THE BARTLETT ENERGY INSTITUTE

How the IMO's mid-term measures might shape shipping's energy choices and transition to e-fuels

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UMAS is an independent commercial consultancy dedicated to catalysing the decarbonisation of the shipping industry. With our deep industry expertise, exceptional analytical capabilities and state-of-the-art proprietary models, we support our clients in navigating the complexities of this transition by providing groundbreaking data, analyses and insights. Internationally recognised for our work, UMAS delivers bespoke consultancy services to the maritime sector (including owners/operators, charterers, OEMs, and energy providers), alongside regulators, governments, and NGOs.

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About UCL

The UCL Energy Institute hosts a world leading research group which aims to accelerate the transition to an equitable and sustainable energy and trade system within the context of the ocean. The Shipping and Oceans Research Group's multi-disciplinary work on the shipping and ocean system leverages advanced data analytics, cutting-edge modelling, and rigorous research methods, providing crucial insights for decision-makers in both policy and industry. The group focuses on three core areas: analysing big data to understand the drivers of shipping emissions, developing models and frameworks to explore the path toward zero-emission shipping, and conducting social science research to examine the policy and commercial structures that enable the decarbonisation of the shipping sector.

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Executive summary

International shipping currently consumes over 200 million tonnes of oil[1] and is responsible for approximately 3% of global GHG emissions[2]. Over the next 25 years, shipping's global regulator, the IMO, has committed to reach net zero GHG emissions and is on track to adopt globally binding policy measures this year (2025) to drive to that outcome.

Headway on these mid-term measures was made in 2024 with the progressing of a draft text for the new regulations (a new chapter in IMO's MARPOL convention). However, many important decisions remain. The architecture and parameters of the measures are expected to be finalised through key negotiations in February (ISWG-GHG 18), April (MEPC 83) and potentially also in October (MEPC/ES.2). This will then crystallise the opportunities and risks for both existing and future assets associated with shipping's energy transition.

To help inform that process of finalisation, we have used the current best available evidence to consider a plausible set of scenarios and investigate the competitiveness of different fuel and technology choices within those scenarios based on a total cost of operation (TCO) assessment of a 14,000 teu containership.

The discussion and results focus on the extent to which e-fuels can be made competitive early in the transition (e.g. the period 2027-2035), relative to alternative low emission fuels and technologies. Unlike e-fuels, these are not expected to be dominant contributors to shipping's energy demand in the long run, whether because they will not be compliant with the increasing stringency of a global fuel standard (e.g. LNG, blue ammonia and CCS) or because they are not scalable and thus unlikely to be as competitive as e-fuels as demand grows (e.g. biofuels).

This study's questions are of critical importance to the viability and costliness of IMO's Revised Strategy targets. With such little time for an energy transition, unless the mid-term measures are able to immediately prompt the transition to e-fuels, the sector could easily be locked into a vicious cycle. Lack of a clear business case for e-fuels will undermine investment and prevent cost reduction through learning effects and supply chain development. This creates a risk that e-fuels will remain scarce and expensive, depriving the sector sight of its long-term transition pathway. Conversely clear signals from the IMO's mid-term measures can unlock long-run investment, stabilise returns and asset values, and unlock a myriad of co-benefits, including in the context of a just and equitable transition.

The analysis builds on modelling undertaken by DNV in 2024 for the IMO's comprehensive impact assessment (Task 2)[3]. It incorporates most of the assumptions from that process, including its low gas / LNG pricing outlook, but we apply more conservative (higher) costs for bioenergy and lower the limit on the abatement potential of CCS. Relative to DNV's assumptions, this makes it less cost-effective to use biofuel and CCS, and makes the use of e-fuels more competitive.

The key findings are summarised below.

[1] IMO: Fuel Consumption (DCS)

[2] IMO: Fourth Greenhouse Gas Study 2020

[3] Full report can be downloaded from IMODOCS (documents MEPC 76/7/13 and MEPC 76/INF.68 and addenda); registration is required

A fuel standard and flexibility mechanism alone is unlikely to start an e-fuel transition before 2040

The results show that a global fuel standard combined with a flexibility mechanism is unlikely to lead to competitive e-fuels before 2044. A combination of fossil fuels (including LNG), biofuels and CCS would be most competitive until up to 2036, thereafter ammonia dual fuel ships would be the lowest cost solution, albeit operating on blue ammonia until 2044. Ships that were more competitive in the period 2027-2035, would have at least a 25% higher total cost of operation from 2040 onwards. This illustrates that if shipowners order tonnage to maximise competitiveness over a short time horizon (e.g. looking only ~5 years ahead), the sector has a major risk of technology lock-in, potentially greater volatility in asset values, and exposure to higher transport costs. This is consistent with the findings in IMO's CIA Task 2.

To address this risk, we explored whether adding a multiplier that 'boosts' the credit given to e-fuels under a global fuel standard plus flexibility mechanism could help to make e-fuel use competitive. We explicitly tested a x2 multiplier (e.g. if the fuel standard limit requires a 50% reduction in GHG intensity, one ship running on zero emissions fuel could generate credits to offset three other similar ships operating on conventional fossil fuels). However, we find that even with the assistance of a x2 multiplier, it is not possible to make e-fuels more competitive than other fuels before 2041. Furthermore, we find that the multiplier would have to be set initially at x15 in 2030 (falling to x10 by 2035) to enable the competitiveness of e-fuels during this period.

Only policies with targeted e-fuel reward could effectively promote shipping's energy transition

The results show that only when there is a specific and targeted reward (e.g. direct subsidy) for the use of e-fuels at a level that closes the TCO gap between e-fuels and the lowest cost of compliance option, is there likely to be significant early (e.g. in the period 2027-2035) adoption of e-fuels.

A targeted e-fuel reward can be coupled to a number of architectures and parameters—both the low levy ($30-$120 per tCO_2e) and high levy ($150-$300 per tCO_2e) scenarios could deliver this type of reward from the revenue each generates. However, the low levy scenario's total revenues are close to the aggregate level of subsidies (if ringfenced only for e-fuels) needed in 2030. This undermines confidence that a low levy will create a sustained promotion of the energy transition and raises the risk of competition between the energy transition and the policy's ability to contribute to a just and equitable transition (another area of revenue use under discussion at the IMO). A high levy scenario would mitigate both those risks.

The levy and reward work in combination to close the competitiveness gap between e-fuels and other lower cost compliance options (LNG, biofuels, CCS, etc.). A high levy price reduces the magnitude of the reward rate needed—our findings show that $28 per GJ is required as the reward rate in this scenario in 2027, compared to $36 per GJ in the low levy price scenario. Both of these reward rates are higher than those used in IMO's CIA Task 2 modelling, which helps to explain why those outputs signalled low take-up of e-fuels in the early years of the transition, even in the high levy scenario.

Adding a flexibility mechanism in levy scenarios does not change the need for a targeted reward under the assumptions used in the modelling, A low levy scenario with a flexibility mechanism requires a higher level of reward to ensure the competitiveness of e-fuels in 2027-2035, than the high levy scenario. Incorporating a multiplier does not alter the reward required in that period but can have an effect on the competitiveness of e-fuels (and thus reduce the reward rate needed) from 2035 onwards.

The reward rate needed to close the e-fuel competitiveness gap is forecast to reduce over time in both this modelling and the analysis conducted in IMO's CIA Task 2. However, as the required reward rate is highly sensitive to a wide range of input assumptions, it will need careful and constant (e.g. annual) review, to ensure that the reward mechanism is effectively and cost-effectively promoting the energy transition. As the reward and levy work in combination, they do not both need to be reviewed and adjusted constantly—the levy price can be fixed for a period with the variation in total effect managed solely through manipulation of the reward rate.

Analysis highlights the sensitivity of scenario modelling to changes in key assumptions

The TCO analysis in this study illustrates how fuel prices and technology cost / performance determine optimal outcomes in response to different policy scenarios. Adjustments to those assumptions can drive materially different outputs to the results presented in the IMO's CIA Task 2 modelling. Changes to the most competitive technology / fuel combinations can then fundamentally shift the expected energy mix.

Adjusting the CCS capture rate and biofuel prices in line with recent studies produces significantly different outcomes in all scenarios relative to those derived by DNV, reducing and shortening the viability of these two options (albeit with them still providing compliance at a competitive cost early in the transition). Ammonia (blue and then e-ammonia) becomes the most cost-effective fuel / technology choice from the mid-2030's. Across the wider range of fuel types, e-fuels have the least cost of compliance through the 2040s, i.e. they are the key for minimising the long-run cost of operation.

Any scenario modelling is highly sensitive to these uncertain parameters. Again, regular (e.g. annual) reviews and clearly stated objectives for review will be needed to ensure that the policies introduced are on track for delivering the IMO's targets, and so that incentives can be adjusted to promote the energy transition in a cost effective manner.

Introduction

The IMO's mid-term measures should support both its near and long-term goals

Shipping is fundamental to international trade and thus the global economy, but it is also responsible for an estimated 3% of the world's greenhouse gas (GHG) emissions[4]. The bulk of these emissions are generated by the deep sea fleet—large ships sailing long distances—for which electrification is unlikely to be a viable option. The decarbonisation of the industry will rely largely on new low and zero emission fuels replacing the fossil fuels currently used. These alternative fuels are currently more expensive than fossil fuels and so regulators will need to step in to mandate their uptake and/or assist in bridging the cost gap.

The EU has adopted both approaches with shipping's inclusion in the EU ETS from 2024 and the introduction of FuelEU Maritime (which obliges the use of lower emission fuels) from 2025. However, the International Maritime Organization (IMO) is likely to be the key driver of shipping's energy transition when its mid-term measures are launched in 2027. This basket of measures will aim to deliver the targets set in the IMO's 2023 Revised GHG Strategy—namely, a reduction in absolute well-to-wake (WtW) GHG emissions from international shipping by a minimum of 20% (striving for 30%) by 2030, 70% reduction (striving for 80%) by 2040, and 100% reduction around 2050, all compared with baseline 2008 WtW GHG emissions[5].

The 2030, 2040 and 2050 targets provide clear signposts, but it is difficult to project which combinations of policies can deliver these goals given the current uncertainty over the future availability and cost of different lower emission fuels, realistically attainable efficiency gains, changing patterns in trade, and the ability of the global fleet to adapt given the typical longevity (~25 years) of ships. Clearly, changes in GHG emissions in response to the measures adopted will need to be assessed on a continuing basis and adjusted appropriately. However, unless the IMO addresses both the short and long-term targets through its mid-term measures, those later goals may be missed.

The IMO's 2030 target (20%–30% reduction in absolute GHG emissions) could be reached through a range of solutions that increase efficiency and/or utilise fuels or technologies which can generate the required marginal improvements in GHG emissions, and the options with the lowest cost of compliance will naturally be selected. However, the pool of viable solutions will shrink as the hurdle for meeting compliance rises, until a point when further reductions in GHG emissions will only be delivered by switching to significantly lower emission fuels. These include biofuels, 'blue' fuels (derived from fossil fuels utilising carbon capture and sequestration on land), and fuels made from renewable energy (e-fuels).

To achieve the level of GHG emissions reductions required from 2040 to 2050, international shipping will need access to large volumes—between 200 and 300 million tonnes of oil equivalent—of zero (or near zero) emission fuels[6]. With the supply of biofuel constrained and a limit on how much the GHG emissions intensity of blue fuels can be lowered through carbon capture, the general consensus is that the scalable and sustainable solution for shipping over the long term will be e-fuels.

[4] IMO: Fourth Greenhouse Gas Study 2020

[5] IMO: 2023 IMO Strategy on Reduction of GHG Emissions from Ships

[6] Getting to Zero Coalition: Climate action in shipping 2024

The key risk to attaining those long-term targets is that e-fuels are currently more expensive to produce than biofuels or blue fuels. Although e-fuels are expected to become more competitive over time as production capacity grows, there will be little organic demand for them until this happens. This could lead to a cliff edge in the final decade of the energy transition when zero (or near zero) emission fuels are needed but are either not available in the quantities required or still much more expensive than less sustainable fuels.

As the IMO determines the optimal combination of policies through which to achieve its targets, it should also consider what actions it can take to support a gradual ramp up in e-fuel use so that the later stages of shipping's energy transition are not exposed to this potential cliff edge.

Understanding the limitations of the IMO's comprehensive impact assessment

Since adopting its Revised GHG Strategy in July 2023, the IMO has carried out a comprehensive impact assessment (CIA) to evaluate which measures can deliver its targets. The final report was submitted in September 2024 and it included a technoeconomic assessment by DNV on the impact of different policy combinations on the make-up of the global fleet out to 2050, the costs associated with meeting the GHG emissions reduction targets, and the level of revenue generated by any charges applied to the industry[7].

DNV's techno-economic modelling estimated the optimal evolution of the global fleet under different policy combinations

In total, DNV modelled 88 discrete scenarios that met the IMO's 2030, 2040 and 2050 targets through varying combinations of the following measures:

1. **GHG Fuel Intensity (GFI) requirement:** This measure sets a limit on the maximum GHG emissions intensity of the fuels used by a ship which reduces over time. The policy was applied in every scenario either on a WtW or tank-to-wake (TtW) basis and the GFI trajectory needed to achieve the IMO's GHG emissions reductions targets in each of those scenarios was an output from the modelling.

2. **GFI flexibility mechanism:** The GFI was modelled both with and without a flexibility mechanism. This gives the option to pool or sell / buy excess compliance to offset undercompliance by other ships.

3. **Levy mechanism:** This measure applies a pre-set price to all GHG emissions from a ship. A high and low levy were modelled by DNV, in conjunction with a pre-determined reward to support the uptake of e-fuels.

4. **Feebate mechanism:** This measure is similar to the levy / reward system in that a fee is applied to all GHG emissions from each ship and a rebate is given to the ships using eligible e-fuels. However, unlike the levy / reward system, the fee is calculated retrospectively each year and is set at a level that balances the aggregate value of all rebates claimed.

[7] Full report can be downloaded from IMODOCS (documents MEPC 76/7/13 and MEPC 76/INF.68 and addenda); registration is required

Across a fixed set of input assumptions, DNV modelled a core set of 16 policy combinations (shown in Table 1). Key assumptions included the cost and GHG emissions intensity of fuels, the capital cost of new ships and of optional technologies (such as dual fuel capability, energy efficiency packages and onboard carbon capture and storage (CCS) systems), estimates of GHG emissions reductions through operational and technological means, and projections of future transport work.

Table 1: Core policy scenarios modelled in the CIA aligned with the IMO's base GHG emissions reduction targets

CIA scenario number	GFI scope	GFI flexibility	Levy	Feebate
21	TtW	No flexibility	No levy	No feebate
22	WtW	No flexibility	No levy	No feebate
23	TtW	Flexibility	No levy	No feebate
24	WtW	Flexibility	No levy	No feebate
25	TtW	No flexibility	High levy	No feebate
26	WtW	No flexibility	High levy	No feebate
27	TtW	Flexibility	High levy	No feebate
28	WtW	Flexibility	High levy	No feebate
29	TtW	No flexibility	Low levy	No feebate
30	WtW	No flexibility	Low levy	No feebate
31	TtW	Flexibility	Low levy	No feebate
32	WtW	Flexibility	Low levy	No feebate
33	TtW	No flexibility	No levy	Feebate
34	WtW	No flexibility	No levy	Feebate
35	TtW	Flexibility	No levy	Feebate
36	WtW	Flexibility	No levy	Feebate

Source: *MEPC 82/INF.8/Add.1 Report of the comprehensive impact assessment of the basket of candidate GHG reduction mid-term measures – full report on Task 2 (Impacts on the fleet)*

For each policy combination, DNV modelled the most economically optimal evolution of the global fleet year-by-year until 2050. This incorporated the building of new ships, the scrapping of old ships, the adoption of optional technologies, improvements in energy efficiency through reductions in speed, and the use of lower emission fuels. The modelling iterated between:

1. **Ship level**: Where the most cost-effective combinations of feasible speed reduction, optional technologies (for both new and existing ships), and use of alternative fuels were estimated from net present value (NPV) calculations (based on discounted cash flows).

2. **Global fleet level:** Where trade-related demand for tonnage (which was also influenced by speed reductions) shaped the required profile of the fleet on an annual basis.

