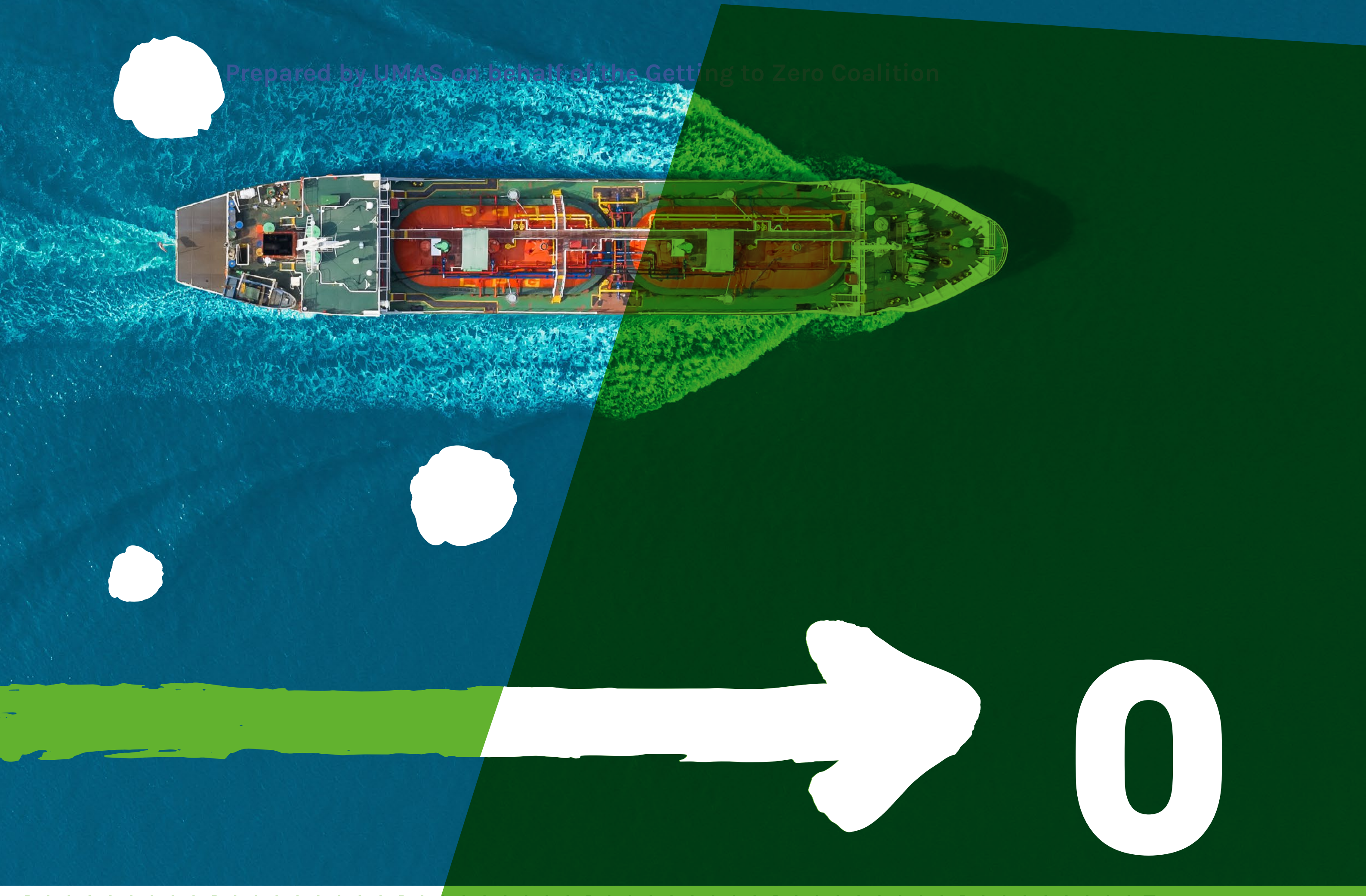
A Strategy for the Transition to Zero-Emission Shipping

An analysis of transition pathways, scenarios, and levers for change

Prepared by UMAS on behalf of the Getting to Zero Coalition



For the Getting to Zero Coalition

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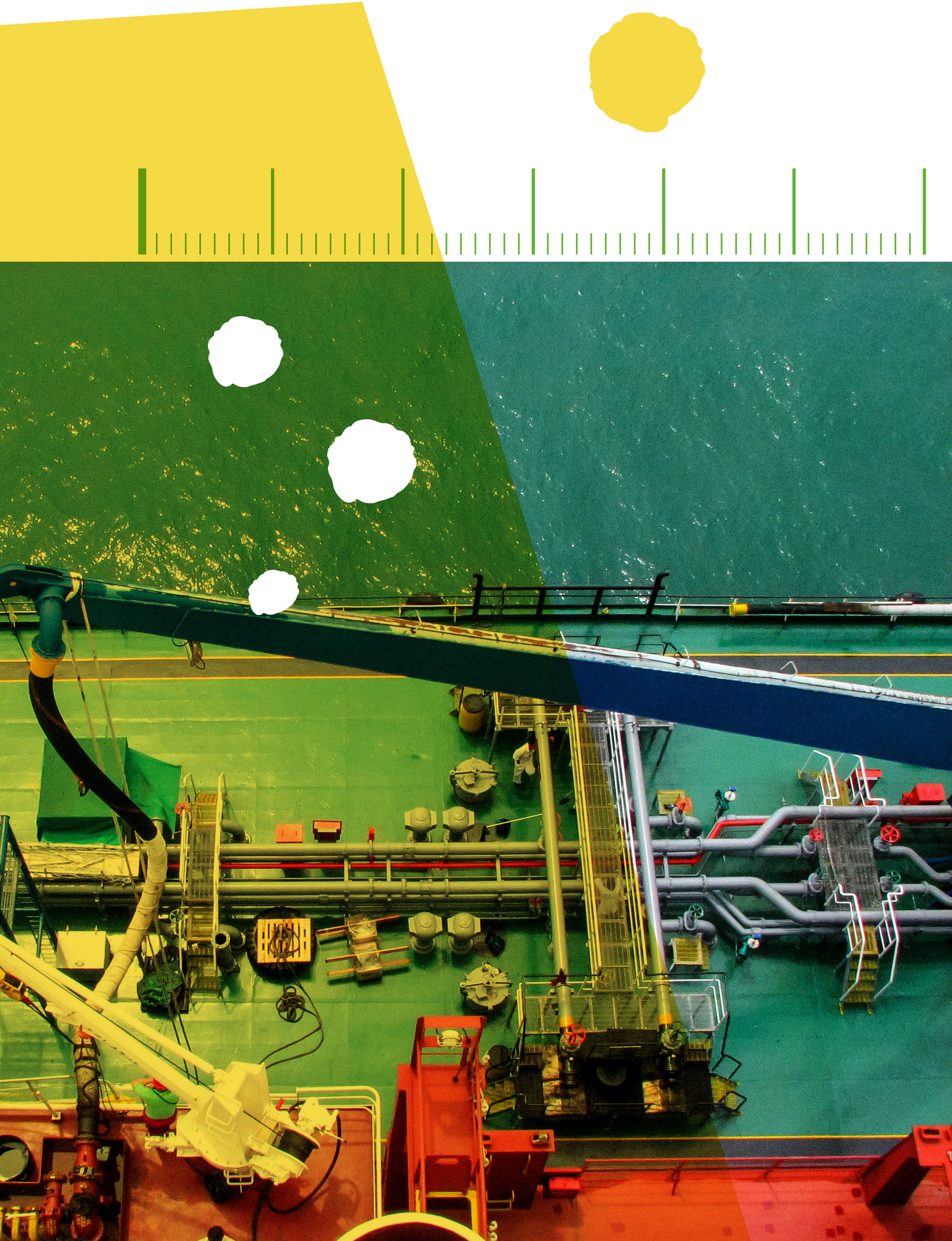


Summary for decision makers

Why is a transition strategy needed?

The need for all sectors, including shipping, to transition away from the use of fossil fuels has been known for some time, and has increasingly gained consensus and commitment politically. The April 2018 adoption at the International Marine Organization of the Initial Strategy on GHG Reduction was an important milestone in this process, indicating that there must be a transition away from fossil fuels as the dominant marine energy source, within the lifespan of today's newbuilt ships.

This has naturally led to a sector-wide discussion of which fuel shipping will use in the future. However, this question is embedded in a larger one – that of how this transition can be stimulated, coordinated, and delivered, not just by the IMO but also by national governments, regional bodies and industry stakeholders.

Objective:

This report aims to provide more clarity on the essential elements of such a transition: the political, technical, economic and commercial requirements, and the actions needed from the sector to deliver on them. Its objective is to add to the knowledge base in the sector, open debate and weaken false narratives across industry actions and national, regional and global policy making.

Key takeaways:

1. The necessary transition is feasible – it can and must accelerate.

Transitions from one dominant technology and supply chain to another are frequent, and many have happened before in shipping and other sectors. Through a study of these, **we find that a transition away from fossil fuels in shipping has much in common with, and can learn from, other transitions**. This does not mean that the transition will not see significant change and require collective decisiveness – indeed **the path the sector is on now requires urgent and drastic correction from both commercial and policy actions to avoid significant risks to the sector and global trade**. The current policy mix, including policy developed since 2018, is not sufficient.

Maximising efficiency will make the transition more feasible by lowering future fuel costs, and both industry action and stringent policy are needed to maximise the potential of existing technology, operational improvements and wind-assistance. **Without maximum efficiency, the transition will be more expensive, more difficult and disruptive, and more prone to failure and delay**.

2. The transition is not all about the IMO. Far from undermining the IMO's authority, national and regional regulation have an important role to play.

Whilst the IMO in many ways 'fired the starting gun' in 2018, the actions that are needed lie with a broad range of actors and sub-global policy regimes – as well as with the IMO. Evidence from past transitions shows that important early-stage actions are normally taken in smaller actor/geographical groupings - before a global regulatory regime of the required stringency is in place.

Industry leadership, collaboration and early-stage investment (public and private) is critical for the 'emergence' phase – in which solutions are tested and evaluated, costs are reduced, opportunities and risks are crystallised. This private sector activity can be taken in close collaboration with the public sector, and strong first mover countries have in the past created the conditions for that investment. Countries can act in parallel or in a more coordinated way. For shipping's transition away from fossil fuel there are several countries that have the potential to act unilaterally, and emerging opportunities to make these moves in concert and create international coherence, to the benefit of the global transition.

Embracing actions at all regulatory levels, and guiding them to maximum coherence and complementarity to IMO policy, is a winning strategy for an effective and efficient transition. It is also more likely to accelerate adoption of IMO solutions by reducing the number of transition levers that such action has to pull.

The IMO's Initial Strategy places emphasis on both fairness and mitigation. Calls and actions to advance policy and ambition at the IMO that focus on mitigation are more likely to be adopted if they are combined with practical solutions that can advance fairness and equity at the same time.

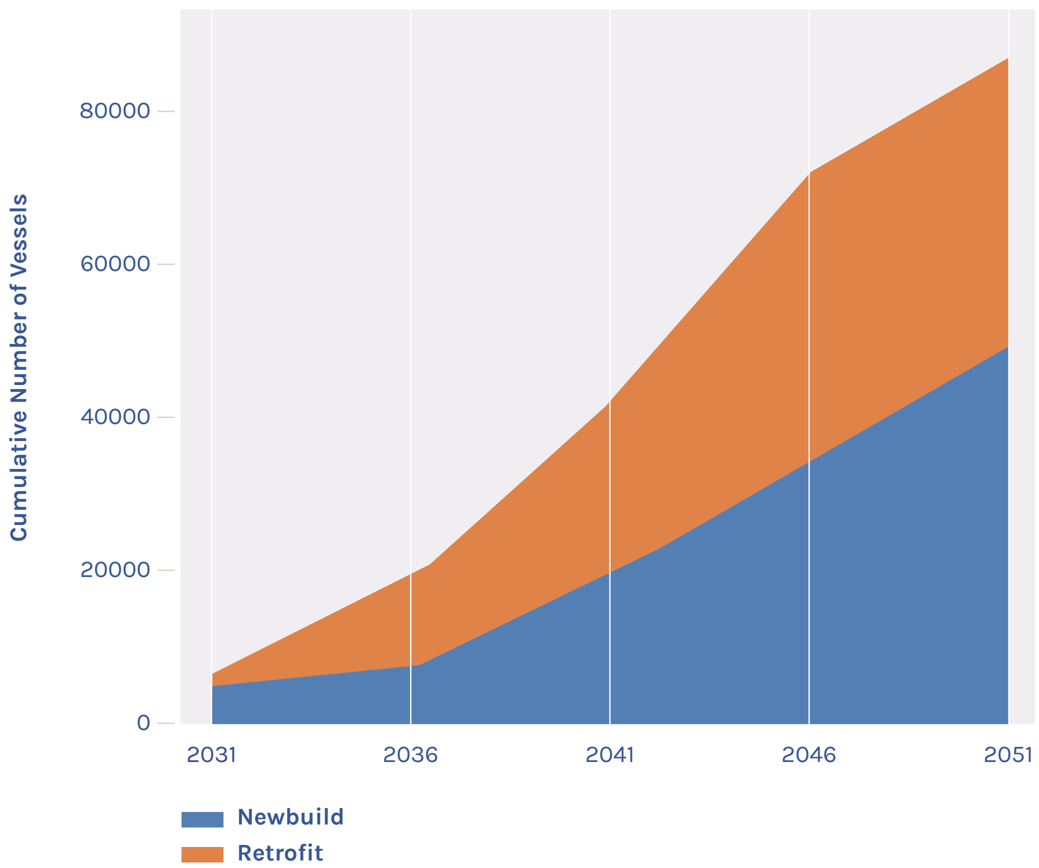
To achieve a rapid, smooth and equitable transition, the **different layers of decision-makers (industry and policymakers from global to local) need to act in concert** – signalling clearly that each will play its important role. Industry action will respond to clear signals from policy, and policy action both nationally and internationally is enabled by clear signals from industry. The essential thing is to move from a stand-off, where each party places conditions on action, to a virtuous cycle, where each party takes what actions it can in order to embolden the actions of the other.

3. The fuel pathway is not predetermined, but will be laid brick-by-brick, and all actors have a responsibility to ensure it is well built.

The last few years have seen a large amount of work undertaken to understand the costs of different alternatives to fossil fuels, including those fuels which are most likely the dominant future fuels, Scalable Zero Emission Fuels (SZEF).[1] However, the evidence shows that transitions are in practice fluid, and outcomes are determined not by equations, but by the interplay of actors and their actions - guiding not just the end point, but the path to get there.

Regardless of technology choice, land-side infrastructure for producing and supplying new fuels will be a critical component of shipping's fuel transition. The likely speed of the transition will put huge pressure on the scalability of production processes,[2] and hydrogen-based fuels are most likely to deliver during this phase. Growing demand for hydrogen and hydrogen-derived fuels will help lower their costs, especially for green hydrogen-based fuels, by driving up scale of production. This is in contrast to fuels dependent on more fundamentally constrained biomass feedstocks – for whom demand growth ultimately raises prices.

Figure 1: Similar magnitudes of newbuilding and retrofitting to SZEF use will be needed, unless ship lives are significantly reduced for the fossil fuelled fleet.



1 Fuels that have the potential to achieve near-zero GHG emissions on a lifecycle basis while also scaling production in line with the pace of the transition.
2 We estimate that, at the peak of the transition, the equivalent of 30 full-scale (1.5 GW) of SZEF production will be required per annum.

For shipowners, builders and their investors, we find that **the number of SZEF retrofits may be roughly equal to newbuilt SZEF ships over the transition**[3], as shown in Figure 1. This retrofitting activity is significant in the 2030s and will need to encompass ships built today, and potentially ships built earlier than 2021. The increasing use of 'optionality' in ship specification – **designing ships to be zero-ready or retrofittable to SZEF -- can reduce some of the risks in the fuel transition**, but these design elements will need to be material to ensure that 'zero-ready' is more than a catchphrase.

The question of fuel pathways is one of cost and technology, but also one of competing narratives, with narratives that gain traction potentially generating self-fulfilling momentum. Some pathways, meanwhile, could require more than one step-change in molecule, fuel production pathway or both. These would pass through overlapping fuel transitions, each with their own emergence/diffusion/reconfiguration phases – adding complexity to the sector's already challenging task of moving away from fossil fuel.

While this dynamic generates uncertainty, it is already clear that **today's investments should be made with the long-run solution of Scalable Zero-Emission Fuels (SZEF) in mind, even if the pathway there involves other steps. Precision and far-sightedness in language and communications by all stakeholders is key, to ensure that actions by the industry, and the signals they send to policymakers, are truly linked to scalable, zero-emission pathways**.

3 The amount of retrofitting that actually takes place may be lower if today's newbuilds are designed for shorter lifespans, or if drop-in alternatives to fossil fuels prove to be cheaper and more available than assessed here.

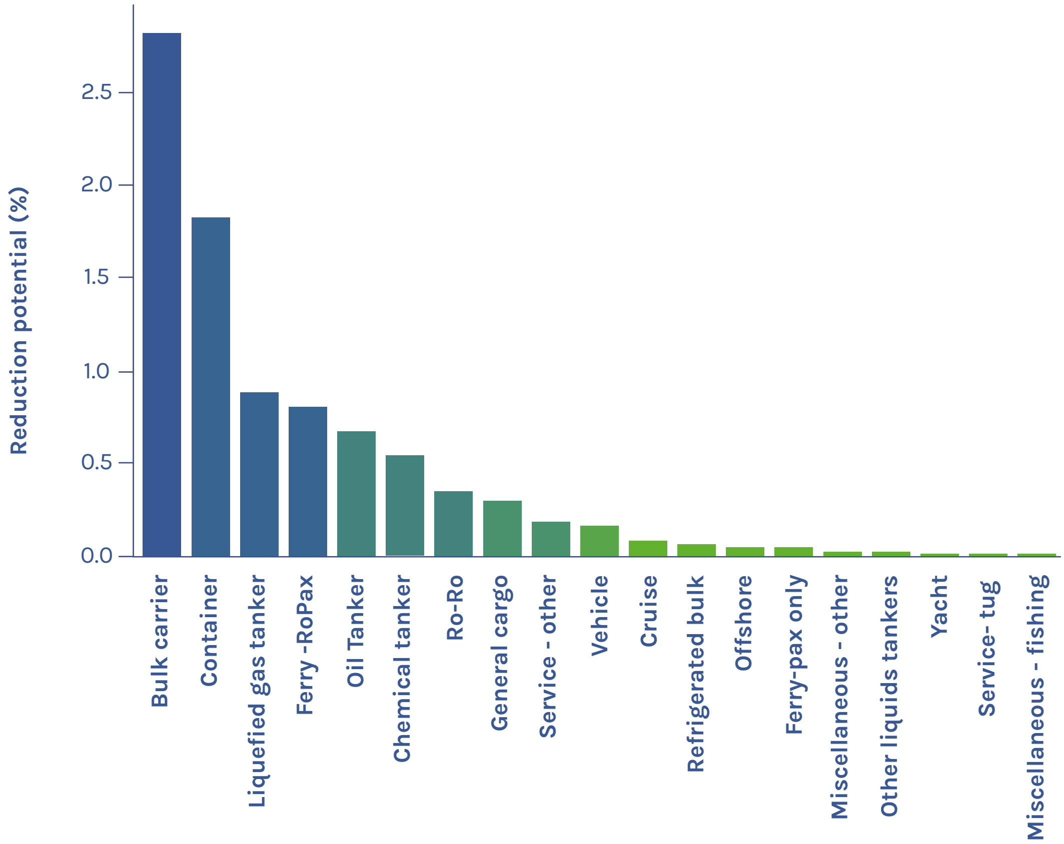
> *4. There are abundant opportunities for SZEF use this decade. Enabling this early use requires concerted action now.*

At this point in shipping's transition, the most urgent actions are those that can contribute to the scaling up of production and use of SZEF to make up at least 5% (by energy content) of total fuel consumption by 2030. **We estimate that this potential exists: about 10% of shipping's total fuel consumption has promising conditions for transitioning to SZEF during the 2020's**.

Figure 2: Identified first mover bilateral trade routes e.g. for ships shuttling back and forth between two ports from hydrogen-advantaged countries.

A good deal of data exists that can underpin decisions on early action, for example as shown in Figure 2. While shipping is a very diverse industry, vessels and fuel production associated with regular journeys in particular geographies, on relatively simple routes with a small number of regular stops, and near low-cost hydrogen production can be prioritised as first movers. The ship types that look attractive on these specifications include passenger and vehicle ferries, container ships, tankers and bulk carriers – the magnitudes of fossil fuel substitution for different ship types on identified first mover liner shipping routes (regular sequences of port calls) are shown in Figure 3.

Figure 3: Vessel type distribution for potential first mover liner routes (all routes).



By definition, these first mover use cases are all domestic, regional or only require small groupings of countries to cooperate. **So there are options to incentivise them through plurilateral action (groups of like-minded countries acting together), or multilateral policy (IMO regulation).**

Some national or regional actors appear particularly well positioned to lead sub-global policy and collaboration: Japan, USA, China, the European Union, and Norway are all potential candidates. The analysis of early adopter routes shows that these countries, either between them or on their key trade routes with third countries, can impact a very significant share of the identified early adoption fuel consumption – such that their plurilateral intervention would be meaningful to the global transition.

Given the urgency of the situation, **global and sub-global incentives for early deployment of SZEF** are both justified.

A multi-stakeholder integrated transition strategy: Synthesis and next steps

The transition to zero-emission shipping is multifaceted. Success does not mean finding a single course of action, but rather requires a series of actions, by different stakeholders, which can reinforce each other to fully decarbonise the sector before 2050. This report has therefore used the analysis of shipping's decarbonisation to conclude with a list and sequence of granular actions that need to be taken, particularly over the near-term to 2030. The actions needed from different players are discrete but interacting. The synthesis is not intended as a prescription, but as a guide and a checklist: actions that do not come to pass as proposed will need to be substituted for. The sequence of actions can be updated and monitored to help understand whether we are on track, and if not, where greater attention is needed.

This report should be seen as a complement to other valuable work done on the transition, both completed and ongoing. These include:

First Movers:

- Osterkamp, Smith, Søgaard (2021). "Five percent zero emission fuels by 2030 needed for Paris-aligned shipping decarbonization."
- Energy Transitions Commision (2020). The First Wave: A Blueprint for Zero-Emission Shipping.
- Forthcoming from the Getting to Zero Coalition, Mission Possible Platform and McKinsey & Co. (2021). The Next Wave: Green Corridors.

Fuel pathways:

- Lloyd's Register, UMAS (2020). "Techno-economic assessment of zero-carbon fuels."
- Krantz, Smith, Søgaard (2020). "The scale of investment needed to decarbonize shipping."

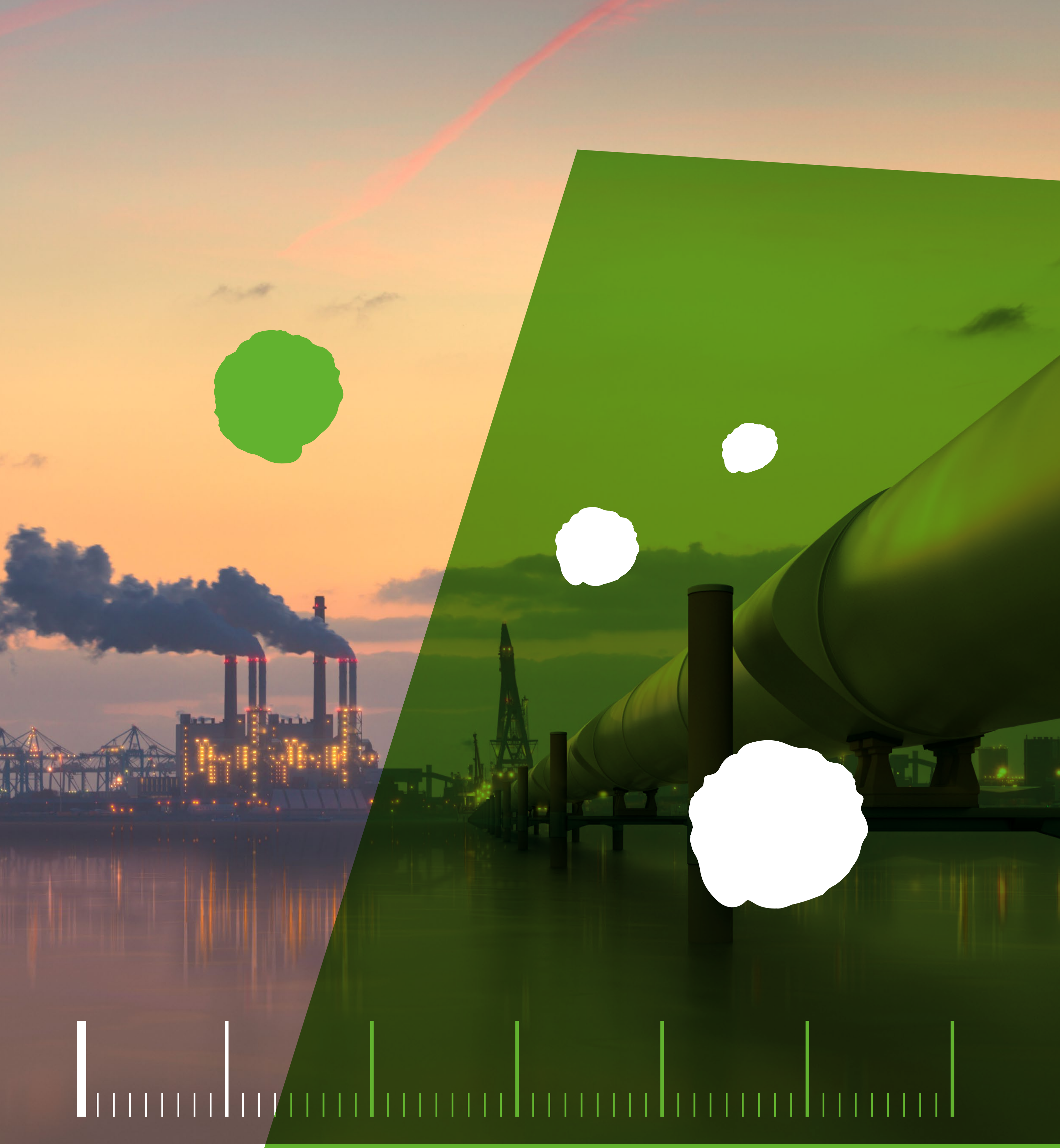
Policy and the equitable transition:

- Rojon (2020). "Decarbonising shipping: Shining a light on the sector's technical and political challenges." Carbon Mechanisms Review.
- Englert, Losos et al. (2021). The Potential of Zero-Carbon Bunker Fuels in Developing Countries. World Bank.
- Forthcoming from UMAS/Global Maritime Forum, Rojon, Blaxekjaer et al (2021). "Policy Options for Closing the Competitiveness Gap Between Fossil and Zero-Emission Fuels in Shipping."

