Low carbon pathways
2050
The greenhouse gas (GHG) emissions of shipping are a consequence of the carbon intensity of shipping’s energy supply, the energy efficiency of shipping, and the demand for shipping. The Paris Agreement confirmed that it was not a question of whether climate change should be addressed but a question of how, and it was clear that everyone will have to contribute.

The International Maritime Organization (IMO), as the organisation responsible for the international regulation of shipping, agreed at the 69th session of the Marine Environment Protection Committee (MEPC) to establish a working group to discuss the matter further at MEPC 70 from 24–28 October 2016. There are a number of submissions to MEPC 70 on this subject and we expect important discussions to take place on how this issue is to be progressed.

Arising from this backdrop are many debates, both in the policy forums and within the industry, as companies – sometimes individually, sometimes collectively – try to consider what their strategy might be for handling the simultaneously inevitable and uncertain changes ahead.

This report aims to contribute towards these discussions by providing information on the potential pathways to the decarbonisation of the global shipping industry, an objective that was recognised in previous submissions to MEPC related to the reduction of the GHG emissions from shipping. This topic has subsequently arisen in discussions with shipping companies – both collectively, through industry forums and initiatives, and individually, via commercial operating companies.

This report focuses on understanding the potential pathways and scenarios for the future of international shipping in the context of wider decarbonisation, consistent with the Paris Agreement. It focuses on the technological and operational specifications of the global fleet and how these may change in relation to a given rate of decarbonisation. It presents the results for a series of scenarios run using a model built to understand the possible futures of international shipping: GloTraM.1

GloTraM works by modelling the profit maximisation of shipowners under different macroeconomic, market and regulatory scenarios. The model is given a number of assumptions about the future availability of and options for different fuels, machinery, technologies and operational measures, and uses these to simulate how different sectors of international shipping might evolve over the coming decades.

The report content is centred on some initial findings as a timely input to the debates and forms part of a longer term study. Subsequent findings will be published in due course.

This is the continuation of an ongoing collaboration between the Low Carbon Shipping project, the Shipping in Changing Climates project and Lloyd’s Register (LR) to develop valuable new knowledge and tools for understanding shipping and its GHG emissions that can contribute to the policy debate.


Katharine Palmer
Manager, Environment and Sustainability
Lloyd’s Register
The scale of the challenge

In December 2015 at the Conference of Parties 21 (COP 21) in Paris, under the United Nations Framework Convention on Climate Change (UNFCCC), nations committed to keeping the global mean temperature increase to well below 2°C of pre-industrial levels by 2100, while aiming for 1.5°C. This means an imminent peaking of total CO2 emissions, and the need for substantial reduction of annual CO2 emissions from then on. To provide some context, depending on the exact pathway taken, this is likely to require net zero emissions by approximately 2035 (1.5°C) and 2070 (2°C). COP 21's more ambitious target means that the 'budget' of carbon emissions from all sectors has been reduced.

What is the scale of shipping's challenge?

The scale and rate of the global fleet's decarbonisation is influenced by both the evolution of demand for shipping and any objective that requires a reduction in shipping's CO2 emissions. Therefore, both are important inputs to any calculation of future scenarios for the shipping industry.

For the demand scenario, this study uses the Third IMO GHG Study RCP 2.6 SSP3 transport demand scenario. This makes the assumption that the global energy system is decarbonising (approximately consistent with a 2°C temperature stabilisation) and consequently modifying the demand for different commodities (e.g. fossil fuels).

A whole-economy CO2 trajectory is derived from one of the models (MAGICC) used in the International Panel on Climate Change (IPCC) AR5 literature. To provide an example of a decarbonisation pathway for shipping, an assumption is made that shipping contributes GHG emissions at a rate consistent with its historic share of emissions (2.33%) and the global economy decarbonises at the rate necessary to achieve 2°C stabilisation with a probability of 50%. Another way of looking at this is that achieving the Paris Agreement's goal of a temperature increase stabilised "well below 2 degrees, aiming for 1.5°" would require a greater rate of whole-economy decarbonisation, meaning shipping's share of CO2 emissions would increase, unless shipping were also to decarbonise.