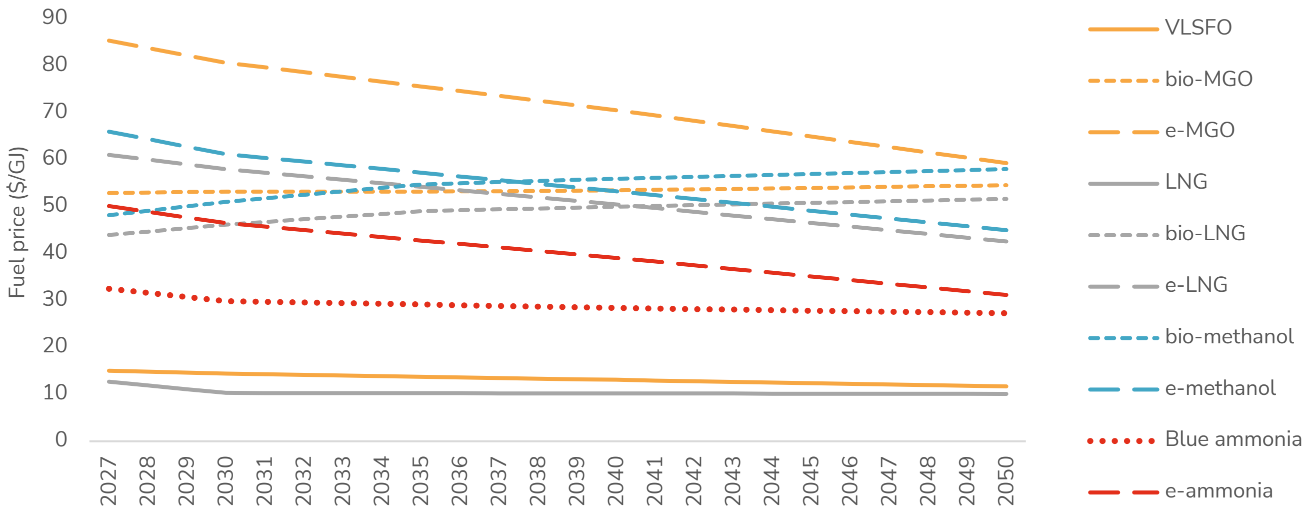
3. **GFI requirement:** Where GFI trajectories were estimated based on the alignment (±5%) of total GHG emissions against the IMO's revised targets.

The outputs from scenario modelling are highly sensitive to the input assumptions applied

Generally, modelling of the energy transition under policy scenarios is extremely sensitive to the inputs used as outcomes determined by NPV calculations typically all converge towards the lowest cost solutions. In DNV's modelling, fuel assumptions (price, availability and GHG emissions intensity) played a large role in driving fuel choice, as did the level of reward set for eligible e-fuels in the policy scenarios with a levy.

The fuel price projections used by DNV reflect a low gas price outlook over the long term which translated into low fossil LNG prices (falling from $680 in 2023 to $440 per tonne of VLSFO equivalent from 2030 onwards). The price of biofuels was dependent on a projected maximum of total supply available to shipping (0.4 EJ by 2030, 2.0 EJ by 2030, and 3.2 EJ by 2050). Once the demand for biofuels in each scenario breached this supply limit, the price of biofuels was assumed to increase to that of the equivalent e-fuel (e.g. biomethanol price rising to that of e-methanol), adjusted for the relative GHG emissions intensity of the bio and e-fuel.

Figure 1: Fuel price projections for major fuels and production pathways used in the CIA



Source: *MEPC 82/INF.8/Add.1 Report of the comprehensive impact assessment of the basket of candidate GHG reduction mid-term measures – full report on Task 2 (Impacts on the fleet)*

In the levy scenarios, a portion of the revenues raised were assumed to be directed to reward the use of eligible e-fuels. DNV calculated pre-defined rewards based on the price spread (adjusted for relative GHG emissions intensity) between e-ammonia (the cheapest e-fuel) and bio-LNG (the cheapest biofuel). In the high levy scenario, the reward was set at 95% of the fuel price spread in 2027, falling to 65% by 2040, and withdrawn thereafter. In the low levy scenario, the reward was set at 105% of the fuel price spread until 2040.

In the long run, fuel choice was less sensitive to the capital cost of any associated technology (i.e. dual fuel capability and/or CCS) as this was quickly outweighed by the increasing volume (and thus cost) of alternative fuel required. However, DNV's estimation of a maximum capture rate of 75% for CCS (the proportion of CO_2 that could feasibly be captured and stored on board a ship) did have a significant impact on the modelling. When combined with cheap fossil LNG, their modelling indicated that the lowest cost option to meet compliance over the short-to-medium term for much of the global fleet would be through LNG dual fuel capability plus CCS—with the CCS extending the period over which fossil LNG could be used.

Testing three key assumptions used in the CIA through TCO analysis at the ship level

This study aims to test the CIA outputs through total cost of ownership (TCO) modelling at the level of an individual ship using a 14,000 teu containership sailing between Asia and Latin America as a proxy. The TCO model calculates the capital, operating and fuel cost for every viable technology and fuel combination for this ship in each year. While an annual TCO has some parallels to the NPV approach used in the CIA, this assessment examines the relative competitiveness of different technology / fuel combinations each year rather deriving than the economically optimal configuration of a ship over its economic life.

The analysis in this report re-uses DNV's input assumptions to maintain as much comparability to the existing results as possible, but adjustments have been made to three key variables:

1. **CCS capture rate:** A lower maximum CO_2 capture rate than used in the CIA has been assumed (in line with a recent study which indicates that the quantity of CO_2 avoided in practice is significantly lower than stated maximum capture rates[8]).

2. **Biofuel pricing:** By removing the supply constraints and instead projecting continuous cost curves for biofuels which reflect demand-driven (including out of sector) pricing, the points at which switching to and away from biofuels occurs is more transparent.

3. **Support for e-fuels:** Rather than set pre-determined rewards for e-fuels in the scenarios with a levy, the reward required to bridge the cost gap (on a TCO basis, i.e. including capital costs) in each year between e-ammonia (the lowest priced e-fuel) and the lowest cost of compliance was derived as an output from the analysis. In the scenarios with a flexibility mechanism, a pooling multiplier was included as a support mechanism for eligible e-fuels. This was not modelled in the CIA as it did not have any political support when the assessment was conducted.

The policies modelled in the CIA were representative of the proposals put forth by member states. Whilst in practice, all these options remain under discussion, the policy debate at the last negotiation (ISWG-GHG 17 and MEPC 82) reached some crystallisation around three key policy parameter specifications with similar magnitudes of political support—1) GFI with a flexibility mechanism but no levy; 2) GFI without a flexibility mechanism but with a levy; and 3) GFI with a flexibility mechanism and a levy[9]. Therefore, to reflect the range of positions in the debate at MEPC 82, the TCO modelling has been based on the following policy scenarios from the CIA (delivering the IMO's base 2030 and 2040 targets):

1. **CIA scenario 24:** WtW GFI plus flexibility mechanism. This scenario has similarities with the International Maritime Sustainable Fuels & Fund (IMSF&F) proposal put forward by China, and supported by Norway, Brazil and the UAE.[10]

2. **CIA scenario 26:** WtW GFI plus high levy / reward. This scenario is aligned with the position of the 6PAC+ alliance of Small Island Developing States which strongly support a high levy.

3. **CIA scenario 32:** WtW GFI plus flexibility mechanism plus low levy / reward.

[8] OGCI: Project REMARCCABLE Report

[9] UCL: IMO MEPC 82 readout

[10] IMO: GHG-EW 3-INF.3 - Factsheet On International Maritime Sustainable Fuels And Fund Mechanism (China) (2).pdf

Basis for TCO modelling: policy scenarios and key assumptions

Understanding the individual and combined impacts of different policy measures

The GFI and the levy exert different pressures and their relative impact over the transition changes. Therefore, it is useful to consider each measure individually, before in combination. The GFI is a technical measure which will drive the decarbonisation of shipping by mandating the use of lower emission fuels, but its effect will increase incrementally through the transition. The levy is an economic measure and its impact will be strongest over the short-to-medium term, but this will fade as shipping decarbonises, even as the levy rises.

Different GFI trajectories were generated for the policy scenarios in the CIA but all largely converge by 2040

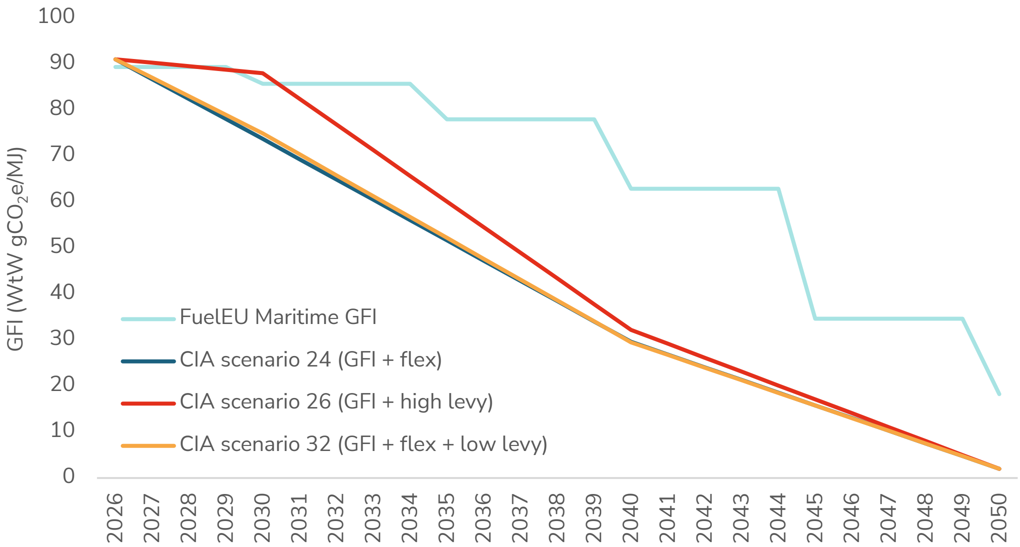
The GFI is intended to deliver an absolute reduction in GHG emissions by necessitating the use of fuels with lower emissions intensity (although technological solutions such as adding wind propulsion or installing CCS could also contribute to compliance with the GFI). As the GFI drives the switch away from fossil fuels to lower emission alternatives, fuel choice will be dictated by the relative spread in the cost of abatement (i.e. a function of fuel price and emissions intensity) with any associated capital costs (i.e. in dual fuel capability) factored in. Where CCS is used to comply with the GFI, the additional longevity granted to fossil fuels needs to be weighed against the additional capital cost.

Shipping in the EU is already exposed to a GFI; FuelEU Maritime came into force at the start of 2025. However, the trajectories derived in the CIA indicate that the IMO will need to apply a GFI with a steeper reduction in emissions intensity (particularly post-2030) to hit its base targets. As the GFI reduces the emissions intensity of the fuels used by ships, the GFI trajectory adopted by the IMO will be shaped by the overall demand for fuel by shipping. This will be influenced by the long-term outlook on trade (and thus the level of shipping activity) and by policies that reduce the quantity of fuels used, i.e. measures that mandate (such as CII) or encourage (e.g. through a levy) increased efficiency. If the GFI measure is introduced with the option to pay a penalty as a means to comply (i.e. 'pay to pollute'), then the GFI trajectory may need to be even steeper to ensure that the IMO's absolute emissions targets are met.

The analysis of each policy scenario in the CIA began with an assessment of the reduction in absolute emissions that could be achieved through increased efficiency, and DNV then iteratively derived the GFI trajectory required to hit the IMO's absolute emissions reduction targets. Every scenario aligned (roughly) with one of two GFI trajectories. High levy scenarios triggered greater adoption of operational (i.e. speed reduction) and technological (i.e. energy efficiency packages) efficiency to reduce the overall level of emissions upon which the levy was applied. All other scenarios assumed smaller efficiency gains and so primarily relied upon the GFI to generate the required reduction in absolute GHG emissions and thus necessitated a steeper GFI trajectory.

The trajectories in Figure 2 illustrate the range of plausible GFIs that the IMO may introduce to attain its base GHG emissions targets. Whether the GFI is closer to the upper or lower boundary will be influenced by projections on trade growth and expectations around potential efficiency gains, whether delivered via the levy or due to the stringency of CII mandating greater efficiency over the near term.

Figure 2: GFI trajectories for base GHG emissions targets calculated for scenarios 24, 26 and 32; shown alongside the FuelEU Maritime GFI



Source: *MEPC 82/INF.8/Add.1 Report of the comprehensive impact assessment of the basket of candidate GHG reduction mid-term measures – full report on Task 2 (Impacts on the fleet)*

The convergence of the derived trajectories by 2040 indicates that subsequent reductions in absolute GHG emissions can only be delivered through the GFI. Post-2040, shipping will need access to sustainable and scalable zero (or near zero) emission fuels. The incrementalist approach to compliance fostered by the GFI means that this measure in isolation is unlikely to trigger significant use of the long-run solutions that shipping will eventually need early in the transition.

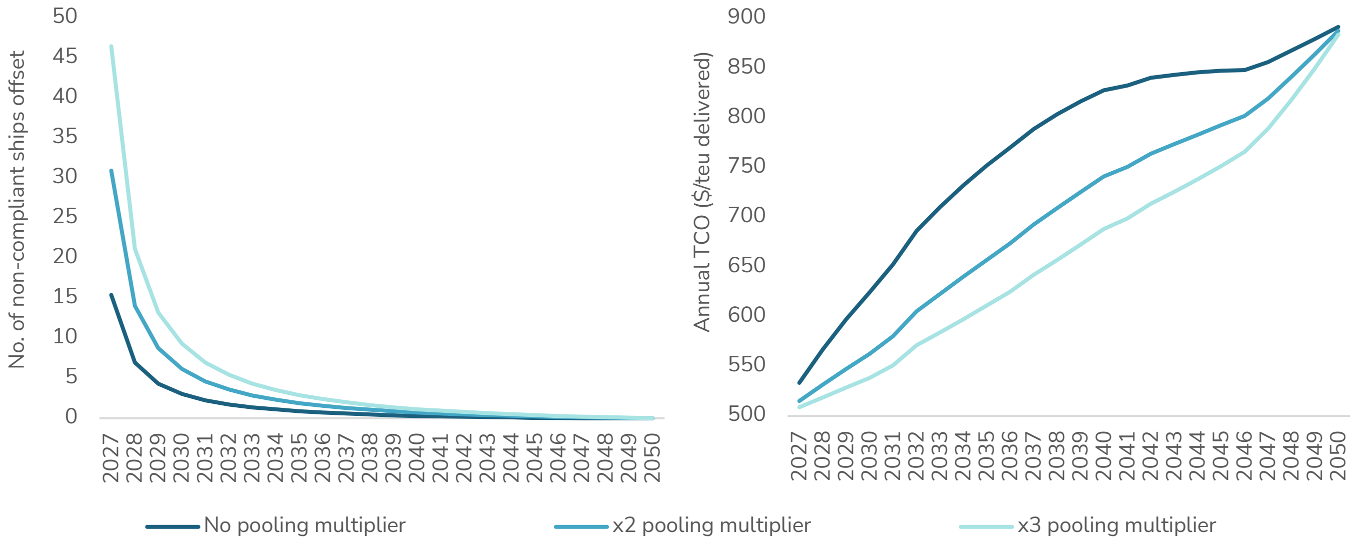
A GFI with a flexibility mechanism allows for capital costs to be pooled; a multiplier could be used to support at eligible e-fuels

A flexibility mechanism allows for overcompliance with the GFI limit by a ship to be used to offset under compliance by other ships. For example, a ship running entirely on a low emission fuel can offset conventional ships continuing to run on VLSFO. This enables capital costs (for dual fuel capability or CCS) to be shared between the pool of ships that compliance is averaged across. The number of non-compliant ships that can be offset is determined by the relative emissions intensity of the GFI and the fuels that the non-compliant and over-compliant ships are using but it decays very quickly as the level of pooled compliance required by the non-compliant ships increases while the surplus from the over-compliant ship falls (Figure 3).