Table 1: Table of actions needed to achieve 1.5°C-aligned and equitable decarbonisation of shipping (black – industry, green – national and plurilateral, red - multilateral).

	Key actions needed to decarbonise shipping	By 2022	By 2025	By 2030	By 2035	By 2040
Policy	Multiple nations make domestic and plurilateral commitments to decarbonise shipping	Green				
	Multiple G20 governments commit to funding for RD&D and pilot projects related to zero-emission shipping	Green				
	Leading countries publish 1.5°C aligned decarbonisation plans for domestic shipping, with aim to fully decarbonise by end of 2030s	Green	Green			
	Leading countries set production targets for zero-emissions fuels (intermodal usage)		Green	Green		
	International agreements on zero-emission shipping route creation (at least 3 global and 3 regional routes)	Green	Green			
	Most national governments completely phase out fossil bunkers in domestic shipping				Green	Green
	Intensified effort at IMO to agree long-term measures for shipping (e.g. market-based measures and non-market-based measures)	Red				
	IMO Clarify feasibility of retrofitting existing fleet	Red	Red			
	IMO require new ships to be zero-emission ready, e.g. “GHG Reduction Plan with zero emission propulsion capability”		Red	Red		
	IMO adopt measures in EEDI, efficiency, other GH gasses & a roadmap to zero	Red	Red			
	IMO adopt guidelines to estimate well-to-tank GHG emissions and regulation/ incentives for zero-emission fuels	Red	Red			
	IMO agrees comprehensive decarbonisation strategy and net-zero by 2050 target	Red	Red			
	Global agreement on gradual phase out and ban of fossil bunkers					Red
	Classification societies adopt robust "zero-emission ready" guidelines	Black				
	Classification societies research and set operational and safety standards	Black	Black			
Finance	Increase transparency in ship finance, improve standard usage, and adopt more stringent Environmental, Social and Governance standards	Black	Black			
	Develop risk-sharing framework (e.g. for first movers) and longer maturities for ship finance (e.g. green bond markets)	Black	Black			
	Mobilise industry and finance support for large scale demonstration projects	Black	Black			
	Rapid deployment of investments on international routes in key countries		Black	Black		
	Mobilise government support (in key nations) for large scale demonstration projects	Green	Green			
	Increasing public finance (i.e. grants, loans) for zero-emission pilots and RD&D	Green	Green			
	Key nations provide financial incentives for creation of zero shipping routes (e.g. subsidies, grants, reduced levies)		Green	Green		
	Other countries ramp up financing for large scale demonstration projects		Green	Green		
	Spread of finance schemes and market-based mechanisms for shipping globally			Green	Green	Green

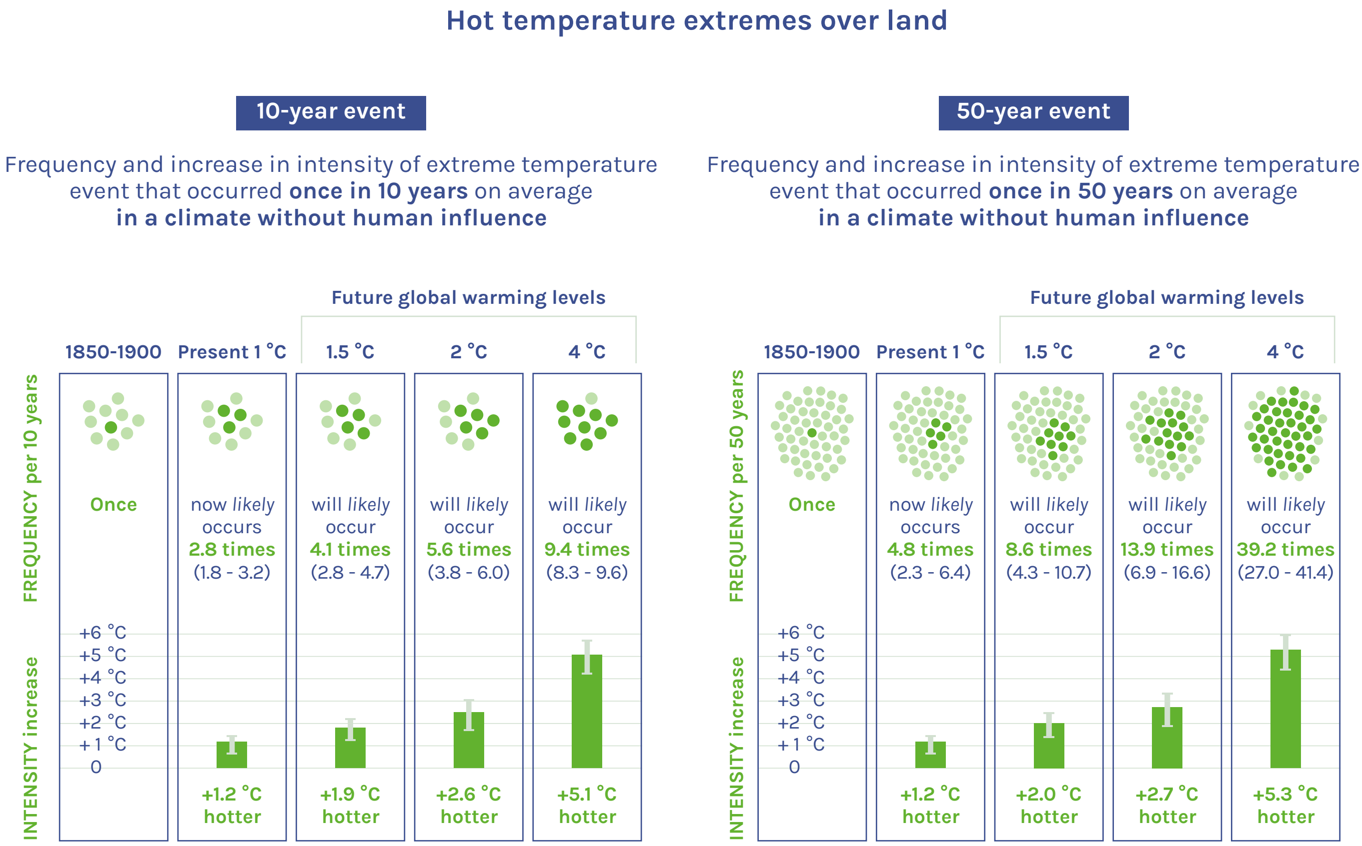
	Key actions needed to decarbonise shipping	By 2022	By 2025	By 2030	By 2035	By 2040
Demand	Freight purchasers commit to price premium for zero-emission shipping					
	Shipowners, charterers and freight purchasers conduct feasibility studies for mid-term SZEF demand with potential producers					
	Container freight purchasers participate in system demonstrations					
	Market/commercialise zero-emission shipping to end customers					
	Freight purchasers commit to use zero-emission shipping by 2040					
	Broad coalitions commit to achieving 10 decarbonised deep sea routes by 2030					
	32 developed nations decarbonise domestic shipping to 30% by 2030					
	Leading countries issue domestic shipping tenders with zero carbon clauses and set out plans for inter-modal zero fuel usage					
Technology/ Supply	Key shipping industry actors commit to net-zero by 2050 and adopt Science Based Targets					
	Cross-industry collaboration to develop smaller zero-emission ships					
	Scale up green hydrogen supply and reduce electrolysis costs					
	Develop small scale green zero emission fuel production facilities [in leading countries]					
	Public-private collaboration to scale up affordable renewable energy [in leading countries]					
	Public-private collaboration on large-scale zero-emission demonstration projects [in leading countries]					
	Public-private collaboration to scale up green zero-emission fuel production [in leading countries]					
	Development of first "Green Corriodors" for zero-emission shipping					
	Shipping companies commit to buying zero-emission propulsion ready vessels					
	Large-scale demonstration projects demonstrate viability of zero-emission shipping					
	Majority of international shipping is fully decarbonised					



1. The Context for the Transition: Shipping's Greenhouse Gas Emissions

Shipping, like all sectors that are still heavy users of fossil fuels and derived commodities, faces radical transitions over the coming three decades. The Intergovernmental Panel on Climate Change (IPCC) analysis of the evidence of the impacts of climate change shows that severe effects are already occurring, in some cases sooner than expected. As shown in Figure 1, these impacts can be expected to increase in intensity and frequency over the coming decades.

Figure 1: Historic, current and forecast changes in frequency and intensity of hot temperature extremes over land, figure SPM.6 from IPCC AR6.



This IPCC science sets the backdrop to the political and societal pressures that will drive these transitions. These pressures will not be static over time, but they will increase as dangerous climate change impacts become more frequent and the time available for a transition that avoids the worse scenarios runs out.

The work of the IPCC suggests that avoiding the worst case scenarios means stabilising the global temperature increase at around 1.5 degrees Celsius.[1] To do so, "global net anthropogenic CO2 emissions decline by about 45% from 2010 levels by 2030 … reaching net zero around 2050".

Expected Trends

Shipping constitutes 2-3% of total anthropogenic emissions.[2] This total share has remained approximately constant as both shipping and non-shipping emissions have grown over time, and it sets the scale of international shipping's emissions at a level equivalent to that of the highest emitting developed economies today (e.g., Germany, Japan).

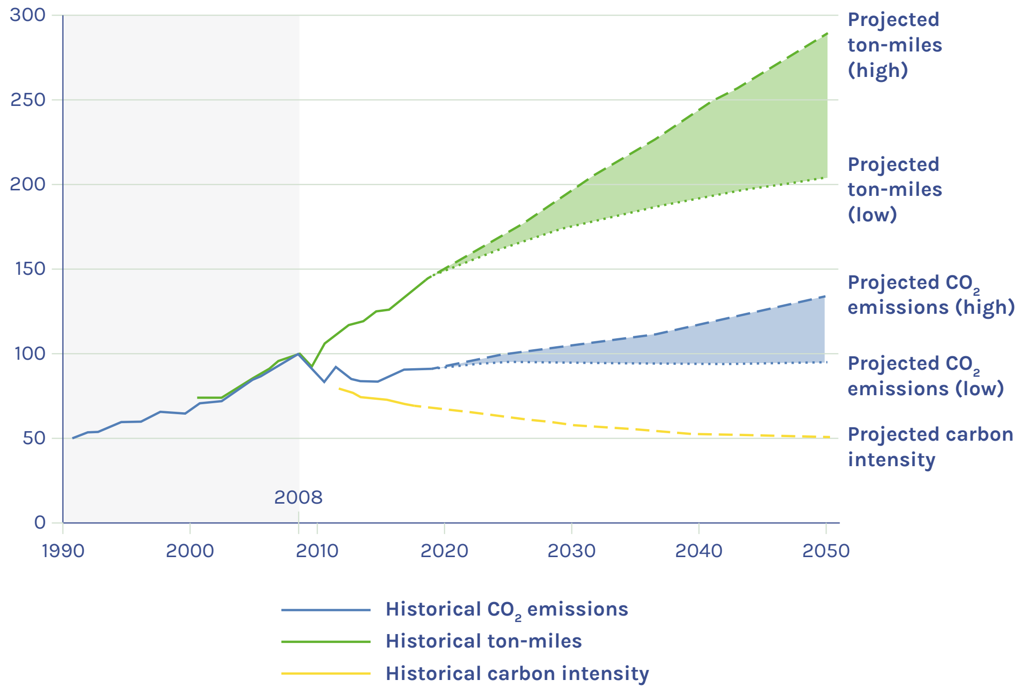
The expected trends in shipping emissions, if no transition is undertaken, were presented in the International Maritime Organization's (IMO) Fourth Greenhouse Gas (GHG) Study.[3] Future trends are driven significantly by the expected growth in demand for shipping overall; itself driven by the growth in global population and wealth, which increases the demand for raw materials and goods to be moved around the world. The expected trend in CO^2 emissions comes in spite of a significant reduction in the carbon intensity of shipping over the last decade and expectations of some further improvements going forward.

1 IPCC. (2018). *Global Warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)].

2 Faber, J., Hanayama, S., Zhang, S., Pereda, P., Comer, B., Hauerhof, E., Schim van der Loeff, W., Smith, T., Zhang, Y., Kosaka, H., Adachi, M., Bonello, J.-M., Galbraith, C., Gong, Z., Hirata, K., Hummels, D., Kleijn, A., Lee, D.S., Liu, Y., Lucchesi, A., Mao, X., Muraoka, E., Osipova, L., Qian, H., Rutherford, D., Suárez de la Fuente, S., Yuan, H., Velandia Perico, C., Wu, L., Sun, D., Yoo, D.-H. & Xing, H. (2020). Fourth IMO GHG Study 2020, MEPC 75/7/15. IMO.

3 Ibid.

Figure 2: Trends in CO2 emissions, transport demand, and carbon intensity under current policy[4] .



There are multiple ways to reduce GHG emissions from shipping. These include reducing demand for shipping, increasing the efficiency of its use of fossil fuels, or reducing the GHG intensity of shipping's fuels. Demand reductions may need to be revisited in the future, but intervening to reduce demand beyond those reductions that occur due to other transitions (e.g., circular economy, onshoring of manufacturing, reduced demand for fossil fuel transport) will be unpopular and difficult both for the sector and society in general. Finding the right balance between society's demand for access to any product anywhere in the world at any time and a shipping and trade system that enables equal access to global opportunity is beyond the scope of this paper. However, this raises the issue that no sector is decarbonising in isolation from other sectors of the economy and/or wider expectations of standards of living and development. Shipping, an enabler of globalisation, is fundamentally linked to and enabling of broader societal prosperity and opportunity, and further work to enrich the consideration of that interaction could benefit the way shipping's decarbonisation is considered in that broader context.

4 UNEP. (2020). Emissions Gap Report 2020. https://www.unep.org/emissions-gap-report-2020

Efficiency Improvements: Real but Insufficient

Carbon intensity reductions have most recently been achieved through the widespread adoption of lower operating speeds (slow steaming) in the period 2009-2013, as well as through an increase in the average size of ships (larger ships perform the same amount of transport work with lower carbon intensity). Some improvements to the technical specifications and operation of ships have also improved their energy efficiency.[5] While there remain opportunities to improve efficiency across the global fleet, efforts to optimise speeds, size, and technological specifications of existing ship technologies will likely face diminishing returns over time.

In June 2021, the IMO Marine Environment Protection Committee's 76th meeting (MEPC 76) adopted new short-term measures intended to drive a further reduction in emissions via efficiency improvements. In its analysis responding to these measures, Climate Action Tracker (CAT) adjusted its rating of the current trajectory for international shipping from "critically insufficient" to "highly insufficient"[6]; an assessment that aligns international shipping's future emissions with a temperature increase of 3-4 degrees. CAT pointed out that the MEPC 76 outcome failed to ensure that the IMO would deliver on its own stated strategy "to peak GHG emissions as soon as possible and by Paris compatible pathways".

Taking the reductions in carbon intensity that are projected from the 4th IMO GHG Study by 2050,[7] and those estimated in a "maximum efficiency" scenarios,[8] the magnitude of further efficiency-led carbon intensity reduction (as a fleet average) is between 25% and 30% from current levels. Thus, the sector must go far beyond efficiency improvements in order to maintain any proximity to a 1.5 degree-aligned pathway.

Emit Now, Pay Later

The IPCC's guidance to policymakers has been used by the Science Based Targets initiative (SBTi) to identify future emissions pathways for shipping, which would be in line with a proportionate response to avoiding dangerous climate change (e.g., shipping holding its share of anthropogenic GHG emissions constant, alongside other sectors all working together to achieve a 1.5 aligned GHG reduction). Figure 3 illustrates different pathways, estimated by SBTi, which achieve the same temperature stabilisation contribution.

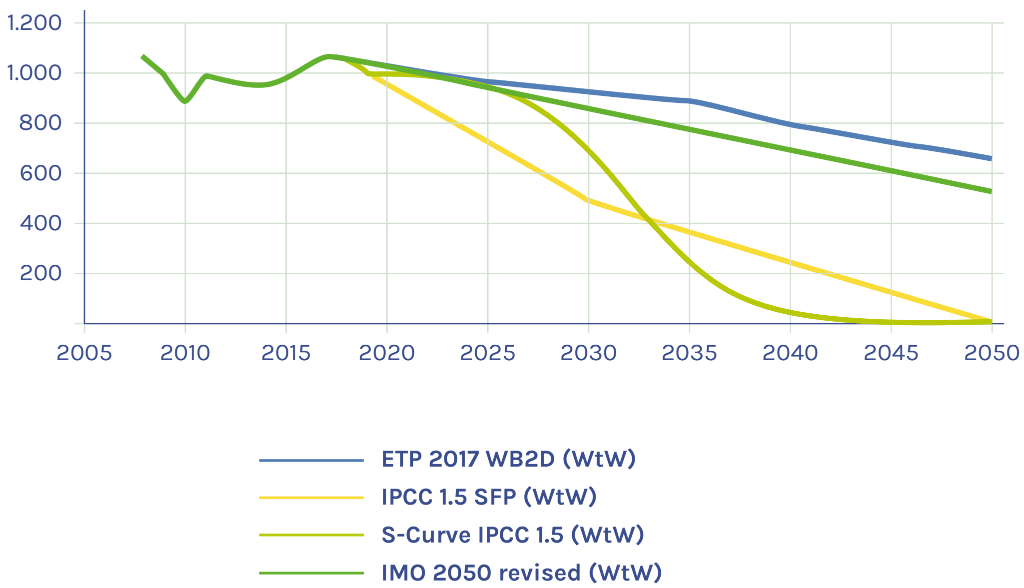
This graph illustrates one of the stark choices that all sectors, including shipping, face. Action to decarbonise can either be taken at a constant rate and distributed approximately evenly over the next three decades, or it can be started softly before a period of even more radical change.

5 Faber, et al.
6 Climate Action Tracker, International Shipping, https://climateactiontracker.org/sectors/shipping/.
7 Faber, J., et al. (2020).
8 IMarEST. (2021). ISWG-GHG 8/3/3 Considerations on the CII targets. IMO.

This is because the avoidance of dangerous climate change is not driven by the absolute emissions at any point in time, but by the cumulative emissions that occur over the coming decades. Starting transitions later squeezes them at both ends, including by bringing their end date forwards. If the IPCC's advice on what is needed in the short term is not achieved by 2030 (a decline of about 45% from 2010 levels by 2030), then the effort required by all sectors to achieve the same will increase.

In theory, all options (and further different shapes of pathway) remain on the table. However, with only a weak policy outcome at MEPC 76 and significant work still needed before new fuels are in widespread use, the likelihood has increased of the S-curve transition pathway. This likely implies a very rapid reduction in GHG emissions in the period from 2030 to 2035, with zero GHG emissions from shipping achieved closer to 2040 than 2050. From the perspective of how costs for shipping's decarbonisation are managed, this would reduce the cost during this decade whilst the sector continues to use fossil fuels. But the large investments associated with decarbonisation both on land and at sea will then be needed over a shorter period of time.[9] Such a disruptive change may generate high costs for some parts of the industry, as relatively new technologies are forced into obsolescence and valuable assets are left stranded.

Figure 3: Well-to-wake GHG (CO2e) pathways for shipping (international and domestic) aligning to 1.5 degrees.



9 Krantz, R., Søgaard, K., Smith, T. (2020). *The scale of investment needed to decarbonize international shipping*. Global Maritime Forum.

Why the Focus on Scalable Zero-Emission Fuels?

The coming phases of the transition will thus require a shift away from today's fuels – a shift that will eventually need to enter a rapid and intensive phase of scaling up. There are multiple fuel options, from lower emission fossil fuels to various alternative fuels that can be produced in different ways.[10] However, there is only a subset of these fuels that has the potential to be both zero emission (on a lifecycle basis) and have production processes that are scalable enough to competitively supply the expected future demand, which will be driven by shipping and other sectors that are moving away from fossil fuels.

Zero or Net Zero?

The terminology "net zero" is commonly used to refer to the end state and ultimate objective of the overall societal transition to control anthropogenic GHG emissions. The "net" refers to the framing in the UNFCCC and Paris Agreement that there are both "sources" and "sinks" of anthropogenic CO2, and net zero is the state reached when these are in equilibrium. Sinks include those sinks which are associated with land use and carbon sequestration processes, which are within the accountancy of nationally-led actions. However, shipping as a sector, and in particular international shipping, does not have access to sinks defined in this way.

Nations could, in combination, achieve a level of negative GHG emissions which counter-balance positive GHG emissions from international shipping. With the current evidence that governments are still far from achieving sustained reductions in absolute emissions, and because shipping has the future potential for a full substitution of fossil fuels, there is no credible basis to expect that there will be a surplus of negative emissions available to shipping.

As a sector, shipping can thus only reach the UNFCCC definition of net zero by achieving zero GHG emissions from its fuel use, on a lifecycle basis. This can include the use of fuels/technologies that are themselves net zero, in the sense that emissions from their use are offset by negative emissions in their production (e.g., the growth of biomass for biofuels).[11]

Throughout this study, the transition of the sector is therefore framed in terms of zero, as opposed to net zero.

10 UNEP. (2020).

11 For a discussion of net zero shipping fuels, see "Definition of zero carbon energy sources" by Dr. Tristan Smith of the UCL Energy Institute for the Getting to Zero Coalition: https://www.globalmaritimeforum.org/content/2019/09/Getting-to-Zero-Coalition_Zero-carbon-energy-sources.pdf

National/Regional/Global Initiatives and Efforts to Address the Challenge

The scale of action and efforts that are needed to decarbonise shipping can appear daunting. However, this should be set against the context of a rapidly changing enabling environment for that action. Particularly in the three years since the adoption by the IMO of the Initial GHG Reduction Strategy,[12] steps have been taken across national governments, regional groupings of governments, in the IMO, and in industry-led fora.

The IMO's initial strategy is expected to be revised in 2023, and this will be an opportunity to clarify the alignment between the IMO's ambitions and the Paris Agreement, as well as the timing of key milestones in the IMO's contribution to global goals.

The IMO's adoption of new short-term measures may not have met, at the point of adoption, the stringency or enforcement necessary. However, it provides a framework that can be significantly built upon in any future revision (expected 2026) to drive not just efficiency improvements but, if stringent enough, the adoption of new fuels.

Regional regulation has advanced significantly this year, with the EU's formal proposal of a package of policies targeting both domestic and international shipping under its "Fit for 55" package. This development strengthens the perception in the industry that if the IMO regulation does not do enough to drive shipping's transition, others will. However, some elements of the EU package (low carbon price, low fuel standard stringency, incentive for fossil fuels (LNG)) are themselves misaligned with a 1.5-degree transition in shipping, and the package should not be seen as setting a ceiling for action at the IMO or elsewhere.

Governments are starting to focus on shipping, both domestic and international. This year, G7 nations made a clear commitment to align international shipping with the 1.5 pathway:[13]

> *"We further recognise the urgent need for effective efforts to reduce emissions from the international aviation and maritime sectors to put both sectors on a pathway of emissions reduction consistent with the mitigation goals of the Paris Agreement."*

12 IMO. (2018). Adoption of the Initial IMO Strategy on Reduction of GHG Emissions from Ships and Existing IMO Activity Related to Reducing GHG Emissions in the Shipping Sector. https://unfccc.int/sites/default/files/resource/250_IMO submission_Talanoa Dialogue_April 2018.pdf

13 G7. (2021). G7 Climate and Environment: Ministers' Communiqué. https://www.gov.uk/government/publications/g7-climate-and-environment-ministers-meeting-may-2021-communique/g7-climate-and-environment-ministers-communique-london-21-may-2021

National regulation is starting to include accountancy of international shipping emissions in 1.5-aligned obligations (so far the only known example is the UK), and governments are taking explicit steps to move domestic shipping in line with a 1.5 degree pathway.

Industry-led initiatives related to shipping's decarbonisation continue to grow. Alongside fora that are primarily discussion-oriented and focused on the sharing of knowledge, a series of more action-oriented steps are also being taken, setting examples of leadership and growing their memberships.

2. What Might Zero Look Like?

There is an understandable desire from the shipping industry, investors, fuel suppliers and policymakers to better understand the major components of the transition to zero-emission fuels: the volumes needed, the investments required, the timelines and prospects for different fuel options.

To a certain extent, these questions can be explored through quantitative modelling of the transition. This modelling has limitations, which are discussed below, but can provide important insights, nonetheless. The modelling underpinning this chapter's analysis was performed in the GloTRAM model by UMAS. Its results reflect a simplified reality wherein the industry's CO2 emissions are constrained by external policy that (broadly) creates a match between the fuel transition and the 1.5-degree pathway (S-curve) discussed in Chapter 1. In addition, the industry's investment and operational choices are made purely to maximise profit within that constraint, with perfect foresight of fuel and technology costs.

The key assumptions defining the scenario are illustrated in full in UMAS' 2019 UK Clean Maritime Report Technical Annex,[14] and summarised in Appendix I.

