RESEARCH BRIEF

SEPTEMBER 2025



# Estimating the maximum potential vegetable oil demand for international shipping under the International Maritime Organization's Net-Zero Framework

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## BACKGROUND

At its 83rd session, the International Maritime Organization (IMO) approved draft amendments to MARPOL Annex VI that, if adopted, would establish a legally binding net-zero framework aimed at decarbonizing international shipping.[1] The IMO Net-Zero Framework will apply to all ships of 5,000 gross tonnage and above engaged in international voyages. At the core of the framework is a two-tiered system that introduces progressively lower greenhouse gas fuel intensity (GFI) targets and associated penalties for non-compliance based on the attained greenhouse gas (GHG) intensity of the fuels that a ship uses. At the end of each year, ships are required to report their attained annual GFI measured on a well-to-wake basis in grams of carbon dioxide equivalent per megajoule (g $CO_2$e/MJ) of fuel and calculate their compliance balance. These emissions reduction targets increase over time, starting at 4% (base compliance) and 17% (direct compliance) reductions from a 2008 baseline (93.3 g $CO_2$e/MJ) in 2028, reaching 30% and 43% reductions, respectively, by 2035. The IMO has agreed that the base target in 2040 will reflect a 65% reduction, and it will set the remaining targets, including direct targets for 2036–2040, by 2032. While the IMO has adopted an overall target of reaching net-zero GHG emissions by or around 2050, no detailed post-2040 targets have been agreed upon, although the entire policy is set to be reviewed every 5 years.

Ships failing to achieve GFI compliance with the base target threshold (Tier 2) must pay elevated non-compliance penalties of $380/tonne $CO_2$e (remedial units) or may alternatively utilize banked credits (surplus units) from ships that have exceeded

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1 International Maritime Organization, *Circular Letter No. 5005* (2025), https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/Circular%20Letter%20No.5005%20-%20Draft%20Revised%20Marpol%20Annex%20Vi%20%28Secretariat%29.pdf.

compliance requirements.  When a ship's GFI is between the base target and the direct compliance target, a reduced penalty applies at $100/tonne $CO_2e$ (Tier 1) with no options to offset this penalty using surplus units.

In its current state, the Net-Zero Framework does not contain any eligibility criteria for fuels used to comply with the emissions trajectory and evaluates them solely on their life-cycle GHG emissions. However, the life-cycle assessment guidelines, which are the basis for emissions quantification, are still in development and do not include safeguards on land-use change and indirect emissions. For this reason, there is a risk that the policy could incentivize fuels that pose sustainability risks outside of their direct supply chain emissions. For example, the ships in scope could blend crop-based first-generation biofuels such as hydroprocessed vegetable oil (i.e., renewable diesel). There is a strong risk that the added demand for these fuels from the IMO's Net-Zero Framework could create additional demand for cropland and lead to indirect life-cycle emissions.

In this research brief, we estimate the potential demand for these biofuels from the marine sector and the amount of vegetable oils necessary to produce them.

## METHODOLOGY

We assumed that waste- and vegetable oil-derived renewable diesel (RD) would be used by fleets in addition to heavy fuel oil (HFO) to keep the emissions below the base target emissions trajectory and avoid paying the $380/tonne penalty.

For the purposes of this analysis, we assumed that the contribution of fossil liquified natural gas (LNG) is exogenous in the early years and not affected directly by the Net-Zero Framework. As LNG is in some cases cost-competitive on an energy basis with HFO, we assumed it can generate GHG reductions more cost-effectively than most biofuel compliance pathways. However, its total contribution is highly constrained due to its relatively high life-cycle GHG emissions, which fall above the base target by 2030–2032, depending on the engine technology.[2] We assumed a life-cycle emission factor of 85.65 g $CO_2e$/MJ for fossil LNG, assuming a low-pressure, two-stroke, dual-fuel engine and 5% marine gas oil used as a pilot fuel.[3] These assumptions may overstate the contribution of fossil LNG, as low-pressure four-stroke engines remain common on the market and exhibit higher methane slip, significantly increasing life-cycle emissions attributable to this fuel pathway.[4]

To estimate the potential magnitude of vegetable oil (VO) demand necessary to produce RD, we developed a cost-optimization approach that determined the aggregate least-cost mix of fuels across the maritime fleet under the Net-Zero Framework through 2035. The minimum cost is achieved via a simplified, two-step approach. First, we assumed that the weighted average carbon intensity of the sector-wide blend will remain at or below the base target GFI to avoid Tier 2 penalties in aggregate; any excess compliance will be traded to avoid Tier 2 penalties. Prior to assessing the cost-optimal mix of biofuels, we included the contribution of fossil

2 S&P Global, "Platts Global Bunker Cost Calculator," accessed August 18, 2025, https://www.spglobal.com/commodity-insights/en/news-research/infographics/content-design-infographics/platts-global-bunker-cost-calculator.