In addition to the benefit of pooling capital costs (which applies across all fuel types), a GFI with a flexibility mechanism could potentially be structured to offer targeted support for eligible e-fuels through a pooling multiplier. This would scale the level of overcompliance generated by e-fuel use. For example, with a x2 multiplier, a ship running entirely on e-fuels would offset double the number of non-compliant ships that a non-eligible fuel of equivalent emissions intensity would.

Support structured in this manner is not linear (with the relative benefit typically peaking in the mid-2030s) and so would naturally sunset as the number of pooled ships diminished. The efficacy of this type of support also decreases as the multiplier is increased. The chart on the left in Figure 3 shows the number of non-compliant ships running on VLSFO that a single ship (of equivalent energy demand) running entirely on e-ammonia offsets under policy scenario 24 (GFI plus flexibility mechanism). The chart on the right shows the pooled TCO calculation for a x2 and x3 multiplier.

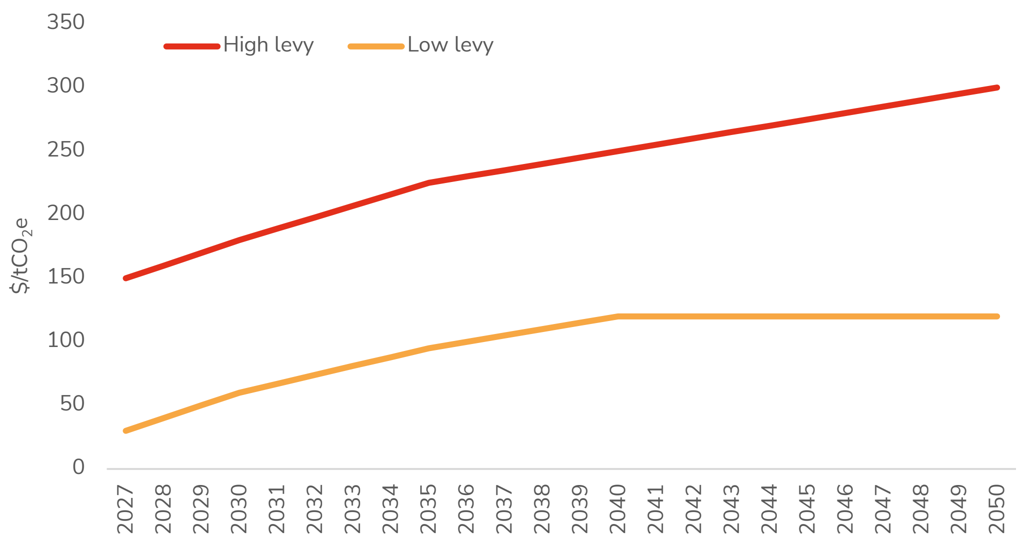
Figure 3: Pooling multipliers for CIA scenario 24—number of equivalent non-compliant ships offset (left) and average pooled TCOs (right)



Adding a levy (GHG price) to a GFI can encourage a reduction in total GHG emissions through increased efficiency

Two different levels of GHG pricing were modelled in the CIA: 1) a high levy which increased from $150 per tCO_2e in 2027 to $300 per tCO_2e in 2050; 2) a low levy which rose from $30 per tCO_2e in 2027 to $120 per tCO_2e in 2050.

Figure 4: High and low levy applied in CIA scenarios



Source: *MEPC 82/INF.8/Add.1 Report of the comprehensive impact assessment of the basket of candidate GHG reduction mid-term measures – full report on Task 2 (Impacts on the fleet)*

These levies apply to total GHG emissions and so provide an economic incentive to reduce total emissions, not just the portion required by the GFI. DNV's modelling concluded that a high levy would trigger increased adoption of operational and technical efficiency measures such as ships sailing at slower, more efficient speeds and installing energy efficiency technologies.

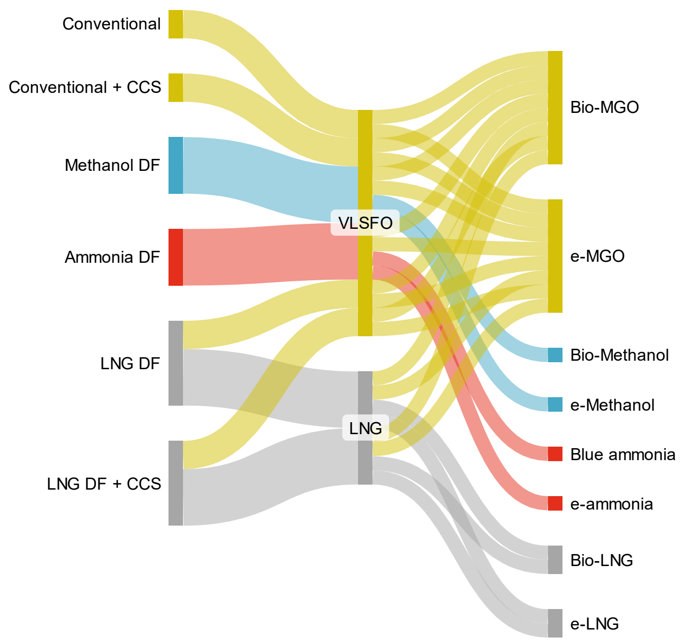
In practice, the degree to which efficiency gains could be achieved will not be uniform across shipping sectors. The opportunity to access operational gains may be constrained (for example, a limited ability to sail more slowly on a scheduled service). Shipping market dynamics may also make speed reduction uneconomical. In tight markets, the cost of chartering a ship for longer may outweigh the additional cost of the fuel and levy charge (an issue that could be compounded by slower sailing ships which will reduce overall supply in shipping capacity and thus raise charter rates). Split incentives—where the shipowner invests in efficiency technologies but the gains from lower fuel and levy costs accrue to the charterer (who is responsible for fuel costs)—means that capital investment in shipping sectors where chartering prevails may also face barriers.

Approach adopted in TCO modelling and adjustments made to CIA assumptions

The TCO analysis is based on a newbuild ship delivered in 2027 and multiple configurations of technology options and fuel choices are modelled. Capital and operating costs are drawn from the CIA, and although that analysis assumes reductions in capital costs for dual fuel capability, cutting edge energy efficiency technologies and CCS due to a learning effect, the TCO outputs (on a relative, if not absolute, basis) should be a reasonable proxy for ships built after 2027.

An annual TCO has been calculated for ships of different technical configurations and for each viable fuel that can be used by that configuration. In total, up to 24 combinations have been evaluated (Figure 5). For each configuration and in each year, multiple TCOs have been calculated based on differing quantities of alternative fuel use and (where applicable) pooling through the flexibility mechanism—and the lowest cost TCO isolated from the analysis.

Figure 5: Technology and fuel combinations assessed in TCO modelling



The TCO analysis is based largely on the assumptions used in the CIA—this includes most fuel prices, the emissions intensity of fuels, ship-related capital and operating costs, the estimated fuel saving from speed reductions and energy efficiency packages, and the GFI trajectories. Voyage data—sailing speed, round trip distance, number of port calls, duration at port, and fuel consumption—is based on examples of modern 14,000 teu containerships sailing between Asia and Latin America, This data has been obtained from the UMAS Fuse database which estimates fuel consumption for all ships based on AIS data.

It is assumed that under scenario 26 (GFI plus high levy / reward), the high levy stimulates an increase in efficiency through slower sailing (a 10% reduction in speed is assumed to reduce fuel consumption by 10%) and additional investment in energy efficiency technologies. This means that the annual level of transport work is lower in scenario 26 compared with the other policy scenarios. Therefore, absolute rather than marginal TCOs have been calculated. The TCOs incorporate the full annualised capital and operating cost of the underlying ship (not just the incremental cost of dual fuel capability or CCS) and outputs are shown in $ per teu delivered to ensure comparability across the policy scenarios.

However, the capital cost of the underlying ship, dual fuel capability, CCS and EETs are all amortised over 25 years at the low (4%) discount rate used in the CIA analysis. In practice, investment in fuel and efficiency related technologies may be amortised over a shorter period and/or at a higher discount rate. Therefore, the TCOs should not be read as definitive costs but instead serve as a guide to the relative spreads in different technology and fuel options over time under these input assumptions and illustrative policy combinations.

While most assumptions align with those used in the CIA, the basis for modelling CCS has been altered. New inputs are drawn from a recent report by OGCI and Stena[11], giving a lower capture rate and also fuel penalty. The main outcome from this adjustment is that 100% VLSFO and fossil LNG have a much shorter viable runway before lower emission alternatives (biofuels and e-fuels) need to be substituted in to maintain compliance with the GFI.

Table 2: Comparison of CCS assumptions used in CIA versus the TCO analysis

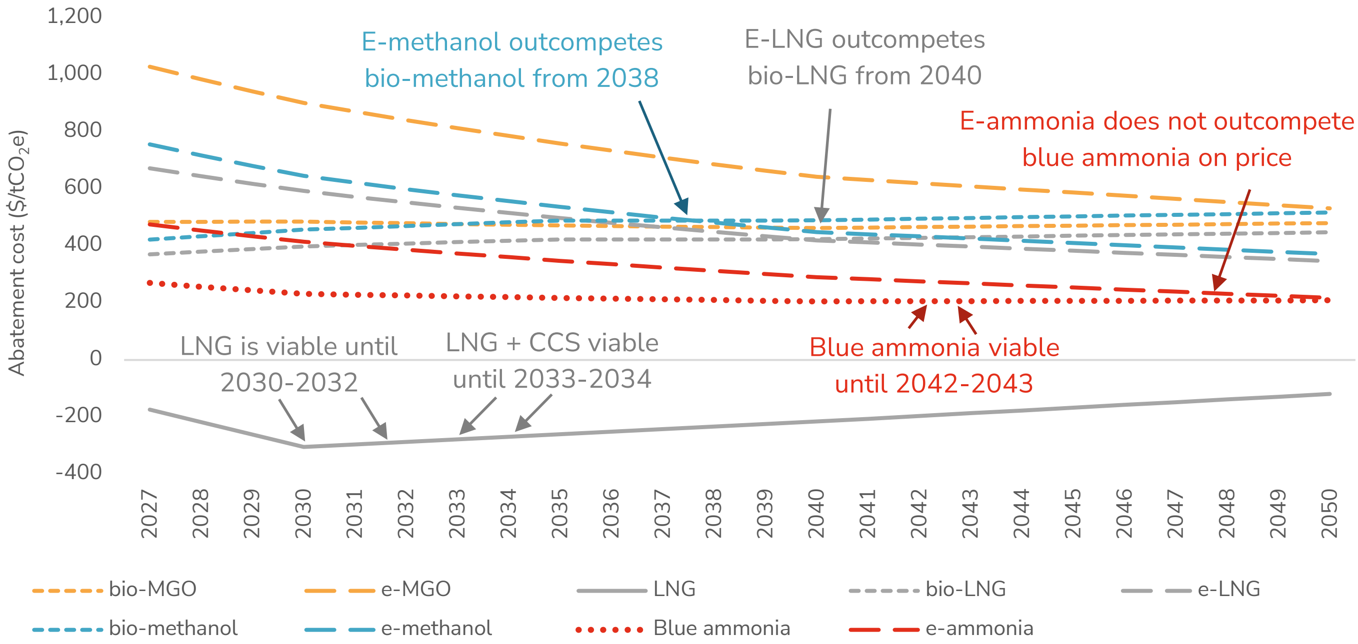
CCS assumption	DNV CIA	OGCI / Stena (TCO analysis)
On board capture rate	75%	27%
Fuel penalty	30%	10%
CAPEX (for deep sea containership)	$28m	
Incremental OPEX	Captured within fuel penalty	1.25% of CAPEX per year
CO_2 sequestration cost	Falling from $80 per tCO_2 in 2027 to $60 per tCO_2 in 2050	

The TCO modelling also incorporates higher biofuel prices to reflect expected upward pressure given constrained supply and out of sector demand (e.g. from aviation). These prices came from analysis conducted under the submission MEPC 79.INF29[12]. Figure 6 shows the abatement costs of all fuels versus VLSFO. DNV's low gas price outlook leads to a negative abatement cost for fossil LNG (although the longevity of 100% fossil LNG use is limited by its emissions intensity to the early 2030s, following which increasing proportions of a lower emission fuel needs to be gradually substituted in) and a low blue ammonia cost of abatement (which has a similarly-driven emissions intensity constraint in the early 2040s).

[11] OGCI: Project REMARCCABLE Report

[12] Full report can be downloaded from IMODOCS (document MEPC 79.INF29); registration is required

Figure 6: Cost of abatement for fuels used in TCO modelling



It should also be noted that the TCOs calculated are based on annual changes in fuel prices and emissions intensity, and so do not reflect any exposure to locked-in pricing through fuel offtake agreements. All key assumptions are listed in the Appendix.

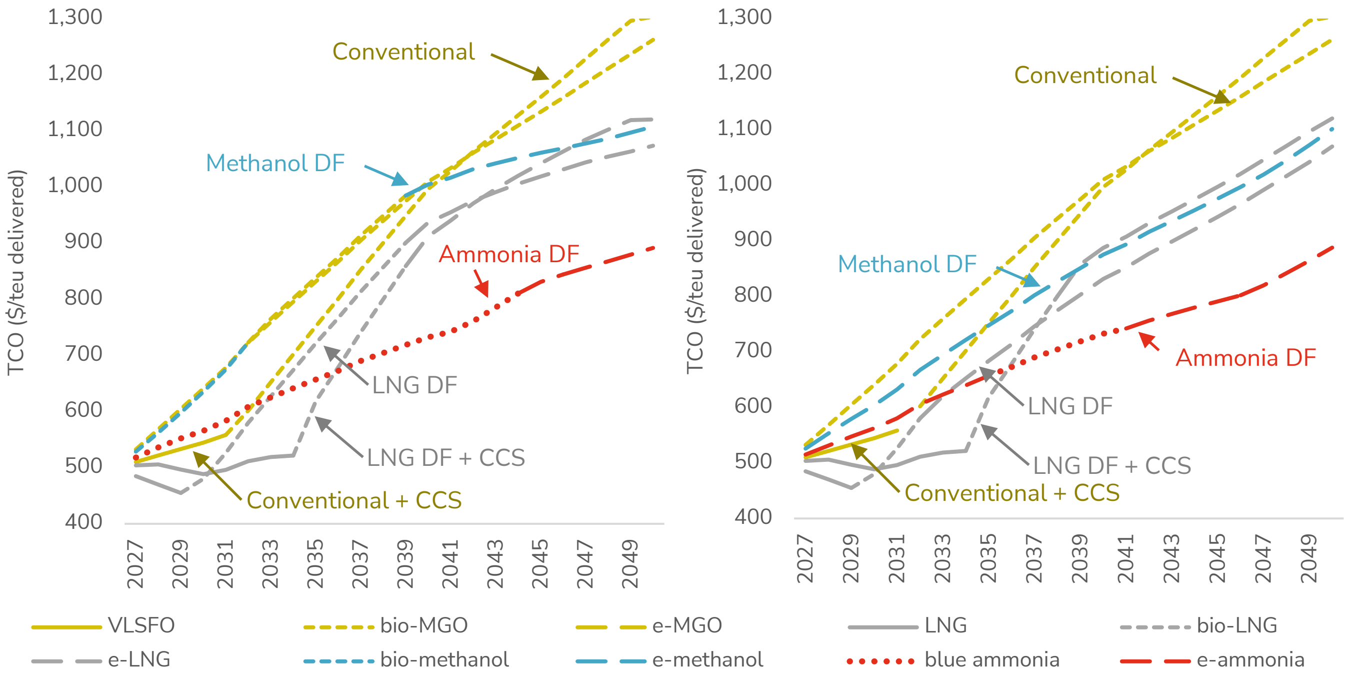
Findings on how different policy options effect the energy transition

Scenario 24: A multiplier cannot make e-fuels competitive over the short-to-medium term

Figure 7 shows the minimum annualised cost of operation of a 2027 newbuild 14,000 teu containership for a range of technology options under scenario 24 (WtW GFI plus flexibility mechanism). Each trajectory reflects the lowest cost fuel option associated with a technology option and changes to the line style indicate when switching between fuel types occurs (e.g. between fossil, bio and e-fuel variants of a given fuel). This change can either be triggered by the emissions intensity of the existing fuel no longer complying with the GFI (in which case the new fuel is substituted in in increasing quantities) or due to the abatement cost of a fuel dropping below that of the existing fuel. Examples of the former are seen in the introduction of bio-MGO, bio-LNG and e-ammonia to dilute VLSFO, LNG and blue ammonia respectively. An example of the latter is the switching from bio-methanol to bio-MGO to e-methanol.