The Third IMO GHG Study 2014 estimates CO2 emissions from shipping from 2007 to 2012 as amounting to 2.33% of global CO2 emissions over that period. Extending this percentage into a future 2°C scenario, this results in an initial estimate of a shipping CO2 budget of 33 Gt over the time period from 2011 to 2050. Consistent with this, Figure 2 highlights two interacting trajectories for the three ship types (bulk carriers, tankers and container vessels) focused on in Smith et al. (2015): the demand trajectories and the required operational CO2 intensity Energy Efficiency Operational Indicator (EEOI) trajectories that satisfy the combination of the demand trajectory and the CO2 trajectory (shown in Figure 1). The EEOI is presented as the required aggregate average EEOI inclusive of all sizes of ship within the ship type at a given point in time (excluding both newbuildings and the existing fleet). This allows for there to be a range of efficiencies of individual ships, varying according to the ship's age, size, specific design, and operational specifications.

This simplified analysis helps show that the scale of the challenge ahead and the ultimate need for decarbonisation are inescapable.

These rates of emission reduction are set within the context of a growing global population with ambitions to continue global economic growth. This will impact all sectors and industries in developed and developing economies alike. Shipping, as an industry, is currently dependent on fossil fuels for propulsion, and fossil fuels also form a large part of shipping cargo; therefore, this fundamental and inevitable change will transform the industry once again.

Shipping currently accounts for 2.33% of global CO2 emissions and there will be no space in the future to allow even the emissions of shipping (currently approximately 1 Gt per annum2) to be ignored.

Fig 1: Whole-economy CO2 trajectories for 2050, including shipping

Fig 2: Demand and required aggregate EEOIs consistent with a 2.33% share of total CO2, and a 2°C stabilisation pathway

3 Meinshausen et al. (2011) a&b.
Having established that there will be a new change in the industry – it’s a question of when and not if – we can try to articulate what potential futures we can expect by exploring a number of possible scenarios.

We demonstrate this by choosing three future scenarios for this initial study for the period 2015–2050. We have chosen three future scenarios where we assume that there is further GHG policy, the world commits to keep warming below 2°C, therefore consistent with a budget of 33 Gt, and there is a commitment towards the decarbonisation of shipping by varying levels. The varying levels we have chosen are:

- Scenario 1, High hydrogen availability – as a baseline, we assume all fuel options are available in all scenarios; however, for this scenario we have added the availability of hydrogen, which is used in fuel cell technology to demonstrate what can be achieved through technology and innovation.
- Scenario 2, High bio-energy availability – this scenario assumes a mid-range market penetration of biofuels in the shipping industry. We have assumed that the shipping industry adopts biofuels in a similar way to road transport, through blending targets and mandates for fossil fuels, and can derive high, medium and low uptake, as detailed in Appendix 1.
- Scenario 3, High percentage of offsetting – the start year of a Market Based Measure (MBM) is 2025 and buying offsets of CO₂, out of sector is allowed for 50% of the revenue generated from carbon pricing. This scenario represents a future where shipping has a higher cost of decarbonisation than other sectors in the economy.

These three future scenarios are compared to a business as usual (BAU) scenario with existing regulatory commitments (e.g. Energy Efficiency Design Index (EEDI), SOx and NOx regulations), but no further GHG policy.

We assume transport demand to be consistent across the three future scenarios and BAU, therefore, this report demonstrates the potential pathways for what is achievable through technology and innovation when there is high uptake of such commitments to decarbonise.

Table 1 provides a summary of the scenarios for this initial study with descriptions of the key parameters, and mandates for fossil fuels, and can derive high, medium and low uptake, as detailed in Appendix 1.

The different scenarios create different pathways in terms of the stringency of in-sector decarbonisation (depending on the amount of offsetting), and therefore for different fuel mixes, machinery choices, design and operating speed choices, and technology take-up. Each of these is considered for individual ship type and size category (e.g. 35–60,000 dwt bulk carriers) in turn, and the results are aggregated for presentation.