Other organisations have done, or are doing, similar modelling of shipping's decarbonisation pathways (e.g., DNV,[15] IEA[16]). The models are broadly similar; like GloTraM, they have forecasts of demand and explore the evolving specifications of a fleet under decarbonisation objectives by looking through a techno-economic lens. Some differences occur with regard to important assumptions, which can explain differences in results. But when similar scenarios (coherent sets of input assumptions) are compared between these models, there is a convergence across these studies: The role of energy efficiency is important but not sufficient for decarbonisation, and the fuel mix needs to move rapidly away from fossil fuels.

The aim of this section in the report is not to undertake a detailed comparative analysis and justification of the modelling of shipping's transition. That is a process which Getting to Zero is undertaking in the fuels thread and in collaboration with the Centre for Zero Carbon Shipping. Instead, our aim is to provide a high-level distillation of modelling results that helps to further break down what actions are needed to achieve the 1.5-aligned decarbonisation of international shipping, and to provide framing and justification for the subsequent chapters.

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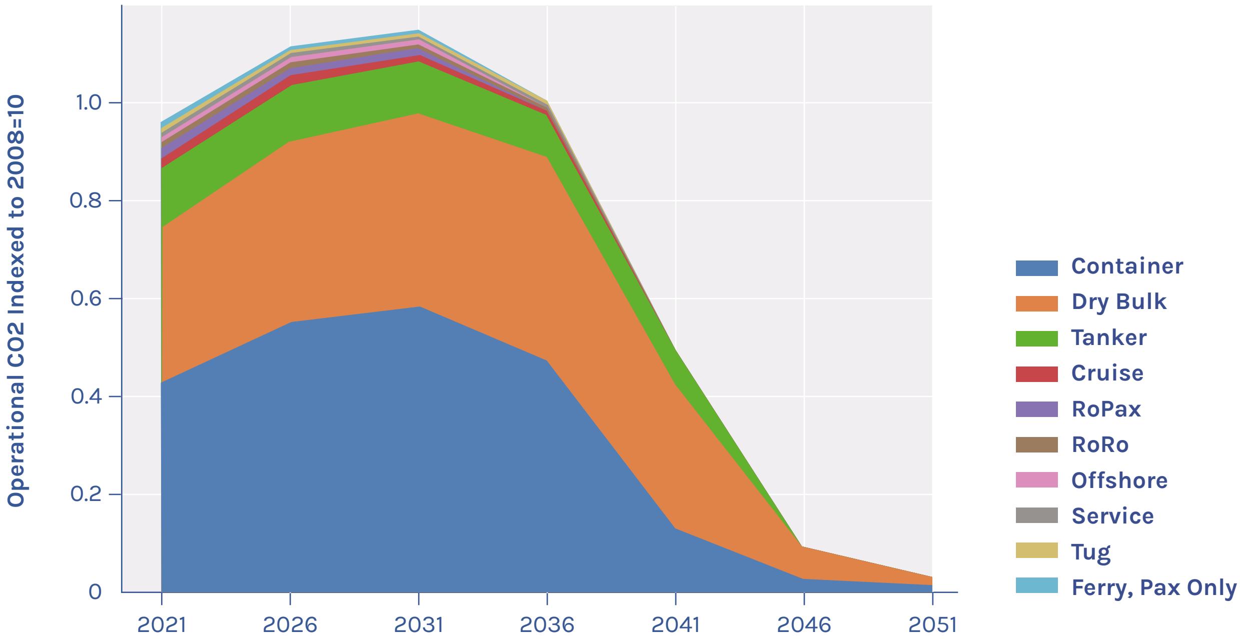
14 UMAS. (2019). *Reducing the Maritime Sector's Contribution to Climate Change and Air Pollution.* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816019/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs-technical-annexes.pdf
15 DNV (2021). Energy Transition Outlook. https://eto.dnv.com/2021.
16 IEA (2020). International Shipping Tracking Report. https://www.iea.org/reports/international-shipping.

Aggregate Trends

Figure 4 presents the 1.5-aligned CO2 pathways for the industry, broken down by some of the key ship types. Shipping GHG emissions are dominated by a small number of ship types and, for this scenario, absolute GHG emission reductions are assumed to be distributed approximately evenly across ship types.

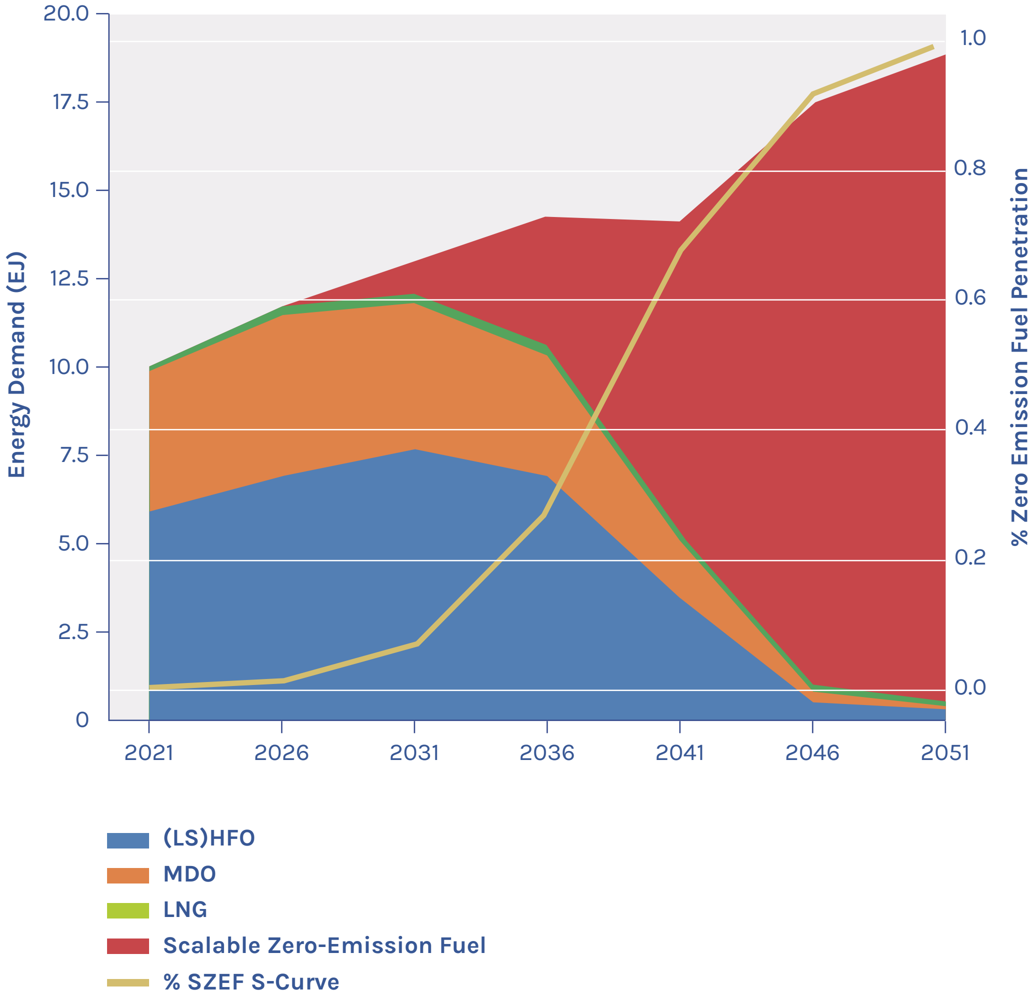
Figure 4: CO2 emissions by ship type, indexed to 2008 emissions.



This emissions pathway then results in the fuel transition pathway shown in Figure 5. Here, scalable zero-emission fuels (SZEFs) are introduced and begin to compete with fossil fuels from 2026, and a step change in growth in use of SZEFs occurs from 2031. Liquified natural gas (LNG) use expands from 2021 to 2026 but, by 2031, it is still only a modest share of the overall fuel mix. LNG use remains constant at a small volume once SZEFs enter the market and dominate newbuilding specifications. The use of all other fossil fuels declines rapidly as SZEFs enter the market.

The aggregate expansion of SZEFs is shown as a market penetration as a percentage over the time period. This share follows an S-curve typical of technology transitions: an initial phase through the 2020s of the emergence of new fuels; a period of rapid growth and diffusion during the 2030s; and a period of full system reconfiguration in the 2040s. These three phases are discussed in more depth in Chapter 4.

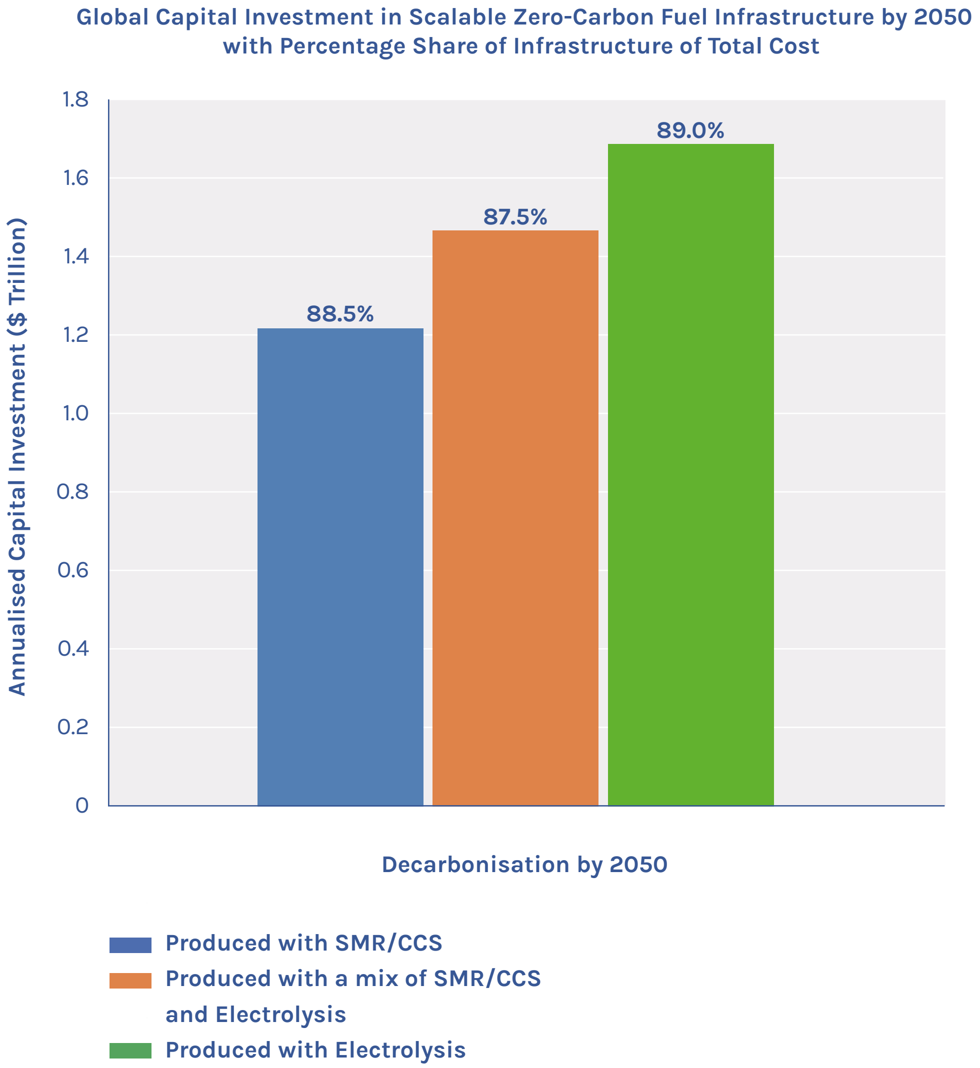
Figure 5: Modelled energy demand mix to 2051.



What Does the Fuel Transition Mean for Costs and Investment?

Calculations in 2019 first estimated the total cost and investment associated with shipping's transition,[17] shown in Figure 6. In aggregate, the total cost was estimated to be up to $2 trillion, with the large majority of that investment needed in the fuel production and supply chains downstream of the point where SZEF is transferred to the ship (bunkering).

Figure 6: Total capital investment in scalable zero-carbon fuel infrastructure by 2050.



17 UMAS. (2019). *Aggregate Investment for the Decarbonisation of the Shipping Industry.* While the fuel used in this analysis was only one of the options considered in the preceding section, two different production pathways were considered, which showed differences in total capital costs/investment.

Another way of picturing the scale of shipping's transition away from fossil fuels is to compare it with a transition that will have to take place alongside the shipping industry. Such an example can be taken from the ammonia sector. Currently, more than 180 million metric tons of ammonia is produced from hydrogen and nitrogen per annum. This is nearly all produced from fossil fuel feedstocks (and the air capture of nitrogen). The production of ammonia will also need to decarbonise, moving to a combination of blue and green hydrogen as feedstocks. It is reasonable to expect that it will need to fully decarbonise within the same timescale as shipping. Figure 7 shows how the overlap between shipping's growing demand for ammonia (using this as an example SZEF) could grow alongside the emerging existing end-use (e.g., agriculture) demand for blue/green ammonia. The ultimate scale of demand once both non-shipping and shipping ammonia are combined represents a significant increase. But, the transition in production that would need to occur could be for similar magnitudes and shared end-use (e.g., a more reliable investment case), out to the mid-2030s.

Figure 7: Using ammonia as an example zero-carbon hydrogen-derived fuel, maritime demand will create additional pressure for the existing industrial ammonia production to decarbonise.

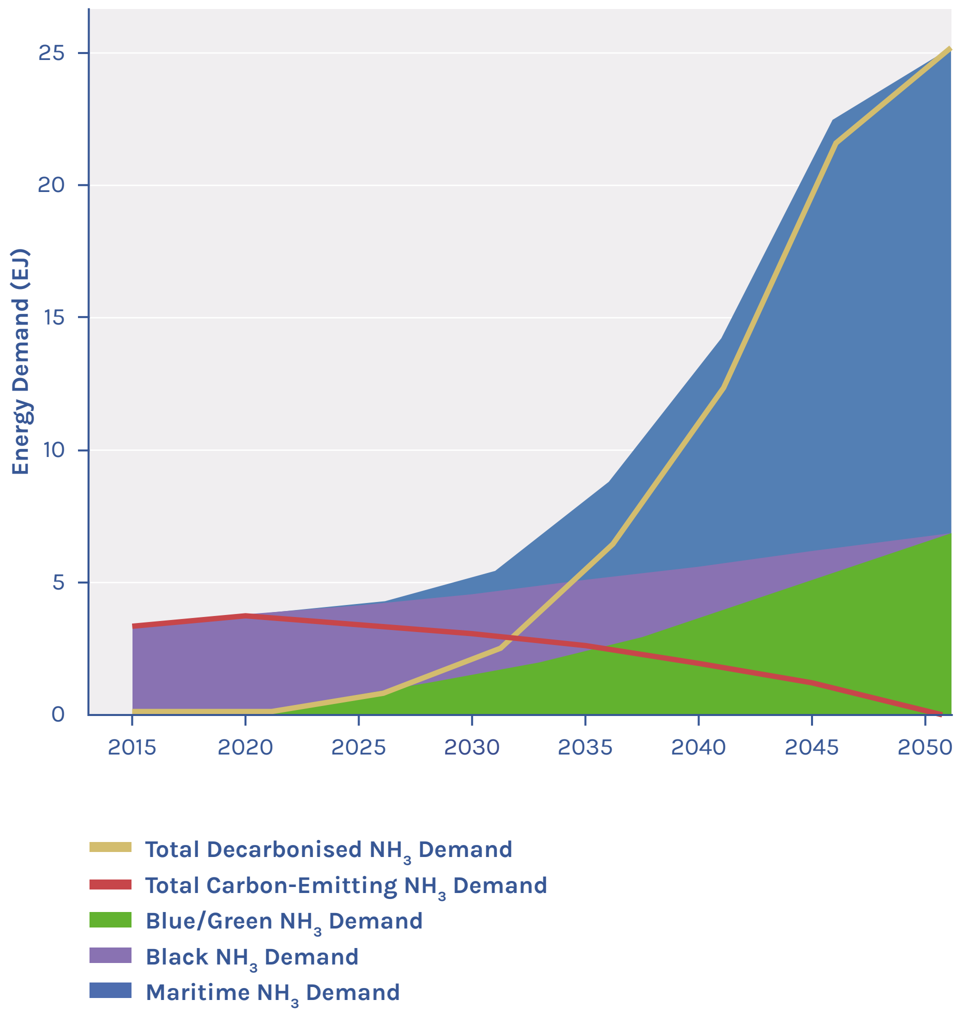
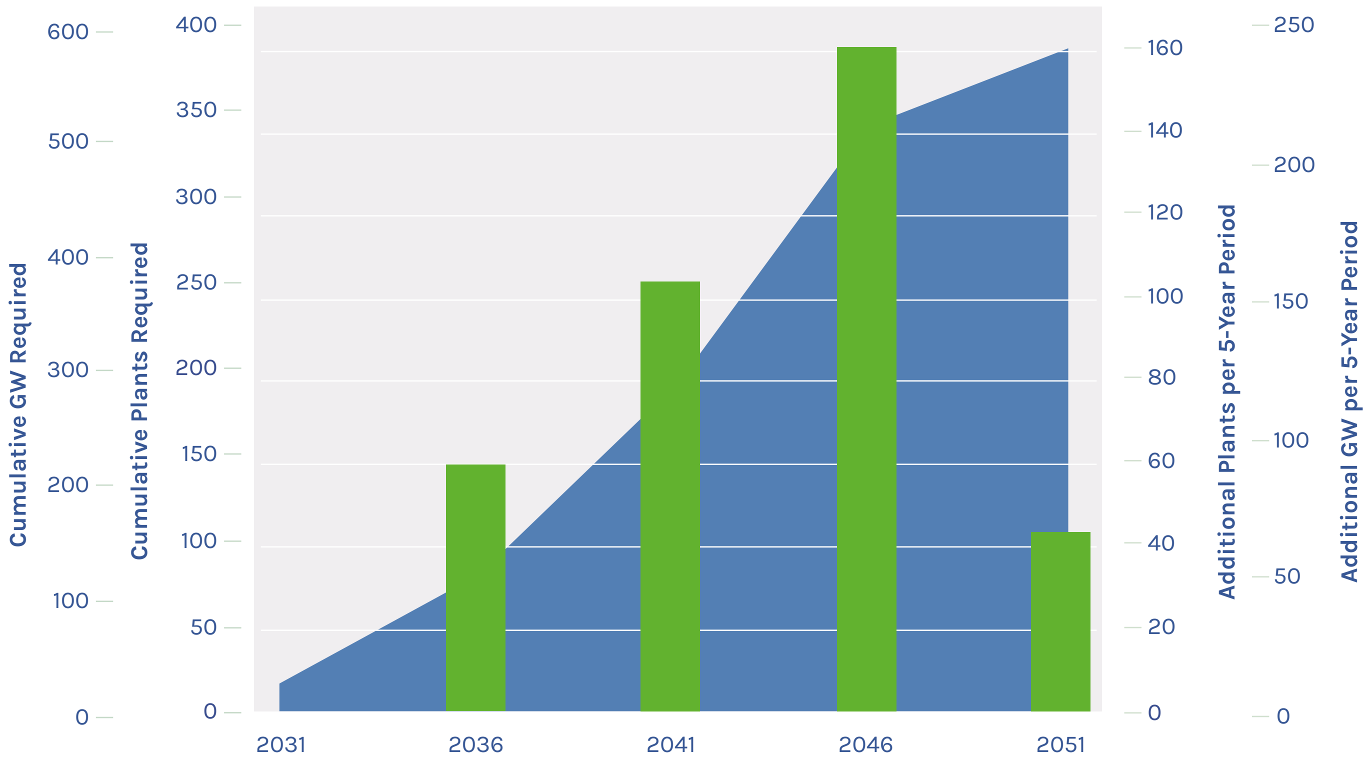


Figure 8 goes a step further to break down the demand for infrastructure into the number of production plants (assuming a given average size of plant) and the total gigawatt (GW) capacity. This also captures the ramp-up rates: The numbers of new plants (and GW) that are needed in each five-year period increases out to 2046 but, from there, it contracts.

Figure 8: Cumulative and additional scalable zero-carbon fuel production plants to meet maritime demand. Assumes 1.51 GW/47.6 PJ per plant-year.



GW numbers in Figure 8 represent output chemical power.

The analysis in Figure 8 shows the scale of new production required to decarbonise a commodity that already falls into country commitments (nationally determined contributions), alongside the scale of shipping's demand for SZEFs. In other words, countries are already committing to produce decarbonised ammonia at scale for national/domestic purposes, and could leverage this to stimulate the decarbonisation of appropriate aspects of their domestic and regional shipping. This provides some credibility to the notion that shipping's fuel transition could be nationally led (including on a plurilateral basis).

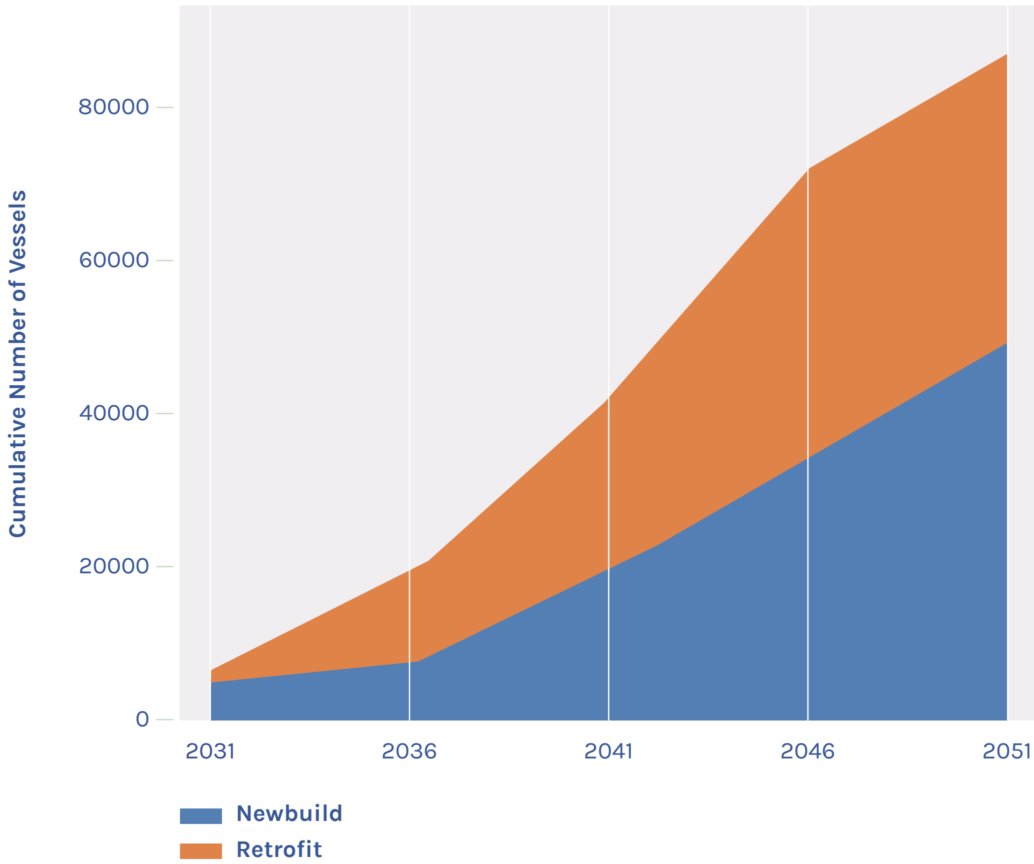
Starting with an assumption that the key production technology is mature, it is undeniable that this trajectory presents challenges in terms of the mobilisation of capital and human resources (i.e., training and allocating workers), even if the non-linear nature of the transition may create opportunities. Earlier work estimated that, by 2030, approximately $390 billion would need to have been spent or secured (additional capital costs for land-side and onboard technology).[18] But, in 2025, this number is significantly lower – around $95 billion of committed or secured investment. Assuming an approximate five-year lag between having secured sufficient capital and a supply chain of SZEFs going online, the transition pathway appears to open a window for resource mobilisation.

While the largest investments will be associated with land-side assets, the investments required to ensure the fleet of ships are able to use SZEFs are significant. These will not be limited to the financing of newbuild ships, but also require significant expenditure on the existing fleet. Figure 8 is the estimate from GloTraM modelling of this decarbonisation scenario for the number of ships that will be either newbuild or retrofitted to use SZEFs. This shows that, in terms of the number of ships, newbuilding and retrofitting activity will be of similar magnitude over the period 2030-2050. The different sectors of shipping are estimated to transition optimally at different points in time and under many circumstances: Larger ships transition sooner due to their operating profile, making returns on investments likely sooner. This means that retrofitting activity is likely to need to start early (for larger ships first) and continue, with a large number of conventionally fuelled ships still needing retrofit in the mid to late 2040s.

18 Osterkamp, P., Smith, T., Søgaard, K. (2021). *Five percent zero emission fuels by 2030 needed for Paris-aligned shipping decarbonization.* Global Maritime Forum. https://www.globalmaritimeforum.org/news/five-percent-zero-emission-fuels-by-2030-needed-for-paris-aligned-shipping-decarbonization

The industry may identify other options that limit this retrofitting requirement somewhat. If, contrary to the assumptions made in this modelling, affordable and sustainable biofuels are available, these may help some ships avoid retrofit. Additionally, it is possible that shipowners design newbuilds in the 2020s for shorter lifespans, taking savings upfront and retiring ships earlier to avoid retrofitting for zero emissions later.

Figure 9: Similar magnitudes of newbuilding and retrofitting to SZEF use will be needed, unless ship lives are significantly reduced for the fossil fuelled fleet".



Which Scalable Zero-Emission Fuel and Pathway?

The fuel transition described in Figure 5 necessarily simplifies a more complicated and confusing landscape, where actors are striving to understand and/or define the specifics of the fuel/energy included in the transition and the pathway from today's technology to that outcome.

One complication comes from the fact that development work on technology is ongoing, and is interlinked to the transitions that are taking place in other sectors. Costs and cost-reduction trajectories of key components of fuel supply and use are uncertain and, therefore, hard to forecast.