The charts reflect the lowest cost TCOs for scenario 24 without (left) and with (right) a x2 pooling multiplier. Initially, the TCOs are closely clustered, a reflection of the pooling effect of the flexibility mechanism on capital costs. The low gas (and thus LNG) price outlook applied in the CIA means that LNG dual fuel and LNG dual fuel plus CCS are the lowest cost technology options until the early-to-mid 2030s until the increasing quantities of bio-LNG required lift those TCOs above that of blue ammonia. Without a multiplier, fuel price-driven switching from bio-LNG to e-LNG and bio-methanol to e-methanol occurs in the late 2030s, while e-ammonia (the lowest cost e-fuel) isn't utilised until 2044 when it starts to be dropped in to compensate for the higher emissions intensity of blue ammonia.

Figure 7: Scenario 24—lowest cost TCO without (left) and with (right) a x2 multiplier

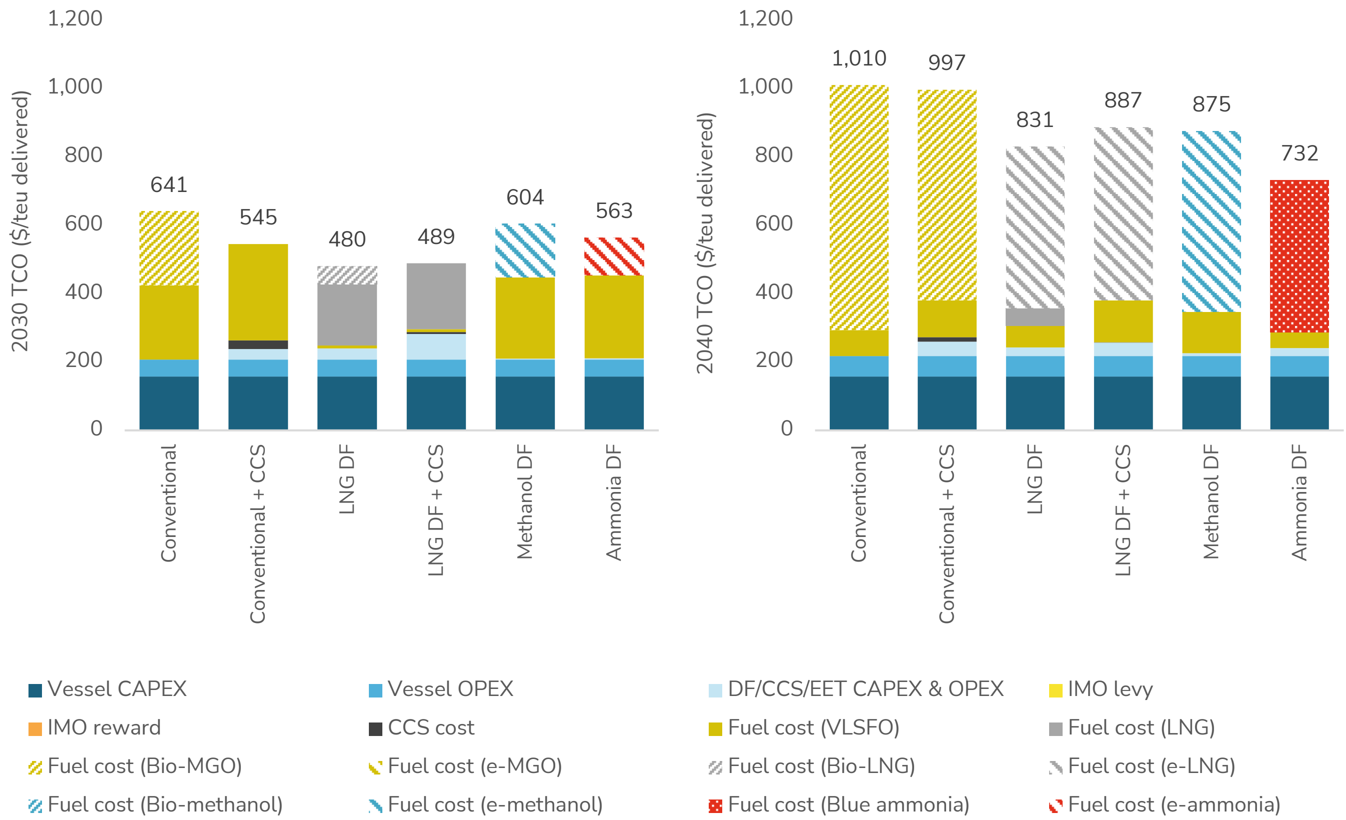


The multiplier triggers earlier switching from bio-methanol and bio-LNG to e-methanol and e-LNG respectively, however it does not offer enough support to enable e-MGO to outcompete bio-MGO. Under the multiplier, neither of these technology options (methanol or LNG dual fuel) becomes competitive relative to ammonia dual fuel.

The multiplier could potentially promote e-ammonia over blue ammonia up to the mid-2030s, but the e-ammonia and blue ammonia TCOs are very close over this period, indicating that a multiplier may be insufficient to drive e-ammonia uptake if fixed price offtake agreements lock in high prices. However, the ammonia dual fuel technology option remains far less competitive than the LNG dual fuel option (using fossil LNG / bio-LNG) until 2034 and the LNG dual fuel plus CCS until 2036, so even with the multiplier, the lowest cost TCO moves from fossil LNG / bio-LNG to blue ammonia.

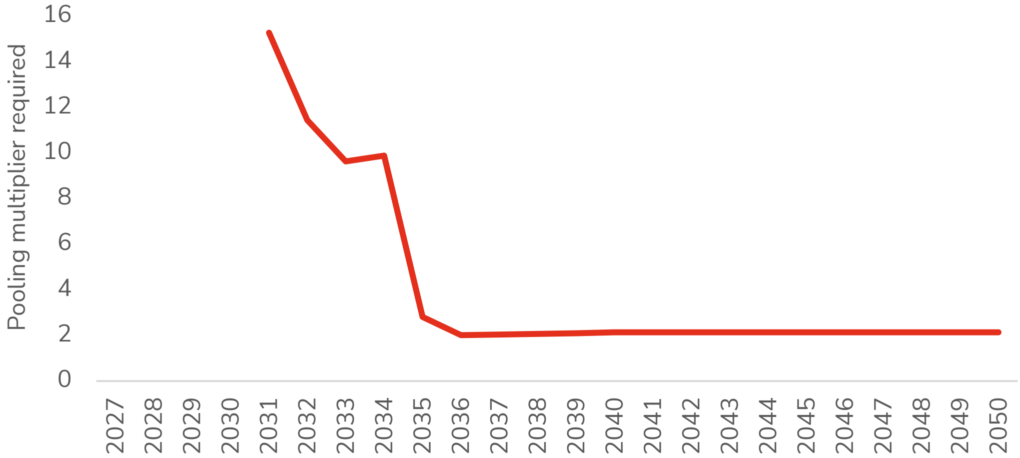
Figure 8 shows the relative size of the TCO components in 2030 and 2040 with a x2 pooling multiplier. The negative cost of abatement for fossil LNG (relative to VLSFO) means that the former displaces the latter in the LNG dual fuel and LNG dual fuel plus CCS technology options. In 2030, total (annualised) capital, operating and fossil fuel costs outweigh the burden of higher price low emission fuels. By 2040, however, alternative fuel costs make up the major portion of the total TCO.

Figure 8: Scenario 24—TCO breakdown in 2030 (left) and 2040 (right) with a x2 multiplier



To offer greater support for e-fuels early on in the transition, a higher pooling multiplier could be introduced. However, the relative benefit of the multiplier does not scale linearly with size. Given the negative abatement cost of fossil LNG, no multiplier would be able to bridge the TCO gap between e-ammonia and the lowest cost LNG dual fuel / LNG dual fuel plus CCS option initially. From 2031 onwards, a pooling multiplier could bridge the TCO gap. The size required falls from approximately x15.3 to x2.1, with the latter sufficient to keep the e-ammonia option on par with blue ammonia through the late-to-early 2030s (Figure 9).

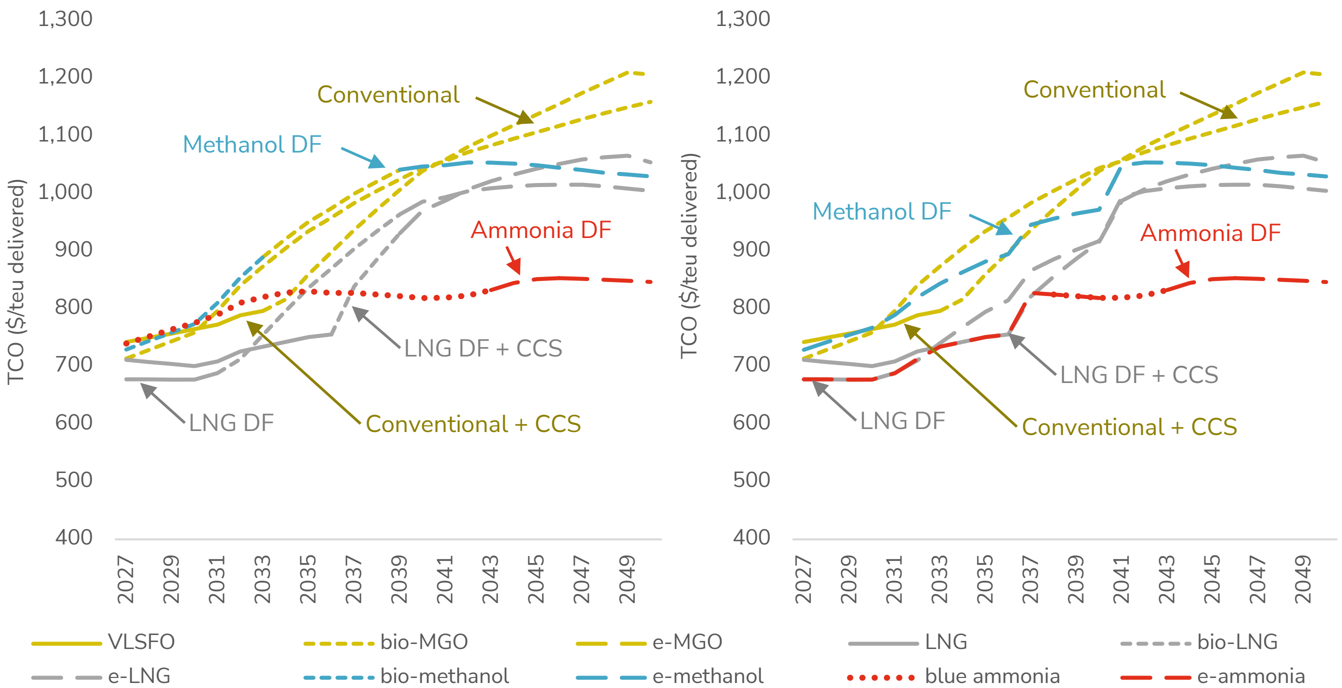
Figure 9: Scenario 24—pooling multiplier required to bridge gap between lowest cost option and e-ammonia TCO



Scenario 26: A high levy can create the revenue needed to subsidise early adoption of e-fuels

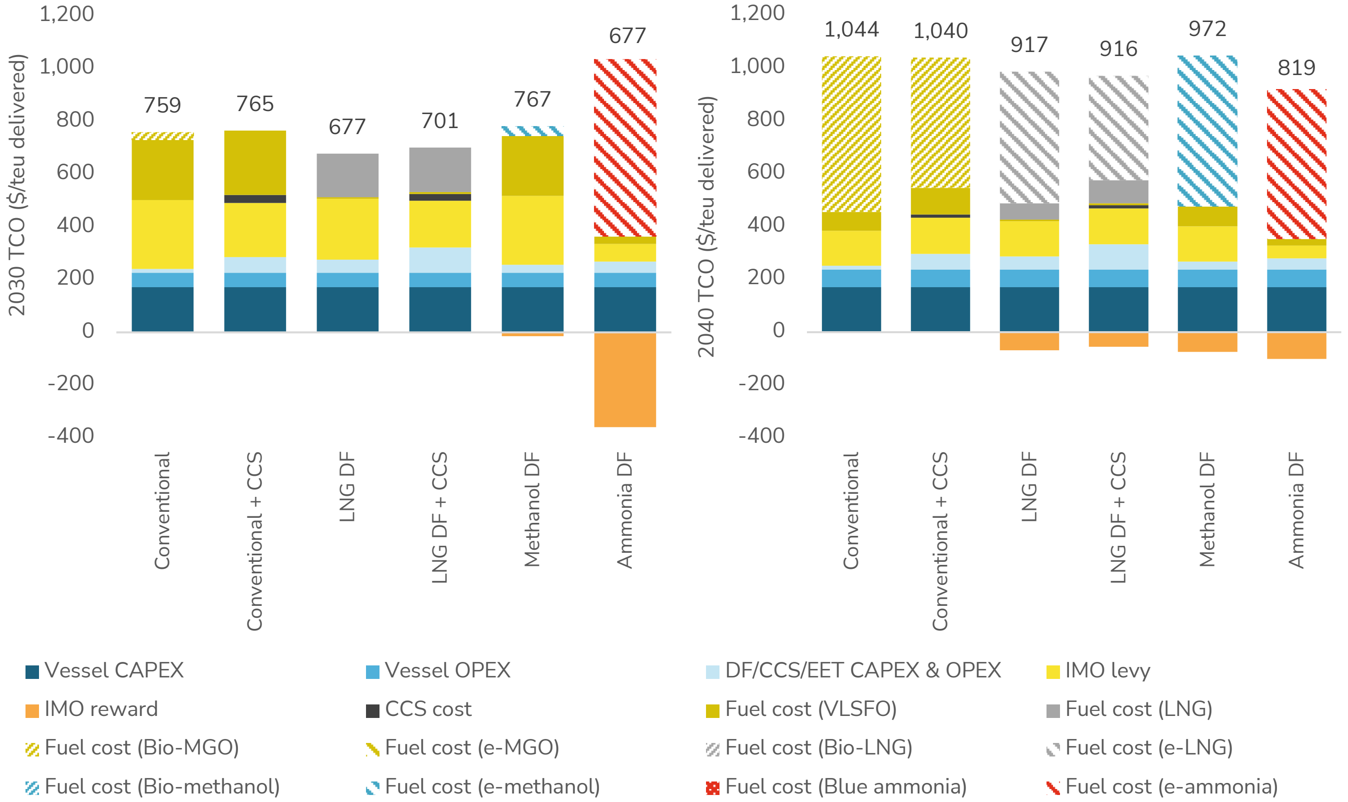
Figure 10 shows the minimum cost of shipping for a range of technology options under scenario 26 (WtW GFI plus high levy / reward). The chart on the left shows TCOs before e-fuels are subsidised and the chart on the right shows TCOs once the reward for e-fuels is applied. The level of reward required in each year has been calculated as the amount required to bridge the TCO gap between the lowest cost e-fuel TCO (e-ammonia) and the overall lowest cost TCO (LNG dual fuel, followed by LNG dual fuel plus CCS, followed by ammonia dual fuel with blue ammonia).

