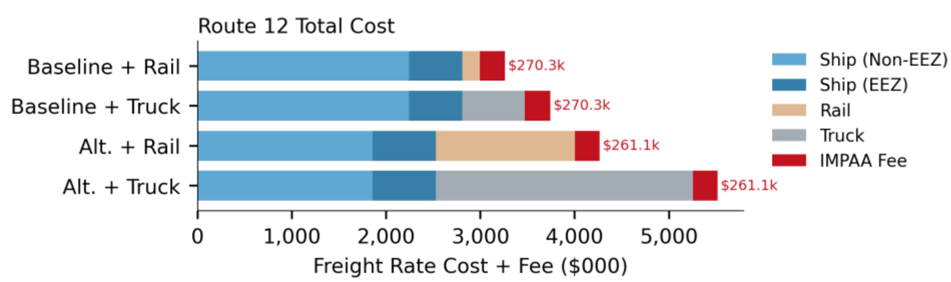
Route 12: Las Vegas, NV – Yantian, China

Baseline route: Ship from Yantian, China to Los Angeles, CA, then overland to Las Vegas, NV
Alternate route: Ship from Yantian, China to Vancouver, CA, then overland to Las Vegas, NV

Emissions	Emissions from a mode shifted route with rail and truck alternatives are higher than from an all-water route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives are higher than from the baseline routes. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 7.8-9.0% and would increase alternate route costs by around 5.0% (truck) to 6.5% (rail).
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
12	Baseline + Rail	Rail	270	541,500	41.4	1.05	0.04	0.01
	Baseline + Rail	Ship (EEZ)	2,380	2,928,200	269.9	3.87	0.12	0.07
	Baseline + Rail	Ship (Non-EEZ)	9,410	11,577,500	1,104.5	22.25	13.08	2.04
	Baseline + Truck	Ship (EEZ)	2,380	2,928,200	269.9	3.87	0.12	0.07
	Baseline + Truck	Ship (Non-EEZ)	9,410	11,577,500	1,104.5	22.25	13.08	2.04
	Baseline + Truck	Truck	470	6,124,500	467.8	11.86	0.40	0.14
	Alt. + Rail	Rail	2,180	4,329,000	330.6	8.39	0.28	0.10
	Alt. + Rail	Ship (EEZ)	2,820	3,474,600	320.2	4.59	0.14	0.08
	Alt. + Rail	Ship (Non-EEZ)	7,780	9,572,000	913.2	18.39	10.82	1.69
	Alt. + Truck	Ship (EEZ)	2,820	3,474,600	320.2	4.59	0.14	0.08
	Alt. + Truck	Ship (Non-EEZ)	7,780	9,572,000	913.2	18.39	10.82	1.69
	Alt. + Truck	Truck	1,930	25,151,600	1,921.1	48.72	1.63	0.58



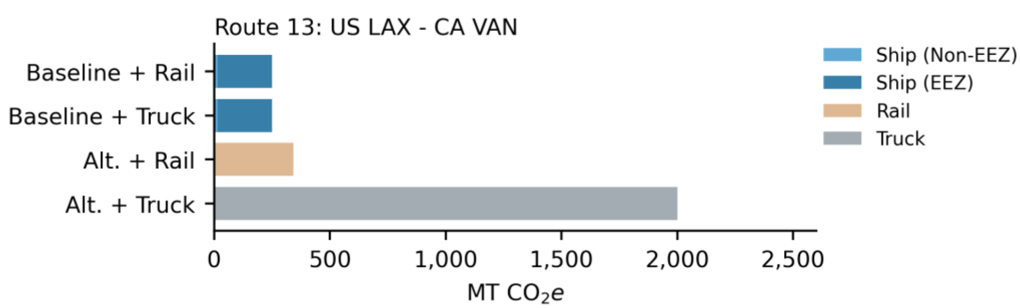


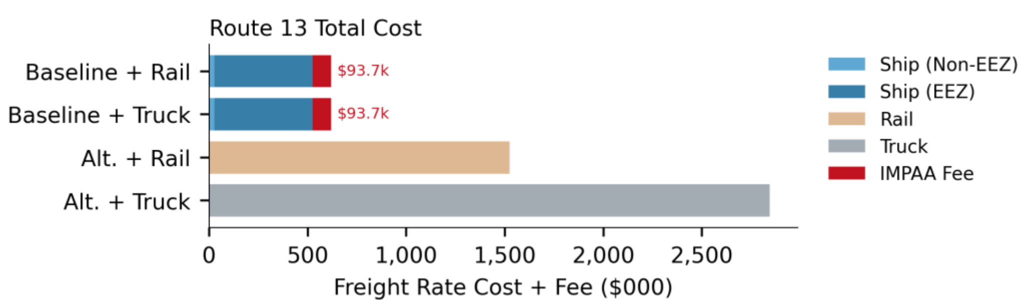
Route 13: San Bernardino, CA – Vancouver, Canada

Baseline route: Ship from Vancouver, Canada to Los Angeles, CA, then overland to San Bernardino, CA
Alternate route: overland from Vancouver, Canada to San Bernardino, CA

Emissions	Emissions from a mode shifted route with rail and truck alternatives are higher than from an all-water route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives are higher than the baseline routes. TheIMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 17.9%.
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
13	Baseline + Rail	Ship (EEZ)	2,080	2,564,500	236.4	3.39	0.10	0.06
	Baseline + Rail	Ship (Non-EEZ)	120	142,900	13.6	0.27	0.16	0.03
	Baseline + Truck	Ship (EEZ)	2,080	2,564,500	236.4	3.39	0.10	0.06
	Baseline + Truck	Ship (Non-EEZ)	120	142,900	13.6	0.27	0.16	0.03
	Alt. + Rail	Rail	2,240	4,463,200	340.9	8.65	0.29	0.10
	Alt. + Truck	Truck	2,020	26,195,600	2,000.8	50.74	1.70	0.60



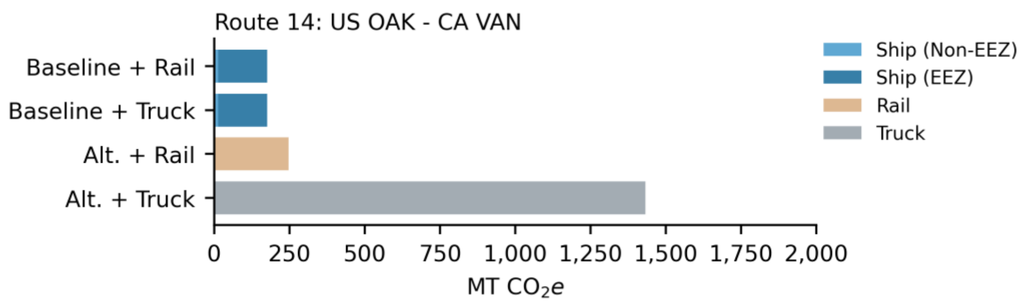


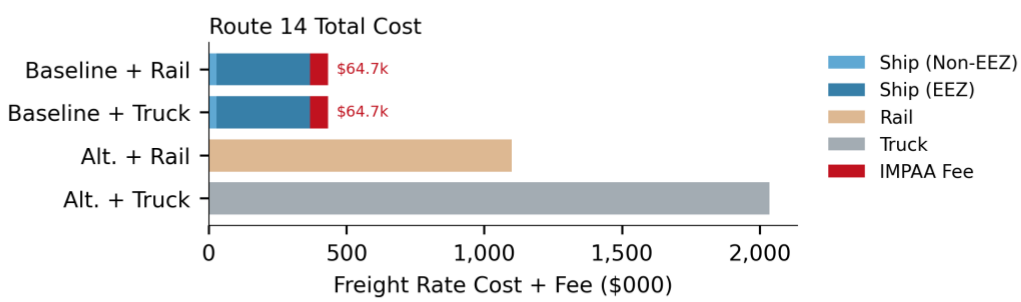
Route 14: Oakland, CA – Vancouver, Canada