**Table 1: Description of scenarios**

<table>
<thead>
<tr>
<th>Regulation scenario</th>
<th>CO₂ Budget</th>
<th>MBM start year</th>
<th>Out-sector offsets</th>
<th>Demand</th>
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<tbody>
<tr>
<td>Scenario 1</td>
<td>33 Gt</td>
<td>2015</td>
<td>20%</td>
<td>20%</td>
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<td>Scenario 2</td>
<td>33 Gt</td>
<td>2025</td>
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**Techno economic**

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<th>RCP 2.6 SSP3</th>
<th>RCP 2.6 SSP3</th>
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<td>High Bio</td>
<td>High Bio</td>
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<tr>
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<tr>
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**NPV year**

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<th>Scenario 2</th>
<th>Scenario 3</th>
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**Fuels option**

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<th>All fuels</th>
<th>All fuels excluding hydrogen</th>
<th>2-degree consistent prices</th>
<th>2-degree consistent prices</th>
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<tbody>
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<tr>
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<tr>
<td>Scenario 3</td>
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<td>Low bound</td>
<td>13.5 million</td>
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**Fuel price**

<table>
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<th>2-degree consistent prices</th>
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**Bio availability**

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<tr>
<td>Scenario 1</td>
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<td>33 Gt</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>Mid-range</td>
<td>33 Gt</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>Low bound</td>
<td>33 Gt</td>
</tr>
</tbody>
</table>

**Table 1: Description of scenarios**

**CO₂ trajectory**

The total operational CO₂ emission trajectories are presented in Figure 3 for the ship types included in this analysis (wet and dry bulk and container shipping); these are not inclusive of any absolute reduction of emissions achieved through offsetting. The BAU scenario shows an increase in CO₂ emissions, which is consistent with similar scenarios estimated in the Third IMO GHG Study. In scenarios 1 and 2, by 2050, shipping net emissions decrease relative to the BAU scenario by approximately 50%. Both scenarios’ emissions peak in 2030 followed by a steadily increasing rate of decarbonisation. In scenario 3, operational emissions continue to increase, with the 33 Gt carbon budget being achieved through the use of offsets.
Fuel mix

The aggregate fuel mix for all scenarios is presented in Figure 4. One of the main contrasts between the scenarios is the difference in the marine fuel mixes.

All scenarios see a continued role for FOs (conventional and low sulphur (0.5% compliant)). The exact mix of Heavy Fuel Oil/Low Sulphur Heavy Fuel Oil (HFO/LSHFO) is highly sensitive to the relative price of the two fuels, since there is only a marginal capital cost differential, and so these scenarios should be viewed with close attention to the fuel price assumptions. This is because, even taking into account the increased capital cost of the abatement technology (e.g. scrubbers and, for new builds, an Exhaust Gas Recirculation (EGR) or Selective Catalytic Reduction (SCR) system to enable Tier III compliance), the fuel choice remains profitable relative to the competing alternatives.

FO’s continued role as a marine fuel in these scenarios can be attributed to its future price, as, in a decarbonising world, oil (particularly HFO) will remain cheap since policy and technology are expected to reduce demand faster than supply-side constraints are encountered. We know that most of these reserves will have to be left un-extracted if the Paris Agreement’s target of well below 2°C (aiming for 1.5°C) is to be met. HFO, being a residual fuel, will still be produced and – as long as no substitute demand appears and any tightening of IMO MARPOL Annex VI regulation of air pollution can be met with onboard technology – could remain economically viable.

However, much of this will depend on how the oil (particularly the refining) industry evolves over the next few decades, both in terms of producing increasingly ‘cleaner’ fuels and as part of wider decarbonisation. If the rest of the economy’s demand for crude-oil-derived fuels is removed, it would seem unlikely that refineries will continue to run just to satisfy shipping’s demand for a residual fuel.

Fuel Oil (FO) in combination with emissions abatement technologies remains important.

Fig 4: Aggregate fuel mix for all scenarios

HFO/LSHFO
MDO/MGO
LNG
Hydrogen
Biofuels

Pathway scenarios
continued
Alternative alternatives

Our initial analysis focuses on LNG, hydrogen and bio-derivative hydrocarbon fuels as potential alternative fuel choices to the current conventional fossil-oil hydrocarbon fuels.

For both scenarios 1 and 2, where we see large amounts of hydrogen take-up, this occurs because, relative to the alternatives, it has been made economically viable by the high carbon price. This high carbon price is needed to compensate for the high capital cost of the propulsion machinery and fuel storage and handling systems, as well as the impact on cargo capacity due to the fuel’s comparatively low energy density.

However, the issue of the practicality of substituting the volume of fossil fuel currently in use by shipping (~300 million tonnes) with some mix of bio and synthetic fuel, in the timescale of decades required by most targets, makes any potential non-fossil fuel switch a significant undertaking. Placed in the context of the current debates – those around the 0.5% sulphur FO availability, which is a comparatively moderate transition for the refinery and bunkering sector – it is clear that careful planning and infrastructure development will be required.