Figure 10: Scenario 26—lowest cost TCO by technology option without (left) and with (right) a reward



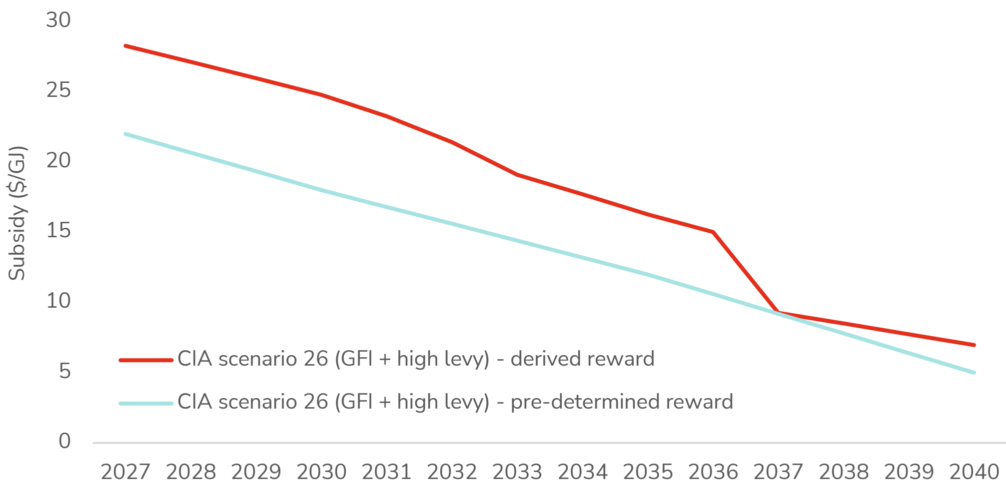
Due to the levy, the overall level of the TCOs is initially higher in scenario 26 compared with scenario 24 (WtW GFI plus flexibility mechanism). Although capital costs cannot be spread across a pool of ships in scenario 26, the shallower trajectory of the GFI means that the volume of lower emission fuel required to comply is relatively small until the early 2030s. As in scenario 24, the negative abatement cost of LNG means that the lowest cost TCOs initially are LNG dual fuel and LNG dual fuel plus CCS ships running entirely on LNG (less pilot fuel).

Figure 11: Scenario 26—TCO breakdown in 2030 (left) and 2040 (right) with a reward



Unlike a pooling multiplier, a reward could be structured to completely bridge the early TCO gap between e-ammonia and the lowest cost technology / fuel combination in each year. The charts below show the level of support derived from the TCO model, compared with the pre-determined reward based on the e-ammonia and bio-LNG price spread applied in the CIA.

Figure 12: Scenario 26—pre-set reward used in the CIA vs reward derived from TCO gap



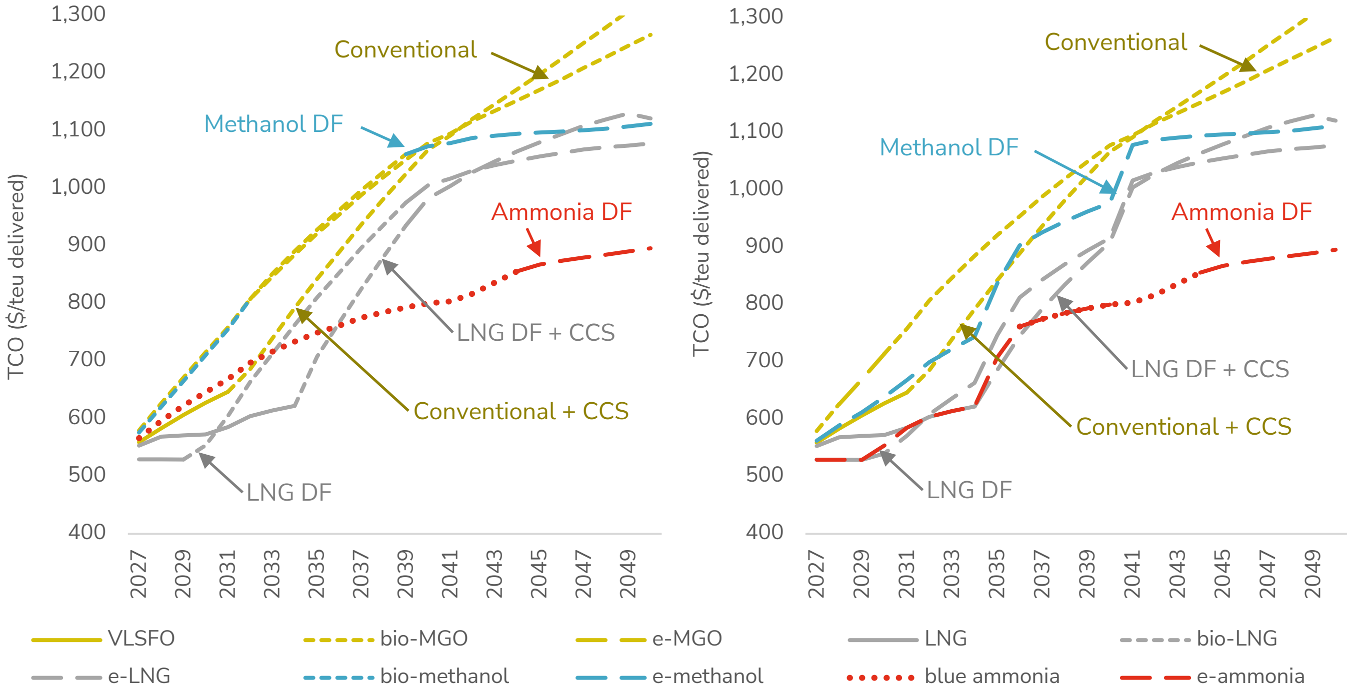
As the reward is channelled through e-fuel usage, it is calculated on the basis that a ship running entirely on e-ammonia (less pilot fuel) is subsidised down to the same total TCO as the lowest cost technology / fuel option. By maximising the volume of GJ subsidised, the $/GJ reward is minimised. A large reward is required initially as the TCO gap that must be bridged is widened by the negative abatement cost of LNG. Although the reward is derived from the gap between e-ammonia and the lowest cost TCO, once that reward is applied to e-LNG, this then becomes the lowest cost TCO for the LNG dual fuel / LNG dual fuel plus CCS options (in lieu of bio-LNG). However, once the TCO of the LNG dual fuel plus CCS option overtakes that of ammonia dual fuel (using blue ammonia) in 2037, the level of reward required falls sharply towards the levels applied in the CIA.

Scenario 32: A low levy requires a larger reward to bridge the TCO gap for e-fuels

The final policy combination modelled—CIA scenario 32 (WtW GFI plus flexibility mechanism plus low levy / reward)—contains elements common to both previous scenarios. Trajectories of the lowest cost TCO for each technology option bear closer resemble to scenario 24 given the similarly sloped GFI reduction, the ability to average capital costs over a pool of ships and because the cost of the levy is much lower than in scenario 26.

Figure 13 shows the lowest cost TCO for each technology option before (left) and after (right) an e-fuel reward is applied. The same pattern in the other scenarios can be seen where the lowest cost TCO runs from LNG dual fuel to LNG dual fuel plus CCS to ammonia dual fuel (with blue ammonia). The application and impact of the derived reward functions similarly to scenario 26, where the e-fuel subsidy triggers increased competitiveness of e-LNG and e-methanol versus bio-LNG and bio-methanol.

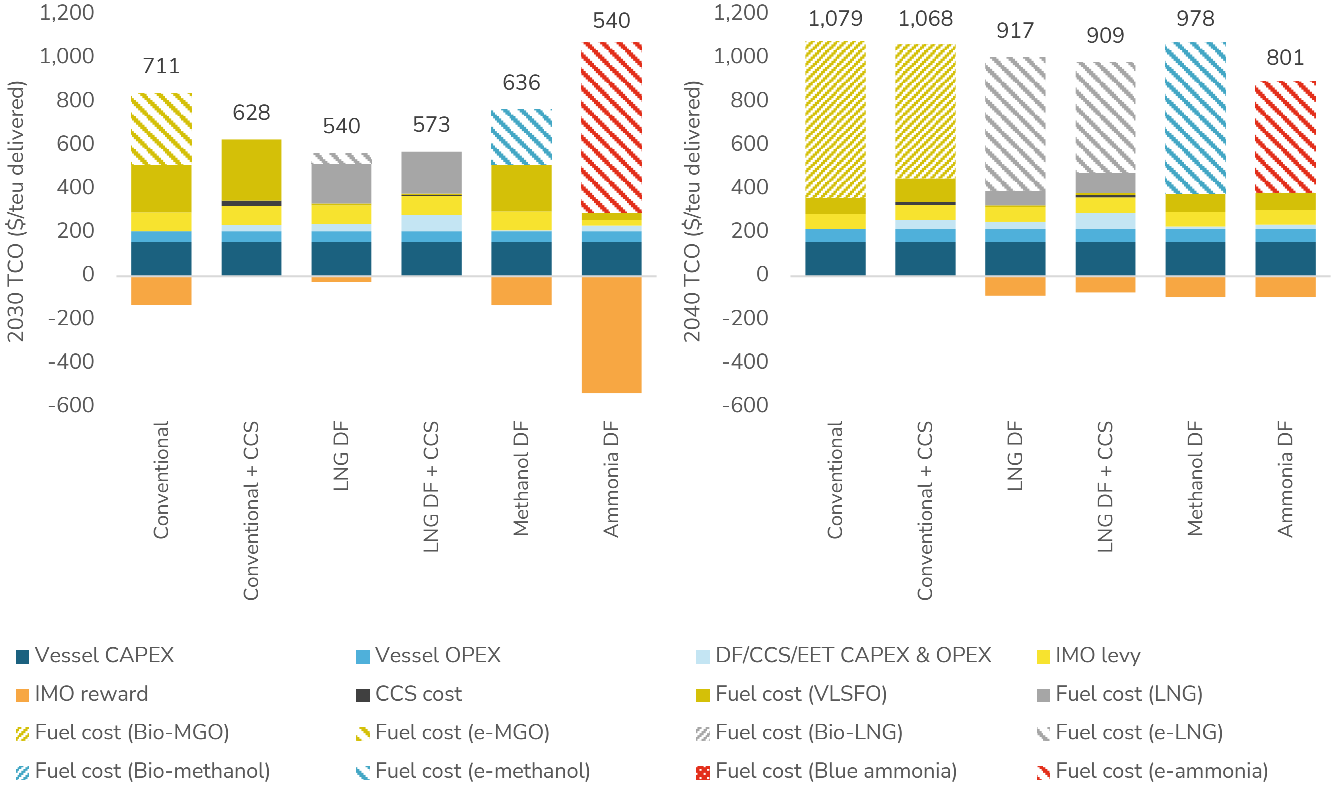
Figure 13: Scenario 32—lowest cost TCO by technology option without (left) and with (right) a reward



However, the reward required to bridge the early TCO gap in scenario 32 is materially larger than the amount derived in scenario 26. For example, in 2030, a total subsidy of $536 per teu delivered is required in scenario 32 while $359 per teu delivered is required in scenario 26. This is due to the lower levy, which bridges less of the TCO gap than the high levy does for fuels of different emissions intensities. The levy is additive to the effect of the reward and can assist in closing the TCO gap and thus enabling the competitiveness of e-fuels (i.e. a higher levy means a lower reward is needed to achieve the same level of support for the overall energy transition).

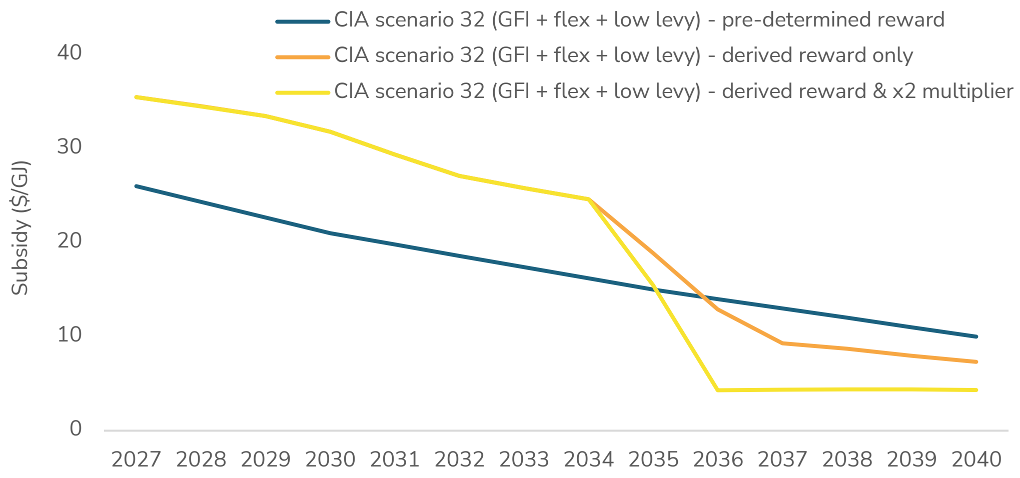
The required reward falls to a similar level as seen in scenario 26 by 2040 as the GFI dictates that the majority of fuels used are of similar (low) emissions intensity. There will be less potential for variance in emissions and the higher cost of these low emission fuels will mute the impact of the levy. However, it may be a challenge to support e-fuels sufficiently in the early stages of the transition under scenario 32 given the cost of support will be greater and the overall revenues raised will be smaller (due to the lower levy).

Figure 14: Scenario 32—TCO breakdown in 2030 (left) and 2040 (right) with a reward



The inclusion of a pooling multiplier as an additional form of support for e-fuels may not assist in bridging the TCO gap early in the transition either. The negative abatement cost of LNG means that as long as 100% fossil LNG in the LNG fuel plus CCS technology option is fully compliant (up until 2034), the e-ammonia TCO needs to be subsidised down to the level of the LNG TCO to remain competitive—i.e. an average pooled TCO across an e-ammonia and non-compliant ships running on VLSFO will be too high. There would be no benefit to pooling e-ammonia and non-compliant ships running on LNG as all ships will bear a similar capital cost burden. However, after 2034, a multiplier could reduce the level of subsidy required to support e-fuels (Figure 15).

Figure 15: Scenario 32—pre-set reward used in the CIA vs the reward derived from TCO gap (with and without a x2 multiplier)



Implications for supporting eligible e-fuels through subsidies

The subsidies derived to close the TCO gap under both scenario 26 and 32 are initially higher than the rewards applied in the CIA (having accounted for higher capital and operating costs, the impact of levies on the cost of abatement, and more conservative assumptions on CCS and biofuel pricing). The TCO analysis indicates that the level of reward required to support e-fuels will be largely dictated by the spread in fuel prices and emissions intensities. This highlights the difficulty of setting up a reward system in an uncertain fuel price environment—particularly if that subsidy is intended to bridge the wider TCO gap rather than just the spread in costs of abatement.

In a low gas price / high biofuel price outlook, one approach could be to peg support to natural gas prices (e.g. via Contracts for Difference (CfD)), which could then segue into support benchmarked against blue ammonia. In practice, regular monitoring will be needed to ensure that reward rates are set at a level that is sufficient to achieve the desired outcome, and to prevent technology lock-in to pathways that will not be as cost-effective for reaching net zero by 2050.

As well as designing an appropriate structure for any scheme supporting e-fuels, the overall level of commitment will also need to be clarified. The CIA projected that the total amount of energy used by international shipping in 2030 will be approximately 10 EJ. Assuming that the IMO will aim to support 5%-10% uptake of eligible e-fuels by 2030 (in line with its 2023 Revised Strategy), depending on the level of levy set, roughly $12-$16 billion could be needed to subsidise 5% and $25-$32 billion to subsidise 10% uptake in just one year. The upper end of this range is at the level of total revenues estimated to be raised under the low levy price scenario in the CIA. This would not allow for any growth in the subsidy beyond 2030, or for additional revenue use associated with ensuring a just and equitable transition.

Conclusion

A fuel standard and flexibility mechanism alone is unlikely to start an e-fuel transition before 2040

The results show that a global fuel standard combined with a flexibility mechanism is unlikely to lead to competitive e-fuels before 2044. A combination of fossil fuels (including LNG), biofuels and CCS would be most competitive until up to 2036, thereafter ammonia dual fuel ships would be the lowest cost solution, albeit operating on blue ammonia until 2044. Ships that were more competitive in the period 2027-2035, would have at least a 25% higher total cost of operation from 2040 onwards. This illustrates that if shipowners order tonnage to maximise competitiveness over a short time horizon (e.g. looking only ~5 years ahead), the sector has a major risk of technology lock-in, potentially greater volatility in asset values, and exposure to higher transport costs. This is consistent with the findings in IMO's CIA Task 2.