Baseline route: Ship from Vancouver, Canada to Oakland, CA
Alternate route: overland from Vancouver, Canada to Oakland, CA

Emissions	Emissions from a mode shifted route with rail and truck alternatives are higher than from an all-water route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives are higher than the baseline routes. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 17.6%.
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
14	Baseline + Rail	Ship (EEZ)	1,430	1,754,200	161.7	2.32	0.07	0.04
	Baseline + Rail	Ship (Non-EEZ)	120	142,900	13.6	0.27	0.16	0.03
	Baseline + Truck	Ship (EEZ)	1,430	1,754,200	161.7	2.32	0.07	0.04
	Baseline + Truck	Ship (Non-EEZ)	120	142,900	13.6	0.27	0.16	0.03
	Alt. + Rail	Rail	1,620	3,223,800	246.2	6.24	0.21	0.07
	Alt. + Truck	Truck	1,440	18,747,300	1,431.9	36.31	1.22	0.43



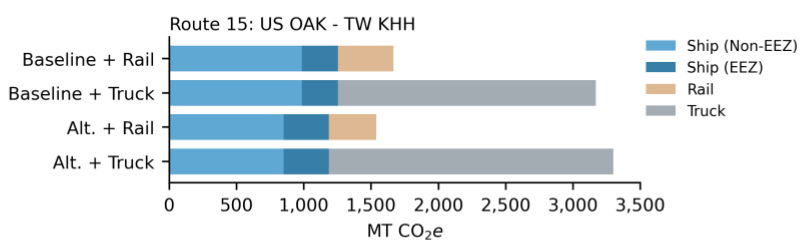


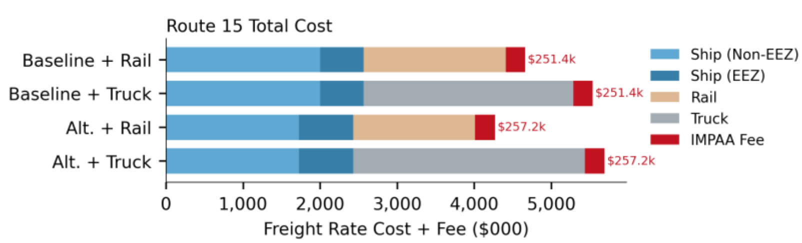
Route 15: Denver, CO – Kaohsiung, Taiwan

Baseline route: Ship from Kaohsiung, Taiwan to Oakland, CA, then overland to Denver, CO
Alternate route: Ship from Kaohsiung, Taiwan to Tacoma, WA, then overland to Denver, CO

Emissions	Emissions from alternate rail routes are lower than the baseline route with rail. Emissions from alternate truck routes are higher.
Freight Rate + IMPAA Fee	Costs from alternate rail routes are lower than the baseline. Costs from alternate truck routes are slightly higher than the baseline. IMPAA fees are not a significant factor in the cost differences. The proposed IMPAA fee would increase baseline route costs by around 4.8-5.7% and would increase alternate route costs by around 4.7% (truck) to 6.4% (rail).
Mode Shift Potential	Moderate-High
Comments	Route explores a West Coast port mode shift within the U.S. Results indicate that it may be more cost-effective and lower emissions to call at Tacoma rather than Oakland, and then move cargo via train to Denver, CO.

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
15	Baseline + Rail	Rail	2,720	5,409,100	413.1	10.48	0.35	0.12
	Baseline + Rail	Ship (EEZ)	2,360	2,898,700	267.2	3.83	0.11	0.07
	Baseline + Rail	Ship (Non-EEZ)	8,400	10,335,100	986.0	19.86	11.68	1.82
	Baseline + Truck	Ship (EEZ)	2,360	2,898,700	267.2	3.83	0.11	0.07
	Baseline + Truck	Ship (Non-EEZ)	8,400	10,335,100	986.0	19.86	11.68	1.82
	Baseline + Truck	Truck	1,930	25,088,400	1,916.2	48.60	1.63	0.58
	Alt. + Rail	Rail	2,330	4,636,900	354.2	8.98	0.30	0.11
	Alt. + Rail	Ship (EEZ)	2,950	3,629,500	334.5	4.79	0.14	0.08
	Alt. + Rail	Ship (Non-EEZ)	7,250	8,912,900	850.3	17.13	10.07	1.57
	Alt. + Truck	Ship (EEZ)	2,950	3,629,500	334.5	4.79	0.14	0.08
	Alt. + Truck	Ship (Non-EEZ)	7,250	8,912,900	850.3	17.13	10.07	1.57
	Alt. + Truck	Truck	2,130	27,677,900	2,114.0	53.61	1.80	0.64



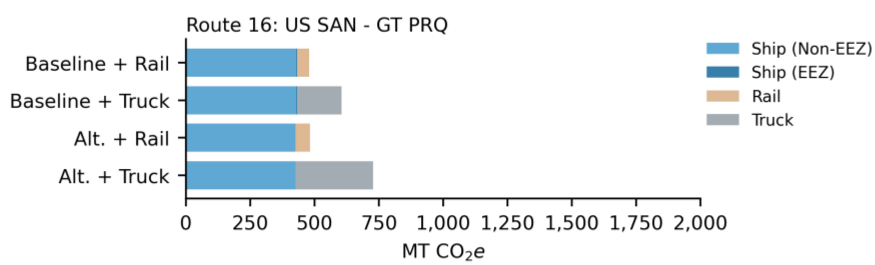


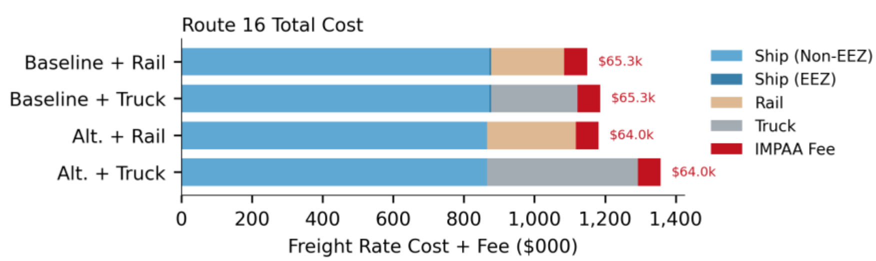
Route 16: San Bernardino, CA – Puerto Quetzal, Guatemala

Baseline route: Ship from Puerto Quetzal, Guatemala to San Diego, CA, then overland to San Bernardino, CA
Alternate route: Ship from Puerto Quetzal, Guatemala to Ensenada, Mexico, then overland to San Bernardino, CA

Emissions	Emissions from baseline and alternate rail routes are comparable. Emissions for the truck alternate routes are higher than its baseline.
Freight Rate + IMPAA Fee	Costs from baseline and alternate routes with truck/rail alternatives are comparable. The baseline rail route is the least cost. The IMPAA fee difference is very small and does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 5.8-6.0% and would increase alternate route costs by around 4.9% (truck) to 5.7% (rail).
Mode Shift Potential	Low-Moderate
Comments	From an economic standpoint, these routes appear substitutable, except for the all-truck alternative. A U.S.-Mexico border crossing is not factored into the analysis, and border crossing would make the mode shift less appealing.