3 There is a range of different engine technologies with different methane slip rates. Though low-pressure four-stroke engines with the highest methane slip continue to constitute the largest share of the maritime fleet, this is expected to shift towards 2045. Xiaoli Mao et al., *Greenhouse Gas Emissions and Air Pollution from Global Shipping, 2016–2023* (International Council on Clean Transportation, 2025), https://theicct.org/publication/greenhouse-gas-emissions-and-air-pollution-from-global-shipping-2016-2023-apr25/.

4 Nikita Pavlenko et al., *The Climate Implications of Using LNG as a Marine Fuel* (International Council on Clean Transportation, 2020), https://theicct.org/publication/the-climate-implications-of-using-lng-as-a-marine-fuel/. LCA emissions in this research brief are based on IMO's 2024 LCA guidelines; de facto emissions for low-pressure dual-fuel engines may be higher based on real-world measurement.

LNG to the fuel mix. We assumed that LNG's share would be around 0.81 exajoules (EJ) in 2035,[5] or approximately 8.1% of projected global maritime energy demand, based on the ICCT's Polaris Model.[6] Next, we estimated the volume of biofuel used for compliance based on life-cycle emission factors for used cooking oil (UCO)- and VO-based RD.

We assumed that one of the most effective near-term compliance strategies would be to first blend UCO-based RD up to its supply limits, since it offers one of the lowest costs of GHG reductions, followed by virgin VO-based biofuels up to the blend level where the Tier 2 penalty is avoided.[7] As long as the cost of blending alternative fuels remains below $380/tonne $CO_2$e, the optimal compliance strategy would be to avoid the Tier 2 penalty and pay only the direct compliance cost of $100/tonne, which is cheaper than blending additional fuel. To support the feasibility of this assumption, we calculated the blending compliance value per avoided GHG for various fuels by calculating the dollars per tonne of $CO_2$ avoided by using that fuel (see the appendix for the methodology). We estimated the weighted carbon intensity of the fuel blend and the policy and blending penalty using the formulas in the appendix.

## RESULTS

Figure 1 illustrates that the use of biofuels is cost-effective relative to the base target compliance cost of $380/tonne $CO_2$e and that UCO-RD is the cheapest compliance pathway within the biofuels analyzed here, followed by biodiesel and other virgin VO-based RD. However, the supply of UCO is highly constrained. The total UCO availability for biofuels production is approximately 14.3 billion liters (Table A1).[8] This amount is enough to produce roughly 13.6 billion liters of renewable diesel globally, sufficient to meet only about 4.9% of energy demand from international shipping under the Net-Zero Framework if all UCO was immediately diverted to the maritime sector.[9] There are other waste fats and oils, such as tallow, but their availability for biofuels production is likely lower than UCO (Table A1). In addition, fuels derived from waste materials are in high demand as they fulfill both GHG reduction goals and sustainable feedstock requirements under various policy frameworks in other sectors.[10] For example, fuels produced from waste fats and oils are already utilized for the road sector and increasingly in aviation.

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5 1 exajoule = 10^12 MJ.

6 Gabe Hillman Alvarez et al., *Polaris v1.3 Documentation*, computer software, International Council on Clean Transportation, 2024, https://theicct.github.io/polaris-doc/versions/v1.3/.

7 Since January 2025, the price of UCO-RD has ranged between $1,540 and $1,870 per tonne in the United States and between $1,850 and $2,480 per tonne in the European Union; see Neste, *European Renewable Diesel* and *US Renewable Diesel Prices*, accessed August 11, 2025, https://www.neste.com/investors/market-data/renewable-products#european-renewable-diesel. Soybean-RD prices ranged between $1,440 and $1,800 per tonne in the United States in 2025; see Neste, *European Renewable Diesel and US Renewable Diesel Prices*. Biodiesel ranged between $1,400 and $1,700 per tonne in the second quarter of 2025, although the prices were around $1,200/tonne in 2024; see IMARC Group, *Biodiesel Prices, Trend, Chart, Demand, Market Analysis, News, Historical and Forecast Data Report 2025 Edition* (Report ID: SR112025A22356), accessed August 11, 2025, https://www.imarcgroup.com/biodiesel-pricing-report#:~:text=Biodiesel%20Prices%20Q4%202024,kept%20the%20price%20trend%20upward.