The experience gained to date with Liquified Natural Gas (LNG) may provide some important lessons. LNG is a fuel that requires significantly different storage, handling and infrastructure, and so gives rise to a number of challenges that are being solved today. This is being managed through:

- the development of bunkering infrastructure,
- containment on board,
- the supply chains for the bunker provider, and
- management of the uncertainty of LNG vs HFO vs Marine Diesel Oil (MDO) prices.

The experiences gained from the transition to the use of LNG could be used to understand and assist with a transition to bio and synthetic fuels.

Rate of change of carbon intensity of transport work

EEDI and EEOI are both carbon intensity indicators used in the shipping industry, so will vary with the modifications to the carbon factor of the fuels (e.g. through the use of bio or synthetic fuel) and with the take up of energy-efficient technology and operational measures. In both instances, a lower value indicates a relative improvement (in carbon intensity or energy efficiency).

The EEOI may have shortcomings when deployed for investigating year-on-year performance trends on an individual ship, due to its high sensitivity to some of the operating parameters (e.g. ship speed and capacity utilisation). However, it can be useful for understanding the rate of change in fleets of ships over long periods of time – where variations over specific vessels and periods of shorter time average out. The trends resulting from the different scenarios can be seen in Figure 5.

The graphs show that the use of low carbon fuels can enable reductions in energy efficiency. For example, in scenario 1 this is because the use of an increasing quantity of low carbon fuel (in this instance hydrogen) enables operating speeds to increase, as lowering speed (as an energy efficiency improvement) is no longer required as the mechanism to achieve a given CO₂ emissions trajectory.
Offsetting

If shipping has a higher cost of decarbonisation than other sectors of the economy, it may be possible to offset some of its CO₂ emissions by purchasing offsets from other sectors. This requires both structures for trading emissions between sectors and other sectors to have ‘spare’ permits available for trading.

To explore this, some amount of offsetting is permitted in each scenario. In Figure 6, the operational CO₂ emissions (e.g. emissions that come out of the exhaust) are compared with the ‘net’ CO₂ emissions, which include reductions achieved by purchasing offsets from other sectors.

The model is designed to simulate, as closely as possible, the operation of a real-world trading system. At each time step, an initial value of the carbon price is used. From the carbon revenue that is raised, some amount of offset is purchased at a global carbon price representing the market of offsets provided by other sectors. The amount of offsets purchased is deducted from the actual operational CO₂ emission to obtain a net emission. If the net emission is greater than the target emission trajectory, then the carbon price is increased, which in turn applies greater in-sector decarbonisation incentives as well as increasing the amount of offsets that can be purchased, lowering the net emissions.

The offset allowance is much greater in scenario 3 than in scenarios 1 and 2. The consequence of this can be seen in Figure 6: the operational CO₂ emissions for scenario 3 continue to rise, with the net reduction only being achieved because a large amount of offsets have been purchased.

When the offsetting allowance is reduced (scenario 1 or scenario 2), shipping has no choice but to achieve the emissions reduction via earlier adoption of technology, which is why we see the earlier appearance of alternative fuels, such as hydrogen, in these scenarios.

This ensures that the industry is well prepared for the transition to zero carbon at some point after 2050 (i.e. by 2050 it will have already achieved a substantive amount of decarbonisation in-sector).

However, because abatement costs are expected to be lower outside shipping than within the shipping industry, there is a corresponding impact on carbon prices. This advantage needs to be weighed up against the various disadvantages associated with offsetting.

Pros:

- Enables multiple sectors to allocate decarbonisation costs in a mutually least-cost way, therefore theoretically reducing the carbon price seen by each sector.

Cons:

- There is added complexity and an administrative burden in having a system that allows the trading of carbon emissions out of shipping. As with any offsetting scheme, care needs to be taken to ensure that an offset emission represents a genuine reduction in CO₂ and is equivalent to a CO₂ reduction in-sector.

- Depending on how policy is made for other sectors, there may not be cost-effective offsets available, which could create issues if a presumption of offsetting is part of the industry’s transition strategy.

- Delays an inevitable transition, so potentially prolongs an intermediate period of build-up problems for the future.

- Enables a flow of capital to other sectors, reducing the amount of capital available for in-sector decarbonisation.

Fig 6: CO₂ operational emissions and CO₂ offsets

BAU
High Hydrogen (Scenario 1)
High Bio (Scenario 2)
High offsetting (Scenario 3)
One of the key drivers of emissions in the shipping industry is transport demand.