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
16	Baseline + Rail	Rail	310	607,100	46.4	1.18	0.04	0.01
	Baseline + Rail	Ship (EEZ)	20	23,500	2.2	0.03	0.00	0.00
	Baseline + Rail	Ship (Non-EEZ)	3,660	4,504,300	429.7	8.66	5.09	0.79
	Baseline + Truck	Ship (EEZ)	20	23,500	2.2	0.03	0.00	0.00
	Baseline + Truck	Ship (Non-EEZ)	3,660	4,504,300	429.7	8.66	5.09	0.79
	Baseline + Truck	Truck	170	2,254,300	172.2	4.37	0.15	0.05
	Alt. + Rail	Rail	370	739,800	56.5	1.43	0.05	0.02
	Alt. + Rail	Ship (Non-EEZ)	3,630	4,469,200	426.4	8.59	5.05	0.79
	Alt. + Truck	Ship (Non-EEZ)	3,630	4,469,200	426.4	8.59	5.05	0.79
	Alt. + Truck	Truck	300	3,942,800	301.1	7.64	0.26	0.09



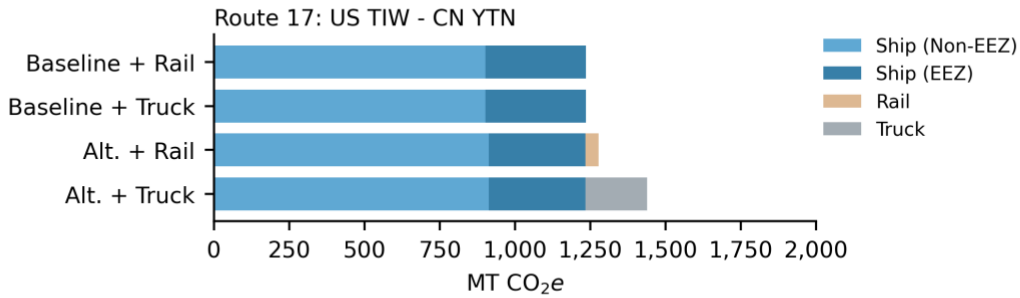


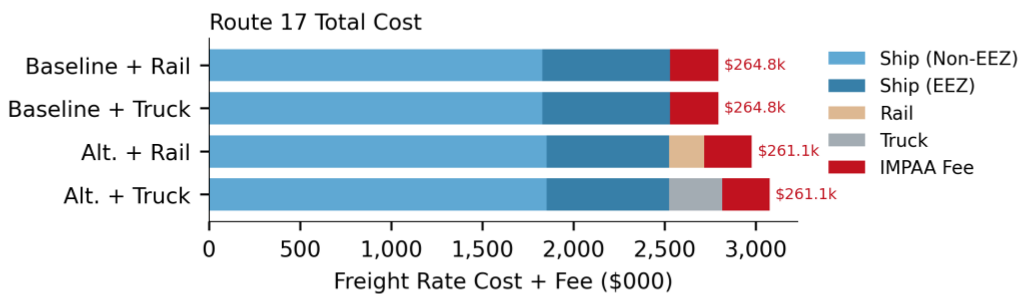
Route 17: Tacoma, WA – Yantian, China

Baseline route: Ship from Yantian, China to Tacoma, WA
Alternate route: Ship from Yantian, China to Vancouver, Canada, then overland to Tacoma, WA

Emissions	Emissions from baseline and alternate rail routes are comparable. An alternative truck route is moderately higher.
Freight Rate + IMPAA Fee	The cost of alternative routes is moderately higher. An alternate rail route is lower than for a truck alternative. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 10.5% and would increase alternate route costs by around 9.3% (truck) to 9.6% (rail).
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
17	Baseline + Rail	Ship (EEZ)	2,950	3,629,500	334.5	4.79	0.14	0.08
	Baseline + Rail	Ship (Non-EEZ)	7,680	9,446,700	901.2	18.15	10.67	1.66
	Baseline + Truck	Ship (EEZ)	2,950	3,629,500	334.5	4.79	0.14	0.08
	Baseline + Truck	Ship (Non-EEZ)	7,680	9,446,700	901.2	18.15	10.67	1.66
	Alt. + Rail	Rail	280	566,800	43.3	1.10	0.04	0.01
	Alt. + Rail	Ship (EEZ)	2,820	3,474,600	320.2	4.59	0.14	0.08
	Alt. + Rail	Ship (Non-EEZ)	7,780	9,572,000	913.2	18.39	10.82	1.69
	Alt. + Truck	Ship (EEZ)	2,820	3,474,600	320.2	4.59	0.14	0.08
	Alt. + Truck	Ship (Non-EEZ)	7,780	9,572,000	913.2	18.39	10.82	1.69
	Alt. + Truck	Truck	210	2,681,900	204.8	5.19	0.17	0.06



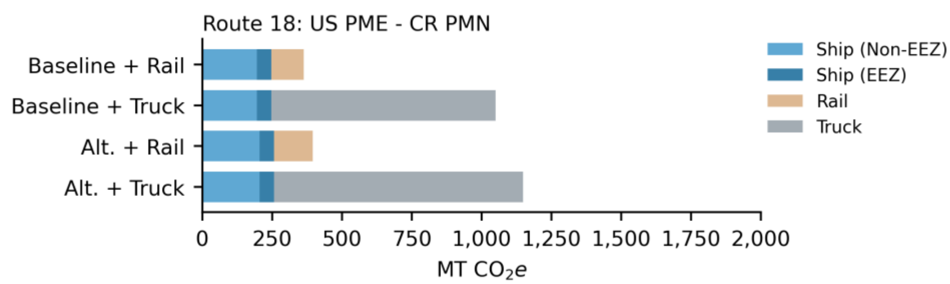


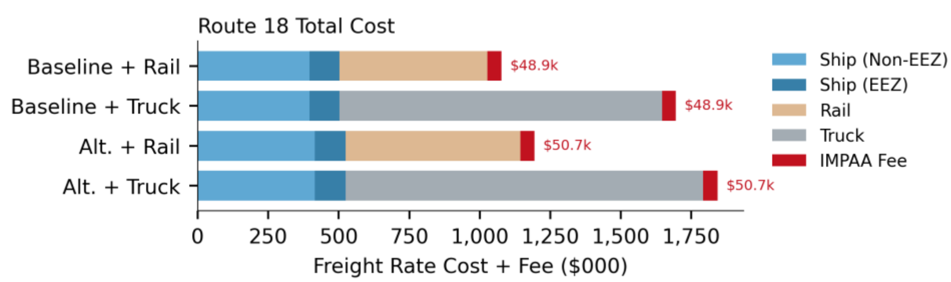
Route 18: Columbia, South Carolina – Bahia de Moin, Costa Rica

Baseline route: Ship from Bahia de Moin, Costa Rica to Port Manatee, FL, then overland to Columbia, SC
Alternate route: Ship from Bahia de Moin, Costa Rica to Palm Beach, FL, then overland to Columbia, SC