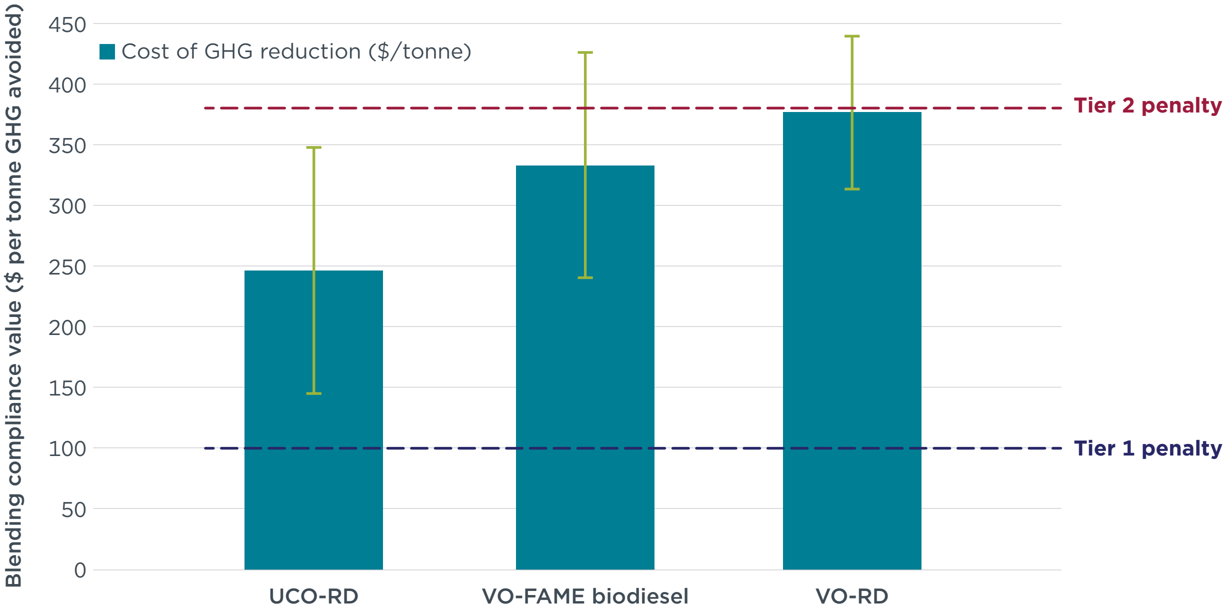
8 Cato Sandford and Chris Malins, *Full Steam Ahead? Environmental Impacts of Expanding the Supply of Maritime Biofuels for the International Maritime Organisation Targets* (Cerulogy, 2025), https://www.cerulogy.com/full-steam-ahead/.

9 1.22 kg oil per kg renewable diesel is assumed.

10 International Energy Agency, *Renewables 2022 Analysis and Forecast to 2027* (2022), https://www.iea.org/reports/renewables-2022.

**Figure 1**

**Cost of compliance under the Net-Zero Framework for various biofuel types**




*Note:* Soybean oil is used as an example for biodiesel (i.e., fatty acid methyl esters, or FAME) and VO-RD; the results would change for different vegetable oils.

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Table 1 illustrates the potential demand for RD in terms of the blend levels of alternative fuels and those fuels' total volumes through 2035, based on the simple relationship between target level, biofuel cost, and compliance penalties. These volumes factor in the contribution of increasing use of LNG in low-pressure dual-fuel engines, which slightly reduces the overall compliance burden. We note that this projection does not consider the contributions of alternative near-term methods of compliance, such as high-pressure fossil LNG engines or renewable natural gas (RNG), thus making this an estimate of the upper end of RD demand from the IMO's Net-Zero Framework.[11]

The table illustrates both the RD blend percentage increasing over the years to meet the compliance targets and the volumetric quantity of RD necessary to reach those blending levels. We estimate that the necessary vegetable oil-based RD blend will increase rapidly, reaching 46% of the energy demand by 2035. While UCO-RD can provide the bulk of compliance in the early years, we find that it reaches a peak contribution of 4.9% by 2030. In the subsequent years, we project that much of the remaining compliance could come from virgin vegetable oils.  The implied vegetable oil demand could reach as high as 139 billion liters by 2035, far in excess of the current quantities of vegetable oil used for existing biofuels policies today.