Here, we have presented three potential scenarios; however, all scenarios are dependent on assumptions that are uncertain, and GloTraM, like any model, requires a number of assumptions to be made in order to simplify the results appropriately. It is important to bear the following points in mind.

• There is uncertainty around how both demand and gross domestic product (GDP) might be related in the future and how global GDP might evolve. Small changes in the annual growth of transport demand could create large changes in total demand over the 40-year period of this study; therefore, this is an important, high-sensitivity uncertainty.

• The amount of energy (fuel) that could be sourced from biomass in the future is highly uncertain and the results have a large sensitivity to this assumption. Biofuels have been considered substitute fuels to fossil fuels with equivalent prices, while uncertainty remains about the relative bio and fossil fuel prices.

• There is uncertainty about the year in which further GHG policy will be implemented in order to control GHG emissions from shipping. This modelling assumes a start year that may not be politically feasible. The later the start year, the greater the rate of decarbonisation, so this parameter is highly sensitive to the trajectory that shipping emissions ultimately take.

• As well as timescale, there is uncertainty about how any further GHG policy might be implemented. The scenarios studied assume a MBM that uses a price signal (on CO2 emissions) as a lever to change shipping technology, fuels and operation. Alternative approaches may become the favoured solution and these might incentivise different choices to those shown here.

• This model has centred on CO2 emissions from ships and not the emissions associated with the production of technologies or fuels, as these have typically been the focus of IMO regulation. However, there is evidence that non-combustion (e.g. upstream and lifecycle) GHG emissions are important for some of the fuels that appear in the pathways, along with the non-CO2 GHGs emitted both during onboard consumption and over the fuel’s lifecycle. Accounting for both of these is important and is the subject of ongoing work, and this could in turn have a large impact on the overall climate impacts of different pathways.

• Historically, air pollution and GHG emission regulations have interacted. While MARPOL Annex VI and the associated SOx and NOx regulations have been taken into account, additional regulations may yet be developed on these and other emissions (e.g. methane, black carbon, PM), which could in turn drive changes in the optimal choices for the combined objective of compliance and profit maximisation.

• A wide range of different technologies and operating measures have been considered and show that there are a number of different combinations that could assist. High uncertainty remains around the potential emission reduction of some technologies (for example, wind-assistance technologies), and the impact of production volume and learning on cost reduction for the different technologies is uncertain. All these uncertainties could impact both the cost of decarbonisation and the technology pathways for the sector.

• On the subject of fuels, we have limited our analysis to a number of fossil, synthetic and biofuels. Different fuels are considered in early-stage research at present, and these, in due course, may be shown to have good potential for managing shipping’s climate impacts.
Conclusion

There are very few certainties about the future of ship design and operation, and, by association, the wider system within which ships operate (ports, bunker suppliers and supply chains, trade, freight handling and logistics, etc.). One important uncertainty is how the regulatory landscape for the control of shipping’s GHG emissions will unfold: when and which incentives and levers might become important drivers of investment and operational decisions in shipping. The designers, owners and financiers of a ship designed today and launched in around 2020 would probably like that ship to retain its commercial viability for several decades. How can we best think that through?

This report sets the detail of the regulatory debates to one side and asks the question: given the current best available evidence, what is a reasonable estimate of how shipping might be required to change and what does this look like? The results of this report show that, in the scenarios considered, shipping is likely to need to start its decarbonisation imminently, and that the associated changes will be fundamental and require a lot of further work and development to minimise disruption.

This is important because, in all parts of the global economy, not just shipping, decarbonisation starts with the ‘low-hanging fruit’. As stringency increases over time, increasingly high-cost mitigation steps are required. Therefore, while it might be tempting (given the timescales at play) to try and ignore the cumulative nature and scale of shipping’s decarbonisation challenge for a bit longer, this work shows that this is not a sound strategy. The later we leave decarbonisation, the more rapid and potentially disruptive it will be for shipping, and the more limited the options both in-sector and out of sector will be. The later we acknowledge the scale of the challenge and the pathways the sector is likely to take, the less prepared the designers, owners and financiers will be for the future.