Emissions	Emissions from baseline and alternate rail routes are comparable, both are much lower than truck alternatives.
Freight Rate + IMPAA Fee	Baseline rail route is the least cost. IMPAA fee is very small and does not affect decision. The proposed IMPAA fee would increase baseline route costs by around 3.0-4.8% and alternate route costs by around 2.8% (truck) to 4.4% (rail).
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
18	Baseline + Rail	Rail	770	1,538,300	117.5	2.98	0.10	0.04
	Baseline + Rail	Ship (EEZ)	450	550,000	50.7	0.73	0.02	0.01
	Baseline + Rail	Ship (Non-EEZ)	1,660	2,047,000	195.3	3.93	2.31	0.36
	Baseline + Truck	Ship (EEZ)	450	550,000	50.7	0.73	0.02	0.01
	Baseline + Truck	Ship (Non-EEZ)	1,660	2,047,000	195.3	3.93	2.31	0.36
	Baseline + Truck	Truck	810	10,535,400	804.7	20.41	0.68	0.24
	Alt. + Rail	Rail	910	1,815,800	138.7	3.52	0.12	0.04
	Alt. + Rail	Ship (EEZ)	450	558,000	51.4	0.74	0.02	0.01
	Alt. + Rail	Ship (Non-EEZ)	1,750	2,147,900	204.9	4.13	2.43	0.38
	Alt. + Truck	Ship (EEZ)	450	558,000	51.4	0.74	0.02	0.01
	Alt. + Truck	Ship (Non-EEZ)	1,750	2,147,900	204.9	4.13	2.43	0.38
	Alt. + Truck	Truck	900	11,688,000	892.7	22.64	0.76	0.27





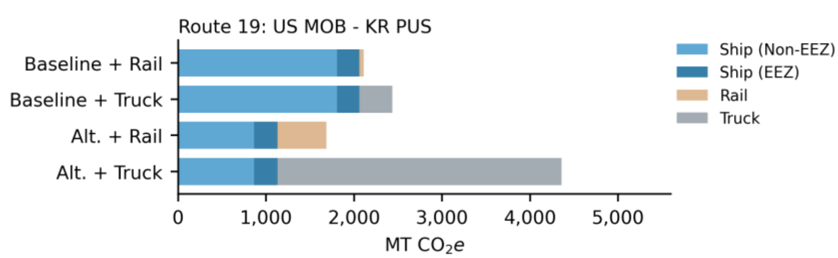
Route 19: Birmingham, AL – Busan, South Korea

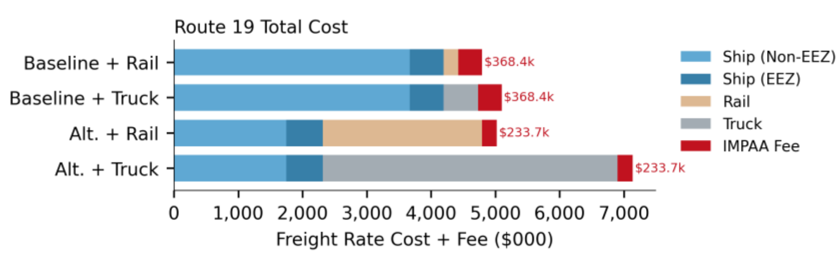
Baseline route: Ship from Busan, South Korea via the Panama Canal to Mobile, AL, then overland to Birmingham, AL

Alternate route: Ship from Busan, South Korea to Los Angeles, CA, then overland to Birmingham, AL

Emissions	An alternate rail route offers the lowest GHG emissions, lower than its baseline. The truck alternate route has the highest emissions.
Freight Rate + IMPAA Fee	The IMPAA fee minimizes the cost difference between rail base and alternate, although the baseline remains favorable. The proposed IMPAA fee would increase baseline route costs by around 7.8-8.3% and would increase alternate route costs by around 3.4% (truck) to 4.9% (rail).
Mode Shift Potential	Low-Moderate
Comments	IMPAA fees do not appear to induce a shift, with cost differences instead driven by the costs of a much longer water route.

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
19	Baseline + Rail	Rail	340	677,500	51.7	1.31	0.04	0.02
	Baseline + Rail	Ship (EEZ)	2,220	2,726,400	251.3	3.60	0.11	0.06
	Baseline + Rail	Ship (Non-EEZ)	15,390	18,935,200	1,806.5	36.38	21.39	3.34
	Baseline + Truck	Ship (EEZ)	2,220	2,726,400	251.3	3.60	0.11	0.06
	Baseline + Truck	Ship (Non-EEZ)	15,390	18,935,200	1,806.5	36.38	21.39	3.34
	Baseline + Truck	Truck	380	4,944,700	377.7	9.58	0.32	0.11
	Alt. + Rail	Rail	3,640	7,253,400	554.0	14.05	0.47	0.17
	Alt. + Rail	Ship (EEZ)	2,380	2,928,200	269.9	3.87	0.12	0.07
	Alt. + Rail	Ship (Non-EEZ)	7,340	9,023,200	860.8	17.34	10.20	1.59
	Alt. + Truck	Ship (EEZ)	2,380	2,928,200	269.9	3.87	0.12	0.07
	Alt. + Truck	Ship (Non-EEZ)	7,340	9,023,200	860.8	17.34	10.20	1.59
	Alt. + Truck	Truck	3,250	42,255,100	3,227.4	81.85	2.75	0.97



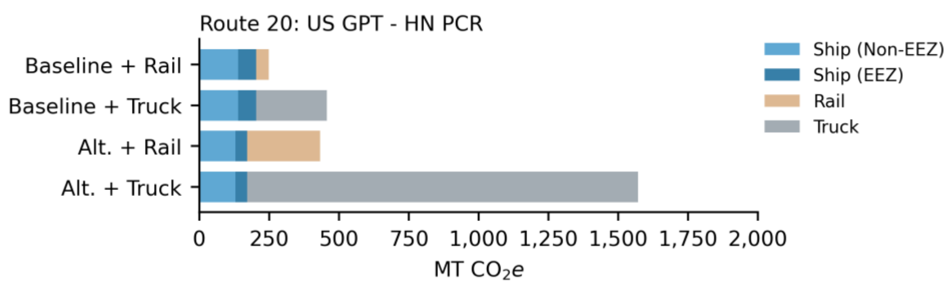


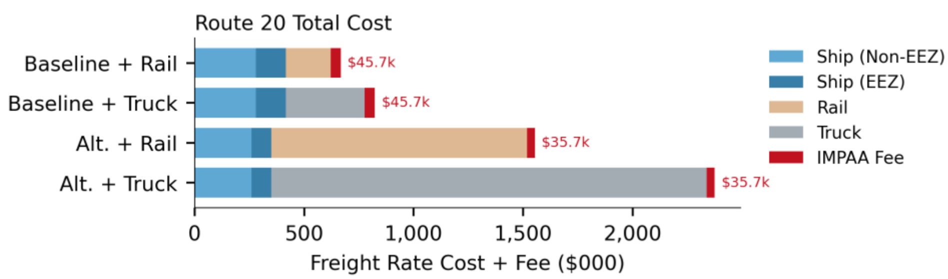
Route 20: Jackson, MS – Puerto Cortes, Honduras

Baseline route: Ship from Puerto Cortes, Honduras to Gulfport, MS, then overland to Jackson, MS
Alternate route: Ship from Puerto Cortes, Honduras to Port Everglades, FL, then overland to Jackson, MS

Emissions	Emissions from a mode shifted route with rail and truck alternatives are higher than emissions from the baseline route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail alternatives are much higher than the baseline routes. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 5.9-7.4% and would increase alternate route costs by around 1.5% (truck) to 2.4% (rail).
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
20	Baseline + Rail	Rail	300	603,600	46.1	1.17	0.04	0.01
	Baseline + Rail	Ship (EEZ)	570	699,700	64.5	0.92	0.03	0.02
	Baseline + Rail	Ship (Non-EEZ)	1,180	1,447,500	138.1	2.78	1.64	0.26
	Baseline + Truck	Ship (EEZ)	570	699,700	64.5	0.92	0.03	0.02
	Baseline + Truck	Ship (Non-EEZ)	1,180	1,447,500	138.1	2.78	1.64	0.26
	Baseline + Truck	Truck	260	3,326,300	254.1	6.44	0.22	0.08
	Alt. + Rail	Rail	1,720	3,422,400	261.4	6.63	0.22	0.08
	Alt. + Rail	Ship (EEZ)	380	462,100	42.6	0.61	0.02	0.01
	Alt. + Rail	Ship (Non-EEZ)	1,090	1,344,200	128.2	2.58	1.52	0.24
	Alt. + Truck	Ship (EEZ)	380	462,100	42.6	0.61	0.02	0.01
	Alt. + Truck	Ship (Non-EEZ)	1,090	1,344,200	128.2	2.58	1.52	0.24
	Alt. + Truck	Truck	1,410	18,322,400	1,399.5	35.49	1.19	0.42