To address this risk, we explored whether adding a multiplier that 'boosts' the credit given to e-fuels under a global fuel standard plus flexibility mechanism could help to make e-fuel use competitive. We explicitly tested a x2 multiplier (e.g. if the fuel standard limit requires a 50% reduction in GHG intensity, one ship running on zero emissions fuel could generate credits to offset three other similar ships operating on conventional fossil fuels). However, we find that even with the assistance of a x2 multiplier, it is not possible to make e-fuels more competitive than other fuels before 2041. Furthermore, we find that the multiplier would have to be set initially at x15 in 2030 (falling to x10 by 2035) to enable the competitiveness of e-fuels during this period.

Only policies with targeted e-fuel reward could effectively promote shipping's energy transition

The results show that only when there is a specific and targeted reward (e.g. direct subsidy) for the use of e-fuels at a level that closes the TCO gap between e-fuels and the lowest cost of compliance option, is there likely to be significant early (e.g. in the period 2027-2035) adoption of e-fuels.

A targeted e-fuel reward can be coupled to a number of architectures and parameters—both the low levy ($30-$120 per tCO_2e) and high levy ($150-$300 per tCO_2e) scenarios could deliver this type of reward from the revenue each generates. However, the low levy scenario's total revenues are close to the aggregate level of subsidies (if ringfenced only for e-fuels) needed in 2030. This undermines confidence that a low levy will create a sustained promotion of the energy transition and raises the risk of competition between the energy transition and the policy's ability to contribute to a just and equitable transition (another area of revenue use under discussion at the IMO). A high levy scenario would mitigate both those risks.

The levy and reward work in combination to close the competitiveness gap between e-fuels and other lower cost compliance options (LNG, biofuels, CCS, etc.). A high levy price reduces the magnitude of the reward rate needed—our findings show that $28 per GJ is required as the reward rate in this scenario in 2027, compared to $36 per GJ in the low levy price scenario. Both of these reward rates are higher than those used in IMO's CIA Task 2 modelling, which helps to explain why those outputs signalled low take-up of e-fuels in the early years of the transition, even in the high levy scenario.

Adding a flexibility mechanism in levy scenarios does not change the need for a targeted reward under the assumptions used in the modelling, A low levy scenario with a flexibility mechanism requires a higher level of reward to ensure the competitiveness of e-fuels in 2027-2035, than the high levy scenario. Incorporating a multiplier does not alter the reward required in that period but can have an effect on the competitiveness of e-fuels (and thus reduce the reward rate needed) from 2035 onwards.

The reward rate needed to close the e-fuel competitiveness gap is forecast to reduce over time in both this modelling and the analysis conducted in IMO's CIA Task 2. However, as the required reward rate is highly sensitive to a wide range of input assumptions, it will need careful and constant (e.g. annual) review, to ensure that the reward mechanism is effectively and cost-effectively promoting the energy transition. As the reward and levy work in combination, they do not both need to be reviewed and adjusted constantly—the levy price can be fixed for a period with the variation in total effect managed solely through manipulation of the reward rate.

Analysis highlights the sensitivity of scenario modelling to changes in key assumptions

The TCO analysis in this study illustrates how fuel prices and technology cost / performance determine optimal outcomes in response to different policy scenarios. Adjustments to those assumptions can drive materially different outputs to the results presented in the IMO's CIA Task 2 modelling. Changes to the most competitive technology / fuel combinations can then fundamentally shift the expected energy mix.

Adjusting the CCS capture rate and biofuel prices in line with recent studies produces significantly different outcomes in all scenarios relative to those derived by DNV, reducing and shortening the viability of these two options (albeit with them still providing compliance at a competitive cost early in the transition). Ammonia (blue and then e-ammonia) becomes the most cost-effective fuel / technology choice from the mid-2030's. Across the wider range of fuel types, e-fuels have the least cost of compliance through the 2040s, i.e. they are the key for minimising the long-run cost of operation.

Any scenario modelling is highly sensitive to these uncertain parameters. Again, regular (e.g. annual) reviews and clearly stated objectives for review will be needed to ensure that the policies introduced are on track for delivering the IMO's targets, and so that incentives can be adjusted to promote the energy transition in a cost effective manner.

Appendix

Input data used in TCO modelling

The data used in the TCO modelling is primarily derived from the CIA, but alternative sources are used to adjust assumptions on biofuel prices and the CCS capture rate, and to model the voyage profile of the illustrative ship.

Fuel GHG emissions intensity and cost data

Table 3 and Table 4 contain the fuel assumptions (yearly price and GHG emissions intensity) used in the TCO modelling. Other than the cost curves for biofuels (which is based on analysis undertaken for MPEC 79), this data is drawn from the CIA.

Table 3: Fuel price projections 2027-2050 in $ per GJ

Year	VLSFO	e-MGO	LNG	e-LNG	e-methanol	Blue ammonia	e-ammonia	CCS storage
2027	15.0	85.4	12.7	61.0	66.0	32.5	50.1	80.0
2028	14.8	83.8	11.9	60.0	64.4	31.6	48.9	79.2
2029	14.6	82.3	11.1	59.0	62.8	30.8	47.7	78.3
2030	14.4	80.7	10.3	58.0	61.2	29.9	46.5	77.5
2031	14.3	79.7	10.3	57.3	60.4	29.8	45.8	76.7
2032	14.1	78.7	10.3	56.5	59.6	29.6	45.0	75.8
2033	14.0	77.7	10.3	55.8	58.8	29.5	44.3	75.0
2034	13.9	76.7	10.3	55.0	58.0	29.3	43.5	74.2
2035	13.8	75.7	10.3	54.3	57.3	29.2	42.8	73.3
2036	13.6	74.6	10.2	53.5	56.5	29.0	42.1	72.5
2037	13.5	73.6	10.2	52.8	55.7	28.9	41.3	71.7
2038	13.4	72.6	10.2	52.0	54.9	28.7	40.6	70.8
2039	13.2	71.6	10.2	51.3	54.1	28.6	39.8	70.0
2040	13.1	70.6	10.2	50.5	53.3	28.4	39.1	69.2
2041	13.0	69.5	10.2	49.7	52.5	28.3	38.3	68.3
2042	12.8	68.3	10.2	48.9	51.6	28.2	37.5	67.5
2043	12.7	67.2	10.2	48.1	50.8	28.1	36.7	66.7
2044	12.5	66.1	10.2	47.3	50.0	28.0	35.9	65.8
2045	12.4	65.0	10.2	46.6	49.2	27.9	35.2	65.0
2046	12.3	63.8	10.1	45.8	48.3	27.7	34.4	64.2
2047	12.1	62.7	10.1	45.0	47.5	27.6	33.6	63.3
2048	12.0	61.6	10.1	44.2	46.7	27.5	32.8	62.5
2049	11.8	60.4	10.1	43.4	45.8	27.4	32.0	61.7
2050	11.7	59.3	10.1	42.6	45.0	27.3	31.2	60.0

Source: *Non-highlighted fuel prices from DNV CIA (Full report can be downloaded from IMODOCS (documents MEPC 76/7/13 and MEPC 76/INF.68 and addenda); registration is required)*

Table 4: Fuel GHG emissions intensity projections 2027-2050 in WtW gCO_2e per MJ

Year	VLSFO	bio-MGO	e-MGO	LNG	bio-LNG	e-LNG	bio-methanol	e-methanol	Blue ammonia	e-ammonia
2027	90.6	12.4	22.2	77.2	12.5	22.2	12.1	23.2	26.0	16.8
2028	90.6	11.8	20.5	77.2	11.9	20.5	11.5	21.5	25.2	15.6
2029	90.6	11.2	18.8	77.2	11.4	18.8	11.0	19.8	24.5	14.4
2030	90.6	10.7	17.1	77.2	10.8	17.1	10.4	18.1	23.7	13.2
2031	90.6	10.0	15.5	77.2	10.1	15.5	9.7	16.4	22.9	12.0
2032	90.6	9.2	13.9	77.2	9.3	14.0	9.0	14.7	22.2	10.8
2033	90.6	8.5	12.3	77.2	8.6	12.4	8.2	13.0	21.4	9.6
2034	90.6	7.7	10.7	77.2	7.9	10.8	7.5	11.3	20.7	8.4
2035	90.6	7.0	9.1	77.2	7.1	9.3	6.7	9.6	19.9	7.2
2036	90.6	6.3	7.5	77.2	6.4	7.7	6.0	7.9	19.1	5.9
2037	90.6	5.5	5.9	77.2	5.6	6.1	5.3	6.2	18.4	4.7
2038	90.6	4.8	4.3	77.2	4.9	4.6	4.5	4.5	17.6	3.5
2039	90.6	4.0	2.7	77.2	4.2	3.0	3.8	2.7	16.9	2.3
2040	90.6	3.3	1.1	77.2	3.4	1.4	3.0	1.0	16.1	1.1
2041	90.6	3.1	1.1	77.2	3.2	1.4	2.8	1.0	16.1	1.1
2042	90.6	2.9	1.1	77.2	3.0	1.4	2.6	1.0	16.1	1.1
2043	90.6	2.7	1.1	77.2	2.8	1.4	2.4	1.0	16.1	1.1
2044	90.6	2.5	1.1	77.2	2.6	1.4	2.2	1.0	16.1	1.1
2045	90.6	2.3	1.1	77.2	2.4	1.4	2.0	1.0	16.1	1.1
2046	90.6	2.1	1.1	77.2	2.2	1.4	1.8	1.0	16.1	1.1
2047	90.6	1.9	1.1	77.2	2.0	1.4	1.6	1.0	16.1	1.1
2048	90.6	1.7	1.1	77.2	1.8	1.4	1.4	1.0	16.1	1.1
2049	90.6	1.5	1.1	77.2	1.6	1.4	1.2	1.0	16.1	1.1
2050	90.6	1.3	1.1	77.2	1.4	1.4	1.0	1.0	16.1	1.1

***Source:** DNV CIA (Full report can be downloaded from IMODOCS (documents MEPC 76/7/13 and MEPC 76/INF.68 and addenda); registration is required)*

Input data on policies (GFI and levy)

Table 5 shows data sourced from the CIA which is used to model the impact of two different measures—the GFI and the GHG levy—under the three policy scenarios explored.

Table 5: GFI requirement and levy applied to total GHG emissions in year

	GFI requirement (WtW gCO_2e / MJ)			GHG pricing ($/$tCO_2e$)	
Year	CIA scenario 24	CIA scenario 26	CIA scenario 32	High levy (Scenario 26)	Low levy (Scenario 32)
2026	91.0	91.0	91.0	-	-
2027	86.7	90.3	87.0	150	30
2028	82.4	89.5	83.0	160	40
2029	78.0	88.8	78.9	170	50
2030	73.7	88.0	74.9	180	60
2031	69.3	82.4	70.4	189	67
2032	64.9	76.8	65.8	198	74
2033	60.5	71.3	61.3	207	81
2034	56.1	65.7	56.7	216	88
2035	51.7	60.1	52.2	225	95
2036	47.2	54.5	47.7	230	100
2037	42.8	48.9	43.1	235	105
2038	38.4	43.4	38.6	240	110
2039	34.0	37.8	34.0	245	115
2040	29.6	32.2	29.5	250	120
2041	26.8	29.2	26.8	255	120
2042	24.1	26.2	24.0	260	120
2043	21.3	23.1	21.3	265	120
2044	18.6	20.1	18.5	270	120
2045	15.8	17.1	15.8	275	120
2046	13.0	14.1	13.0	280	120
2047	10.3	11.1	10.3	285	120
2048	7.5	8.0	7.5	290	120
2049	4.8	5.0	4.8	295	120
2050	2.0	2.0	2.0	300	120

Source: *DNV CIA (Full report can be downloaded from IMODOCS (documents MEPC 76/7/13 and MEPC 76/INF.68 and addenda); registration is required)*

Ship, voyage and fuel consumption data

Table 6 contains the remaining data used to model the TCO of an illustrative 14,000 teu containership sailing between Asia and Latin America. Data on the voyage profile is obtained from the UMAS Fuse model, other ship assumptions are from the CIA, and assumptions regarding the capture rate of CCS come from a recent study.

Table 6: Ship and voyage inputs to TCO model under different CIA policy scenarios

Variable	Unit	CIA scenarios 24 and 32	CIA scenario 26	Source
Vessel size	teu	14,000		
Sailing distance (round trip)	nautical miles	22,836		UMAS Fuse model
Average speed	knots	15.8	14.2	UMAS Fuse model
Avg. days at sea (round trip)	days	60.2	66.9	UMAS Fuse model
Avg. days at port (round trip)	Days	17.3	17.3	UMAS Fuse model
Avg. days per round trip	Days	77.5	84.1	UMAS Fuse model
Avg. no. round trips pa	#	4.7	4.3	UMAS Fuse model
Fuel at sea	GJ pa	1,066,089	883,237	UMAS Fuse model
Fuel at port	GJ pa	42,724	39,329	UMAS Fuse model
Fuel per trip	GJ pa	1,108,813	922,566	UMAS Fuse model
Cargo carried per round trip	teu	12,278		UNCTAD
Newbuild ship cost	$m	143.2		DNV CIA (based on 14,500-18,999 teu containership newbuild cost plus enhanced energy efficiency package)
Discount rate	%	4%		DNV CIA
Economic life	years	20		DNV CIA
Scrap value	$m	43.0		DNV CIA
Pilot fuel (LNG)	%	3%		DNV CIA
Pilot fuel (methanol)	%	9%		DNV CIA
Pilot fuel (ammonia)	%	12%		DNV CIA
Energy efficiency package cost	$m	0.0	9.4	DNV CIA (based on 14,500-18,999 teu containership advanced energy package)
Energy efficiency package saving	%	0%	5%	DNV CIA (based on 14,500-18,999 teu containership advanced energy package)
LNG DF premium	$m	22.0		DNV CIA (based on 14,500-18,999 teu containership)
Methanol DF premium	$m	10.0		DNV CIA (based on 14,500-18,999 teu containership)
Ammonia DF premium	$m	17.0		DNV CIA (based on 14,500-18,999 teu containership)
CCS system premium	$m	28.0		DNV CIA (based on 14,500-18,999 teu containership)
CCS capture rate	%	27%		OGCI / Stena report
CCS fuel penalty	%	10%		OGCI / Stena report
OPEX (0-4yrs)	$/day	7,970		DNV CIA (based on 14,500-18,999 teu containership)
OPEX (5-9yrs)	$/day	9,200		DNV CIA (based on 14,500-18,999 teu containership)
OPEX (10-14yrs)	$/day	9,590		DNV CIA (based on 14,500-18,999 teu containership)
OPEX (15-19yrs)	$/day	10,182		DNV CIA (based on 14,500-18,999 teu containership)
OPEX (20+yrs)	$/day	10,394		DNV CIA (based on 14,500-18,999 teu containership)
DF / CCS / EET OPEX premium	% of CAPEX	1.25%		DNV CIA (OPEX as % of EET CAPEX; assumed to apply to DF CAPEX and CCS CAPEX)

***Source:** UMAS; UNCTAD; DNV CIA (Full report can be downloaded from IMODOCS (documents MEPC 76/7/13 and MEPC 76/INF.68 and addenda); registration is required); OGCI / Stena*

Outputs from TCO modelling

The table below shows the level of reward required under policy scenarios 26 and 32 derived from the TCO modelling (based on the subsidy required in each year to bridge the cost gap between the e-ammonia TCO and the overall lowest TCO). This is followed by tables that show the breakdowns of the lowest cost TCO's for each technology option under each policy scenario.