These initial results from the different scenarios suggest that there are foreseeable technological changes and mechanisms (such as offsetting – bearing in mind the unresolved questions of how reliable, robust and long term a solution this could be) that, in various combinations, could enable any of the potential pathways. So, all are ‘possible’ options for achieving absolute reductions of a scale and timeliness consistent with the Paris Agreement. However, they all need significant changes to international shipping for that to come to fruition.

The specifics of how shipping might change vary depending on the assumptions made. The scenarios cannot envisage the role that innovation might play in any transition, as they are limited to the mix of technologies defined as input assumptions. However, we can show that different scenarios have different consequences for the technology mix of the industry, and show that further work is needed if shipping is to manage its transition while maximising resilience and minimising the risks of technological obsolescence. Innovation can produce lower cost alternatives as well as help to reduce the cost or increase the performance of technologies that have already been identified.

In addition to the fact that the cost of known technologies is uncertain (a known unknown), there is also the issue that technologies may evolve that we have not yet conceived of in terms of their application to the sector’s GHG emissions reduction (an unknown unknown). However, one key finding is that most of the pathways will require a substitute for fossil fuel, because energy efficiency improvements alone will not be sufficient in the medium to longer term: Energy storage in batteries and renewable energy sources (wind and solar) will undoubtedly have important roles to play, but are likely to still leave a requirement for a liquid fuel source. The evolution of the global fleet and its technological and operational characteristics are just some of the considerations that need to be taken into account for the shipping industry’s transition to a low carbon future. Costs and economic impacts, as well as legal, policy and societal dimensions all need to be considered, and their exclusion at this stage is not in any way a dismissal of their significance – just an attempt to temporarily simplify and focus on a subset of the discussion.

How the shipping industry decarbonises is most likely to be a trade-off between costs and steps being undertaken by other sectors and economies. The consequences of the different pathways for both the shipping industry and the global trade and economic system require careful consideration and analysis.

Taking the above into consideration, the sooner the shipping industry has a clear high-level target, and has identified associated potential pathways for technology transitions, the easier these important conversations with the impinging stakeholders will be, and the sooner assumptions about any non-fossil fuel can be improved.

"Shipping is likely to need to start its decarbonisation imminently."
What will happen next?

The first steps for further GHG regulation in both the EU and IMO debates have been the design of Monitoring Reporting and Verification (MRV) and Data Collection System (DCS) schemes. Both appear likely to be in use from the latter part of this decade. Both will produce important data and information that can assist the sector's decarbonisation.

- Given the uncertainty in future transport demand scenarios, and the difficulty of accurately estimating present transport demand, it will be important for these schemes to measure cargo carried so that actual carbon intensities (e.g. emissions relative to cargo carried) can be calculated. Without such metrics, absolute increases or decreases in carbon emissions could be spuriously misinterpreted as positive or negative trends in the short term, leaving signals for corrective action to be missed until the mid-term, when gross changes become observable.

- Given the scale of the change required, this data will provide an important time series that can be repeatedly revisited to review the consequences of any policy and check for unintended consequences (positive and negative). The more open this data is, the more organisations can make their own estimates of the impacts on the sector during the transition and improve the likelihood of negative consequences being spotted sooner rather than later.

- Given the existence of market barriers and failures in the sector, the more these schemes can address this by providing greater transparency on fuel consumption and efficiency (which could be used to ensure these factors are reflected in the market), the lower the carbon price signal to achieve a given amount of decarbonisation will need to be.

While the administrative burden associated with any scheme should not be trivialised or ignored, the above implies the importance of these schemes for the wider GHG objective.

Although shipping was not mentioned explicitly in the COP 21 Paris agreement, it signals a new era for shipping. Coupled with the scale of the change that is needed for shipping, it is clear that global action will increase the importance of regulatory compliance, and clear long-term input into the formulation of direction and derivative policies appear to be demanded by many shipping stakeholders. The regulation needs to provide the right incentive to drive the change needed and it is hoped that business strategies and consistent policies can be combined to reduce shipping emissions.

Shipping, through the IMO, can choose to be either a leader or a follower. If taking a follower role, it could identify a fair share derived from these existing commitments and wait for the ratchet mechanism to increase stringency. Alternatively, shipping could anticipate the inevitable ratcheting up of ambition and identify its fair share relative to the expected longer term stringency.

An obvious advantage of anticipating a longer term and more stringent ambition now is that the shipping industry will have the time it requires to mature and adopt new technologies. The sooner a reliable signal is provided for that change, the better.

What is LR doing?