Renewable diesel produced from other fats and waste oils, such as tallow and brown grease, may contribute another 2% to the total energy demand in 2028, although we did not include them in our calculations for Table 1. While we estimate that fossil LNG could increase to 8.1% of the overall fuel mix by 2035, its impact is muted due to the high emissions of low-pressure engines. We estimate that fossil LNG reduces the quantity of VO-RD required by approximately 3.4 billion liters in 2035; even with an assumption of faster uptake, the impact of LNG on RD demand would be limited.[12]

11 There is substantial uncertainty concerning the contribution of RNG, based on the economic availability of different RNG pathways and their final LCA methodology used to assess their emissions.

12 When using a more aggressive estimate of 1.74 EJ of maritime LNG demand from a 2022 International Council on Clean Transportation study, we estimate that 7 billion liters of RD would be displaced by 2030.

**Table 1**

**UCO-RD and VO-RD blend ratios and volumes to comply with the base target emissions trajectory**

| | Shipping energy demand (EJ) | Base target trajectory (g $CO_2$e/MJ)[a] | Fossil LNG (% energy demand) | UCO-RD (% energy demand/ billion liters) | VO-RD (% energy demand/ billion liters) | UCO demand (billion liters) | VO demand (billion liters) |
|---|---|---|---|---|---|---|---|
| **2028** | 9.38 | 89.57 | 6.9 | 3.5 / 9.7 | 0 / 0 | 10.2 | 0 |
| **2029** | 9.49 | 87.70 | 7.1 | 4.9 / 13.6 | 1.4 / 4.0 | 14.3 | 4.1 |
| **2030** | 9.58 | 85.84 | 7.3 | 4.9 / 13.6 | 5.2 / 14.5 | 14.3 | 15.0 |
| **2031** | 9.66 | 81.73 | 7.5 | 4.8 / 13.6 | 13.3 / 37.7 | 14.3 | 39.0 |
| **2032** | 9.74 | 77.63 | 7.7 | 4.8 / 13.6 | 21.5 / 61.2 | 14.3 | 63.4 |
| **2033** | 9.83 | 73.52 | 7.8 | 4.7 / 13.6 | 29.7 / 85.2 | 14.3 | 88.3 |
| **2034** | 9.92 | 69.42 | 8.0 | 4.7 / 13.6 | 37.9 / 109.7 | 14.3 | 113.7 |
| **2035** | 10.0 | 65.31 | 8.1 | 4.6 / 13.6 | 46.0 / 134.5 | 14.3 | 139.3 |

*Notes:* UCO-based renewable diesel availability is used as a constraint, and the rest of the demand is assumed to come from soy oil-based renewable diesel. UCO and VO demand to reach the estimated renewable diesel volumes are included. Estimations for shipping energy demand for ships of ≥ 5,000 gross tonnage are from the ICCT's POLARIS Model; see Alvarez et al., *Polaris v1.3 Documentation*.

[a] The weighted carbon intensity of the blended fuel matches the base target trajectory.

Our results illustrate that the IMO's Net-Zero Framework could create substantial new demand for virgin vegetable oils.  However, we estimate the 2024 global consumption of vegetable oils and waste fats in biofuels production (Table A1) to be 60.1 billion liters (40 billion liters without waste fats). This suggests that even with a high degree of diversion from other transport sectors, the existing supply of vegetable oils and waste fats is insufficient to meet rising maritime demand under the Net-Zero Framework. We estimate that the supply of virgin vegetable oils is insufficient to meet the Net-Zero Framework targets beyond 2032 without the use of additional cropland or diversion from non-transport sectors.

# APPENDIX

## FORMULA FOR THE CALCULATION OF THE COST OF COMPLIANCE

$$\textit{Cost of compliance (\$/(t CO}_2\textit{e avoided))} = 10^6/(CI_{HFO} - CI_{fuel}) \times (\textit{Cost fuel} - \textit{Cost HFO})$$

Where:

| | |
|---|---|
| $CI_{fuel}$ | Carbon intensity of the fuel in g $CO_2e$/MJ |
| $CI_{HFO}$ | Carbon intensity of heavy fuel oil in g $CO_2e$/MJ |
| Cost fuel | in $/MJ |
| Cost HFO | in $/MJ |
| $10^6$ | Conversion from g $CO_2e$ to t $CO_2e$ |

*Notes:* Soy-renewable diesel is used as a vegetable oil example; soy-RD carbon intensity: 42.3 g $CO_2e$/MJ (RED II);[13] soy-FAME biodiesel carbon intensity: 35.74 g $CO_2e$/MJ; $1,000–$1,400/tonne price range used for FAME-biodiesel and $1,255–$1,535/tonne for RD (equal to $0.032/MJ for both at the baseline); lower heating value for soy-RD: 43,980MJ/tonne, soy-biodiesel: 37,841MJ/tonne.[14]

UCO-RD CI: 13.1 g $CO_2e$/MJ (calculated using GREET 2024[15] for domestic UCO), $1,067–$1,778/tonne price range is used (equal to $0.032/MJ at the baseline, lower heating value UCO-RD: 43,980MJ/tonne).