Because of the whole-system nature of the transition, encompassing both ships and land-side infrastructure, the commercial business case for investment along any technology pathway is not purely determined by an analysis of which solution carries the lowest cost. It is also significantly influenced by expectations of the future system, and the power of different narratives to shape decisions along the way. A narrative that argues for a given fuel pathway may have its own merits, but it will also be judged on how influential it is likely to be for decision-makers considering a range of priorities. This likelihood is not just derived from the credibility of the arguments in isolation, but also the likelihood that a given narrative will become widely adopted and dominant in debates, which in turn increases the likelihood of the outcome.

Further uncertainty comes from the existence of different transition scenarios, wherein different forms of leadership and influence predominate at different times. These scenarios are explored in depth in Chapter 4. Depending on how they play out, each of them risks stimulating competition between these different options. The politics of that competition is an important factor that cannot (yet) be captured in the type of modelling used here. Suffice it to say, the resulting pathways could be different from those derived from a model.

There are many pathways to 2050 which are more complicated and involve more than one step change in molecule or fuel production specification: for instance, the use of currently mature, but less scalable, interim solutions, while less mature options are developed. This can be seen as a set of transitions, perhaps interacting with each other, but constrained by the compressed timescale needed to achieve the overall outcome in absolute GHG reduction terms.

Because of the above considerations, the question of "which fuel pathway" requires a qualitative evaluation, starting with an inventory of the current options and their characteristics in Table 1.

Table 1: Fuel pathway options characterised.

Pathway	Who is this attractive to?	Why might this be attractive to a broader audience?	What does its narrative rely on?
LNG dual fuel, and then bio-/e-LNG, or ammonia	Those who already have significant investment/exposure in natural gas/LNG (oil/gas majors, governments, existing LNG propelled fleet owners)	LNG investments have already been made and are still being made today. It is available now in many locations Current regulations are based on operational CO_2 emissions and not wider GHG or upstream emissions, which flatters LNG LNG produces virtually no sulphur emissions (and therefore lower PM) fuel than LSFO/MDO, and so is often branded/perceived as “cleaner” LNG dual fuel today can be designed for retrofit to ammonia in the future LNG has long been championed as a major new marine fuel and enjoys strong support	A durability in the LNG business case into the 2030s (e.g., that the additional capex on LNG “now”, and ammonia conversion “then” is paid off from lower LNG prices now) Good availability and competitive price (relative to other bio and synthetic fuels) of low lifecycle CO_2e bio-LNG Significant further investment into management of supply chain and onboard methane emissions LNG global supply chains continue to grow and are not displaced by renewable energy and hydrogen
Methanol dual fuel	Methanol interests Early adopters of “zero”, especially those wanting to differentiate from conventional biofuel users	Methanol dual fuel is generally lower additional capex vs. hydrogen-based alternatives Methanol solutions are more mature (already in-use) than ammonia and the safety issues are perceived to be more manageable Methanol dual fuel today can be designed for retrofit to ammonia in the future “Methanol” sounds better than biofuel	Access to sustainable carbon input (e.g., via bioenergy with CCS – BECCS) until direct air capture is feasible Bio-methanol supply and supply chains rapidly scale and reduce in cost during the 2020s DAC (direct air capture) technology matures and is invested in at scale in the 2020s and 2030s Very low price and high volume zero-carbon electricity
Ammonia dual fuel	Hydrogen and ammonia interests (new entrants and existing) Governments with hydrogen production potential or export ambitions	Ammonia is consistently analysed as the lowest cost way to use hydrogen as a marine fuel It is already in widespread use as a commodity, and traded at sea, so there is established ship-shore transfer experience in certain locations, and onboard storage technology, which could be built upon for the bunkering applications Ammonia does not contain carbon so is easily perceived as a zero-emission fuel Future price competitiveness is independent of biomass feedstocks and DAC technology	The ammonia safety cases (bunkering, onboard use, spill) being resolved Ammonia technology matures on track to be available by 2023/24/25 Air emissions risks ($NOx/NH_3/N_2O$) are cost-effectively managed Hydrogen and ammonia production and supply chains and pilot fuel decarbonising Compatible decarbonised pilot fuel (small volume of a different fuel used to improve combustion) being available
Hydrogen	Hydrogen interests Governments with hydrogen production potential or export ambitions Environmental organisations	Hydrogen use in a fuel cell produces no problematic broader emissions Hydrogen does not have the toxicity and spill risk of ammonia Hydrogen is an attractive option for smaller scale ships and can be scaled up Hydrogen can be compatible with today’s fuel cell technology	Development of safe and affordable solutions for compression/ liquefaction and storage onboard Safe and politically acceptable in land-based and onboard storage Hurdles proving too high for other hydrogen-based fuels

Nuclear	Governments wanting to secure supply chains Governments with existing nuclear experience and technology China, Russia	Existing domestic shipping (including military) experience demonstrates the viability generally New developments are perceived to be on the horizon, which may reduce costs and improve safety The transition would be less dependent on the evolution of new energy supply chains than other solutions	The nuclear safety case being sufficiently resolved Breakthroughs in maturing of new technologies that reduce lifecycle costs and improve safety Political obstructions to safety and non-proliferation risks managed (e.g., through international agreement and cooperation to operate on certain routes) Specialisation to nuclear shipping of key supply chains and consolidation of volumes on some of the main bilateral routes
Onboard carbon capture for subsequent sequestration	Fossil fuel producing companies and countries	Does not require a reconfiguration of land-side energy production and supply chains Continues significant use of existing technology and therefore skillsets Compatible with LNG	The maturity of onboard carbon capture technology International agreements on classifying/certifying key types of sequestration Captured carbon reception and sequestration infrastructure The trading of carbon emissions between international shipping sources and member state sinks
The transition will not happen any time soon, no new technology is needed	Those without financial resources or technical capacity to consider alternatives	IMO has moved slowly in the past, and the early steps taken to implement the IMO Initial GHG Reduction Strategy are not impressive Requires no additional capex on optionality now, which can increase competitiveness at least in the near-term Costs of new technology are expected to reduce over time, so early adopters are expected to pay more	That residual-value risks to incumbent assets are low and manageable – that actors will identify when to sell their assets before the markets damage their value That access to capital and clients in the short-term will not be materially affected by not starting to align investment/operation now That future market shares are not significantly impacted by actions taken now (there is a low future opportunity cost to not being an early adopter)

All of these pathways are technically credible. It is possible to describe the component steps needed to get to the point where both the land-side infrastructure and a fleet of ships with the required technology are in operation. So, the expectations on technical viability are not a means to differentiate and identify which fuel(s) are optimal.

Nuclear and onboard carbon capture and storage (CCS) narratives currently face the highest hurdles to their widespread adoption, with persistent difficulties related to societal/political acceptance (nuclear) and physical and policy infrastructure (CCS) having slowed development and deployment in other sectors for several decades.

The industry remains sceptical about pure hydrogen pathways for deep-sea shipping, and barriers to other options (possibly related to sustainability risks) would likely need to be raised for hydrogen fuel to be considered feasible.

"No transition" is also still an option, but not a helpful subject of further study, if the goal is to understand the potential of different future fuels.

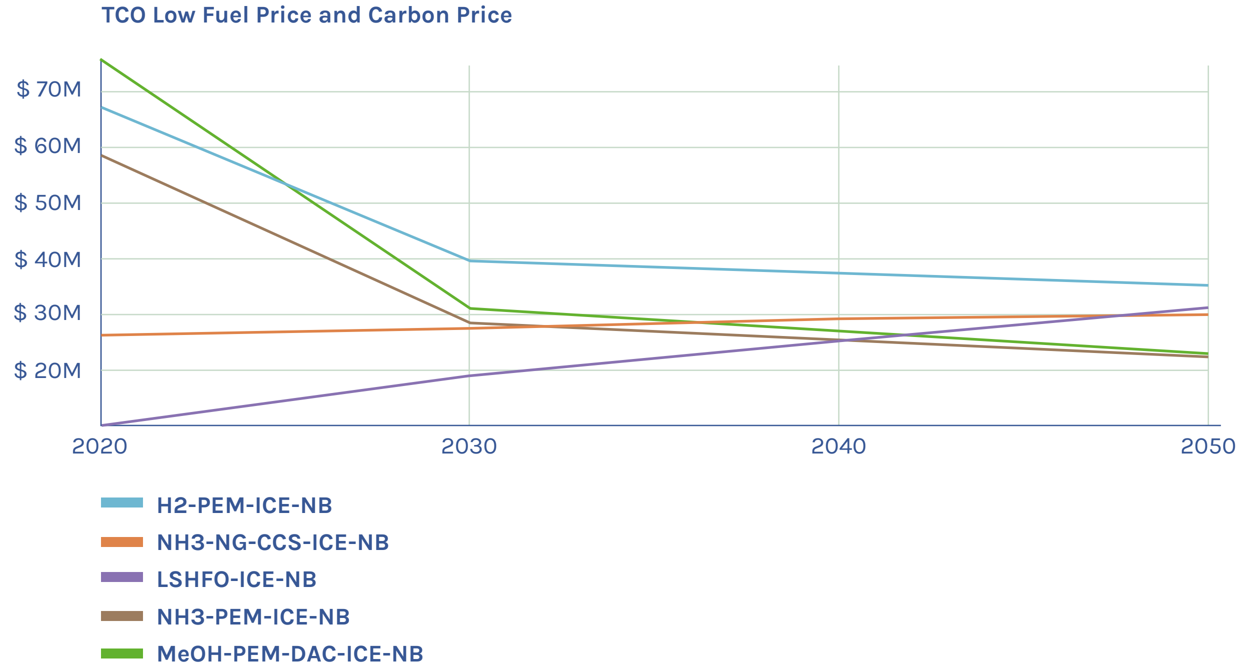
Key Determinants of the Fuel Pathway

The most important determinants of the fuel pathway are likely to be:

- Costs
- Maturity of technology
- Speed and dynamics of the transition

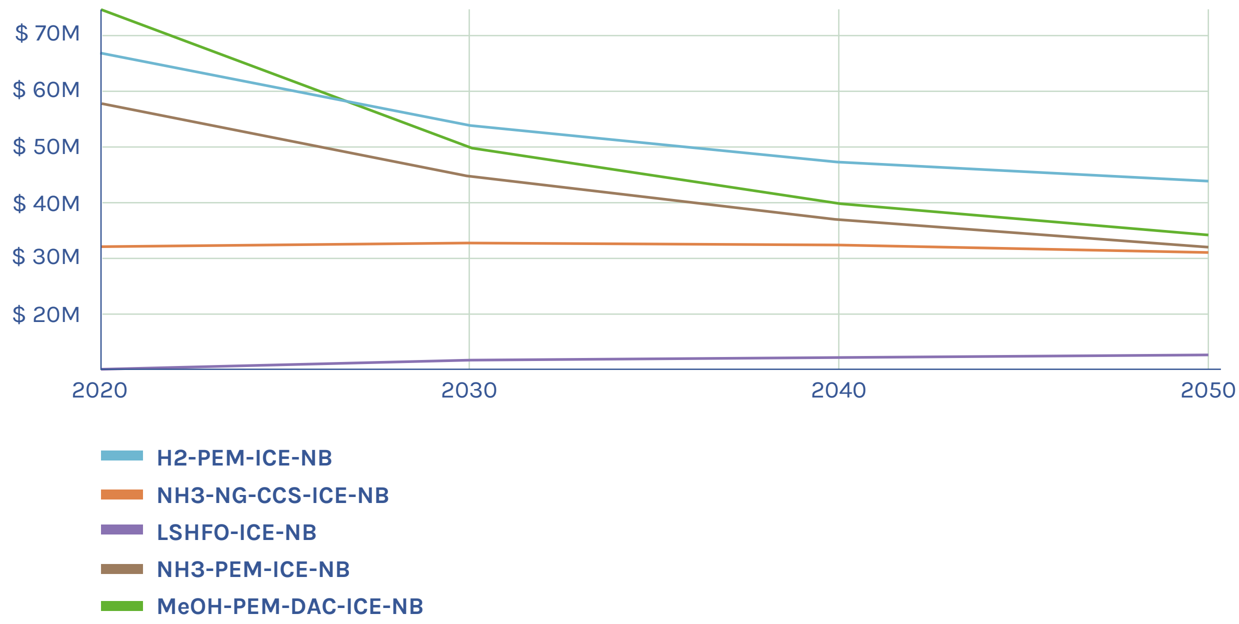
As noted above, there is evidence that, when taking a total cost from the operation perspective (e.g., factoring in all the elements of cost as seen by a shipowner/operator), ammonia would be the lowest cost option. Figure 10 presents results from the ongoing modelling of different candidate production pathways, fuel and machinery combinations.[19]

Figure 10: Total cost of ownership (TCO) of different fuels and production pathways, based on ongoing UMAS/GtZ work.



19 Green methane (e-LNG) has not been modelled, but would face similar costs to green methanol.

TCO High Fuel Price



Aside from costs, technology maturity and acceptance will play an important role in decision-makers' consideration of these narratives. Whilst there is no evidence yet that any maturity/acceptance challenges will be insurmountable for the leading candidate fuels, this is an important area of evolving work. Maturity and acceptance in transitions is a product of the emergence phase and can be expected to be addressed through "first of a kind" trials and the dissemination of the results from those trials. There are now a large number of pilots for the leading candidate fuels that have been announced, and which it is credible to expect will be added to. So, this report starts from the assumption that maturity and acceptance will emerge and the actions to enable that are already being taken.

Perhaps the most important factor, other than cost, is the range of expectations about the speed at which emissions reductions will actually be required (i.e., policy adoption and stringency). If investors expect pressure to reduce carbon emissions (regulatory or otherwise) to be delayed or weak, transition pathways that can make use of mature but less-scalable or sustainable elements (e.g., bioenergy, LNG) may gain an advantage. If expectations are that the speed of the transition will be in line with the 1.5-degree pathway described in Chapter 1, then these pathways may feature risks of disruption and stranded assets.

Political dynamics may matter as much as the absolute pace of emissions reductions. Certain countries will have interests in certain pathways, for example, if they are pursuing an export-led industrial or resource management strategy. This has long been associated with fossil fuel exporters, but it could potentially be seen from countries with aggressive hydrogen strategies or extensive biomass resources in the future. Chapters 4 and 5 take a deeper look at the role of political economy at different levels in shaping the nature of any transition.

The Limitations of Bio-Based Fuels Compared to Hydrogen-Derived Fuels

LNG, methanol and ammonia-led pathways are all compatible with a period of biofuel use. Bioenergy (bio-LNG) can help prolong the competitiveness of LNG assets and biomethanol can enable a methanol investment to have use today, before green methanol becomes competitive. There are also several bioenergy products that can and are being used in conventionally fuelled ships today. The same biofuels could be used as an interim fuel for dual-fuel ammonia ships, until such a point as ammonia becomes the more competitive lower carbon fuel.

A key assumption of these narratives is that there will be sufficient supply of competitively priced biofuels such that they can meet not just shipping's needs, but those of all other sectors that seek a biomass feedstock (not limited to sectors needing biomass for energy).

The mounting evidence shows that the constraints on supply leave no space for the material supply of bioenergy for shipping:[20] These system interactions are important. Political pressure to decarbonise shipping broadly rises along with pressure on all sectors, including those other sectors that have bioenergy as a potential interim source of energy before needing to move to hydrogen, and those sectors that may be dependent on biomass for the long run (e.g., materials, aviation). The kind of accelerated transition implied by the S-shaped emissions curve in Chapter 1 is not unique to shipping. Almost inevitably, then, a successful transition will see a period where multiple sectors are rapidly demanding both biofuel and hydrogen. Given underlying supply constraints, growing demand for biomass will increase its price. On the other hand, growing demand for hydrogen will help lower its costs (once potential supply chain bottlenecks are overcome), by driving economies of scale in production.

Signs We are Approaching a Narrative Shift – the 'Optionality' Paradigm

Given the inevitable trade-off between maximising short-term gains while positioning for managing future risks, we can expect to see narratives from actors in the transition evolve or shift as the focus moves from holding ground to keeping pace. In fact, we do see this with organisations with a track record, until recently, of promoting fossil technology as the near-term market solution and the SZEF options as a distant solution now looking for ways to promote their developing work on SZEFs.

With all the uncertainty regarding the timing of the implementation of stringent GHG policy and the clarity of the technology pathway, there is neither an incentive to place a firm bet on any one technology now nor to incur the capital costs for additional technology at a period when technology prices are high but expected to come down.

LNG, methanol and ammonia-led pathways all rely on the communication of optionality – that dual or even tri-fuel compatibility can give the confidence to proceed down the pathway now, whilst leaving flexibility to adapt to potential long-run pathways as they emerge. We now see this dimension of the narrative having an impact on the pathway in practice, both in the actual development of flexible technological options (dual fuel designs) and in the broader trend towards "zero-ready" vessels and commercial strategy for new ships.

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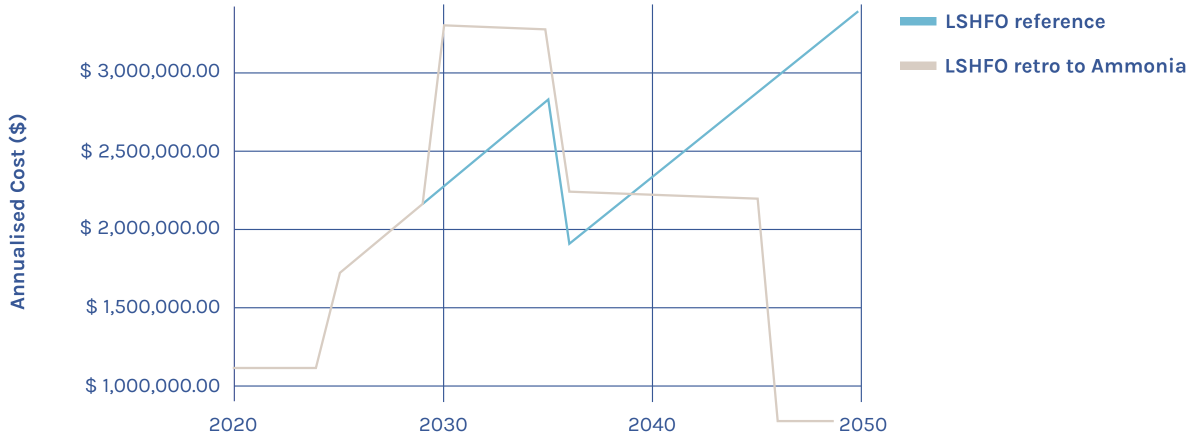
20 Englert, D., Losos, A., Raucci, C., Smith, T. (2021). *The Potential of Zero-Carbon Bunker Fuels in Developing Countries.* World Bank. https://openknowledge.worldbank.org/handle/10986/35435; Energy Transitions Commission. (2021). *Bioresources within a Net-Zero Emissions Economy: Making a Sustainable Approach Possible.* https://www.energy-transitions.org/publications/bioresources-within-a-net-zero-emissions-economy/; Sustainable Shipping Initiative. (2019). SSI Report: *The role of sustainable biofuels in shipping's decarbonisation.* https://www.sustainableshipping.org/news/ssi-report-on-the-role-of-sustainable-biofuels-in-shippings-decarbonisation/

From a technical point of view, a zero-ready approach integrates plans for a future retrofit to a non-conventional and less energy dense fuel into the specification for a newbuild. It is important to note that truly designing a ship to be retrofitted for zero-emission fuels will require a realistic view of the costs of that retrofit. The simplest and least credible definition of zero ready may simply mean that space has been left for additional fuel storage. Making a future retrofit more feasible may require more extensive modifications (i.e., installing tanks or pipework able to handle future fuels today, and filling them with conventional fuels for the time being). Class societies will play an important role in ensuring that zero ready is not a label applied to ships that have few prospects of being retrofitted economically in the future.

A zero-ready commercial strategy for a ship will consider the need for significant additional capex, for example, at future dry dockings (five and 10 year points). This strategy responds to the finding in Figure 9 that a large portion of the fleet will need to be retrofitted through the 2030s to the most competitive zero-emission fuel. Given this expectation, it is better to plan for retrofit than risk being caught out technically/commercially.

This choice can be illustrated with a commercial case study for how the additional costs might unfold in practice.

Figure 11: Evolution of annualised costs (carbon price and low fuel price scenario.



Under assumptions that CO_2 will be regulated, either by a market-based mechanism or by “shadow price” in regulation, we see that the initial period of higher costs of SZEF vessel ownership is offset by the future period when annual costs become more competitive.

In some cases, future savings may sufficiently offset near-term costs on a lifecycle basis. But there are also options for commercial strategies that lower the cost of this initial period. On a dual-fuel installation, a ship may continue to use fossil or biofuels (e.g., LSFO/HVO), but operate selectively on SZEF, increasing its use over time or during certain charters. This kind of dual-fuel operation has been shown, in the case of LNG, to lower the business case threshold for the adoption of new fuels (see LNG case study, Chapter 4). Maximising the efficiency of dual-fuel SZEF ships will be important to capture the flexibility of having two (smaller) engines.

Vessel owners and charterers may also seek market opportunities and customers able to pay the price premium for zero-emission shipping. Finally, they may be able to secure support (e.g., public funding, subsidies, etc.) for SZEF use from governments or financial institutions that are actively stimulating the transition.

The increasing emphasis on zero readiness points to a manifestation of an evolving narrative. A narrative that very recently was focused on incremental solutions, then transition solutions, and now zero-ready solutions; the next obvious phase being zero solutions.

3. The Landscape for First Movers to Scalable Zero-Emission Fuels

The shape of the curves for emissions reduction (Figure 7) and the adoption of zero-emission fuels (Figure 8) above shows the rapid acceleration of the transition from 2030. This means that, until that point, we can expect a relatively small part of the industry to transition to zero-emission fuels.

However, this S-curve logic has a technological dimension as well, with the initial, comparatively limited adoption of zero-emission fuels from 2025-2030 playing a crucial role in allowing these technologies to "emerge" – essentially to prove their technical and economic viability – and for the policy environment to prepare for a period of rapid diffusion, where a coordinated effort to promote scale and improve performance drives rapid adoption (See Chapter 4 for more detail on the emergence and diffusion process).

An analysis produced for the Getting to Zero Coalition by UMAS and the COP 26 Climate Champions showed that the diffusion phase could reasonably begin in 2030 if around 5% of shipping fuels globally had by then shifted to scalable zero-emission fuels.[21] This 5% adoption threshold would fit the S-curve and qualitatively suggests a wide enough deployment to establish viability.

Questions remain about when this emergence process could begin. Until zero-emission shipping becomes commercially viable, targeted action from governments and industry will be needed. Two important questions to address at this stage are:

- Do enough viable first mover opportunities exist to get to this 5% tipping point?
- Do we have information that can help target the routes and segments for early action?

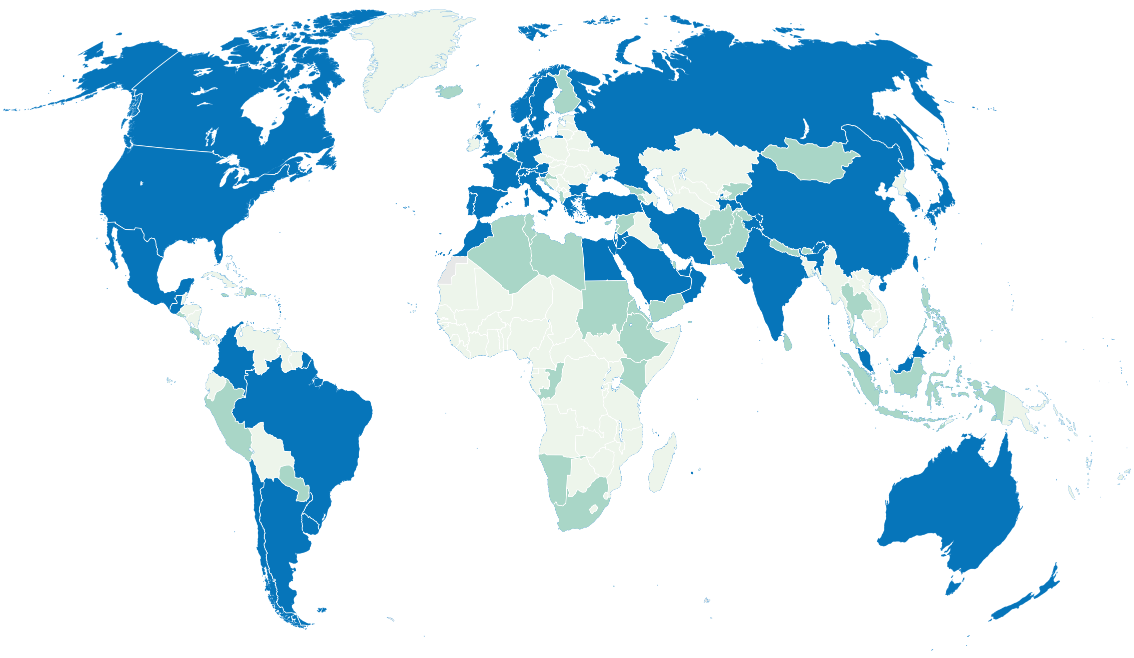
21 Osterkamp, P., Smith, T., Søgaard, K. (2021). *Five percent zero emission fuels by 2030 needed for Paris-aligned shipping decarbonization.* Global Maritime Forum. https://www.globalmaritimeforum.org/content/2021/03/Getting-to-Zero-Coalition_Five-percent-zero-emission-fuels-by-2030.pdf

Identifying Conditions for First Movement

The likely key determinants for first mover action will be: 1) the cost and availability of SZEFs; and, 2) the nature of shipping operations, in terms of geography and complexity.

There are geographical variations in the conditions for producing hydrogen and hydrogen-derived fuels (fundamental to SZEFs). Early action, therefore, will be enabled by a good potential for the production of competitively priced, decarbonised (e.g., blue/green) hydrogen alongside access to significant shipping activity. This analysis was the focus of work undertaken by the World Bank and UMAS.[22] A summary of some of the key results identifying countries well positioned for this pre-condition is shown in Figure 12.

Figure 12: Analysis of different countries' hydrogen production potential [23].