Rewards derived from TCO modelling

Table 7: Rewards for e-fuels derived from TCO modelling (shown alongside rewards applied in the CIA)

$ per GJ	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Derived rewards														
CIA scenario 26 (GFI + high levy)	28.3	27.1	26.0	24.8	23.3	21.4	19.1	17.7	16.3	15.0	9.3	8.5	7.7	7.0
CIA scenario 32 (GFI + flex + low levy) - reward only	35.5	34.5	33.5	31.8	29.4	27.1	25.8	24.6	18.9	12.9	9.3	8.7	8.0	7.3
CIA scenario 32 (GFI + flex + low levy) - reward & x2 multiplier	35.5	34.5	33.5	31.8	29.4	27.1	25.8	24.6	15.5	4.3	4.4	4.4	4.4	4.3
CIA rewards														
CIA scenario 26 (GFI + high levy)	22.0	20.7	19.3	18.0	16.8	15.6	14.4	13.2	12.0	10.6	9.2	7.8	6.4	5.0
CIA scenario 32 (GFI + flex + low levy)	26.0	24.3	22.7	21.0	19.8	18.6	17.4	16.2	15.0	14.0	13.0	12.0	11.0	10.0

Lowest cost TCOs generated for each policy scenario

Table 8: Breakdown of lowest cost TCO for each technology under scenario 24 (assuming no pooling multiplier)

$ per teu delivered	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Conventional unabated																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VLSFO	288	284	280	276	273	271	269	266	264	261	259	256	254	251	248	246	243	240	238	235	232	230	227	224
Aggregate TCO	**496**	**492**	**488**	**483**	**481**	**486**	**484**	**481**	**479**	**476**	**476**	**474**	**471**	**469**	**466**	**467**	**464**	**462**	**459**	**456**	**455**	**452**	**450**	**447**
Conventional																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VLSFO	274	254	236	218	201	185	170	155	141	127	113	100	88	76	67	59	51	44	36	29	22	15	8	2
Bio-MGO	51	107	162	216	270	322	374	425	476	525	574	622	670	717	749	780	812	845	877	909	941	973	1,006	1,038
Aggregate TCO	**532**	**569**	**605**	**641**	**678**	**723**	**759**	**796**	**832**	**867**	**905**	**940**	**975**	**1,010**	**1,034**	**1,061**	**1,085**	**1,110**	**1,134**	**1,159**	**1,186**	**1,211**	**1,237**	**1,262**
Conventional + CCS																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	7	15	22	30	38	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	41
CCS cost	6	13	19	26	32	33	31	28	25	23	21	18	16	14	12	11	9	8	7	5	4	3	1	0
VLSFO	290	287	284	282	280	266	244	223	202	181	162	143	125	107	95	84	73	62	51	41	31	21	12	2
Bio-MGO	0	0	0	0	0	45	121	195	268	340	410	480	549	617	661	706	750	795	840	884	929	974	1,019	1,038
Aggregate TCO	**510**	**522**	**533**	**545**	**558**	**602**	**652**	**702**	**752**	**801**	**852**	**901**	**949**	**997**	**1,028**	**1,063**	**1,096**	**1,128**	**1,161**	**1,194**	**1,229**	**1,262**	**1,296**	**1,304**
LNG DF																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
VLSFO	9	9	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7	7	7	7	1
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
LNG	236	221	206	180	167	154	142	130	118	106	95	84	73	66	59	51	44	37	30	23	16	9	2	0
Bio-LNG	0	0	0	52	111	170	229	289	348	405	460	515	570	0	0	0	0	0	0	0	0	0	0	0
e-LNG	0	0	0	0	0	0	0	0	0	0	0	0	0	613	638	662	685	707	728	747	766	783	800	792
Aggregate TCO	**485**	**470**	**455**	**480**	**526**	**580**	**627**	**674**	**722**	**767**	**813**	**857**	**901**	**937**	**955**	**975**	**991**	**1,006**	**1,019**	**1,032**	**1,044**	**1,054**	**1,064**	**1,074**

$ per teu delivered	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
LNG DF + CCS																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	9	19	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74
CCS cost	4	8	0	6	12	19	25	28	24	22	20	17	15	13	11	10	9	7	6	5	4	3	1	0
VLSFO	255	214	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7	7	2
LNG	29	58	206	193	194	195	196	196	169	153	136	121	105	92	83	73	63	53	44	34	24	14	5	0
Bio-LNG	0	0	0	0	0	0	0	0	127	207	285	362	439	0	0	0	0	0	0	0	0	0	0	0
e-LNG	0	0	0	0	0	0	0	0	0	0	0	0	0	507	546	584	622	656	690	722	752	781	809	822
Aggregate TCO	**504**	**506**	**497**	**489**	**496**	**511**	**519**	**522**	**618**	**679**	**741**	**800**	**859**	**912**	**940**	**971**	**996**	**1,020**	**1,042**	**1,064**	**1,084**	**1,102**	**1,119**	**1,120**

Methanol DF																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	1	2	3	3	4	5	5	6	7	8	8	9	10	11	12	12	13	13	14	14	15	15	15	15
VLSFO	274	254	236	218	201	186	170	155	141	127	113	100	88	80	72	63	55	47	39	31	24	17	9	2
Bio-MGO	0	0	0	0	0	0	374	425	476	525	574	622	670	0	0	0	0	0	0	0	0	18	51	83
Bio-methanol	47	99	152	207	262	317	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e-methanol	0	0	0	0	0	0	0	0	0	0	0	0	0	696	716	735	753	771	787	802	816	814	799	785
Aggregate TCO	**529**	**562**	**598**	**635**	**675**	**723**	**765**	**802**	**838**	**875**	**913**	**949**	**985**	**1,005**	**1,017**	**1,032**	**1,042**	**1,052**	**1,061**	**1,069**	**1,078**	**1,086**	**1,097**	**1,108**

Ammonia DF																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	2	4	5	7	9	11	13	14	16	17	19	21	22	24	25	25	25	25	25	25	25	25	25	25
VLSFO	271	248	227	206	187	169	151	135	118	103	87	73	59	45	36	27	19	12	29	28	24	16	9	2
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	51	88	0	0	18	50	83	115
Blue ammonia	38	77	112	145	180	213	246	277	308	337	366	393	420	446	464	474	469	464	141	42	0	0	0	0
e-ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	415	527	566	553	540	526
Aggregate TCO	**518**	**536**	**552**	**566**	**584**	**609**	**625**	**641**	**657**	**673**	**690**	**705**	**719**	**732**	**742**	**761**	**786**	**810**	**831**	**844**	**856**	**868**	**880**	**892**

Table 9: Breakdown of lowest cost TCO for each technology under scenario 24 (assuming x2 pooling multiplier)

$ per teu delivered	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Conventional unabated																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VLSFO	288	284	280	276	273	271	269	266	264	261	259	256	254	251	248	246	243	240	238	235	232	230	227	224
Aggregate TCO	**496**	**492**	**488**	**483**	**481**	**486**	**484**	**481**	**479**	**476**	**476**	**474**	**471**	**469**	**466**	**467**	**464**	**462**	**459**	**456**	**455**	**452**	**450**	**447**
Conventional																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VLSFO	274	254	236	218	201	185	170	155	141	127	113	100	88	76	67	59	51	44	36	29	22	15	8	2
Bio-MGO	51	107	162	216	270	322	374	425	476	525	574	622	670	717	749	780	812	845	877	909	941	973	1,006	1,038
Aggregate TCO	**532**	**569**	**605**	**641**	**678**	**723**	**759**	**796**	**832**	**867**	**905**	**940**	**975**	**1,010**	**1,034**	**1,061**	**1,085**	**1,110**	**1,134**	**1,159**	**1,186**	**1,211**	**1,237**	**1,262**
Conventional + CCS																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	7	15	22	30	38	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	41
CCS cost	6	13	19	26	32	33	31	28	25	23	21	18	16	14	12	11	9	8	7	5	4	3	1	0
VLSFO	290	287	284	282	280	266	244	223	202	181	162	143	125	107	95	84	73	62	51	41	31	21	12	2
Bio-MGO	0	0	0	0	0	45	121	195	268	340	410	480	549	617	661	706	750	795	840	884	929	974	1,019	1,038
Aggregate TCO	**510**	**522**	**533**	**545**	**558**	**602**	**652**	**702**	**752**	**801**	**852**	**901**	**949**	**997**	**1,028**	**1,063**	**1,096**	**1,128**	**1,161**	**1,194**	**1,229**	**1,262**	**1,296**	**1,304**
LNG DF																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
VLSFO	9	9	8	8	8	8	85	85	83	80	76	72	67	63	58	54	49	44	38	33	27	21	15	3
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
LNG	236	221	206	180	167	154	98	89	82	75	69	62	57	51	46	41	36	31	26	20	14	8	2	0
Bio-LNG	0	0	0	52	111	170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e-LNG	0	0	0	0	0	0	199	240	281	320	360	398	437	475	504	534	565	597	629	663	698	734	771	787
Aggregate TCO	**485**	**470**	**455**	**480**	**526**	**580**	**620**	**652**	**683**	**714**	**746**	**775**	**803**	**831**	**852**	**877**	**899**	**921**	**943**	**967**	**992**	**1,016**	**1,042**	**1,070**

$ per teu delivered	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
LNG DF + CCS																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	9	19	74	74	74	74	74	74	74	74	74	74	36	39	42	45	48	51	55	58	62	66	70	74
CCS cost	4	8	0	6	12	19	25	28	24	22	20	17	1	0	1	1	1	1	1	1	1	1	1	0
VLSFO	255	214	8	8	8	8	8	8	8	8	8	8	136	123	113	102	92	80	69	57	45	32	19	2
LNG	29	58	206	193	194	195	196	196	169	153	136	121	0	0	0	0	0	0	0	0	0	0	0	0
Bio-LNG	0	0	0	0	0	0	0	0	127	207	285	362	0	0	0	0	0	0	0	0	0	0	0	0
e-LNG	0	0	0	0	0	0	0	0	0	0	0	0	468	507	534	562	591	621	652	683	716	749	784	822
Aggregate TCO	**504**	**506**	**497**	**489**	**496**	**511**	**519**	**522**	**618**	**679**	**741**	**800**	**858**	**887**	**907**	**932**	**953**	**975**	**997**	**1,021**	**1,046**	**1,071**	**1,097**	**1,120**
Methanol DF																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	0	1	2	2	3	3	4	5	5	6	6	7	8	8	9	10	10	11	12	12	13	14	14	15
VLSFO	280	266	253	239	228	216	204	192	180	168	157	145	133	121	111	101	90	79	67	56	43	31	18	5
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	49	82
Bio-methanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e-methanol	38	79	118	155	194	233	272	310	347	384	421	457	493	528	556	585	614	645	675	707	740	760	769	777
Aggregate TCO	**526**	**553**	**579**	**604**	**632**	**668**	**695**	**722**	**748**	**774**	**802**	**827**	**851**	**875**	**894**	**916**	**936**	**956**	**976**	**997**	**1,019**	**1,044**	**1,073**	**1,101**
Ammonia DF																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	1	2	3	4	5	6	7	8	9	17	19	21	22	24	25	25	24	23	23	23	23	24	24	25
VLSFO	280	268	255	242	231	219	207	195	183	103	87	73	59	45	36	34	44	49	51	51	43	30	17	4
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	47	80	114
Blue ammonia	0	0	0	0	0	0	0	0	0	337	366	393	420	446	464	431	317	217	125	38	0	0	0	0
e-ammonia	26	55	82	109	138	166	194	222	250	0	0	0	0	0	0	45	163	270	371	469	515	518	520	522
Aggregate TCO	**515**	**532**	**547**	**563**	**580**	**606**	**623**	**640**	**657**	**673**	**690**	**705**	**719**	**732**	**742**	**757**	**769**	**780**	**791**	**802**	**820**	**841**	**864**	**888**

Table 10: Breakdown of lowest cost TCO for each technology under scenario 26 (including reward for e-fuels)

$ per teu delivered	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Conventional unabated																								
Ship CAPEX	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171
Ship OPEX	55	55	55	55	55	63	63	63	63	63	66	66	66	66	66	70	70	70	70	70	71	71	71	71
Tech CAPEX + OPEX	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
IMO levy	224	239	253	268	282	295	309	322	335	343	350	358	365	373	380	388	395	403	410	417	425	432	440	447
IMO reward	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VLSFO	247	244	240	237	235	233	230	228	226	224	222	220	218	215	213	211	209	206	204	202	199	197	195	192
Aggregate TCO	**712**	**723**	**734**	**746**	**757**	**777**	**788**	**799**	**811**	**816**	**824**	**829**	**835**	**840**	**845**	**854**	**859**	**865**	**870**	**875**	**881**	**887**	**892**	**897**
Conventional																								
Ship CAPEX	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171
Ship OPEX	55	55	55	55	55	63	63	63	63	63	66	66	66	66	66	70	70	70	70	70	71	71	71	71
Tech CAPEX + OPEX	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
IMO levy	223	236	248	261	256	250	243	233	222	206	189	171	152	132	122	112	101	89	77	65	52	38	24	10
IMO reward	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VLSFO	246	240	235	229	211	193	176	160	144	128	113	99	85	71	64	56	48	41	34	27	21	14	8	2
Bio-MGO	4	13	21	29	89	148	206	263	320	375	430	483	537	589	619	649	679	709	739	770	800	830	861	891
Aggregate TCO	**714**	**729**	**744**	**759**	**797**	**841**	**874**	**905**	**935**	**959**	**984**	**1,005**	**1,025**	**1,044**	**1,057**	**1,073**	**1,084**	**1,096**	**1,107**	**1,118**	**1,130**	**1,140**	**1,150**	**1,159**
Conventional + CCS																								
Ship CAPEX	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171
Ship OPEX	55	55	55	55	55	63	63	63	63	63	66	66	66	66	66	70	70	70	70	70	71	71	71	71
Tech CAPEX + OPEX	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
IMO levy	171	183	194	205	216	226	236	240	229	212	194	176	156	136	126	115	104	92	80	67	53	39	25	6
IMO reward	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CCS cost	31	31	31	30	30	30	29	28	26	23	20	18	15	13	11	10	9	7	6	5	4	2	1	0
VLSFO	254	251	247	243	241	239	237	228	205	183	161	140	120	101	90	79	68	58	48	39	29	20	11	0
Bio-MGO	0	0	0	0	0	0	0	26	107	187	265	342	418	493	535	577	619	661	703	745	787	829	871	898
Aggregate TCO	**743**	**750**	**757**	**765**	**773**	**789**	**797**	**816**	**860**	**898**	**937**	**973**	**1,007**	**1,040**	**1,059**	**1,082**	**1,100**	**1,119**	**1,137**	**1,156**	**1,175**	**1,193**	**1,211**	**1,207**
LNG DF																								
Ship CAPEX	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171
Ship OPEX	55	55	55	55	55	63	63	63	63	63	66	66	66	66	66	70	70	70	70	70	71	71	71	71
Tech CAPEX + OPEX	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
IMO levy	191	204	217	230	241	250	243	233	222	206	189	171	152	132	122	112	101	89	77	65	52	38	24	10
IMO reward	0	0	0	0	0	-4	-31	-52	-69	-82	-61	-66	-68	-69	0	0	0	0	0	0	0	0	0	0
VLSFO	7	7	7	7	7	7	7	7	7	7	7	7	7	6	6	6	6	6	6	6	6	6	6	1
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21
LNG	203	190	177	164	164	162	147	133	120	107	95	84	73	62	55	49	42	35	29	22	15	9	2	0
e-LNG	0	0	0	0	0	11	90	162	230	292	350	403	452	498	523	546	569	591	612	631	650	667	684	680

Aggregate TCO	**678**	**678**	**677**	**677**	**689**	**711**	**740**	**768**	**795**	**815**	**867**	**886**	**903**	**917**	**994**	**1,005**	**1,010**	**1,013**	**1,015**	**1,015**	**1,016**	**1,013**	**1,009**	**1,005**
$ per teu delivered	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
LNG DF + CCS																								
Ship CAPEX	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171
Ship OPEX	55	55	55	55	55	63	63	63	63	63	66	66	66	66	66	70	70	70	70	70	71	71	71	71
Tech CAPEX + OPEX	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
IMO levy	149	158	168	178	187	196	205	214	223	228	194	176	156	136	126	115	104	92	79	67	53	39	25	10
IMO reward	0	0	0	0	0	0	0	0	0	0	-28	-40	-49	-55	0	0	0	0	0	0	0	0	0	0
CCS cost	26	25	25	25	25	24	24	24	24	23	19	17	14	12	11	9	8	7	6	5	3	2	1	0
VLSFO	8	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6	6	6	6	6	6	6	1
LNG	208	195	182	169	169	169	168	168	168	168	137	119	103	87	78	69	59	50	41	32	23	14	5	0
Bio-LNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e-LNG	0	0	0	0	0	0	0	0	0	0	160	245	323	396	434	472	508	541	574	605	636	664	691	705
Aggregate TCO	**711**	**708**	**704**	**701**	**709**	**726**	**734**	**743**	**751**	**756**	**822**	**856**	**887**	**916**	**988**	**1,008**	**1,022**	**1,033**	**1,044**	**1,051**	**1,059**	**1,064**	**1,066**	**1,055**