HFO CI: 92.78 g $CO_2e$/MJ (calculated using the emission factors for $CO_2$, methane, and nitrous oxide from HFO).[16] HFO price: $511/tonne ($0.013/MJ).

## FORMULA FOR THE CALCULATION OF WEIGHTED GFI

Tier 1 deficit: $\textit{Direct Target GFI} < \textit{Weighted GFI}_{blend} \leq \textit{Base Target GFI}$

$$\textit{Weighted GFI}_{blend} = (UCO_{RD}\,\% \times UCO_{RD}\,CI) + (VO_{RD}\,\% \times VO_{RD}\,CI) + ((1 - UCO_{RD}\,\% - VO_{RD}\,\%) \times HFO\,CI)$$

Where:

| | |
|---|---|
| $VO_{RD}$ | Vegetable oil-based renewable diesel |
| $UCO_{RD}$ | Used cooking oil-based renewable diesel |
| HFO | Heavy fuel oil |
| CI | Carbon intensity in g $CO_2e$/MJ |

13 Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources (Recast), *Official Journal of the European Union* L 328/82 (2018), https://eur-lex.europa.eu/eli/dir/2018/2001/oj.

14 Argonne National Laboratory, *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET)*, version GREET2_2024, 2024, https://greet.es.anl.gov/index.php.

15 Argonne National Laboratory, *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET)*.

16 International Maritime Organization, *Resolution MEPC.391(81) (Adopted on 22 March 2024) 2024 Guidelines on Life Cycle GHG Intensity of Marine Fuels (2024 LCA Guidelines)*, 2024, https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.391(81).pdf.

## FORMULA FOR THE CALCULATION OF POLICY PENALTY

The volume of $UCO_{RD}$ is used as a constraint, and by optimizing the % of vegetable oil blended, the minimum total cost is achieved.

*Policy penalty* ($/*liter*)

$$= (Weighted\ GFI_{blend} - Direct\ Target\ GFI) \times LHV_{blend} \times Tier\ 1\ penalty/10^6$$

Where:

| | |
|---|---|
| GFI | In g $CO_2$e/MJ |
| LHV | Lower heating value of the blend calculated as a weighted average (MJ/liter) |
| Tier 1 penalty | $100/tonne $CO_2$ |
| $10^6$ | Conversion from g $CO_2$e to t $CO_2$e |

## FORMULA FOR THE CALCULATION OF THE BLENDING PENALTY

*Blending penalty* ($/*liter*)

$$= \Big((UCO\_RD\ \% \times UCO\_RD_{price}) + (VO\_RD\ \%\ x\ VO\_RD_{price}) + (HFO\ \% \times HFO_{price})\Big) - HFO_{price}$$

**Table A1**

**Waste fats/oils and vegetable oils used for biofuels synthesis in 2024**

| | Million tonnes [a] | Billion liters |
|---|---|---|
| **UCO** | 12.9 [b] | 14.3 |
| **Tallow** | 4.9 | 5.4 |
| **Rapeseed/canola** | 8.6 | 9.3 |
| **Soy** | 12.4 | 13.5 |
| **Palm** | 13.7 | 15.4 |
| **Corn** | 1.9 | 2.1 |
| **Total** | **54.4** | **60.1** |

[a] U.S. values from U.S. Energy Information Administration, "Monthly Biofuels Capacity and Feedstock Update with Data for May 2025, Feedstocks Consumed for Production of Biofuels," July 31, 2025, https://www.eia.gov/biofuels/update/. EU values from U.S. Department of Agriculture Foreign Agricultural Service, *Biofuels Annual, European Union* (2024), https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_The%20Hague_European%20Union_E42024-0024.pdf. China values from U.S. Department of Agriculture Foreign Agricultural Service, *Biofuels Annual, China-People's Republic Of* (2024), https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_Beijing_China%20-%20People%27s%20Republic%20of_CH2024-0100. UK values from UK Department of Transport, "Official Statistics, Renewable Transport Fuel Obligation Statistics 2024: Third Provisional Release," February 12, 2025, https://www.gov.uk/government/statistics/renewable-transport-fuel-obligation-statistics-2024-third-provisional-release. Brazil values from U.S. Department of Agriculture Foreign Agricultural Service, *Biofuels Annual, Brazil* (2024), https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_Brasilia_Brazil_BR2024-0022.pdf.

[b] Value from Sandford and Malins, *Full Steam Ahead?*

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