22 Englert, D., et al. (2021).
23 Ibid.

However, production only constitutes the supply side and will not, in itself, enable emergence unless it can reach significant demand volumes. Matching this potential to feasible sources of demand is the next challenge. In practice, demand will likely come from multiple industries, with shipping in places "piggy-backing" on other sectors' need for green energy carriers. This analysis simplifies that reality by looking only at shipping demand.

Both international and domestic shipping can broadly be subdivided into two types of operation:

- Liner shipping (bus-like – operating between two or more ports on a regular timetable)
- Tramp shipping (taxi-like – operating more randomly and calling at ports to suit the evolving demand for transport)

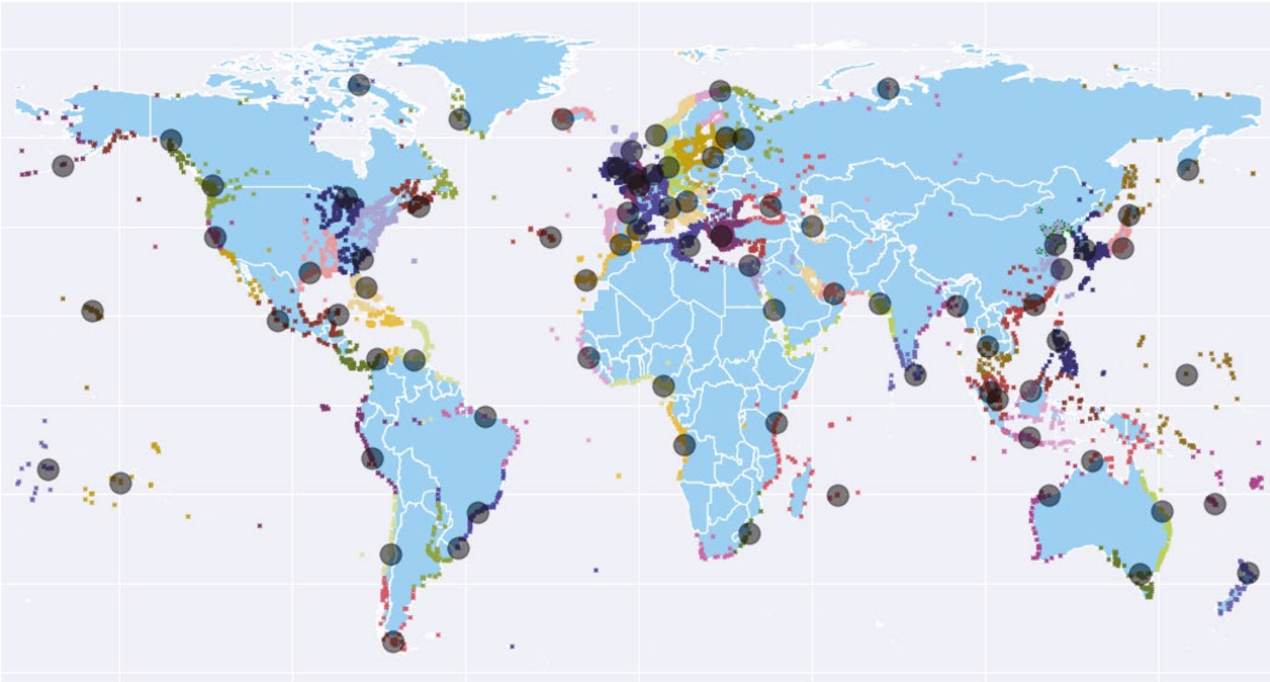
The tramp fleets face a tougher case for early action, given that this segment of the fleet would either need new fuels to be available at many different ports or use these fuels only selectively (e.g., on specific voyages) in a way that may not justify the investment needed in the ship for fuel flexibility.

Shipping activity that could potentially support early demand for SZEFs would thus need a higher degree of predictability in terms of its bunkering needs in order to assure that it could be matched to fuel availability. This kind of activity could take, roughly, three shapes:

1. A liner route (a ship with a small number of regular port calls)
2. An intra-cluster route (a ship that only operates within a local region)
3. A bilateral route (a ship that shuttles between two ports or clusters of ports)

It is possible to analyse ports in terms of geographically similar clusters, with each cluster representing a potential innovation niche for being a first mover. These clusters of ports are associated with one or more countries and, in some cases (e.g., China, US), there is more than one cluster per country. Shipping activity is then analysed relative to those clusters. These clusters can be seen in Figure 13.

Figure 13: Grouping port geography vs. energy demand. To form the clusters, an estimate of each port's energy demand (the energy used by all voyages departing from each port) was used to produce a weighting and aggregation. Shaded dots denote the highest demand port per cluster.



Shipping Activity and Fuel Availability: First Mover Potential is More Than Sufficient

Table 2 summarises the amount of shipping activity (in terms of fuel use) that meets one of these descriptions and occurs in countries/clusters with high hydrogen production potential.

*Table 2: **Summary of all vessels' fuel consumption and emissions, classified as operating exclusively from H2 strong potential ports, split by their domestic and international operational profile.***

<table>
<tr><th>Operational type of strong H2 potential only</th><th>Domestic/ International split of vessels' operation</th><th>Average no. of countries</th><th>Average no. of port calls</th><th>Aggregated MDOe (Mt)</th><th>International reduction potential (%)</th><th>Aggregated domestic reduction potential (%)</th><th>Aggregated total reduction potential (%)</th><th>Total reduction potential (%)</th></tr>
<tr><td rowspan="3">1 Intra-cluster</td><td>Dom/Int</td><td>2.02</td><td>9.41</td><td>0.89</td><td>0.14</td><td>0.24</td><td>0.38</td><td rowspan="3">2.09</td></tr>
<tr><td>Dom only</td><td>1.00</td><td>5.69</td><td>3.70</td><td>0.00</td><td>1.57</td><td>1.57</td></tr>
<tr><td>Int only</td><td>1.74</td><td>2.25</td><td>0.32</td><td>0.14</td><td>0.00</td><td>0.14</td></tr>
<tr><td rowspan="3">2 Bilateral</td><td>Dom/Int</td><td>1.44</td><td>4.30</td><td>0.12</td><td>0.02</td><td>0.03</td><td>0.05</td><td rowspan="3">1.10</td></tr>
<tr><td>Dom only</td><td>1.00</td><td>6.58</td><td>1.49</td><td>0.00</td><td>0.63</td><td>0.63</td></tr>
<tr><td>Int only</td><td>2.05</td><td>3.46</td><td>0.98</td><td>0.42</td><td>0.00</td><td>0.42</td></tr>
<tr><td rowspan="3">3 Liner</td><td>Dom/Int</td><td>3.71</td><td>16.50</td><td>11.80</td><td>4.16</td><td>0.86</td><td>5.02</td><td rowspan="3">7.44</td></tr>
<tr><td>Dom only</td><td>1.00</td><td>19.99</td><td>3.50</td><td>0.00</td><td>1.49</td><td>1.49</td></tr>
<tr><td>Int only</td><td>3.95</td><td>7.48</td><td>2.20</td><td>0.93</td><td>0.00</td><td>0.93</td></tr>
<tr><td colspan="4">Sub total</td><td>25.61</td><td>5.80</td><td>4.84</td><td>10.64</td><td>10.64</td></tr>
</table>

For some of the smaller or shorter-range ships included within this analysis, a SZEF may be less competitive than battery electrification. The method, therefore, filters out those ship types and sizes (such as shorter-range Ro-pax vessels and some coastal freight shipping), which earlier work has indicated have strong electrification potential.[24]

24 Raucci, C., Smith, T., Kat Deyes, K. (2018). *Reducing the UK Maritime Sector's Contribution to Air Pollution and Climate Change: Potential Demands on the UK Energy System from Port and Shipping Electrification A Report for the Department for Transport.* UK Department for Transport. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816017/potential_demands_on_UK_energy_system_from_port_shipping_notification.pdf

This is done conservatively to ensure that the subset of the fleet, energy demand, and emissions that remains is more likely to be a lower bound estimate than an upper bound estimate of the SZEF opportunity. Furthermore, if the restriction on hydrogen production potential is eased, the size of the fleet in question increases significantly.

Based on this analysis, a total of 10.64% of fuel consumption can be classified as having a strong first mover potential. This is significantly higher than the targeted threshold for emergence, and shows that there are multiple ways to achieve this outcome. Further, there is potential to more precisely understand what these options for early action look like.

First Movers Within Clusters

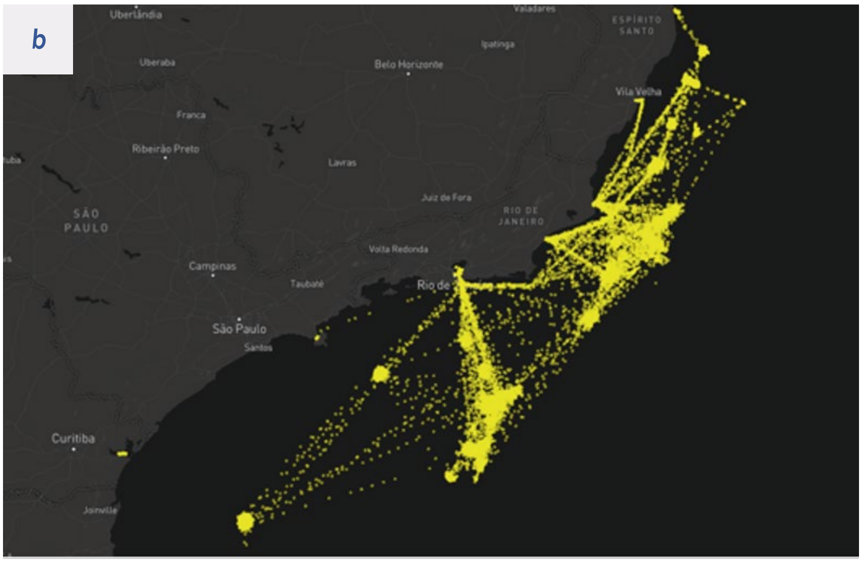
This category of first movers operates within a very geographically constrained area. They are perhaps the most obvious group of first movers because they will have some of the shortest ranges, and they should be able to work with very local supply chains for SZEF production and distribution (perhaps using only a single supply chain).

Because a cluster is not limited to a single country, but is more related to geographical proximity, fuel consumption and emissions are not exclusively accounted as domestic fuel/emissions, but the majority of fuel consumption/emissions is classified as domestic.

Intra-cluster route fuel consumption with first mover viability accounts for nearly 2.1% of total fuel consumption, and around 1.2% occurs in just ten countries. This shows that a large contribution of the overall zero-emission fuel consumption could be stimulated if a relatively small number of countries produced progressive regulation/incentives for ships operating within their jurisdictions or bilaterally with their immediate neighbours.

Around a third of the fuel demand in this category of first movers comes from large ferry ropax vessels (1.12%), with the remainder coming from the smallest sized categories of other ship types (e.g., those servicing coastal or local distribution needs only). To harness a net saving of 2.0% for this category, a total of around 3,650 vessels would need to take up SZEFs.

Figure 14:
a) Identified intra-cluster first movers. Map showing activity of 85 top emitting with a combined reduction potential of 0.51% alone. Note that all the mentioned vessels operate in Europe, Canada and China only.
b) Sample of intra-cluster vessels operating in the Sao Paulo/Rio de Janeiro cluster. A total of 229 vessels operate have a reduction potential of 0.038% equivalent to 46.3 kt of H2 equivalent.



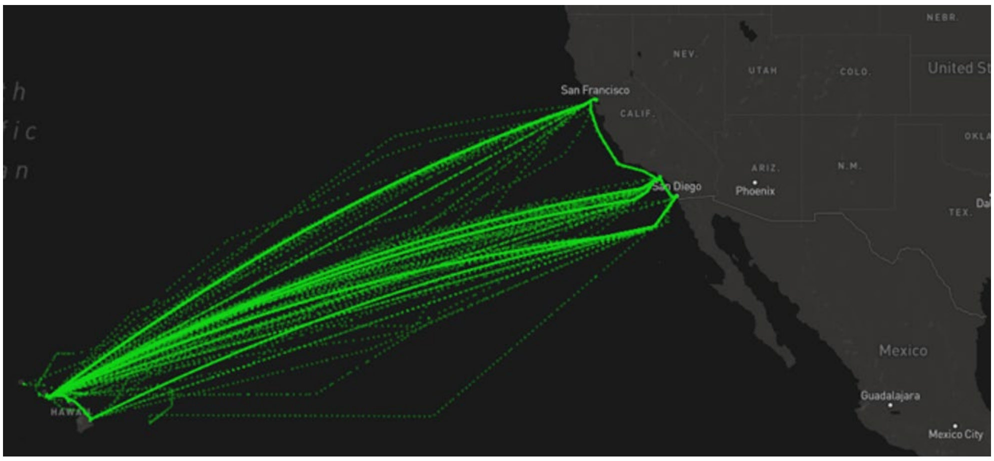
First Movers Between Clusters

The subset of ships that trade bilaterally between clusters is, on average, larger and has a longer range than the intra-cluster first movers (with some bilateral voyages being very long range). The infrastructure requirements can be simpler (fewer port calls) and larger scale than for intra-cluster first movers.

With a combined reduction potential of 1.1%, bilateral trading vessels have a 40/60 split of fuel consumption between those vessels that operate between two countries (international) and those operating within two clusters in a single country (domestic).

The vessel type classification for the bilateral category is led by bulk carriers (0.3%) and Ferry-Ropax with (0.29%). They are followed by mid-sized Ro-Ros and small-to-medium sized containers and tankers. These results suggest that, by converting a relatively small number of 515 vessels to SZEFs, all the strong potential of bilateral trading can be harnessed (1.1%), with the top five accounting for 0.97% for 386 vessels.

Figure 15: Identified bilateral route first movers. Map showing activity of the 75 top emitting vessels, with a combined fuel consumption equivalent to 0.51% alone. These are mainly LNG carriers, Ro-Ros, big ferries and container ships.



First Movers on Liner Routes

Liner route first movers include ships that have a regular voyage pattern and, therefore, the infrastructure can be built to expect a stable demand for SZEFs. This group of ships has a greater number of port calls and cluster interactions than the inter-cluster first movers, and collaboration with a greater number of ports (and regulatory regimes) may be required. Depending on the route and storage capacity on board, it may not be necessary to bunker SZEFs at each cluster stop but, to be conservative, the requirement in this analysis is that all clusters called at have high potential for hydrogen/SZEFs.

To identify the most likely first movers from this pool of 4,936 vessels, the analysis focused on vessels that stop at a maximum of three clusters. These ships were assumed to have an easier transition path, while accounting for a combined fuel use potential of 2.94%.

While a great deal of attention tends to be paid to international liner routes, the reduction potential for liner routes within countries is actually greater. Within this group, routes through Japan have the highest SZEF use potential of 0.517%, with bulk carriers being the predominant type and visiting an average of 24 different ports each year. Chinese routes, also dominated by bulk carriers, include 20 different ports and a SZEF use potential of 0.516%.

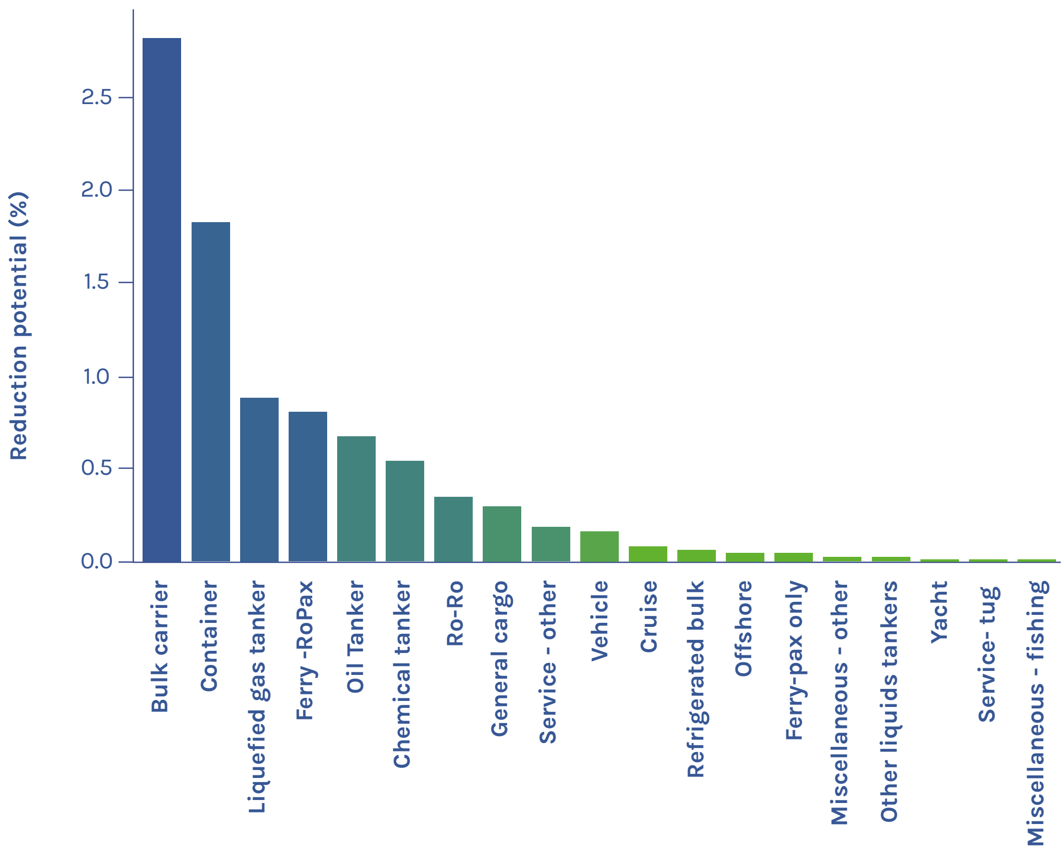
When considering only liner routes that move between at least two countries, the picture is indeed different. As seen in Figure 16, where a subset of these vessels is presented, the range of travel increases. Asia-Oceania, the Pacific, the US West Coast, the Gulf of Mexico, and the New York-Singapore route can be highlighted as the predominant routes with first mover potential.

Figure 16: Identified liner route first movers. Map showing activity of a subset of liners stopping at two countries.

The China-Australia and Japan-Australia routes top the list, with an added potential of 0.23% covered by 43 vessels. The most common vessel type for this selection is the bulk carrier. This is followed by the containers route between Japan and China (0.08%) and between the US and China/Japan, with a combined potential of 0.12% for 16 containers.

Figure 17 describes the reduction potential per vessel type for the full liner routes. Bulk carriers top the list with a potential of 2.5%, followed by container ships, three types of tankers, ferries and Ro-Ros. The predominance of bulk carriers can be partly explained by the fact that the most common vessel size is larger than for other ship types (between 60,000-100,000 DWT), generating a larger share of overall fuel consumption.

Figure 17: Vessel type distribution for potential first mover liner routes.




5M
.8
.6
.4
.2
4M

4. Shipping Transition Scenarios

The “what”, “when”, and “where” of shipping’s transition have been analysed in the sections above by assessing what an S-curve for emissions reductions implies for the rollout of new fuels, the selection of fuel pathways, and opportunities for early action by first movers. All of this analysis, however, will be strongly impacted by the “how” of shipping’s transition: the ways in which different players decide to act and interplay between these decisions.

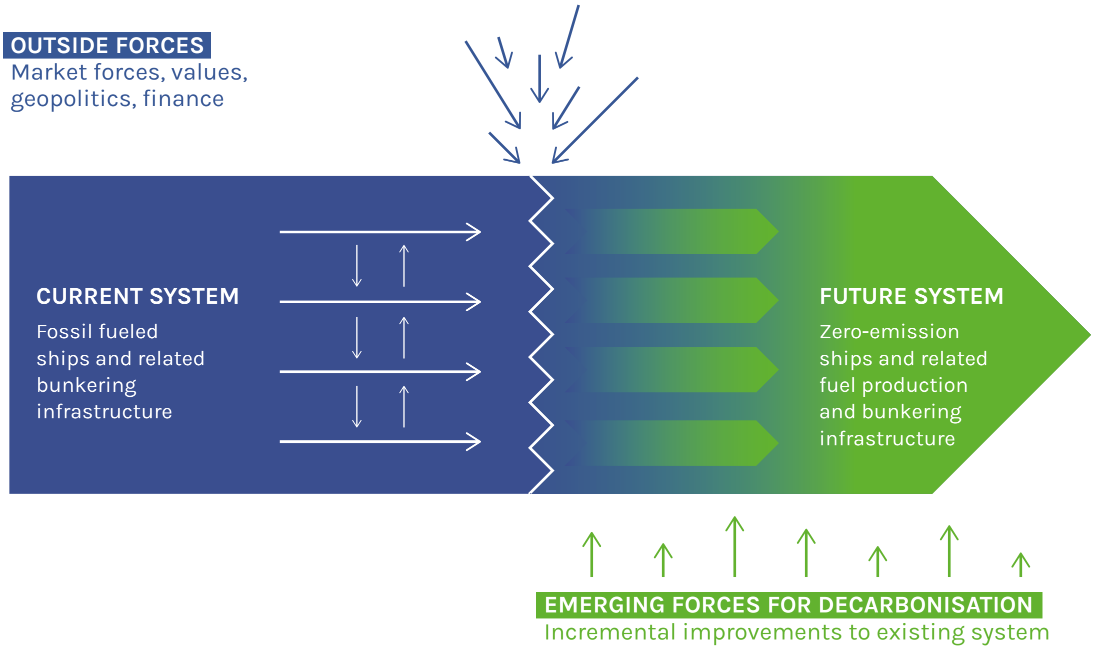
This “how” is highly uncertain and difficult to quantify. However, it is not impossible to analyse. Studies of technological and industrial transitions in shipping and other sectors can tell us a lot about the way change driven by human decisions typically happens.[25] It is even possible to create broad archetypes for these transitions, which can be used to evaluate the technical and economic pathways assessed above in a new light and identify levers for change.

The Transition Background – How Can a Maritime Transition Take Place?

Broadly speaking, industrial and technical transitions take place when a given system – here the system that binds together the shipping sector and its energy supply – comes under pressure from outside forces in society, politics and the environment. These forces create openings for new actors with alternative solutions to enter the system and pressure existing actors in the system to change their arrangements and interactions. Figure 18 presents this process in a schematic.

25 Most of this work is connected to, or has its origin in, the academic field of socio-technical and sustainability transitions research, and is connected to heuristic frameworks such as the multilevel perspective (MLP) (Geels, 2002).

Figure 18: Schematic of shipping transitions[26] .



Much work has been done on fuel transitions and their scope[27], but only recently has work on maritime fuel transitions begun to gather pace. Many historical transitions in shipping have taken place, including the transitions from wind to steam and from steam power to motorships, to name the two most pronounced. More recently, energy efficiency improvements, and the move away from heavy fuel oil (HFO) to distillates and, in certain niche segments, to LNG as a ship fuel have also been observed. This study takes insights from all of these transitions to develop a mechanism of fuel transitions. However, the key case study used to inform this report is that of the adoption of LNG as a marine fuel. Unlike the other named transitions, this is the first maritime fuel transition that took place more recently which required a complete overhaul of safety regulations, bunkering infrastructure, fuel supply chains, and vessel operations. In addition, political as well as environmental forces (i.e., concerns around NOx emissions from HFO) facilitated the transition. In this sense, the adoption of LNG as a marine fuel has many components which would likely exist in future marine fuel transitions (i.e., technical reconfiguration, bunkering overhaul, new regulations, etc.) and that, therefore, make it a valuable case study.

26 Based on Geels (2002), and informed by work done by Baresic (2020).
27 Work in academia by individuals such as Hansen and Coenen et al. (2012), Hansen (2015) exploring sustainability transitions has shown how much multiple factors of space and geography can play a role in transitions

Table 3: Forces acting on shipping's transition.

LEVELS	CURRENT SYSTEM	FUTURE SYSTEM
OUTSIDE FORCES	**Dominant market forces:** • Failure to internalise costs of climate change • Prices for oil and gas • Demand for least cost shipping • Values-based drivers: • Emergent climate change movements • Shipping pollution opposition (i.e., SOx, NOx, PM) **International relations:** • Trade and energy security dominant • Climate commitments increasingly important **Finance:** • Small, fragmented financing (public and private) of zero carbon pilot projects • First moves towards transparency on climate alignment	**Dominant market forces:** • Internalisation of climate costs • Transition from fossil fuels • Renewable electricity prices • R&D and economies of scale for SZEFs • Demand for green shipping routes **Values-based drivers:** • Broad awareness of climate change • Increased transparency in shipping operations **International relations:** • Climate commitments overriding priority **Finance:** • Large scale deployment of capital into zero-emission shipping on a commercial basis • Transparency and governance enable engagement of all investor classes
SYSTEMS	**System components:** • Existing bunkering infrastructure and safety rules • Oil & gas production/supply chains • International shipping routes shaped by existing market forces • IMO structures struggle to adjust to required transition • National and supranational (i.e., EU) bodies regulating domestic and regional shipping • Flagging and class systems poorly understood in society • Industry associations fragmented on transition issues	**System components:** • Novel bunkering infrastructure for SZEFs, including handling and safety procedures • Full-scale SZEF production/supply chains including import/export capabilities • Widespread creation of "green corridors" • IMO decisions aligned with transition to zero • Improved transparency and regulation increases industry credibility • Industry associations aligned on decarbonisation
EMERGING FORCES	**Forces driving incremental improvements:** • Energy costs and GHG awareness driving operational efficiency improvements, scrubbers and low sulphur fuels, wind assistance • Changes to meet air pollutant pressures (i.e., SOx/NOx) reformulated in terms of GHG benefits • Fragmented discussions around multiple future fuels and pathways	**Forces driving whole industry transition:** • Decarbonisation, the primary drivers of technological change • Incremental technologies (efficiency, etc.) implemented to enable full decarbonisation • Well-to-wake analysis centres change around SZEFs

In shipping, which is a globalised sector with domestic components, understanding the role of space and geography is paramount. Due to the overall dominance of international shipping emissions, which account for 70% of total fuel demand from the sector,[28] [29]the main focus of the transition must eventually be international shipping.