Methanol DF																								
Ship CAPEX	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171
Ship OPEX	55	55	55	55	55	63	63	63	63	63	66	66	66	66	66	70	70	70	70	70	71	71	71	71
Tech CAPEX + OPEX	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
IMO levy	223	236	248	261	256	250	243	233	222	206	189	171	152	132	122	112	101	89	77	65	52	38	24	10
IMO reward	-3	-7	-11	-15	-42	-64	-78	-92	-101	-108	-75	-77	-76	-75	0	0	0	0	0	0	0	0	0	0
VLSFO	246	240	234	228	209	190	173	157	141	126	112	99	87	75	67	59	51	44	37	29	22	15	9	2
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	41	71
Bio-methanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e-methanol	6	17	27	37	110	178	242	300	355	405	452	495	535	572	592	611	630	647	664	679	694	698	686	674
Aggregate TCO	**729**	**742**	**755**	**767**	**789**	**820**	**844**	**864**	**883**	**895**	**946**	**957**	**966**	**972**	**1,049**	**1,054**	**1,054**	**1,052**	**1,049**	**1,045**	**1,041**	**1,036**	**1,033**	**1,030**

Ammonia DF																								
Ship CAPEX	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171	171
Ship OPEX	55	55	55	55	55	63	63	63	63	63	66	66	66	66	66	70	70	70	70	70	71	71	71	71
Tech CAPEX + OPEX	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43
IMO levy	63	65	66	67	67	66	66	65	64	61	58	55	52	49	105	107	101	89	77	65	52	38	24	10
IMO reward	-409	-393	-376	-359	-337	-310	-276	-256	-236	-218	-134	-123	-112	-101	0	0	0	0	0	0	0	0	0	0
VLSFO	30	29	29	28	28	28	28	27	27	27	27	26	26	26	26	25	20	25	24	24	22	15	9	2
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	8	38	68	99
Blue ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	410	408	406	254	160	68	0	0	0	0
e-ammonia	726	708	691	673	662	652	641	630	620	609	598	587	577	566	0	0	0	194	306	413	486	475	463	452
Aggregate TCO	**678**	**678**	**677**	**677**	**689**	**713**	**734**	**743**	**751**	**756**	**828**	**825**	**822**	**819**	**819**	**824**	**833**	**845**	**852**	**853**	**852**	**851**	**849**	**847**

Table 11: Breakdown of lowest cost TCO for each technology under scenario 32 (including reward for e-fuels only)

$ per teu delivered	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Conventional unabated																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IMO levy	52	69	87	104	116	129	141	153	165	174	182	191	200	208	208	208	208	208	208	208	208	208	208	208
IMO reward	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VLSFO	288	284	280	276	273	271	269	266	264	261	259	256	254	251	248	246	243	240	238	235	232	230	227	224
Aggregate TCO	**548**	**561**	**574**	**588**	**597**	**615**	**624**	**634**	**644**	**650**	**659**	**665**	**671**	**677**	**675**	**676**	**673**	**670**	**668**	**665**	**663**	**661**	**658**	**655**
Conventional																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IMO levy	50	64	76	86	90	93	95	96	95	91	87	81	75	68	62	55	49	43	36	30	24	17	11	5
IMO reward	0	0	-105	-130	-152	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VLSFO	275	256	234	217	200	188	173	157	142	128	114	101	88	75	67	59	51	44	36	29	22	15	8	2
Bio-MGO	47	99	0	0	0	311	364	417	469	520	570	620	669	718	750	781	813	845	877	909	941	974	1,006	1,038
e-MGO	0	0	257	331	412	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aggregate TCO	**580**	**627**	**413**	**380**	**346**	**808**	**847**	**885**	**922**	**955**	**989**	**1,020**	**1,050**	**1,079**	**1,096**	**1,117**	**1,135**	**1,153**	**1,171**	**1,190**	**1,210**	**1,229**	**1,248**	**1,267**
Conventional + CCS																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	6	14	21	28	36	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	41
IMO levy	50	64	77	88	93	96	98	98	98	94	89	84	77	70	63	57	50	44	37	31	24	18	11	5
IMO reward	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CCS cost	6	12	18	24	30	34	31	28	26	23	21	18	16	13	12	11	9	8	6	5	4	3	1	0
VLSFO	290	287	284	281	280	271	248	226	204	183	163	144	125	107	95	84	72	62	51	41	31	21	12	2
Bio-MGO	0	0	0	0	0	29	107	183	258	332	405	478	548	618	663	707	752	796	841	885	930	974	1,019	1,038
Aggregate TCO	**559**	**584**	**607**	**628**	**647**	**686**	**740**	**792**	**843**	**890**	**938**	**982**	**1,026**	**1,068**	**1,092**	**1,121**	**1,147**	**1,172**	**1,199**	**1,225**	**1,253**	**1,280**	**1,308**	**1,308**
LNG DF																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
IMO levy	45	59	74	86	90	93	95	96	95	91	87	81	75	68	62	55	49	43	36	30	24	17	11	5
IMO reward	0	0	0	-27	-66	-97	-124	-148	-135	-107	-86	-90	-90	-89	0	0	0	0	0	0	0	0	0	0
VLSFO	9	9	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7	7	7	7	1
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
LNG	236	221	206	183	168	154	141	129	117	106	95	85	75	65	58	51	44	37	30	23	16	9	2	0
e-LNG	0	0	0	50	129	202	269	331	389	442	491	535	577	615	640	663	686	708	728	748	766	784	800	792

Aggregate TCO	**530**	**529**	**529**	**540**	**570**	**609**	**637**	**664**	**721**	**788**	**844**	**870**	**895**	**917**	**1,017**	**1,031**	**1,041**	**1,049**	**1,056**	**1,062**	**1,068**	**1,072**	**1,075**	**1,078**
$ per teu delivered	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
LNG DF + CCS																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	8	17	74	74	74	74	74	79	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74
IMO levy	50	64	74	86	91	95	97	98	98	94	89	84	77	70	63	57	50	44	37	31	24	18	11	5
IMO reward	0	0	0	0	0	0	0	0	-46	-53	-53	-63	-69	-74	0	0	0	0	0	0	0	0	0	0
CCS cost	3	7	0	4	11	17	24	29	24	22	20	17	15	13	11	10	9	7	6	5	4	3	1	0
VLSFO	257	220	8	8	8	8	8	-7	8	8	8	8	8	8	8	8	7	7	7	7	7	7	7	2
LNG	27	53	206	192	193	194	195	208	171	154	137	122	107	92	82	73	63	53	43	34	24	14	5	0
Bio-LNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e-LNG	0	0	0	0	0	0	0	0	133	219	300	375	444	509	548	586	623	657	691	722	753	782	809	818
Aggregate TCO	**553**	**569**	**571**	**573**	**585**	**605**	**615**	**622**	**677**	**734**	**793**	**834**	**874**	**909**	**1,005**	**1,028**	**1,048**	**1,064**	**1,080**	**1,095**	**1,109**	**1,120**	**1,130**	**1,122**

Methanol DF																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	1	2	3	4	4	5	6	7	8	8	9	10	11	11	12	12	13	13	14	14	15	15	15	15
IMO levy	50	64	76	86	90	93	95	96	95	91	87	81	75	68	62	55	49	43	36	30	24	17	11	5
IMO reward	-37	-74	-106	-132	-154	-170	-187	-201	-172	-128	-100	-101	-98	-96	0	0	0	0	0	0	0	0	0	0
VLSFO	273	253	234	216	199	182	167	152	139	125	113	101	90	80	71	63	55	47	39	31	24	17	9	2
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	51	83
Bio-methanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e-methanol	69	137	199	255	316	373	426	475	520	562	600	635	668	697	717	736	754	771	787	802	817	814	799	785
Aggregate TCO	**563**	**589**	**613**	**636**	**664**	**700**	**723**	**744**	**805**	**874**	**927**	**945**	**963**	**978**	**1,079**	**1,088**	**1,092**	**1,095**	**1,098**	**1,099**	**1,101**	**1,104**	**1,108**	**1,112**

Ammonia DF																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	25	25	25	25	25	25	25	25	13	15	16	17	18	20	25	25	25	25	25	25	25	25	25	25
IMO levy	15	19	23	26	28	29	30	31	95	91	87	81	75	68	62	56	50	45	36	30	24	17	11	5
IMO reward	-598	-582	-564	-536	-495	-457	-435	-415	-167	-125	-99	-100	-98	-96	0	0	0	0	0	0	0	0	0	0
VLSFO	35	34	34	33	33	33	32	32	142	129	116	103	91	80	35	27	19	12	29	28	24	16	9	2
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	52	89	0	0	19	51	83	115
Blue ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	465	474	469	464	139	41	0	0	0	0
e-ammonia	846	825	805	784	772	759	747	734	378	409	438	465	489	512	0	0	0	0	418	529	566	553	540	526
Aggregate TCO	**530**	**529**	**529**	**540**	**570**	**604**	**615**	**622**	**677**	**733**	**775**	**784**	**793**	**801**	**804**	**817**	**837**	**856**	**868**	**875**	**880**	**885**	**891**	**896**

Table 12: Breakdown of lowest cost TCO for each technology under scenario 32 (including reward for e-fuels and x2 multiplier)

$ per teu delivered	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Conventional unabated																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IMO levy	52	69	87	104	116	129	141	153	165	174	182	191	200	208	208	208	208	208	208	208	208	208	208	208
IMO reward	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VLSFO	288	284	280	276	273	271	269	266	264	261	259	256	254	251	248	246	243	240	238	235	232	230	227	224
Aggregate TCO	**548**	**561**	**574**	**588**	**597**	**615**	**624**	**634**	**644**	**650**	**659**	**665**	**671**	**677**	**675**	**676**	**673**	**670**	**668**	**665**	**663**	**661**	**658**	**655**
Conventional																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IMO levy	51	66	81	94	101	108	113	117	119	91	87	81	75	68	62	55	49	43	36	30	24	17	11	5
IMO reward	-19	-38	-57	-73	-88	-100	-114	-127	-92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VLSFO	280	268	255	243	231	219	207	194	182	128	114	101	88	75	67	59	51	44	36	29	22	15	8	2
Bio-MGO	0	0	0	0	0	0	0	0	0	520	570	620	669	718	750	781	813	845	877	909	941	974	1,006	1,038
e-MGO	45	93	140	185	238	291	343	395	447	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aggregate TCO	**520**	**503**	**487**	**471**	**452**	**441**	**421**	**399**	**425**	**955**	**989**	**1,020**	**1,050**	**1,079**	**1,096**	**1,117**	**1,135**	**1,153**	**1,171**	**1,190**	**1,210**	**1,229**	**1,248**	**1,267**
Conventional + CCS																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	6	14	21	28	36	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	41
IMO levy	50	64	77	88	93	96	98	98	98	94	89	84	77	70	63	57	50	44	37	31	24	18	11	5
IMO reward	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CCS cost	6	12	18	24	30	34	31	28	26	23	21	18	16	13	12	11	9	8	6	5	4	3	1	0
VLSFO	290	287	284	281	280	271	248	226	204	183	163	144	125	107	95	84	72	62	51	41	31	21	12	2
Bio-MGO	0	0	0	0	0	29	107	183	258	332	405	478	548	618	663	707	752	796	841	885	930	974	1,019	1,038
Aggregate TCO	**559**	**584**	**607**	**628**	**647**	**686**	**740**	**792**	**843**	**890**	**938**	**982**	**1,026**	**1,068**	**1,092**	**1,121**	**1,147**	**1,172**	**1,199**	**1,225**	**1,253**	**1,280**	**1,308**	**1,308**
LNG DF																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
IMO levy	45	59	74	86	90	93	109	113	116	115	113	110	105	100	92	85	77	68	59	50	40	29	18	6
IMO reward	0	0	0	-27	-66	-97	-88	-104	-78	-25	-29	-34	-37	-41	0	0	0	0	0	0	0	0	0	0
VLSFO	9	9	8	8	8	8	85	85	83	80	76	72	67	62	58	53	49	44	38	33	27	21	15	3
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
LNG	236	221	206	183	168	154	100	90	83	76	69	63	57	51	46	41	36	31	26	20	14	8	2	0
e-LNG	0	0	0	50	129	202	190	232	274	315	356	396	436	476	505	535	566	598	630	664	698	734	771	787

Aggregate TCO	**530**	**529**	**529**	**540**	**570**	**609**	**633**	**655**	**716**	**799**	**827**	**850**	**871**	**891**	**945**	**963**	**976**	**990**	**1,003**	**1,017**	**1,032**	**1,046**	**1,060**	**1,076**
$ per teu delivered	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
LNG DF + CCS																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	8	17	74	74	74	74	74	79	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74
IMO levy	50	64	74	86	91	95	97	98	98	94	89	84	77	70	95	88	79	71	61	52	41	30	19	5
IMO reward	0	0	0	0	0	0	0	0	-38	0	-25	-32	-38	-44	0	0	0	0	0	0	0	0	0	0
CCS cost	3	7	0	4	11	17	24	29	24	22	20	17	15	13	1	1	1	1	1	1	1	1	1	0
VLSFO	257	220	8	8	8	8	8	-7	8	8	8	8	8	8	113	102	91	80	69	57	45	32	19	2
LNG	27	53	206	192	193	194	195	208	171	154	137	122	107	92	0	0	0	0	0	0	0	0	0	0
Bio-LNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e-LNG	0	0	0	0	0	0	0	0	133	199	300	375	444	509	535	564	592	622	653	684	716	750	784	818
Aggregate TCO	**553**	**569**	**571**	**573**	**585**	**605**	**615**	**622**	**685**	**767**	**821**	**865**	**905**	**939**	**1,004**	**1,020**	**1,033**	**1,046**	**1,059**	**1,073**	**1,088**	**1,102**	**1,116**	**1,122**

Methanol DF																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	0	1	1	2	3	3	4	4	5	6	6	7	8	8	9	10	10	11	12	12	13	14	14	15
IMO levy	51	66	81	94	101	108	113	117	119	118	116	112	108	102	94	86	78	70	61	51	41	30	18	7
IMO reward	-19	-39	-58	-74	-89	-101	-115	-128	-92	-29	-33	-36	-40	-43	0	0	0	0	0	0	0	0	0	0
VLSFO	280	267	255	242	230	218	206	194	182	169	157	145	133	121	111	100	89	78	67	55	43	31	18	5
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	49	82
Bio-methanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e-methanol	35	73	108	143	183	223	263	302	341	379	418	455	492	529	557	586	615	645	676	708	740	760	769	777
Aggregate TCO	**556**	**576**	**595**	**614**	**636**	**666**	**685**	**704**	**770**	**859**	**882**	**901**	**919**	**935**	**989**	**1,004**	**1,015**	**1,026**	**1,037**	**1,048**	**1,061**	**1,075**	**1,091**	**1,108**

Ammonia DF																								
Ship CAPEX	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157	157
Ship OPEX	50	50	50	50	50	58	58	58	58	58	61	61	61	61	61	64	64	64	64	64	66	66	66	66
Tech CAPEX + OPEX	25	25	25	25	25	25	25	25	9	10	11	20	22	15	25	25	24	23	23	23	23	24	24	25
IMO levy	15	19	23	26	28	29	30	31	120	119	116	81	75	102	62	59	60	58	55	49	40	29	18	6
IMO reward	-598	-582	-564	-536	-495	-457	-435	-415	-89	-28	-32	0	0	-43	0	0	0	0	0	0	0	0	0	0
VLSFO	35	34	34	33	33	33	32	32	185	172	160	73	59	121	35	35	44	49	51	51	43	30	17	4
Bio-MGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	47	80	114
Blue ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	465	427	314	215	124	36	0	0	0	0
e-ammonia	846	825	805	784	772	759	747	734	245	274	303	392	420	388	0	49	166	272	373	471	515	518	520	522
Aggregate TCO	**530**	**529**	**529**	**540**	**570**	**604**	**615**	**622**	**685**	**762**	**775**	**785**	**794**	**801**	**804**	**816**	**829**	**839**	**846**	**852**	**860**	**871**	**882**	**894**