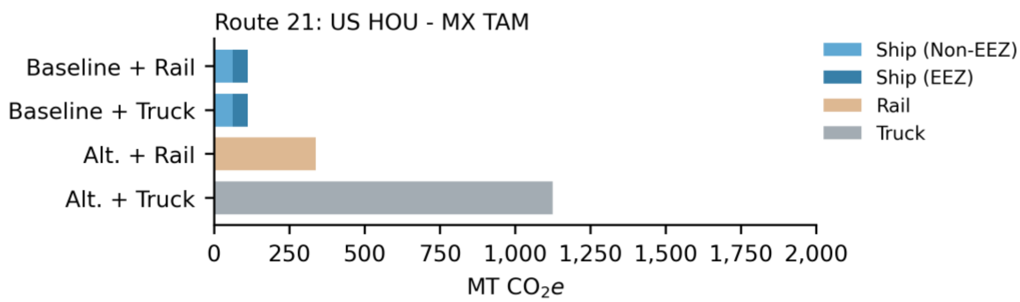


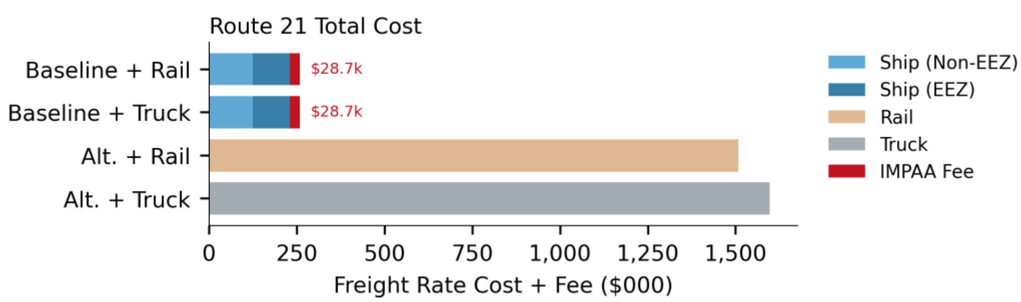
Route 21: Houston, TX – Tampico, Mexico

Baseline route: Ship from Tampico, Mexico to Houston, TX
Alternate route: overland from Tampico, Mexico to Houston, TX

Emissions	Emissions from a mode shifted route with rail and truck all-land alternatives are higher than emissions from the baseline route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail all-land alternatives are much higher than the baseline routes. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 12.5%.
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
21	Baseline + Rail	Ship (EEZ)	440	544,400	50.2	0.72	0.02	0.01
	Baseline + Rail	Ship (Non-EEZ)	520	644,600	61.5	1.24	0.73	0.11
	Baseline + Truck	Ship (EEZ)	440	544,400	50.2	0.72	0.02	0.01
	Baseline + Truck	Ship (Non-EEZ)	520	644,600	61.5	1.24	0.73	0.11
	Alt. + Rail	Rail	2,220	4,417,200	337.4	8.56	0.29	0.10
	Alt. + Truck	Truck	1,130	14,710,800	1,123.6	28.49	0.96	0.34



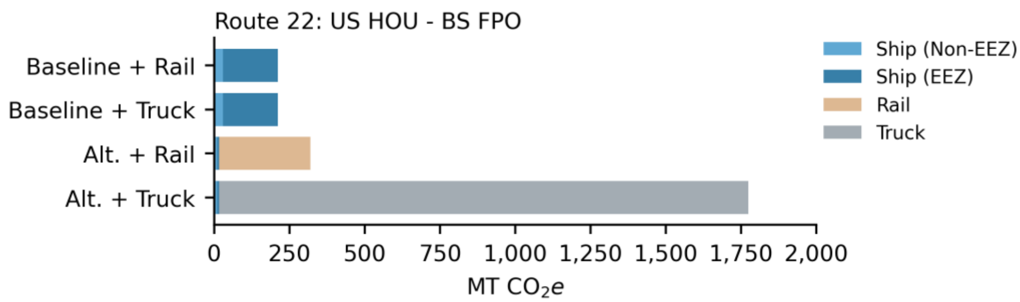


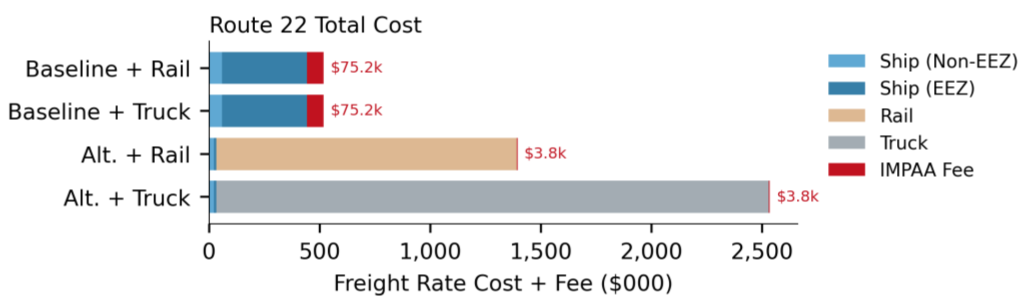
Route 22: Houston, TX – Freeport, Bahamas

Baseline route: Ship from Freeport, Bahamas to Houston, TX
Alternate route: Ship from Freeport, Bahamas to Port Everglades, FL, then overland to Houston, TX

Emissions	Emissions from a mode shifted route with rail and truck all-land alternatives are higher than emissions from the baseline route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail all-land alternatives are much higher than the baseline routes. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 17.0% and would increase alternate route costs by around 0.2% (truck) to 0.3% (rail).
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
22	Baseline + Rail	Ship (EEZ)	1,610	1,984,800	182.9	2.62	0.08	0.05
	Baseline + Rail	Ship (Non-EEZ)	240	300,400	28.7	0.58	0.34	0.05
	Baseline + Truck	Ship (EEZ)	1,610	1,984,800	182.9	2.62	0.08	0.05
	Baseline + Truck	Ship (Non-EEZ)	240	300,400	28.7	0.58	0.34	0.05
	Alt. + Rail	Rail	2,000	3,977,200	303.8	7.70	0.26	0.09
	Alt. + Rail	Ship (EEZ)	50	63,500	5.9	0.08	0.00	0.00
	Alt. + Rail	Ship (Non-EEZ)	90	108,200	10.3	0.21	0.12	0.02
	Alt. + Truck	Ship (EEZ)	50	63,500	5.9	0.08	0.00	0.00
	Alt. + Truck	Ship (Non-EEZ)	90	108,200	10.3	0.21	0.12	0.02
	Alt. + Truck	Truck	1,770	23,008,100	1,757.4	44.57	1.50	0.53