However, many countries have substantial domestic shipping sectors. Countries such as the US have sizeable domestic shipping fleets; in its case, accounting for around 20 million tonnes of CO_2 emissions annually.[30] As an archipelago nation, Indonesia has a large shipping fleet that plays a crucial role in its economy. On the energy side, many countries are developing local hydrogen and renewable electricity production plans. Germany estimated a demand for hydrogen of 90 to 110 TWh until 2030.[31] Under these circumstances, understanding what role national governments can play in speeding up shipping's transition to zero-carbon fuels is highly important.

28 Faber, J., et al. (2020).
29 Bottom-up estimate for 2018.
30 Environmental Protection Agency. (2018). *Greenhouse gas inventory data explorer.* https://cfpub.epa.gov/ghgdata/inventoryexplorer/#industry/allgas/source/all
31 Federal Government of Germany. (2020) Die Nationale Wasserstoffstrategie.

Fuel Transitions: What Can Be Learned From the Development of LNG as a Shipping Fuel?

The development of LNG as a marine fuel, which first took place in Norway and then in other Nordic countries, supported by EU funding mechanisms and regional regulations such as Emission Control Areas (ECAs), provides some lessons about how national action on shipping can spread to the international arena.

Significant Role for National Players in a Fuel Transition

Norway acted as a first mover country, deploying LNG as a fuel in its local ferry industry. Norwegian policy actors such as the Norwegian government and parliament played a crucial role in presenting LNG as a viable fuel for Norwegian domestic shipping: As early as the late 1980s, political actors in Norway began to explore ways in which domestic action could promote new demand sources for natural gas. The idea of "Norway as a gas nation" began to take hold in policy circles.[32] Politically, there was a strong desire to implement regulatory mechanisms that could benefit the oil and gas industry, and LNG was seen as an ideal storage method for natural gas in a country where gas pipelines were not economically viable in many areas.

The domestic ferry industry provided an ideal testbed for LNG, as it was government- controlled and could provide a market for Norwegian LNG that was relatively shielded from price fluctuations. The ferry industry could issue tenders for gas-fuelled ferries and the government could coordinate financial support mechanisms for R&D through existing research programmes (i.e., SPUNG and GAVOT). Statoil, the state-owned oil and gas enterprise, was involved in developing LNG as a marine fuel and worked closely with both state and Norwegian private enterprises on technological developments.

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32 MoIE (Norwegian Ministry of Industry and Energy Affairs). (1995). White Paper 44 (1994–1995)

Financing Mechanisms and International Fuel Spread

The Norwegian NOx Fund was established to support the financing of low NOx technologies for vessels operating in Norwegian territorial waters,[33] and many shipowners tapped into the fund to develop LNG-fuelled vessels. Shipowners from Denmark and Sweden, who operated in Norwegian waters, also applied for support from the NOx Fund, facilitating the development of some of the first LNG projects in southern Sweden (the chemical tanker sector) and in Denmark (the cruise ferry industry).

Over time, the LNG-fuelled Swedish and Danish vessels, financed by the NOx Fund, provided the inspiration and proof of concept to other shipowners in their respective countries, who then decided to build LNG-fuelled vessels, even when they were not eligible for NOx Fund financial support.

Swedish and Danish vessels benefitted from the early development of LNG bunkering infrastructure in Norway. Vessels with dual-fuel engines could operate in Norway with LNG and on HFO/MDO in Sweden and Denmark. Of course, this supported the national interests of Norway. Aside from expanding the market for gas, it also landed many contracts for Norwegian ship designers and small local shipbuilders. Over time, the resulting Swedish and Danish ships provided the base demand for the establishment of bunkering infrastructure, not to mention regulatory frameworks, in their own countries.

It is important to note that Norway's neighbours were members of the European Union (EU). The EU has significant innovation structure, networks, and funding that companies can draw on to develop and demonstrate new technologies. Many of the pilot LNG ships developed in Sweden, Denmark, and Finland (e.g., the Viking Grace, Megastar, Fure West, etc.) benefitted from EU financial support through programs such as TEN-T and CEF. Additionally, early LNG bunkering infrastructure developments (e.g., Seagas and Coralius bunkering vessels, Port of Gothenburg small scale LNG bunkering facilities, etc.), especially in the Baltic Sea, also benefitted from EU finding. In some cases, it is quite likely that, without this additional source of financial support, these projects would have never got off the ground. Thus, it can be concluded that Norway played an important role as a first mover and facilitator for technological development, but financial support from the EU, as well as national support mechanisms in place in countries such as Finland and Sweden, played a pivotal role in supporting the growth of the fuel, in terms of new ships and bunkering infrastructure in the Baltic Sea area.

33 Confederation of Norwegian Enterprise. Business Sector's NOx Fund. https://www.nho.no/samarbeid/nox-fondet/the-nox-fund/articles/the-nox-agreement/

Global Growth Drivers – The Case of LNG Safety Rules

The emergence of LNG as a marine fuel was a story of national interest driving the emergence and regional spread of a new marine fuel. Yet, international institutions became increasingly important as the technology began to spread. Commitments made at the IMO to tackle SOx and NOx emissions (i.e., IMO ECAs and IMO 2020 sulphur limit),[34] [35] pollution from ships (i.e., MARPOL ANNEX VI),[36] and international regulatory developments to facilitate a set of unified safety rules for the operation of gas-fuelled ships (i.e., IGF Code)[37] were important in enabling a global configuration for the sub-sector. The Norwegian government helped provide momentum early in this process, but it could not have driven it internationally without the IMO. Early safety developments in Norway fed into the pool of knowledge, which would shape developments at the IMO and in other countries. In the early 2000s, learning from the development of the first LNG-fuelled ferry Glutra in Norway, and later work on PSVs, provided the understanding that a new set of rules beyond the IGC Code was necessary in order for LNG to become a well-regulated and safe shipping fuel.[38] Through this process, government institutions worked closely with class and technology providers, and this process was replicated many times in Norway and in neighbouring countries. In some instances, the experience from Norway proved a good foundation, whereas in other instances, local conditions necessitated different approaches.[39]

The transition to zero-emission fuels has many parallels with the LNG journey, including the need to overcome the chicken-and-egg problems of developing supply, demand, and bunkering, the need to de-risk the choices of first movers, and the need to develop and globalise procedures for the handling, transport, and usage of new marine fuels. Given this, there is good reason to expect that this transition might begin in a similar way, by building on the national interests of one country, or a few in parallel, before shifting to the international arena by way of plurilateral networks and, eventually, the IMO.

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34 IMO. (2011) *Resolution MEPC.203(62): Amendments to the annex of the protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978.*

35 *IMO. (2018). Sulphur oxides (SOx) and Particulate Matter (PM) – Regulation 14.* http://www.imo.org/en/ourwork/environment/pollutionprevention/airpollution/p./sulphur-oxides-sox-%E2%80%93-regulation-14.aspx

36 IMO. (1997). *Resolution MEPC.7540: Amendments to the Annex of the protocol of 1978 relating to the International Convention for the Prevention of Pollution from Ships, 1973*

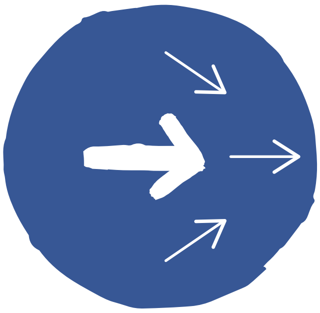
37 IMO. (2014). *New Code of Safety for Ships using Gases or other Low flashpoint Fuels (IGF Code) agreed in draft form by IMO Sub-Committee.* http://www.imo.org/en/MediaCentre/PressBriefings/Pages/28-CCC1IGF.aspx#.XzAsUpZKg2w

38 IMO. (1983). *International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)*, MSC.5(48). 193. https://www.imo.org/en/OurWork/Safety/Pages/IGC-Code.aspx

39 Baresic, D. (2020). *Sustainability transitions in the maritime transport industry: The case of LNG in northern Europe*. University College London. https://discovery.ucl.ac.uk/id/eprint/10112016/

Three Scenarios For a Zero-Carbon Marine Fuel Transition

In order for a fuel transition to take place in shipping, and for that transition to spread globally, there are three likely pathways/scenarios. These processes have been explored and based on transitions theory thinking developed through the Maritime Sustainability Transitions Framework (MarSTF).[40] They can be summarised here as follows:



Scenario 1: Spread From a Strong First Mover Country to Others

- Single nation plays a key role in facilitating early growth and adoption
- Domestic developments in the dominant nation support international developments
- Important role for spread from the dominant nation to those it has strong trade links with and to neighbouring nations, especially in the early stages of the transition

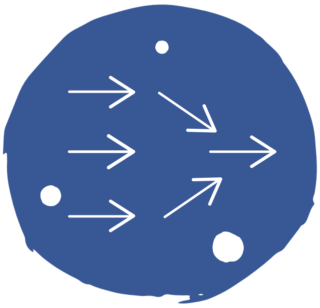
One strong first mover nation could lead the way in multiple areas with regard to SZEFs. In the early stages of the transition, zero-carbon fuel production and supply chain development are heavily concentrated in one country with a large domestic market. At a local and national level, the country invests heavily in R&D, pilot projects, and a fuel production system, which eventually facilitate a complete national system reorientation towards the new fuel.

This process would require strong policy support mechanisms such as grants, taxation, and subsidies to support first movers and form markets for alternative fuels. It would also involve the creation of alternative fuel bunkering hubs and likely a strategy to become an exporter of technological solutions, as well as the fuel itself, to those who follow. The national shortsea shipping segment is used as a testbed for the novel technology. The nation uses its soft power to facilitate international debate and the creation of rules, which make the fuel more viable. In parallel, international pilot projects for zero-carbon international shipping routes (“green corridors”) would be developed, with the first mover country likely taking part in one or more.

Such a country would require a strong existing shipping RD&D cluster, a dynamic shortsea shipping industry with niches that can support paying a premium for the more expensive fuel, an environmentally minded shipping industry, and potential for the development of necessary policy support mechanisms.

40 Baresic, D. (2020).

From a national political perspective, the policymakers and political players could see opportunities for job creation, exports, and positive national image creation in the transitions. These could be formed around fuel supply (i.e., opportunities for production of renewable hydrogen/ammonia), or shipbuilding and ship design, or equipment manufacture, focusing on the growth and modernisation of incumbent industries or the creation of new business segments. A strong potential for domestic usage of the alternative fuel, especially in other sectors, would create an added incentive. In addition to domestic sales of the fuel, the proximity to international shipping lanes could create potential for export.



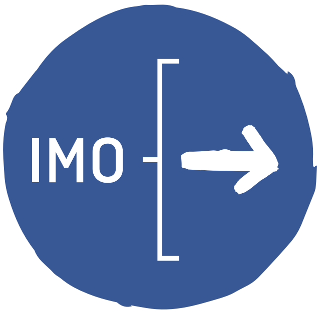
Scenario 2: Independent National-Level Spread

- Fuel transitions occur independently in multiple countries
- National developments play a key role in the early stages of transition
- International developments (e.g., zero-carbon shipping routes, shipbuilding, energy production) are strongly supported by national action between first mover countries

This scenario shares similarities with Scenario 1, in that national interests drive much of the early transition and national governments play a key role. However, in this scenario, these interests play out across multiple countries in parallel, possibly reflecting the relative advantages of these countries in terms of shipping segments or parts of the zero-emission shipping value chain. In this scenario, the role of international developments, such as "green corridor" implementation and global supply chain emergence, is greater.

In Scenario 2, large international actors, such as shipowners, charterers, and operators who facilitate global seaborne trade, learn from and interact more heavily with national and local actors. Local actors, such as small shipowners, mid-sized ports and national governments, facilitate the development of pilot projects and the shortsea scale-up of zero-carbon fuel usage. The role of national governments in moving the transition forward through financial support and favourable policies is paramount in driving the transition. On a national level, some countries with hydrogen strategies scale up the production of such fuels for domestic consumption, primarily on land. Developing countries with renewable energy endowments and access to shipping lanes pursue export-led strategies for production of hydrogen-based fuels, supported by international financial institutions. In multiple countries, national policies are enacted to close the price gap in the production of zero-carbon fuels, and grants are given for the development of zero-carbon shipping vessels. Quickly (i.e., by the late 2020s), these policies become more stringent, with the aim of a rapid phase out of fossil fuels in domestic shipping.

This process takes place independently in multiple countries at a domestic level, in parallel with international pilot project developments and pilot international zero-carbon shipping routes between ports, many of which are located in countries leading the domestic shipping decarbonisation push. A positive feedback loop develops and, over time, these domestic developments and international low carbon routes interconnect and form a global network of international shipping, and eventually a global system change.



Scenario 3: Global Actions Drive International Spread

- Global international action is the primary driver of fuel transition
- The IMO plays a key role in setting the pace, shape, and regulatory framework for transition
- International shipping is the key bedrock for the innovation and adoption of new fuels from the earliest stages of the transition

In Scenario 3, national action is superseded by a global agreement at the IMO or other international fora. While national and local action plays a role in the emergence of new solutions, the main dynamic is not a spread of these solutions from one country to another. Instead, a global policy regime is established that facilitates a rapid global transition away from fossil fuels towards low carbon alternatives. It should be noted that such a transition can also occur in theory through action outside of the IMO, in which most of the global shipowners decide unilaterally to transition away from fossil fuels, under growing international pressure. However, such a pathway is significantly less likely due to the economic risks for corporations posed from a loss of tonnage and competition from less proactive shipowners.

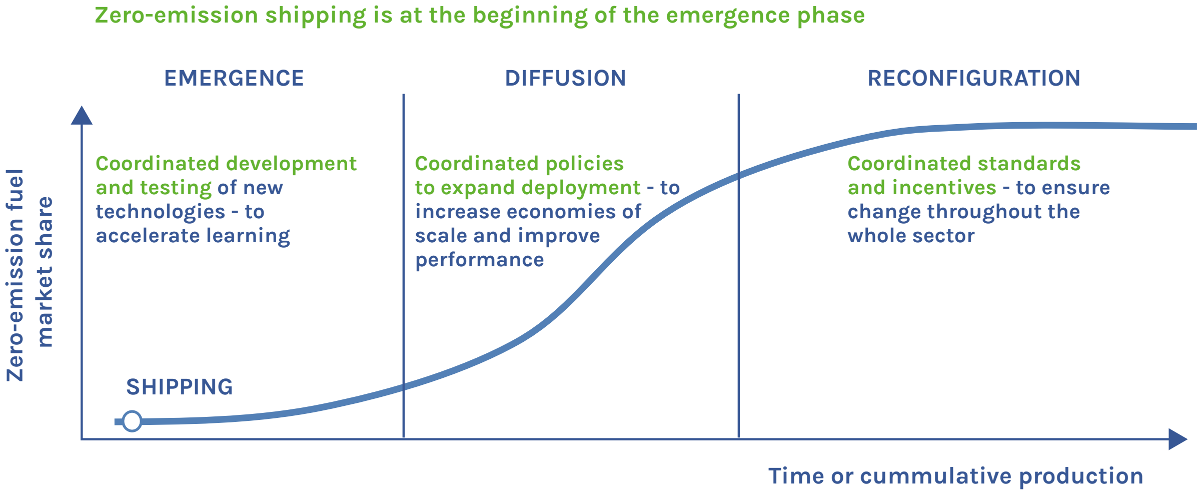
The above three pathways give a framework, which can be used to understand how various stakeholders can interact, what potential stimuli (i.e., policies and various soft measures) can be utilised, and how these can translate into specific pathways. These scenarios are based on theoretical underpinnings, but aspects of them are already being observed in the real world, whether in terms of country-level action as is seen in nations such as Norway or the UK, schemes encompassing larger regions such as the EU ETS or other ETS schemes globally (e.g., China), and global developments at the IMO (i.e., the IMO “Initial Strategy”). The pathways are discussed further in the following sections.

Three Phases of a Transition to Zero-Carbon Marine Fuels

As noted in earlier chapters, the adoption of zero-emission fuels in shipping is likely to follow an S-curve, both because of the emissions reductions required and the patterns observed in most previous industrial transitions. This type of fuel transition has three phases:

- **Emergence phase:** National and international action, learning, R&D, and a rapid increase in expertise narrow the price gap between alternatives and fossil fuels. At this stage, adoption of the fuel is still relatively low as most of the progress is observed in R&D and non-commercial pilot projects. Shipping is only now entering the emergence phase of the zero-emission fuel transition.
- **Diffusion phase**: The cost of the new technology is lowered considerably, primarily as a result of economies of scale and optimisation in the supply chain, as well as through improvements in technological performance. This lower cost makes commitment from industry (in the form of commercial-scale investment) and policymakers (in the form of taxes and subsidies) more feasible. These moves support the rapid adoption of the zero-carbon fuel, positive feedback loops, growing confidence in the transition, and the further lowering of costs.
- **Reconfiguration phase:** The curve reaches saturation as the zero-emission fuel is now the principal fuel of the shipping industry and the replacement of the original fossil fuels has been completed.

Figure 19: Zero-emission fuel S-curve adoption rate (modified from: Victor et al.(2019).



All three scenarios will feature all three transition phases. On a scale of decades, the curves should follow a similar shape, with the main differences being the timing and location of specific developments. The main characteristics of the three scenarios are given in the following text with a ***heat map*** outline of the key common characteristics regarding the location of shipping developments, the type of actors (by scale), the intensity of learning activities, fuel, and policy developments.

IMPORTANCE IN EACH PHASE OF TRANSITION:

- Low
- Medium
- High
- Very high

		Location			Actors			Learning			Fuel			Policies			
		Global	Liner routes	Domestic	National	International	IMO	RD&D	Pilots	Economies of scale	Production	Distribution (global)	Bunkering (global)	National	Bi-lateral	Multilateral	Global
Scenario 1	Emergence	Low	Low	Very high	Low	Low	Very high	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Very high
	Diffusion	Medium	High	High	Low	Medium	Very high	Medium	Medium	High	Medium	Medium	Medium	Low	Medium	High	Very high
	Reconfiguration	Very high	Very high	Very high	Low	High	Very high	Very high	Medium	High	Very high	Very high	Very high	Low	High	Very high	Very high
Scenario 2	Emergence	High	Medium	High	Low	High	High	Medium	Medium	High	Medium	Medium	Low	Low	Low	High	Very high
	Diffusion	Very high	High	Very high	Low	Very high	Very high	High	High	Very high	High	High	High	Low	High	Very high	Very high
	Reconfiguration	Very high	Very high	Very high	Low	Very high	Very high	Very high	High	Very high	Very high	Very high	Very high	Low	Very high	Very high	Very high
Scenario 3	Emergence	Low	High	Very high	Very high	High	Low	High	High	Very high	High	High	Medium	Very high	Medium	Low	Low
	Diffusion	High	Very high	Very high	Very high	Very high	High	Very high	Very high	Very high	Very high	Very high	High	Very high	Medium	Medium	Medium
	Reconfiguration	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Medium	Medium	High

		Location	Actors	Learning	Fuel	Policies
Scenario 1	Emergence	Medium	Low	Low	Medium	Medium
	Diffusion	Medium	Medium	Medium	Medium	High
	Reconfiguration	High	Very high	High	High	Very high
Scenario 1	Emergence	Medium	Medium	Medium	Medium	High
	Diffusion	High	High	High	High	Very high
	Reconfiguration	High	Very high	Very high	High	Very high
Scenario 1	Emergence	Medium	Medium	High	Medium	Medium
	Diffusion	Medium	Medium	Very high	Very high	Very high
	Reconfiguration	High	Very high	Very high	Very high	Very high

Scenario 1 S-Curve:

Emergence: Starts in one country and spreads to trade partners and connected/neighbouring countries, before global emergence
Diffusion: Spreads to trade partners, connected/neighbouring countries from the first mover, and spreads globally rapidly
Reconfiguration: Occurs globally, with delay in some Small Island Developing States (SIDS) and Least Developed Countries (LDCs)

The emergence phase is concentrated in one leading country. The leading country, at a national level, is the key facilitator of policy developments, which support alternative fuel adoption. Over time, some neighbouring countries and those linked via trade adopt similar policies, principally driven by political support from the leading country.

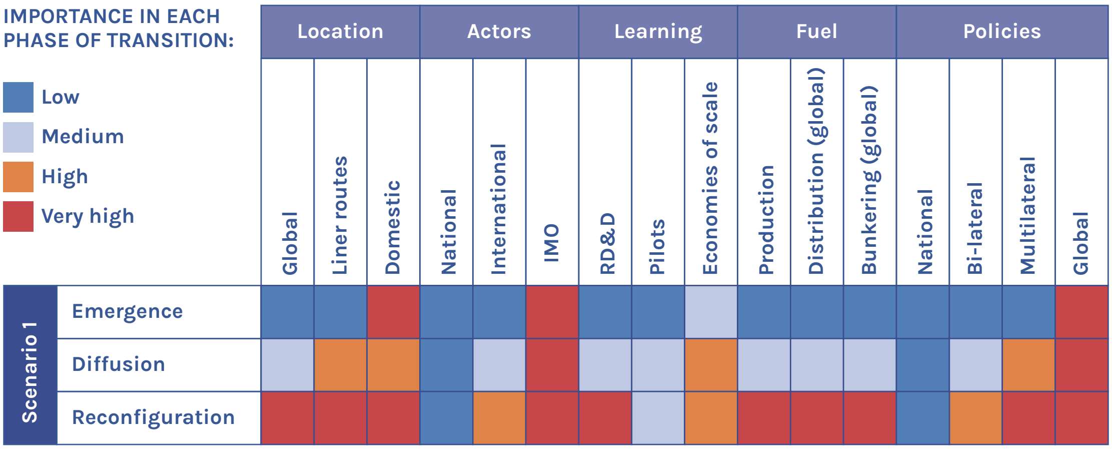
The majority of learning occurs in this single country, meaning that the process is relatively slow compared to the other scenarios due to the relatively limited availability of human capital and facilities for development. All these constraints imply a relatively long emergence phase. In particular, this is the case with learning-by-doing regarding pilot projects, technical solutions, and regulatory procedures. Most of the key actors (policy, technology, and fuel supply) are based in the leading country as well.

Internationally, emergence is connected to a few specific international routes trialling the new technology, energy production trials, and globalised industry segments (e.g., large engine manufacturers, shipbuilders). Fuel production, distribution, and bunkering development are the slowest in this scenario due to the limited number of countries and resources involved. The localised nature of the transition in the early stages means that there is limited demand for fuels and also a relatively constrained requirement for bunkering in only a few locations. Production is constrained by leading country production capacities and exports of the fuel are limited.

Once the diffusion phase begins in the leading country, neighbouring countries and key trading partners go rapidly through the emergence phase to catch up and begin the diffusion phase with a delay. Leading country actors play a key role in facilitating the spread of the fuel into connected countries through investment, contracts, and partnerships. These actors include both incumbent national actors who reoriented to the new fuel and new emerging actors who, over time, build linkages and become international actors by spreading the technology to countries connected to the leading country. Once the international presence of actors is established, a global, rapid emergence phase begins, and the rest of the global industry enters the diffusion phase. At this stage, a rapid increase in global fuel production and distribution begins to take hold.

The reconfiguration phase is reached first in the leading country and connected/neighbouring countries, in terms of their shortsea fleets, quickly followed by most globalised economies, which observe a rapid take up of zero-carbon fuels as a result of the early adoption of zero-carbon fuels in international shipping routes. However, low-income countries, and particularly SIDS and LDCs may be left behind due to a lack of global IMO policies to support diffusion.

Figure 20: Heat map, scenario 1.



Scenario 2 S-Curve:

Emergence: Starts in several countries and spreads to others, part of emergence global
Diffusion: Starts in leading countries, but spreads globally rapidly
Reconfiguration: Occurs globally, with delay in some SIDS and LDCs

The emergence phase is developed rapidly in several leading countries. Initially, domestic policies in those countries play a key role in facilitating development. In these countries, the greatest focus is on learning, through RD&D and pilot developments, often targeting certain segments or parts of the value chain. The learning process gathers pace quickly, and leading countries quickly connect and begin knowledge sharing.

Once the adoption of regulatory measures, technological solutions, and successful policies occurs, the emergence phase spreads to other countries. Internationally, emergence takes place in distinct technological and industrial segments, on specific shipping routes, and in highly globalised segments (e.g., large engine manufacturers, shipbuilders).

Once the diffusion phase begins in the leading countries, it spreads rapidly to all other countries, which almost completely avoid emergence and head straight into diffusion. Bilateral agreements on policies to support the development of zero-emission routes lead to the rapid adoption of international policies to support fuel adoption.

Domestic and incumbent actors from the key countries play a key role in forming mutual partnerships and spreading the transition. They form mutual cooperation agreements to facilitate liner route developments, for example, to secure fuel supply, bunkering infrastructure, and necessary trade agreements.

Fuel production, distribution, and bunkering starts off relatively slowly in the emergence phase due to uncertain demand, but it develops faster than in Scenario 1 due to the larger number of nations involved facilitating more cooperation and international fuel distribution. The reconfiguration phase is reached globally, with some SIDS and LDCs potentially being left behind due to a lack of global IMO policies to support equity.

Figure 21: Heat map, scenario 2.

IMPORTANCE IN EACH PHASE OF TRANSITION: Low / Medium / High / Very high

Scenario 2	Location			Actors			Learning			Fuel			Policies			
	Global	Liner routes	Domestic	National	International	IMO	RD&D	Pilots	Economies of scale	Production	Distribution (global)	Bunkering (global)	National	Bi-lateral	Multilateral	Global
Emergence	High	Medium	High	Low	High	High	Medium	Medium	High	Medium	Medium	Low	Low	Low	High	Very high
Diffusion	Very high	High	Very high	Low	Very high	Very high	High	High	Very high	High	High	High	Low	High	Very high	Very high
Reconfiguration	Very high	Very high	Very high	Low	Very high	Very high	Very high	High	Very high	Very high	Very high	Very high	Low	Very high	Very high	Very high

Scenario 3 S-Curve:

Emergence: Begins globally and worldwide
Diffusion: Continues as a global process, first with some key trade routes
Reconfiguration: Occurs globally with support for SIDS and LDCs agreed via IMO

The emergence phase occurs globally, but with certain countries leading in specific segments (e.g., where shipbuilding/engine manufacturing is most developed, or energy production for zero-carbon fuels is most favourable, etc.). Most policies are agreed through global mechanisms and thus are quite similar globally. Learning is a global process with significant capital investments from many countries. This global effort creates a rapid increase in economies of scale facilitating a relatively fast emergence phase. Most involved actors, both incumbent and emerging, have a global presence, and are developing their operations globally. However, due to agreement at the IMO, the emergence phase is principally concentrated in the international shipping industry segment, with a rapid take-up on international shipping routes from the beginning. Unlike Scenarios 1 and 2, the international shipping segment leads the way in terms of emergence and diffusion.