As a thought leader, the LR group is convening industry roundtable discussions on the findings of this report and facilitating the development of future possible scenarios in collaboration with the industry to create and share knowledge and tools that can contribute to reducing GHGs from shipping.

"Shipping, through the IMO, can choose to be either a leader or a follower."

"Although shipping was not mentioned explicitly in the COP 21 Paris agreement, it signals a new era for shipping."
Appendix 1 – Assumptions

Transport demand

One single transport demand projection has been assumed and it was obtained from the Third IMO GHG Study. In particular, such a transport demand is composed of the SSP3 trajectories and the RCP 2.6 trajectories of the Third IMO GHG Study.

The SSP3 trajectories are characterised by a continuation of the typical trends of recent decades, with most economies being politically stable with partially functioning and globally connected markets. There is a slowly decreasing fossil fuel dependency. Some countries are making relatively good progress in development, while others are being left behind.

The RCP 2.6 trajectories will likely be characterised by a radiative forcing of 2.6 W/m² by 2100. Ambitious GHG emissions reductions would be required to reach such forcing levels.

The world population is projected to reach 9 billion by the year 2100, and there will be a decline in the use of oil, while the use of croplands will increase due to bio-energy production. The energy intensity will therefore be low and methane emissions will be reduced by 40%.

In this report, it is assumed that such a transport demand projection is in line with a 2°C scenario. So we are assuming that demand for dry non-coal and container will increase while demand for dry coal and tanker will decrease due to the decarbonisation of the world, which will mean demand for oil and coal is reduced.

Fuel options

In this work, conventional marine fossil fuels are represented by one category that includes marine distillates (MDO/MGO), and two categories that include residual fuel of different sulphur contents (HFO and LSHFO). The LSHFO category includes petroleum fuels with a sulphur content equal to or less than 0.50% m/m. The alternative fuel choices implemented for this work include LNG, hydrogen and biomass-derived products and their equivalents or substitutes.

In this report, the international shipping fleet is assumed to adopt biofuels in a similar way as the road transport sector is already doing, given the blending targets and mandates for fossil fuels. We assume the final share of the international shipping industry is expected to be 2.42% of the global share in 2050. Based on this, we define three levels of marine biofuel availability as:

- lower bound: 1 EJ (38 EJ global)
- mid-range: 4 EJ (127 EJ global)
- upper bound: 11 EJ (460 EJ global)

Fuel price projections

In this report, we use two fuel price projection scenarios: ‘2-degree price’ and ‘LNG low’. The only difference between the two scenarios is the projection of LNG price. If possible, fuel price projections for the period from 2015 to 2050 should be obtained using the output of the model TIAM-UCL. The model is a linear programming cost optimisation model that generates equilibria between supply and demand for each commodity of the global energy system. For example, the oil price falls if demand dries up faster than supply reduces. HFO, MDO, and hydrogen prices are directly derived from the scenario of TIAM-UCL, in which the average global temperature rise is below 2°C.

LSHFO, which complies with the likely global 0.5% sulphur content limit, will enter the market in 2020. Its price is linked to the MDO price by a factor of 1.28 (based on the historical average of LSHFO/HFO and MDO/HFO).

LNG price projection can be divided by period. In the first period (2015 to 2020), LNG price is linked to HFO price. In the second period, the price is linked to TIAM-UCL's projection for HFO, MDO and hydrogen. The price in the first period is obtained by calculating, first, the "LNG price parity", which is the LNG price that would be equal to that of HFO on an energy basis. Eventually, this price is discounted by a representative coefficient of $30/ton.

Technology options

A matrix of compatibility exists within the model, which combines fuels with main engine technologies. A fuel can be used in different types of main engines. For example, LNG can be used with fuel cells, dual fuel engines and gas engines, while hydrogen is assumed to only be used with fuel cells.

A number of technologies and operational interventions are made available to the model for selection (as a function of fuel price and policy).
References

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Acronyms

dwt deadweight tonnage
EDDI Energy Efficiency Design Index
EEOI Energy Efficiency Operational Indicator
GHG Greenhouse Gas
HFO Heavy Fuel Oil
IMO International Maritime Organization
IPCC International Panel on Climate Change
LNG Liquefied Natural Gas
LSHFO Low Sulphur Heavy Fuel Oil
MBM Market Based Measure
MDO Marine Diesel Oil
MEPC Marine Environment Protection Committee
NPV Net Present Value

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