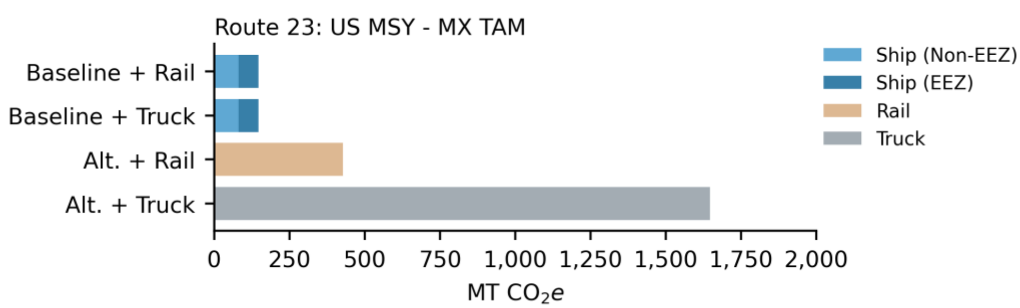


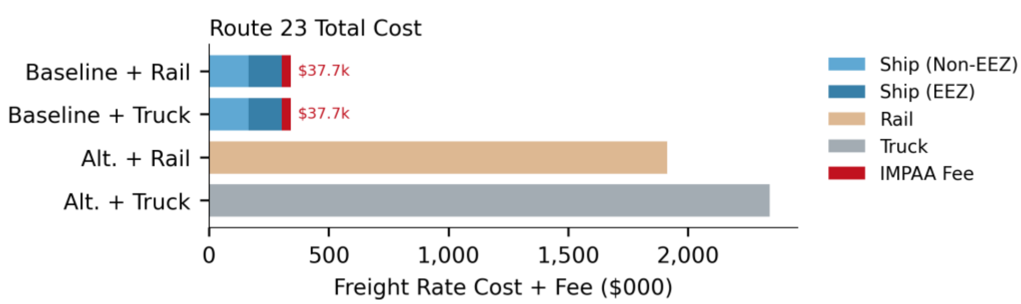
Route 23: New Orleans, LA – Tampico, Mexico

Baseline route: Ship from Tampico, Mexico to New Orleans, LA
Alternate route: overland from Tampico, Mexico to New Orleans, LA

Emissions	Emissions from a mode shifted route with rail and truck all-land alternatives are higher than emissions from the baseline route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail all-land alternatives are much higher than the baseline routes. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 12.5%.
Mode Shift Potential	LOW
Comments	-

					MT			
Route	**Scenario**	**Mode**	**Length (km)**	**Energy (mj)**	**CO_2e**	**NOx**	**SOx**	**PM**
23	Baseline + Rail	Ship (EEZ)	580	716,800	66.1	0.95	0.03	0.02
	Baseline + Rail	Ship (Non-EEZ)	690	845,100	80.6	1.62	0.95	0.15
	Baseline + Truck	Ship (EEZ)	580	716,800	66.1	0.95	0.03	0.02
	Baseline + Truck	Ship (Non-EEZ)	690	845,100	80.6	1.62	0.95	0.15
	Alt. + Rail	Rail	2,820	5,603,300	428.0	10.85	0.36	0.13
	Alt. + Truck	Truck	1,660	21,563,500	1,647.0	41.77	1.40	0.50



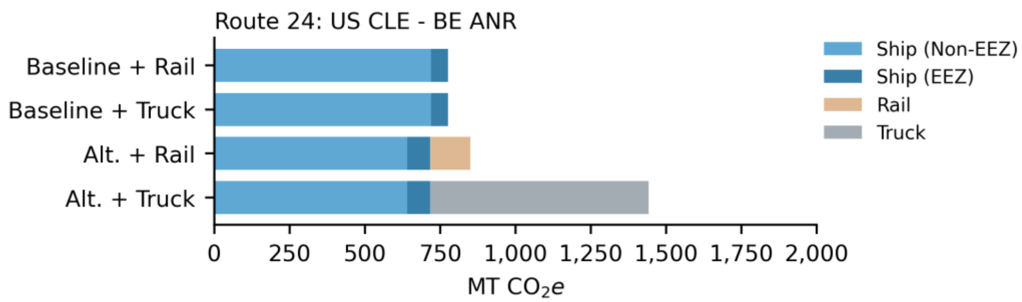


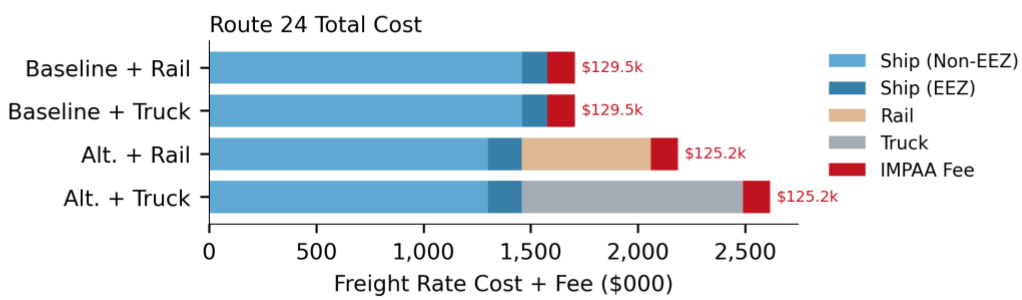
Route 24: Cleveland, OH – Antwerp, Belgium

Baseline route: Ship from Antwerp, Belgium to Cleveland, OH via Lake Ontario and Lake Erie
Alternate route: Ship from Antwerp, Belgium to New York, NY, then overland to Cleveland, OH

Emissions	Emissions from a mode shifted route with a rail alternative are slightly higher than emissions from the baseline all-water route.
Freight Rate + IMPAA Fee	Costs from mode shifted routes with truck/rail all-land alternatives exceed the baseline routes, though ship transport costs are lower. The IMPAA fee does not affect the decision. The proposed IMPAA fee would increase baseline route costs by around 8.2% and would increase alternate route costs by around 5.0% (truck) to 6.1% (rail).
Mode Shift Potential	LOW
Comments	-

					MT			
Route	Scenario	Mode	Length (km)	Energy (mj)	CO_2e	NOx	SOx	PM
24	Baseline + Rail	Ship (EEZ)	490	604,500	55.7	0.80	0.02	0.01
	Baseline + Rail	Ship (Non-EEZ)	6,130	7,539,600	719.3	14.49	8.52	1.33
	Baseline + Truck	Ship (EEZ)	490	604,500	55.7	0.80	0.02	0.01
	Baseline + Truck	Ship (Non-EEZ)	6,130	7,539,600	719.3	14.49	8.52	1.33
	Alt. + Rail	Rail	890	1,766,200	134.9	3.42	0.11	0.04
	Alt. + Rail	Ship (EEZ)	660	816,000	75.2	1.08	0.03	0.02
	Alt. + Rail	Ship (Non-EEZ)	5,460	6,715,300	640.6	12.90	7.59	1.18
	Alt. + Truck	Ship (EEZ)	660	816,000	75.2	1.08	0.03	0.02
	Alt. + Truck	Ship (Non-EEZ)	5,460	6,715,300	640.6	12.90	7.59	1.18
	Alt. + Truck	Truck	730	9,515,600	726.8	18.43	0.62	0.22





Results Summary

The analysis indicates minimal potential for mode shift in response to IMPAA fees. While costs will, of course, increase under the proposed IMPAA fee structure, the majority of the baseline routes remain more cost-effective and produce fewer emissions compared to the alternate rail and road routes. Out of the 24 OD pairings evaluated, only two demonstrated low-to-moderate mode shift potential, and only one showed moderate-to-high potential for mode shifts. In these cases, the cost or emissions differences were small enough to make the routes comparable or competitive with each other, independent of the IMPAA fees, suggesting that these specific routes may already be substitutable under certain conditions.