The diffusion phase begins almost simultaneously globally, with IMO agreed procedures in place to support SIDS and LDCs. Fuel production, distribution, and bunkering develop at the fastest pace in Scenario 3. The global nature of the transitions facilitates a rapid increase in demand and rapid high volume fuel production leading to the fast growth of an international distribution network and thus supporting investment in bunkering infrastructure. Scenario 3 is more likely if onshore sectors beyond shipping also undergo similar decarbonisation pathways where other sectors adopt a low carbon fuel, which is used by shipping as well. This way the shipping industry does not have to bear the whole cost of fuel pathways development. In addition, the scenario would likely lead to a global set of financing measures in place to support bunkering infrastructure development. The reconfiguration phase is also reached at the same time globally.

Figure 22: Heat map, scenario 3.

IMPORTANCE IN EACH PHASE OF TRANSITION:

- Low
- Medium
- High
- Very high

		Location			Actors			Learning			Fuel			Policies			
		Global	Liner routes	Domestic	National	International	IMO	RD&D	Pilots	Economies of scale	Production	Distribution (global)	Bunkering (global)	National	Bi-lateral	Multilateral	Global
Scenario 3	Emergence	Low	High	Very high	Very high	High	Low	High	High	Very high	High	High	Medium	Very high	Medium	Low	Low
	Diffusion	High	Very high	Very high	Very high	Very high	High	Very high	Very high	Very high	Very high	Very high	High	Very high	Medium	Medium	Medium
	Reconfiguration	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Medium	Medium	High

5. Levers for Change

There are a number of levers (policy, industry-led initiatives, etc.) that can contribute to the decarbonisation of shipping and, in particular, we will discuss the role of each lever, its uncertainties or shortcomings, and the possibility of harmonising multiple levers to achieve a zero-carbon transition.

Considering the three main phases of a transition, we can place levers into categories according to what they need to achieve for each of those three stages:

Phase 1: Enable emergence

Lever 1: Unambiguous signals of long-run intent
Lever 2: Activation of the innovation system (creating coalitions of stakeholders)
Lever 3: Incentives for first movement towards long-run solutions

Phase 2: Enable diffusion

Lever 4: Improved efficiency (reducing fuel use and the cost of the transition)
Lever 5: Unambiguous but more granular and timescale-specific signals of long-run intent
Lever 6: Strong incentives (CO2 prices, taxes/subsidies) and/or fuels mandate with coordination of land-side and seagoing assets

Phase 3: Enable reconfiguration

Lever 7: Mandate on scalable zero-emission fuel land-side and seagoing assets
Lever 8: Incentive to dispose of fossil fuel centric assets

Based on the logic of the scenario analysis and the assessment of fuel pathways undertaken, there is reason to believe that shipping's fuel transition can be achieved in all the scenarios outlined in Chapter 4.

However, to the extent that the scenarios are primarily about which actors take the lead in which phase, it is important to note that these leadership roles can interact with one another in hybrid scenarios. In particular, the national and plurilateral actions highlighted in Scenarios 1 and 2 are likely enablers of IMO-led action of the kind seen in Scenario 3. To the extent that national and plurilateral actions increase political confidence in the viability and maturity of solutions, and provide evidence that impacts on the industry are manageable, they lower the thresholds for action at the IMO.

There is, therefore, a strong likelihood that shipping's actual transition will look like a hybrid of these scenarios and combine the levers that they see employed. Effective choreography of these levers may increase the likelihood of delivering a 1.5-aligned pathway for the sector.

Levers Associated With a Strong First Mover Country

Scenario 1 considers a strong first mover country initiating a transition that spreads to other countries and eventually globally. A strong first mover country ideally requires a large domestic fleet and ambitious climate policies (e.g., NDC), which can help to justify significant domest decarbonisation action and the need for the country to be a strong first mover. Additionally, these countries will need to have the capacity to influence neighbours or “connected” countries, both indirectly through trade and economic linkages and directly through planned plurilateral action on, for example, “green corridors”. Chapter 3 above provides an in-depth quantification of some of the opportunities for countries to move their neighbours and trade partners towards decarbonised shipping.

Phase 1: Levers Enabling Emergence in Scenario 1

Phase 1: Keys to Emergence	Strong First Mover County	
	Feasibility	Impact
Unambiguous signals of long-run intent (incl equity dimensions)	High	Medium
Bringing together the innovation system	High	Medium
Incentivise first movement	High	Low

Lever 1: Unambiguous signals of long-run intent

It is relatively simple for a national government to create helpful signals of long-run intent, most simply regarding the decarbonisation of domestic shipping. But, having a significant impact on international shipping with these signals will be more challenging. A first mover country with economic and strategic influence might make it clear from the outset that it will apply measures to all shipping (domestic and international) passing its borders. It might also exert "soft" influence on its neighbours and trade partners, as seen in the LNG example in Chapter 4. The shipping measures in the EU Green Deal could be seen as an example of the former approach. The partnerships being struck by Japan and Germany on hydrogen-based fuels (relevant to many sectors, including shipping) could be seen as an example of the latter approach.

Lever 2: Activation of the innovation system (creating coalitions of stakeholders)

Strong first-mover action can be effective in bringing together innovation systems, which tend to have strong national cores and associations with industrial strategies. However, in most cases, this would be limited to a specific country's innovation system and may not then be effective in ensuring the development of the broad innovation system needed to achieve diffusion. Some impact may be achieved through a country's ability to influence national champions in a given sector that have a global reach. Yet, for truly global companies, this influence is likely to be limited.

Lever 3: Incentives for first movement towards long-run solutions

A strong first mover can deploy public spending and, usually, more quickly than supra-national, regional, or multilateral processes can. In a large economy where shipping decarbonisation supports other aspects of a country's decarbonisation or industrial strategy, the scale of this spending may still be able to incentivise a large amount of first movement.

Candidate countries for leadership, and the special case of the European Union

Japan: Japan has a strong track record for innovation and global market leadership in technology (including hydrogen) and industrial strategy. Japan has committed to reach zero emissions by 2050, it has a large domestic shipping fleet that requires rapid decarbonisation, and it has signalled that its energy system will need large volumes of imported hydrogen (likely to be transported by sea as ammonia) as a result. It already has targets in place and incentives to enable the development of this outcome in the near term (2030). Japan has large shipbuilding, equipment manufacturing, and ship owning expertise, and it has long been a leader at the IMO.

China: China has successfully become a leading global manufacturer for many of the key components of the future decarbonised economy, including renewable energy technology, batteries, and electric vehicles, and it is a leading shipbuilder. It is also a crucial global hub for shipping activity. Whilst its NDC is less ambitious than many other countries, it has been an early advocate and adopter of a “National Action Plan” for expressing its intent to drive shipping decarbonisation nationally.

US: The US has the industrial and economic capacity to lead a transition, significant domestic shipping activity (which is overdue modernisation), an ambitious NDC, and has recently been vocal on the global stage about the importance of shipping’s rapid decarbonisation.

Norway: Norway led shipping’s most recent transition to new fuels (LNG and then battery electrification) under the “strong first mover” model, and has a strong industrial base and track record for industrial strategy generally. There are already a number of relevant new projects based in Norway domestically, and Norway is leading global initiatives aiming to build action towards shipping’s decarbonisation (e.g., Green Voyage). Norway’s close cooperation (i.e., Nordic Council) with and proximity to other Nordic countries means that it has a unique position to facilitate the spread of any fuel transition if done in agreement to the rest of the region.

European Union: The scenarios explored above focus especially on the role of nation states in driving the early stages of the transition. Yet, the most ambitious actor to date has not been a traditional nation state, but rather the EU.

From the perspective of these scenarios, the EU has many of the characteristics of a nation state, and two that will be crucial to the transition. It has a large role in shipping globally and a significant share of shipping emissions. It has a large innovation infrastructure that is well financed both publicly and privately. It has a large and open market, and it has the ability to act on several key policy issues, either through directives, in the areas of energy and transport policy, or through direct regulation, in the area of climate.

In some respects, its ability to act is incomplete: Energy strategies and policies are still ultimately determined at the national level, shipping industries are still strongly tied to and steered by individual countries, and member countries plan and maintain their own infrastructure. Yet, in other ways the EU is a “super actor” in the context of the shipping transition: It has member states (and in the UK and Norway, deeply integrated neighbours and allies) who are already acting in their own self-interest on zero-emission fuels and shipping, while the EU itself has the regulatory power, scale of public investment, and influence on global markets to amplify these interests considerably, as long as they are in line with overall EU objectives.

The package of shipping policies enacted as part of the “Green Deal” is an indication that the EU sees itself as a leader in the transition. On the 14th July, 2021, the EU Commission released its latest proposal for the inclusion of shipping in the EU Emissions Trading System (ETS).[41]The ETS will now cover all emissions from intra-EU voyages and half of the emissions from extra-EU voyages, as well as emissions occurring at berth in an EU port. This system is to be linked to the EU monitoring, reporting, and verification system for administration with potential assistance from other EU maritime bodies (e.g., the European Maritime Safety Agency). A reporting and review clause is included to monitor not only the implementation of this, but to take account of any relevant policy developments from the IMO (ibid).

This is a significant lever for decarbonisation on a regional level with the potential for a global signalling effect.

41 European Commission. (2021). *Proposal for a directive of the European Parliament and of the Council amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union, Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757 2.*

Phase 2: Levers Enabling Diffusion in Scenario 1

Phase 2: Keys to Emergence	Strong First Mover Country	
	Feasibility	Impact
Improve efficiency and reduce volume of fuel needed	Low	Low
Granular signals of lung-run intent (incl equity dimensions)	Medium	Medium
Incentives for asset investment	High	Medium

Lever 4: Improved efficiency (reducing fuel use and the cost of the transition)

Regulation on the efficiency of international shipping has so far not been attempted through independent national action at any scale. Initiatives that can exist include the implementation of voluntary schemes that incentivise on the basis of port calls, which may be encouraged nationally. Since efficiency improvements are most easily realised through whole-system optimisations, the feasibility and impact of national action are limited.

Lever 5: Unambiguous but more granular and timescale-specific signals of long-run intent

A single country's detailed long-run intentions – signalled, for example, in a national strategy or roadmap for decarbonisation – would struggle to have a direct impact on international shipping. However, if a powerful or influential first mover is able to inspire or encourage similar signals from important neighbours and trading partners, confidence in the viability of technologies and pathways can be promoted globally. This may be simpler in plurilateral context like that emphasised in Scenario 2. Nonetheless, a coordinated group of countries led by a strong first mover has good potential to send important signals about global shipping.

Lever 6: Strong incentives (CO2 prices, taxes/subsidies) and/or fuels mandate with coordination of land-side and seagoing assets

A strong first mover country can apply incentives to land-side assets that are within its jurisdiction and not exposed to international competition (e.g., many ports). Such incentives can enable supply of new energy and technology but not necessarily determine its use internationally.

By including international shipping's inclusion in its Green Deal regulations, the European Union is pushing at this frontier, impacting all shipping that passes through a large and economically important region. It may be that this demand side regulation has major effects internationally, both directly and through signalling.

First mover countries can also create a positive and nurturing environment for new technologies by facilitating the creation of a strong public image around the need to decarbonise and increasing the visibility of decarbonisation through certification and public campaigns. Such developments can facilitate the creation of a niche consumer market which is willing to pay a premium for "green" shipping.

Here too, a group of coordinated countries could have a larger impact than a single actor – something that may be more feasibly arranged in Scenario 2, but not impossible with a single country taking leadership on establishing "green corridors" with integrated incentives for zero-emission shipping.

Levers Associated With Parallel National-Level and Plurilateral Spread

Scenario 2 features multiple countries initiating and driving the shipping transition in parallel, based on national interests, capabilities, and opportunities. Yet, because this scenario features multiple countries acting at the same time, the likelihood of and scope for plurilateral action through, for example, linkages in global value chains or the purposeful establishment of "green corridors", is greater. In assessing the levers for action available at different phases of the transition in this scenario, many of the dynamics relate to national interests and policymaking, and are similar to Scenario 1 (and not repeated here). However, the additional dimensions created by parallel action and the potential for powerful coalitions of the willing is an important distinguishing factor.

Phase 1: Levers Enabling Emergence in Scenario 2

Phase 1: Keys to Emergence	Independent national-level spread	
	Feasibility	Impact
Unambiguous signals of long-run intent (incl equity dimensions)	High	High
Bringing together the innovation system	High	High
Incentivise first movement	Medium	High

Lever 1: Unambiguous signals of long-run intent

As in Scenario 1, national governments have significant scope to send signals about the long-run transition. The main difference in this scenario is that many countries are sending the signals simultaneously, which is significant. While in Scenario 1, the impact of these signals on international shipping would be determined by direct trade and political relationships with a single country, in Scenario 2, such signals would benefit from network effects by being broadcast from many countries at the same time.

Lever 2: Activation of the innovation system (creating coalitions of stakeholders)

As in Scenario 1, national governments are well-positioned to activate innovation systems in the interest of zero-emission domestic shipping, as well as the production of zero-emission fuels tha may have multiple uses domestically and as exports. The main difference in Scenario 2 is that the parallel efforts in multiple countries are very likely to prove synergistic, either via connections in global value chains or through intentional efforts to build coalitions, co-funding innovations, and targeting first mover “green corridors”.

Lever 3: Incentives for first movement towards the long-run solutions

Here again, national governments have advantages in creating and deploying subsidies that impact the supply side of zero-emission shipping (and domestically, the demand side). Compared to the sending of political signals or the engagement of innovation actors, the extension of these incentives across national boundaries is more challenging. Very large actors such as the EU may be able to do so unilaterally, but the coordination of such economic instruments as taxes and subsidies between multiple nation states may prove more difficult, as countries seek to ensure that domestic industries receive more than taxpayers give. For this reason, “green corridor” strategies which target such incentives more narrowly on specific shipping lanes may be key points for this lever.

“Green Corridors” and Coalitions for Plurilateral Action

One way to leverage national interest in the transition to zero-emission shipping in a way that impacts international shipping is through the creation of so-called “green corridors”. As noted in Chapter 4, there is significant potential for early action along specific shipping routes, including internationally. In their forthcoming report on the topic, “Next Wave”, the Getting to Zero Coalition, Mission Possible Platform, and McKinsey & Company define a “green corridor” as “a shipping route between two major port hubs (including intermediary stopovers) on which the technological, economic and regulatory feasibility of the operation of zero-emission ships is catalysed through public and private actions”. For international routes, such actions would be plurilateral by definition and likely involve some alignment on policy between nations (and their ports). This arrangement has been likened to the creation of special economic zones (SEZs) for international shipping.

The Next Wave report considers factors that could make certain international routes good candidates for such pluriateral action. Aside from the operational and technical dimensions, the analysis considers economic feasibility, including the impact of higher cost fuels on the final cost of the traded goods, and the policy and stakeholder environment, including emerging political and industry initiatives to reduce emissions or promote the development of zero-emission fuels. A non-comprehensive review identified multiple international container ship routes, the trade in iron ore between Australia and Japan, and Ro-Ro shipping as being highly interesting candidates for collaboration on “green corridors”, reinforcing the notion that potential first mover countries might use such mechanisms to amplify their national interests in the shipping transition.

One interesting arena for such plurilateral action could be the Quadrilateral Security Dialogue, or Quad, a series of strategic talks between the United States, Japan, India, and Australia. While initiated as a security dialogue, in 2021, the participants established both a Climate Working Group and a Critical Emerging Technology Working Group. Given the relevance of the maritime and energy sectors to security, and the key placement of the participating countries in high-potential “green corridors”, this forum may play a role in advancing early action internationally.

In 2021, Mission Innovation, the multilateral initiative on clean energy innovation, launched the Zero-Emission Shipping Mission. The mission is led by Denmark, the United States, and Norway, along with the Global Maritime Forum and Maersk Mc-Kinney Moller Center for Zero Carbon Shipping (CZCS), with participation from the UK, India, Morocco, Singapore, Ghana, France, and South Korea. The mission seeks to create a coalition of high-ambition countries and private sector actors to “develop, demonstrate, and deploy zero-emission fuels, ships, and fuel infrastructure together by 2030 and make zero-emission ocean going shipping the natural choice for ship owners". One of the anticipated arenas for action for the mission is "green corridors", where new solutions can be piloted and demonstrated with support from multiple participating countries.

Figure 23: "Green corridor" prioritisation framework. Source: Next Wave (Forthcoming from Getting to Zero Coalition, Mission Possible Platform, and McKinsey & Co.).

Phase 2: Levers Enabling Diffusion in Scenario 2

Phase 2: Keys to Emergence	Independent national-level spread	
	Feasibility	Impact
Improve efficiency and reduce volume of fuel needed	Low	Low
Granular signals of lung-run intent (incl equity dimensions)	High	High
Incentives for asset investment and coordination	Medium	High

Lever 4: Improved efficiency (reducing fuel use and the cost of the transition)

As with Lever 3, the feasibility and impact of levers employed to promote efficiency and save fuel will be tied to the implementation of mutually agreed regimes targeting specific routes, as in “green corridors”. However, the shift to alternate fuels may be more replicable, from a single route or corridor to a broader system, than efficiency strategies, which rely to a significant extent on the optimisation of journeys and traffic patterns.

Lever 5: Unambiguous but more granular and timescale-specific signals of long-run intent

As with Lever 1, the feasibility of individual countries sending granular signals about the long-term transition through, for example, roadmaps and strategies, is high, and the potential impact is increased in Scenario 2 as multiple countries acting in parallel have the possibility and, probably, incentive to coordinate efforts.

Lever 6: Strong incentives (CO2 prices, taxes/subsidies) and/or fuels mandate with coordination of land-side and seagoing assets

Here again the scope for independent national action is, on face value, significant, as national governments control the primary regulatory and fiscal levers. However, the incentives for diffusion involve large impacts on national budgets, which may make coordination between governments challenging, especially if independent national action is partially competitive. If governments do manage to coordinate on such measures, however, the impact can be large. Indeed, in a scenario where the major shipping powers act in coordination, the result can create a de facto global carbon price.

Levers Associated With Global Action

Global action, such as IMO regulation, has the advantage that it can be applied to all of international shipping at the same time, so the fuel consumption and emissions impacted by these levers is generally greater. Global levers would encompass regulations drafted and adopted within the IMO. Today, such levers are classified as short-term levers, or mid- to long-term levers. The Initial GHG Strategy, adopted by the IMO in 2018, includes a list of candidate short-, mid- and long-term policy measures (i.e., measures that could be finalised and agreed between 2018 and 2023, between 2023 and 2030, and beyond 2030, respectively.[42] So far (in 2021), the IMO has adopted a package of short-term measures, and is starting the discussion about mid-term measures.

A Global Price on Shipping Emissions

Chapter 2 suggests that we can expect a significant competitiveness gap between incumbent fossil fuels and zero-emission alternatives, such as ammonia and methanol. The price difference between fuels is, at the very least, double from the 2030s to 2050s across different fuels with the largest price gap projected at around ten times the price of fossil fuels.[43]

Global regulation could be applied to close this gap. For example, IMO could regulate a mandate to move from one fuel to another (as has been done for controlling sulphur emissions, by mandating the maximum suplhur content of marine fuels)[44]. However, given the scale and differences in energy/fuel production pathways, fleet specifications, and the extent of system reconfiguration needed, there are good reasons to consider policy mechanisms that would allow more flexibility for the industry. These could include carbon taxes/levies, emissions trading systems, feebates, contracts for difference, subsidies, etc. Each of these have different features, however, they all seek to make GHG emissions reductions economically valuable, and thus reshape market behaviour.

42 IMO. (2018a). *Resolution MEPC.302(72), Initial IMO Strategy on Reduction of GHG Emissions from Ships.*
43 LR and UMAS. (2019). *Zero-emission vessels: Transition Pathways.*
44 IMO. (2018b). *Sulphur oxides SOx and Particulate Matter PM – Regulation 14, Our Work.* http://www.imo.org/en/ourwork/environment/pollutionprevention/airpollution/p./sulphur-oxides-sox-%E2%80%93-regulation-14.aspx

There are now many studies on the magnitude of carbon price needed to decarbonise shipping. According to Baresic et al., a policy that seeks to directly close the competitiveness gap between fossil and zero-emission fuels should create a target-consistent average price of:

- US$173/tonne CO2 for 50% decarbonisation by 2050
- US$191/tonne CO2 for full decarbonisation by 2050

Both price scenarios assume that carbon pricing would begin in the 2020s and rise significantly over the 2030s and 2040s.

A key advantage of adopting an economic measure, depending on the design and price level,[45] is the potential to generate revenue. One use of this revenue would be as a subsidy for early adoption in the transition. This can then also lower the carbon price needed to achieve decarbonisation. For example, if 100% of the revenue generated by a carbon pricing mechanism was reinvested into the shipping industry (through subsidising R&D and infrastructure), the carbon price required to close the competitiveness gap could, theoretically, be cut in half.

Another potential use of revenue is to assist in addressing negative impacts associated with the implementation of the measure. This may include reducing the risk of transport cost increases or, more generally, deploying revenues to assist with mitigation and adaptation or direct compensation. This analysis strictly looked at closing the competitiveness gap, and did not assess whether the funding needed an equitable transition, for example, addressing disproportionate negative impacts on certain countries and ensuring that all countries can participate in the transition, regardless of resources, can also be met. Revenues from carbon pricing could be reallocated for this purpose, but no quantification of this need was included in these price assessments.

In addition to price setting considerations, for any economic instrument that generates revenue, there are also considerations around monitoring, administration, collection, and apportionment of revenues generated. However, if revenue recycling is used effectively, there is potential to cover the majority of the projected investment needed for shipping, whether this is the $1-1.4 trillion to decarbonise 50% by 2050 or the $1.4-1.9 trillion needed for full decarbonisation by 2050.[46]

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45 Baresic, D., Rojon, I., Shaw, A., Rehmatulla, N., Smith, T. (2021). *Closing the Gap: An exploration of the policy options for a zero-carbon fuel transition in shipping.* UMAS.
46 Raucci, C., Bonello, J.M., Suarez de la Fuente, S., Smith, T., Søgaard, K. (2020). *Aggregate investment for the decarbonisation of the shipping industry.* UMAS.

In terms of long-term measures, one option would be to adopt market-based measures that place an economic value on emissions reductions (see text box for an in-depth look at market-based measures). An alternative might be a command-and-control measure mandating the reduction and cessation of fossil fuel use in the industry. From the fuel transition perspective, such a ban would have a high degree of impact during the diffusion phase of the zero-carbon fuel transition. While such a ban presents a policy that might be considered less flexible and more disruptive than market-based policy, there is evidence of these bans working on a smaller scale. In the UK, for example, there is a ban on the sale of new petrol and diesel cars and vans from 2030 and the sale of new petrol and diesel trucks from 2040.[47]

IMO policy is normally applied to a ship, but this does not limit what can be incentivised. IMO's fuel sulphur regulation requires the use by shipping of fuels with a specific maximum sulphur content. The specification of fuel is recorded on the Bunker Delivery Note (BDN), which is a document exchanged between the bunker fuel supplier and the operator of a vessel. By requiring a certain fuel specification before a fuel can be eligible for purchase in the industry, this regulation has indirectly regulated the landside assets that supply shipping fuel. For IMO policy to achieve a decarbonisation of fuel supply alongside a decarbonisation of shipping's emissions, it will need to achieve a similar level of regulation on the upstream (e.g., well-to-tank) emissions of a fuel. Whilst, technically, this is harder than the regulation of a fuel's sulphur content, as it requires new verification/certification of production processes, life cycle accountancy processes are already in place in other sectors (e.g., in aviation via ICAO).

Phase 1: Levers Enabling Emergence in Scenario 3

Phase 1: Keys to Emergence	Global actions	
	Feasibility	Impact
Unambiguous signals of long-run intent (incl equity dimensions)	Medium	High
Bringing together the innovation system	Low	Low
Incentivise first movement	Low	Low

47 Dunne, D., (2021). *Britain to ban sale of all new petrol and diesel trucks by 2040*, The Independent. https://www.independent.co.uk/climate-change/news/uk-ban-petrol-diesel-trucks-vehicles-b1883538.html

Lever 1: Unambiguous signals of long-run intent

An IMO-led process has already delivered a signal of long-run intent in the initial strategy. However, this signal is also ambiguous. It states both the intention to be aligned to the Paris Agreement temperature goals and an absolute GHG reduction target. When the GHG reduction target is taken as a minimum ambition (e.g., a 50% reduction in absolute GHG), it is not aligned to the Paris Agreement temperature goals. Even with this ambiguity, the IMO's initial strategy created a step change in action globally and has already triggered the earliest stages of the transition. Through the IMO's revision of the initial strategy, there is scope to reduce the ambiguity.

Lever 2: Activation of the innovation system (creating coalitions of stakeholders)

The IMO does have initiatives that might bring the innovation system together (GloMEEP, Global Industry Alliance). However, as a regulator, these are not natural actions. When the policy debate is sensitive (which is often the case for GHG), it can be hard for these IMO-hosted convenings to have the frank and transparent mission and dialogue needed to be effective at bringing the innovation system together. Thus, even in the event of robust IMO action on decarbonisation, additional measures from industry and government (i.e., plurilateral action) could be needed to support the formation and development of the innovation system.