While a few alternate routes showed potential for cost and emissions reductions, the differences were not substantial enough to guarantee that shippers would definitively choose to switch modes. The IMPAA fees alone do not introduce a strong enough economic implication for a widespread shift away from existing, established shipping practices. Cost differentials were typically due to operating costs unrelated to the IMPAA fees.

The three routes with the highest potential of mode shift are as follows:
(B=baseline, A=alternate)

1	2	2
Moderate-to-high	**Low-to-moderate**	**Low-to-moderate**
Kaohsiung, Taiwan to Denver, CO via the Port of Oakland (B) or the Port of Tacoma (A) (Route 15)	Puerto Quetzal, Guatemala to San Bernardino, CA via the Port of San Diego (B) or the Port of Ensenada (A) (Route 16)	Busan, South Korea to Birmingham, AL via the Port of Mobile (B) or the Port of Los Angeles (A) (Route 19)

The first OD pair with potential for mode shift (Route 15) found that shipping to Tacoma instead of Oakland, followed by rail transport to Denver, CO may be more cost-effective and generate fewer total emissions, when originating from Kaohsiung, Taiwan. This route was studied to evaluate how West Coast shipping costs may be affected by the proposed IMPAA fees, enabling the comparison of ports in the Pacific Northwest with ports in Northern California for shipping goods to states in the center of the country. The alternate route using trucks for land-based transport has slightly higher costs and emissions compared to the baseline, making it a less favorable option for inducing mode shift. Despite the ship spending more time within the U.S. EEZ on the Tacoma route, the reduced cost and emissions from the alternate rail segment make it a potentially favorable option.

The next OD pair with potential for mode shift (Route 16) suggests that shipping into Mexico, followed by transporting the cargo to San Bernardino by either truck or rail, could serve as a viable alternative to the baseline pathway entering the U.S. via the Port of San Diego, when originating from Quetzal, Guatemala. Notably, this modeling does not account for additional costs of border crossing and delay, nor does it account for increased traffic and dwell time (the amount of time that a shipping vehicle spends at a facility while cargo is unloaded). Given these factors, and that potential freight rate differences are minimal, the potential for mode shift on this route is minor. Among the alternatives, the rail option results in fewer total emissions compared to the truck route. While the baseline rail route has the lowest overall costs, the cost differences between the baseline and alternate rail and truck routes are relatively minor, making all options comparable in terms of economic feasibility. While route choices appear similar, shipping into San Diego may still present an advantage in terms of reliability and lower border-related costs and/or time delays. The logistics of the U.S.-Mexico border crossing are not factored into this analysis, which could make the alternative route less attractive for mode shift.

The final OD pair with a greater potential for mode shift (Route 19) involves shipments from Busan, South Korea headed to Birmingham, AL. The baseline route travels through the Panama Canal and the ship unloads at the Port of Mobile, with overland transport of the cargo to Birmingham. The costs of the baseline water + rail and water + truck routes are both lower than their alternatives, however the rail routes have a very minimal difference. The IMPAA fee minimizes the cost difference between the rail base and alternate, making the baseline slightly more favorable in comparison despite the cost increase. The total emissions of the alternate rail route are the lowest emissions of the route and mode choices, supporting the potential shift. The base and alternate rail routes are relatively substitutable economically, as the IMPAA fees alone do not provide enough incentive to drive a mode shift, and the cost differences are attributable to the length and complexity of the route. The alternate truck route would have the highest emissions and costs of the all route options, making this an unfavorable choice for mode shift.

The analysis of the 24 OD pairings shows that there is some potential for mode shifts under a few specific routes. Although, the economic impacts of the IMPAA fees are non-trivial, they are not substantial enough to drive widespread shifts from baseline routes; the three cases with the highest potential for mode shift were influenced by other factors of reduced transportation costs and/or emissions, and they do not account for supply chain factors such as border crossings, transit time, or transiting the Panama Canal.

The majority of baseline shipping routes remain more economically and environmentally favorable with the proposed IMPAA fees. The following summary table presents a concise comparison of the emissions, costs, and mode shift potential of alternate routes for the OD pairs compared to the baselines.

Summary Table

Table 13: OD Pair IMPAA Fee Alternate Routes Comparison to Baseline Routes

Route	Origin-Destination	Alt. Emissions Δ	Alt. Cost Δ	Mode Shift Potential
1	Baltimore, MD to Halifax, NS	Higher	Higher	Low
2	Philadelphia, PA to Cartagena, Colombia	Higher	Higher	Low
3	New York, NY to Busan, Korea	Rail lower Road higher	Higher	Low
4	New York, NY to Algeciras, Spain	Higher	Higher	Low
5	Albany, NY to Le Havre, France	Higher	Higher	Low
6	Charleston, SC to Colon, Panama	Rail comparable Road higher	Higher	Low
7	Palm Beach, FL to Halifax, NS	Higher	Higher	Low
8	Savannah GA to Bremerhaven, Germany	Higher	Higher	Low
9	Wimington, DE to Puerto Castilla, Honduras	Higher	Higher	Low
10	Oxnard, CA to Lazara Cardenas, Mexico	Higher	Higher	Low
11	San Bernardino, CA to Busan, Korea	Moderately higher	Moderately higher	Low
12	Las Vegas, NV to Yantian, China	Higher	Higher	Low
13	San Bernardino, CA to Vancouver, BC	Higher	Higher	Low
14	Oakland, CA to Vancouver BC	Higher	Higher	Low
15	Denver, CO to Kaohsiung, Taiwan	Rail moderately lower Road moderately higher	Rail lower Road moderately higher	Moderate to high
16	San Bernardino, CA to Puerto Quetzal, Guatemala	Rail comparable Road higher	Rail comparable Road higher	Low to moderate
17	Tacoma, WA to Yantian, China	Rail comparable Road moderately higher	Moderately higher	Low
18	Columbia, SC to Bahia de Moin, Costa Rica	Rail comparable Road moderately higher	Moderately higher	Low
19	Birmingham, AL to Busan, Korea	Rail lower Road higher	Rail comparable Road higher	Low to moderate
20	Jackson, MS to Puerto Cortes, Honduras	Higher	Higher	Low
21	Houston, TX to Tampico, Mexico	Higher	Higher	Low
22	Houston, TX to Freeport, Bahamas	Higher	Higher	Low
23	New Orleans to Tampico, Mexico	Higher	Higher	Low
24	Cleveland, OH to Antwerp, Belgium	Rail moderately higher Road higher	Higher	Low

Conclusions

This analysis incorporated IMPAA fees into the base freight rates for the OD pairs, established using factors outlined in Transportation Cost Data (e.g. basic operating costs). This analysis does not account for additional costs and determining factors tied to mode shift, such as increased dwell times, delays, additional repositioning and container yard moves and handling fees, inspection fees, border crossings, increased road and railway traffic, and so forth. Results presented here are conservative, as including those additional costs would increase overall costs of shifting cargo between modes and introduce logistical challenges.

IMPAA is a potential path towards a maritime decarbonization transition. Including IMPAA fees in the fuel cost calculation increases the effective price of consuming a ton of fuel outside the EEZ by around $565 per metric tonne of fuel based on the IMPAA fee on CO_2e emissions. For MDO consumed inside the U.S. EEZ, the IMPAA fees may increase effective prices by around $1,460 per metric tonne of fuel, when considering fees on GHGs and criteria pollutant emissions. Given current price differentials with alternative fuels (Table A2), the conventional fuel prices plus IMPAA fees may be less competitive with some low-GHG alternatives.

Alternative fuel prices are not as broadly available as bunker data. Through a set of prior projects,[54] and updated in this report, EERA has identified representative costs for alternative marine fuels (Table A2). Spot market prices are also available,[55] indicating that bio- and renewable diesel prices in the U.S. are around $350-$415 dollars more expensive than VSLFO per tonne, and global green and bio-methanol prices are on the order of $1,600 more per tonne equivalent. Green ammonia prices are higher still, globally trading at around $2,100 to $2,400 more per tonne equivalent. With those prices considered, the additional IMPAA fees (around $1,460 per MT MDO in the EEZ) bring the net price of conventional fuels plus fees in closer alignment with deeply decarbonized fuels, but do not fully close the price gap.

By combining regulatory and economic measures, policies can work in tandem to reinforce compliance, align with polluter pays principles, reward greener practices, and narrow the price gap between fossil fuels and low-GHG alternatives. The IMPAA CO_2e fee on ships entering U.S. waters is intended to complement other domestic and international measures to reduce emissions and incentivize a shift towards low-carbon marine fuels. While the CSA would set strict regulatory emission limits, IMPAA adds an economic incentive by imposing a fee on any remaining emissions.[56] By imposing a fee on emissions, IMPAA aims to incentivize the transition to low-GHG alternatives by narrowing the price gap between conventional and deeply decarbonized fuels.

The results of the geospatial modeling using GREEN-T and including estimated IMPAA fees do not show evidence for a mode shift. IMPAA fees narrow the price gap between conventional and deeply decarbonised fuels, but they do not close the gap fully. IMPAA fees would increase the cost of waterborne transport with conventional fuels by up to around 18%. Mean and median estimated freight rate increases are moderate, on the order of 6.1-6.7%, and they are not estimated to increase mode shift potential.

[54] e.g. https://oceanconservancy.org/wp-content/uploads/2023/03/Approaches-Decarbonizing-US-Fleet.pdf

[55] Argus September 2024 Snapshot: https://futurefuels.imo.org/home/latest-information/fuel-prices/

[56] IMPAA fees are compatible with other potential economic measures. See this report's section on Policy Interpretations.

Appendix

Table A1: 2022 Rail Freight Costs per Ton-Mile of Commodities by STCC2 Code

STCC2	Commodity Name	Mean (USD/ton-mile)	Median (USD/ton-mile)
1	Farm products	0.1004	0.0594
8	Forest products	0.1340	0.1139
9	Fresh fish	0.1029	0.0754
10	Metallic ores	0.1344	0.0961
11	Coal	0.1887	0.0382
13	Crude, natural gas or gasoline	0.1065	0.0883
14	Nonmetallic ores, minerals, excl. fuel	0.4055	0.0720
19	Ordnance or accessories	0.4903	0.2195
20	Food and kindred products	0.1121	0.0697
21	Tobacco products, excl. insecticides	0.1091	0.1168
22	Textile mill products	0.2226	0.1152
23	Apparel or other finished textile	0.3075	0.1214
24	Lumber or wood products	0.1183	0.0750
25	Furniture or fixtures	0.1805	0.1268
26	Pulp, paper, or allied products	0.1755	0.1074
27	Printed matter	0.1297	0.0825
28	Chemicals or allied products	0.1859	0.0947
29	Petroleum or coal products	0.2101	0.0989
30	Rubber or misc. plastics products	0.2441	0.1146
31	Leather or leather products	0.2446	0.1726
32	Clay, concrete, glass, stone	0.1559	0.1031
33	Primary metal products	0.1948	0.1122
34	Fabricated metal products	0.2312	0.1097
35	Machinery, excluding electrical	0.3581	0.1958
36	Electrical machinery or supplies	0.3281	0.1761
37	Transportation equipment	0.4264	0.2727
38	Instruments & optical goods	0.1820	0.1024
39	Misc. products of manufacturing	0.2212	0.1526
40	Waste or scrap materials	0.1425	0.0915
41	Misc. freight shipments	0.4088	0.2264
42	Empty containers & trailers	0.2197	0.1006
43	Mail or contract freight	0.2241	0.2448
44	Freight forwarder traffic	0.1483	0.1136
45	Shipper association or similar	0.3328	0.1398
46	Freight all kinds, mixed shipments	0.1632	0.1092
47	Less than car-/truckload shipments	0.1765	0.1393
48	Hazardous materials or waste	0.2665	0.1104
50	Other – bulk shipments	0.4206	0.4124

Table A2: Price ranges for alternative marine fuels

Fuel Type	Fuel	Low Price	High Price	Unit	Source
Conventional	VLSFO	0.0110	0.0260	USD/MJ	Lagouvardou et al.[57]
	MGO	0.0120		USD/MJ	Lindstad et al.[58]
Biofuel	Bio-diesel	0.0260	0.0360	USD/MJ	Lagouvardou et al.
	FAME biofuel	0.0300	0.0490	USD/MJ	EERA / Ocean Conservancy[59]
	HVO biofuel	0.0370	0.0610	USD/MJ	EERA / Ocean Conservancy
	FT-Diesel	0.0380	0.1050	USD/MJ	EERA / Ocean Conservancy
	DME biofuel	0.0140	0.0210	USD/MJ	EERA / Ocean Conservancy
Hydrogen	Fossil LH2	0.0263		USD/MJ	Lindstad et al.
	Fossil LH2	0.0080	0.0230	USD/MJ	EERA / Ocean Conservancy
	Fossil LH2	0.0330	0.0680	USD/MJ	Lagouvardou et al.
	Fossil-CCUS LH2	0.0150	0.0680	USD/MJ	Lagouvardou et al.
	Fossil-CCUS LH2	0.0130	0.0340	USD/MJ	EERA / Ocean Conservancy
	E-LH2	0.0220	0.0416	USD/MJ	Lindstad et al.
	E-LH2	0.0210	0.0500	USD/MJ	EERA / Ocean Conservancy
	E-LH2	0.0220	0.0680	USD/MJ	Lagouvardou et al.
Methanol	Bio-MeOH	0.0180	0.0270	USD/MJ	Lagouvardou et al.
	Bio-MeOH	0.0160	0.0390	USD/MJ	EERA / Ocean Conservancy
	Fossil MeOH	0.0250	0.0580	USD/MJ	Lagouvardou et al.
	Fossil MeOH	0.0050	0.0130	USD/MJ	EERA / Ocean Conservancy
	E-MeOH	0.0312	0.0742	USD/MJ	Lindstad et al.
	E-MeOH	0.0320	0.1070	USD/MJ	Lagouvardou et al.
	E-MeOH	0.0400	0.0800	USD/MJ	EERA / Ocean Conservancy
Ammonia	Fossil NH3	0.0263		USD/MJ	Lindstad et al.
	Fossil NH3	0.0140	0.1080	USD/MJ	Lagouvardou et al.
	Fossil NH3	0.0300	0.0320	USD/MJ	EERA / Ocean Conservancy
	Fossil-CCUS NH3	0.0320	0.0430	USD/MJ	EERA / Ocean Conservancy
	Fossil-CCUS NH3	0.0150	0.0610	USD/MJ	Lagouvardou et al.
	E-NH3	0.0220	0.0410	USD/MJ	Lindstad et al.
	E-NH3	0.0220	0.0610	USD/MJ	Lagouvardou et al.
	E-NH3	0.0860	0.0990	USD/MJ	EERA / Ocean Conservancy

[57] https://www.nature.com/articles/s41560-023-01334-4
[58] https://doi.org/10.1016/j.trd.2021.103075
[59] https://oceanconservancy.org/wp-content/uploads/2023/03/Approaches-Decarbonizing-US-Fleet.pdf