Lever 3: Incentives for first movement towards the long-run solutions

The IMO does not have a strong track record for incentivising first movement towards long-run solutions. A limited example of this is the IMO's implementation of Emission Control Areas (ECAs) which apply greater stringency on air pollution control in certain geographies and in which solutions were first trialled for SOx and NOx abatement, which then became more globally used (including following subsequent more global regulation).

A counter example of this is the regulation on ballast water treatment, which has taken a long time to enter into force partly due to concerns over a lack of availability/maturity of technology. This experience has reinforced views in some member states that the IMO is not suited to "technology forcing" regulation (e.g., regulation that is used to force the development and maturity of a new technology).

Phase 2: Levers Enabling Diffusion in Scenario 2

Phase 2: Keys to Emergence	Global actions	
	Feasibility	Impact
Improve efficiency and reduce volume of fuel needed	High	High
Granular signals of lung-run intent (incl equity dimensions)	Medium	High
Incentives for asset investment and coordination	Medium	High

Lever 4: Improved efficiency (reducing fuel use and the cost of the transition)

The IMO has already implemented regulation to improve efficiency, both for newbuild ships (EEDI) and, more recently, the existing fleet (EEXI/CII). These regulations are not yet at a level of stringency/effectiveness that can maximise the efficiency of the global fleet, but they have the potential to be strengthened to improve both of these aspects.

Lever 5: Unambiguous but more granular and timescale-specific signals of long-run intent

The IMO has the potential to produce more granular and timescale-specific signals of long-run intent. These may be part of the revision of the IMO's strategy. However, the achievement of this step may also be hindered for the same reasons as the IMO achieving strong incentives/mandate on landside and seagoing assets (see below).

Lever 6: Strong incentives (CO2 prices, taxes/subsidies) and/or fuels mandate with coordination of land-side and seagoing assets

The IMO's greatest potential contribution to the transition is its ability to apply strong incentives/mandates to the global shipping system. However, in practice, there are many obstacles to achieving this and prerequisites that must normally be satisfied before strong incentives/mandates are adopted as policy.

The issue with the two long-term levers discussed above (economic instruments, such as a carbon levy, and command-and-control regulation) is whether they can be adopted and implemented plausibly with the speed and stringency necessary. While there is generally a global willingness to decarbonise in the face of climate change, this does not necessarily translate into action from within the IMO for a variety of reasons, including practical and conceptual issues, and conflicts of interest.

From a practical standpoint, regulation within the IMO is slow. It can take a number of meetings over years to achieve consensus around key regulation. Multiple proposals, commentary, and information papers submitted must be considered and/or discussed in detail. Taking an economic instrument as an example, a general consensus would be needed to select an economic instrument and its main characteristics before it could reach a drafting stage, where again, general agreement among member states would involve a drafting group writing and scrutinizing the text before passing it to the main committee for adoption. At each stage, the stringency of any regulation is likely to be watered down, as the natural process of consensus in the IMO involves the enrolment of support from its member states. If member states do not agree with a regulation, they simply do not have to sign on to enforce it.

Included in the IMO Initial GHG Strategy is an additional requirement for socio-economic impact assessments on states, as well as the assessment of disproportionally negative impacts and suggestions of how these may be addressed.[48] Again, this adds barriers, time, and levels of complexity to the process of creating and adopting a global lever.

For any policy adopted under the IMO Initial Strategy on GHG reduction, there is a need to be cognisant of the principle of common but differentiated responsibilities and respective capabilities (CBDRRC), in light of different national circumstances. CBDRRC is enshrined in the UNFCCC and the Paris Agreement and combines the concept of a common responsibility of all countries to fight climate change with an acknowledgement of countries' different levels of responsibility for climate change and capacity to address it. The language in the strategy was a hard-fought-for political compromise that, unfortunately ,does not specify how the principle should be interpreted or operationalised.[49] This is one of the factors that adds significant complexity to the process of developing global regulation in the IMO. But its inclusion shows the high importance accorded to fairness and equity in the Initial GHG Strategy. Whether IMO manages to adopt sufficiently ambitious GHG reduction measures to decarbonise shipping on a Paris-aligned trajectory will to a large extent depend on policymakers' abilities to operationalise these considerations and enable an equitable transition without compromising the measures' environmental effectiveness.

Another complication of the IMO process is the conflicts of interest at play. These take multiple forms and are likely to threaten the efficiency and effectiveness of the regulatory process. Firstly, there are conflicts of interest between member states. Not only do some member states hold more strongly to different principles, outlined above, but, within their own agendas, they may experience conflicting interests. This is exemplified by some of the SIDS and LDCs. There is often a national willingness to take part in the climate effort, which is displayed in other international fora as well as national plans and commitments. However, within the IMO these countries frequently need to balance this will for change with transport costs, which regulations potentially may increase. Some member states derive a significant part of their GDP from trade/exports, while others are dependent on imports to meet basic food, water, or energy needs, motivating a resistance to wholesale change through the IMO.

48 Faber, J., et al, (2020).
49 Rojon, I. (2020). *Decarbonising shipping: Shining a light on the sector's technical and political challenges.* Carbon Mechanism Review, 2, pp. 30-35.

What the Adoption of Short-Term Measures Can Teach Us About the Future of Mid-Term Measures

In June 2021, MEPC 76 adopted regulations which will apply technical efficiency standards to existing ships (Energy Efficiency Existing Ship Index, EEXI).[50] Ships will also need to achieve a specified annual operational Carbon Intensity Indicator (CII). Short-term levers, at best, should either require the reduction of GHG emissions through targets or standards or promote energy efficiency, which in turn reduces emissions. Furthermore, the impact of the regulations should be clear, measurable, and incentivise investment in energy efficiency.

These policies (EEXI and CII) are not considered to be as powerful as they might have been. Conceptually, EEXI is limited, in the same way as EEDI, to being a crude way to regulate shipping, given it is based on the theoretical technical performance of a ship, as assesssed by a simplified metric measured in idealised conditions. Both EEDI and EEXI have significant shortcomings for incentivising a fuel transition because they only evaluate a ship's carbon intensity at a discrete point in time. Operational decisions about the specification of fuel used, especially when many of the technical pathways involve dual or multi-fuel machinery, cannot be monitored and, therefore, cannot be incentivised.

CII is potentially powerful because it regulates operational emissions and includes the actions of all stakeholders who influence a ship's GHG emissions. For example, unlike EEXI, it incentivises all measures to reduce operational emissions; a charterer's responsibility in operational choices (like speed) is included alongside a shipowner/financier's choices around technical specification. And, because it uses annually reported data on fuel used, the policy can incentivise an evolving choice of lower GHG impact fuels over time (if combined with LCA).

However, the CII policy specification, as adopted in MEPC 76 ,has only weak stringency (and, for now, only defined to 2026), and ship owners/operators who do not manage to achieve the targeted reductions in operational carbon intensity face only weak consequences (only after multiple years of not achieving the target does any penalty appear, and the penalty only constitutes the need to produce an action plan). Both policies will be reviewed by 2026, including for stringency and enforcement mechanisms.

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50 IMO. (2021a). *Further shipping GHG emission reduction measures adopted.* https://www.imo.org/en/MediaCentre/PressBriefings/pages/MEPC76.aspx

The explanation for this outcome is a salient lesson for the viability of the IMO to adopt 1.5-aligned mid-term policies (including carbon pricing). While many states were strongly calling for a target to be set in the CII-related policy that aligned to 1.5 CO2 pathways, the MEPC 76 debate was only able to agree targets that reach a much lower rate of carbon intensity reduction than this requires and only specified the carbon intensity pathway to 2026, rather than providing the degree of clarity of future intent needed at this time.

Three explanations with implications for the development of mid-term measures are:

- Potential for negative and disproportionately negative impacts on states – these were discussed at length in the short-term measures debate. Many countries felt that the impacts from the short-term measures could be material and would need to be addressed through an additional measure or justified modifying the proposed measure, for example, through exempting compliance on certain routes and ship types. Ultimately, the debate did not agree to a classification of disproportionately negative impacts (this was left ambiguous, given the absence of a definition of "disproportionately" in this context) and, by association, also no additional measure's development was initiated. Mid-term measures and the transition away from fossil fuels has the potential to trigger a much greater increase in transport costs and other negative impacts, and so it will face the same tension on how this will be addressed as well as how the wider request by many that the sector experiences an equitable transition is addressed.

- Technology uncertainty – the short-term measures were expected to primarily incentivise the implementation of existing technologies and operational improvements, particularly those associated with improving the energy efficienciency of the existing fleet. Whilst these are mature, the magnitude of the efficiency improvement that can be achieved with these improvements over the global fleet is uncertain. That uncertainty adds risk to the regulatory process and incentivises conservatism in stringency – to mitigate the risk that there are unintended consequences and impacts arising from the policy. A slight difference to the mid-term measures debate is that, for now at least, the technologies that will be incentivised by mid-term measures (SZEF) are not mature, nor are there established supply chains and distribution, likely raising further uncertainty and incentivising even greater conservatism in the way mid-term measures are specified and adopted at IMO.

- Regulatory instrument experience – the short-term measure's CII is the first policy application of data from IMO's Data Collection System, and the first time that existing fleet operational efficiency/carbon intensity has been directly regulated. Many states and NGOs pointed to the many stakeholders and factors related to operational efficiency "outside of the control" of the shipowners (or those tasked with compliance with the regulation). This introduces an element of the unknown to the regulatory process and another risk that there may be unforeseen and unintended negative consequences from the policy's implementation.

> The mechanisms that might be used for mid-term measures – especially economic instruments and market-based measures which are new to the IMO – are also new policy instruments. Whilst there are many examples of such measures already in use elsewhere globally, there is likely still to be an incentive for conservatism in the stringency applied to these arising from the novelty of their application at the IMO.

The mid-term measures debate at the IMO could benefit from seeing these three items as prerequisites that will need to be met before any policy of 1.5-aligned stringency could be implemented.

The Promise and Limits of Private Standards and Stakeholder Collaboration as Levers in a Transition

The concept of levers that create change most often refers to regulation and policy (i.e., governance approaches). This could be undertaken by national governments, regional structures (e.g., EU), or by international organisations (e.g., IMO). However, private sector initiatives can play an important role in the different phases of the transition, and in all three scenarios.

Although private initiatives do not require regulation, the way in which they are developed can be significantly influenced by regulation. At the point of publication of Scott et al[51] examined 10 different initiatives, created before the adoption of the IMO GHG Strategy, focused on the development of common standards, including:

- monitoring, reporting and verification (MRV) systems
- environmental management systems
- ship rating schemes, and
- ship finance standards

In the absence of specific regulation, these standards were assessed as having the potential to reduce GHG emissions from shipping by acting to reduce or remove the market barriers hindering market-driven emission reductions. They did this by:

- increasing the availability of information and promoting information disclosure;
- improving companies' internal procedures for measuring and mitigating GHG emissions; and
- increasing the opportunities for capital investments by mitigating the split incentive problem.

51 Scott, J., Smith, T., Rehmatulla, N., Milligan, B. (2017). *The Promise and Limits of Private Standards in Reducing Greenhouse Gas Emissions from Shipping.* Journal of Environmental Law. Volume 29, Issue 2, July 2017, Pages 231–262. https://doi.org/10.1093/jel/eqw033

Scott et al. concluded that the initiatives in existence at the time were variously affected by limited transparency, low levels of ambition, and low reliability of data. The collective impacts of these initiatives were, therefore, viewed as limited. However, the focus of these private standards in 2017 was on increasing energy efficiency and linked to the commercial motivation to reduce the fuel costs and realise financial savings. They did not address the absolute reduction in emissions, and none was focused on the transition of shipping away from fossil fuel use.

This situation is now changing, and there are more ambitious standards in place. In addition to having clearer levels of ambition, these new standards also improve transparency. Some of the standards utilise data generated for IMO's Data Collection System (IMODCS) in combination with advances in satellite-data-derived estimates of emissions, which is also improving data reliability and quality. Table 13 lists some of the more recent private standard initiatives, alongside some of the longer-running initiatives.

Table 13: Examples of long-running and more recent private standard-setting initiatives.

Name	Date Established	Overview
Cargo Owners Zero Emission Vessel Initiative	August 2020	Under this initiative, shippers/buyers make commitments to provide a specific volume of freight to the first zero-ready ocean-going vessel(s) and set targets for exclusively buying zero-emission maritime freight by a future year.[52] It also urges carriers to sign up to scope 3 GHG reduction benchmarks through the Science Based Targets initiative.[53]
Sea Cargo Charter	October 2020	The Sea Cargo Charter provides a global framework for aligning chartering activities with responsible environmental behaviour to promote international shipping's decarbonisation.[54] This initiative is aimed at charterers.
Poseidon Principles	June 2019	The Poseidon Principles provide a framework for integrating climate considerations into lending decisions to promote international shipping's decarbonisation.[55] This initiative is aimed at financiers.
Environmental Ship Index	2011	The Environmental Ship Index identifies seagoing ships that perform better in reducing air emissions than required by the current emission standards of the IMO.[56]
Clean Cargo Working Group	2004	The Clean Cargo Working Group is focused on improving environmental performance in marine container transport using standardised tools for measurement, evaluation, and reporting.[57]

52 Cargo Owners Zero Emission Vessel Initiative. https://www.aspeninstitute.org/blog-posts/corporate-buying-power-can-be-harnessed-to-decarbonize-shipping/
53 Scope 3 emissions are all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions.
54 Sea Cargo Charter. https://www.seacargocharter.org/
55 Poseidon Principles. https://www.poseidonprinciples.org/#home
56 Environmental Ship Index. https://www.environmentalshipindex.org/
57 Cleaner Cargo Working Group. http://www.globalgreenfreight.org/green-freight/clean-cargo-working#:~:text=The%20Clean%20Cargo%20Working%20Group,Responsibility)%20and%20founding%20industry%20members.

Aside from standard-setting initiatives, voluntary industry action can also take other forms. The transition away from fossil fuels requires broad collaboration across actors. The production and distribution of new fuels engages at least energy producers, ports, transport/distribution networks, and financiers, and this needs to be matched to actions taken to ensure a demand for that fuel from compatible fleet by owners, class societies, and equipment manufacturers, charterers, financiers. In particular, the emergence phase of the transition demands that multiple companies work closely with each other, often in pre-competitive collaboration.

These collaborations can be formal and established under the umbrella of a single entity (e.g., the Maersk Mc-Kinney Moller Center for Zero Cabon Shipping, the Global Centre for Maritime Decarbonisation), or they can be more informally derived from convenings which provide the opportunity for like-minded companies to form mutually beneficial connections and relationships (e.g., the Getting to Zero Coalition, Sustainable Shipping Initiative). These broad fora can lead eventually to the formation of narrower consortia that may focus on challenges related to technology piloting or demonstration, or the development of shared safety routines.

Levers Enabling Emergence Through Private Industry Initiatives

In terms of levers for change, private sector initiatives are likely to have their biggest impact on the emergence phase and its three main levers.

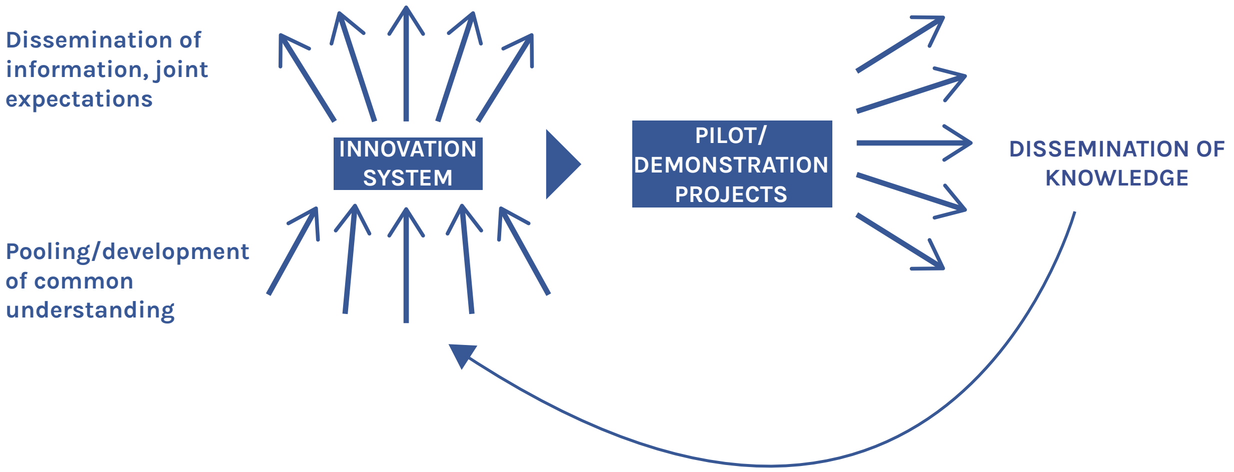
Lever 1: Unambiguous signals of long-run intent

New standards provide intra-industry signalling of long-run intent to decarbonise and a trajectory of the intended rate of GHG reduction for the next three decades. While the individual trajectories vary, with some aligned to a conservative interpretation of the IMO's Initial Strategy and others unambiguously aligned to a 1.5 degree pathway, all of the standards require absolute GHG reductions that can only be achieved by a shift away from the use of fossil fuels from the late 2020s onwards.

To a certain extent, and especially for those standards that are particularly linked to the IMO's level of ambition (e.g., 50% reduction in 2008 absolute GHG emissions by 2050), these standards are the industry's codification of the intent already expressed by the IMO in its strategy. As a result, they also express confidence that the IMO and others will deliver policy that will support the transition in a timely fashion, and they expect that for those stakeholders (clients, etc.) covered by the commitments, they will at least be in compliance with that future policy. These standards, therefore, are an important mechanism to achieve acceptance of, and progress on, the decarbonisation transition from key industry members/actors.

Lever 2: Activation of the innovation system (creating coalitions of stakeholders)

Figure 24: Illustration of innovation system required for shipping's transition.



The innovation system is created by the dissemination of information and the pooling and development of a common understanding of the decarbonisation challenge (and its potential solutions). In addition, it involves the formulation of specific pilot and demonstration projects that then lead to the development and dissemination of relevant new knowledge. There exists an opportunity to connect these phases of activity with identifying gaps in knowledge that are then solved by pilot and demonstration projects and then improve the common understanding. This improved common understanding supports the creation of joint expectations around the new technology among multiple actors, which leads to a maturing network of connections and an expanding knowledge base.

Evidence that the innovation system required for shipping's transition is already forming can be seen from the "mapping of zero emission" pilots and demonstration projects carried out by the Getting to Zero Coalition. This mapping is part of a focus on first movers in the shipping industry, and it charts the scale and diversity of zero emission pilot projects in a global context.[58] There have been two editions thus far. In the 2020 edition, the study identified 66 relevant projects around the world and, by the second edition, only one year later in 2021, this rose to 106.[59] This indicates the growth in innovation and first mover activity.[60]

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58 Getting to Zero Coalition. (2021). *Mapping of Zero Emission Pilots and Demonstration Projects.* https://www.globalmaritimeforum.org/content/2021/03/Mapping-of-Zero-Emission-Pilots-and-Demonstration-Projects-Second-edition.pdf
59 Ibid.
60 This represents a 60% increase over the course of a year, although this is based on the assumption that all additional projects in the second report are new developments, rather than having been in existence in 2020 but not identified as part of the first round of mapping work.

Private sector action to bring together the innovation system often works alongside government action, and it can help to understand these two levers in combination. Government action includes providing public funding that can incentivise collaboration by de-risking some of the effort put into pre-competitive collaboration (where the business return is still not clear and, therefore, harder to make an internal case for investment). But, government action is also limited in the extent to which it can influence the direction of the innovation system's evolution, especially given rules around state-aid, the knowledge gaps that can exist in government for understanding the problem an innovation system has to solve, and the general preference in governments to be technology neutral. The success of any government support will depend on many factors, including the relationship between the public and private sectors in the respective country and the influence government has on the private sector.

Lever 3: Incentives for first movement towards long-run solutions

These new standards and collaborations can even be effective in increasing the availability of capital, lowering the cost of that capital, and closing the gap between operation on incumbent fossil fuels and alternative future fuels. Below, we explore two such mechanisms for this lever.

1. **Identification of market opportunities.** First movers can gain new clients and markets through the new products/services offered and the positive brand associations generated through their actions or credentials. These opportunities can be realised by both incumbent companies, which reorient to the novel technology and new entrants. This is proving to be especially important downstream in the shipping value chain, where cargo owners can potentially create brand value and competitive advantages based on products with a smaller carbon footprint (including from shipping). The coZEV and Clean Cargo Working Group initiatives, in part, reflect this potential.

2. **Managing shared exposures to long-run risks.** This is a component of several of the finance initiatives (CBI, PP, NZAOA) and relates to the downside risk that assets dependent on fossil fuels are exposed to through the transition: The risk that they can become less competitive or even stranded as low/zero carbon alternatives appear and regulation strengthens against GHG emissions.[61]

61 Assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities.

6. Implications for the Transition and Synthesis of Actions Needed

This analysis shows that countries (unilateral), groups of countries (plurilateral), and organisations (e.g., IMO, multilateral) could all stimulate parts of both the emergence and diffusion phases of shipping's decarbonisation transition. Private standards and convening initiatives can have a strengthening and, in many cases, critical enabling role across all three scenarios of transition.

However, the analysis also shows the shortcomings of the dominant modes of action in each of the different transition scenarios. In Table 5, we propose a set of actions which draws from all three scenarios in order to best enable a successful transition.

The IMO, an Advantage and a Curse

Shipping's advantage over many of the sectors anticipating a turbulent transition away from fossil fuel use is the presence of a global regulator that can set a uniform policy globally. This "one stop shop" has the potential to be hugely powerful, effective, and efficient at driving the transition, and, when set up through comparative language against alternatives (unilateral and plurilateral), can be easily argued to be the only rational way forwards for managing shipping's decarbonisation. However, this is also an organisation which has very limited track record of implementing policies of the kind that can stimulate the emergence phase of a transition. Progress on efficiency/short-term measures shows that achieving consensus at the IMO, or even a majority position, is currently not feasible on the evidence of the need alone.

Even though the political pressure to act on climate change might be a greater imperative than anything the IMO and its member states have experienced before, the barriers to achieving consensus on stringent policy are also more fundamental. And, the IMO policy measure debate to date provides evidence of the substantial prerequisite of broad and balanced support that needs to be in place if a multilateral agreement is likely to succeed.

The downside of the potential advantage of driving a transition exclusively through the IMO is that it becomes hard for stakeholders to see the merit in alternatives. This is the curse of this potential advantage.

The Critical Role of Private Standards and Convening – For All Scenarios of Transition

The scenarios identified have focused on a jurisdictional (e.g., national/plurilateral/multilateral) driving of transition. This is primarily because of the large additional costs that can be expected if no policy action is taken. However, it is also clear that private sector initiatives such as standard setting, convening, and the development of project consortia are a valuable catalyst for public sector action. Many tools exist to support this (e.g., data transparency, which can be enabled through digitalisation), as well as platforms that encourage open innovation, public/private risk, and opportunity. Much of this is already in process, but can yet be independently evaluated, added to, and reinforced.

The Strong Potential for a Transition Reinforced by a Mix of National, Plurilateral and Multilateral Actions

This analysis indicates that shipping's transition is most effectively enabled not only by the use of all the levers described in this section, but by the potential for a given set of actions by a given set of actors (e.g., industry or national governments) to improve the likelihood of successful action by others (e.g., IMO).

Emergence

Chapter 3 shows that there is more than adequate potential to achieve critical emergence volumes of zero-emission fuel use in a small number of countries, especially if they combine their efforts to create frameworks that incentivise first movement not only in domestic shipping, but in international shipping operating bilaterally between them. There are a number of candidate countries with strong leadership credentials and track records, alongside the potential to drive coalitions and collaborations. Private standards and convening have a critical role to play if emergence is driven through unilateral and plurilateral networks, de-risking the actions of individual companies and motivating efficient public spending support. The IMO also possesses some instruments that could support emergence (particularly a levy that redeploys revenue to support deployment).

Diffusion

The structures that could drive emergence are not necessarily the same as those that can drive diffusion. This is a step for which global coverage (e.g., IMO regulation) is more important, but it is also a step for which IMO has a better track record as an enabler, as long as sufficient penetration of new technology and infrastructure has occurred through emergence. Private standards and convening can continue to play an important role beyond emergence and in enabling efficient diffusion, especially through converting expectations for one actor (e.g., the ship owner/operator) across multiple actors that all need to align.

Reconfiguration

Though not analysed in depth here, the most obvious levers for achieving reconfiguration come from the IMO, given its global coverage, at least, of international shipping. However, this does not, in itself, define Scenario 3 as the preferred scenario, given that the steps in Scenario 1 and 2 can enable implementation of policy at the IMO.

The Need for a New Strategy That Embraces All Drivers of Decarbonisation

The landscape to enable such a neatly choreographed vision is challenging. Policy dialogues are often polarised within each forum (e.g., around preferences for different approaches and policy instruments), and between for a, as seen in the tension between action taken by the EU (MRV, EU ETS) and the IMO. Language from the respective organisations to justify their actions suggests that this is a battle about who is in control and who has responsibility. This dynamic, that sees these different levers as competitive rather than synergistic, is not limited to governments and policymakers, but it is also clear in the language of industry leaders and organisations. However, industry leaders' role in advocating one approach or another is complicated if it overlaps with self-interest, such as the establishment of lenient regulations. For example, opposition to national/plurilateral-led transitions may be perceived as rational support for the "efficient" global regulator, or as simply an attempt to slow down the process, given the challenges of working through the IMO.

A Need to Adopt Strategies That Are Resilient to Different Timescales and Mixtures of National, Plurilateral and Multilateral Transitions

All three scenarios might result in similar end results but demand different types of strategies from companies as they optimise their journeys through transition. Rather than presume any one scenario at this point in time, it is, therefore, an advantage to have a corporate strategy that might express a preference for a scenario, while retaining enough resilience to be able to adapt to the mix of actions and emergence/diffusion drivers that actually occurs.

Synthesis of Actions That Can Increase the Synergies Between Transition Levers and Clarify and Accelerate the Transition

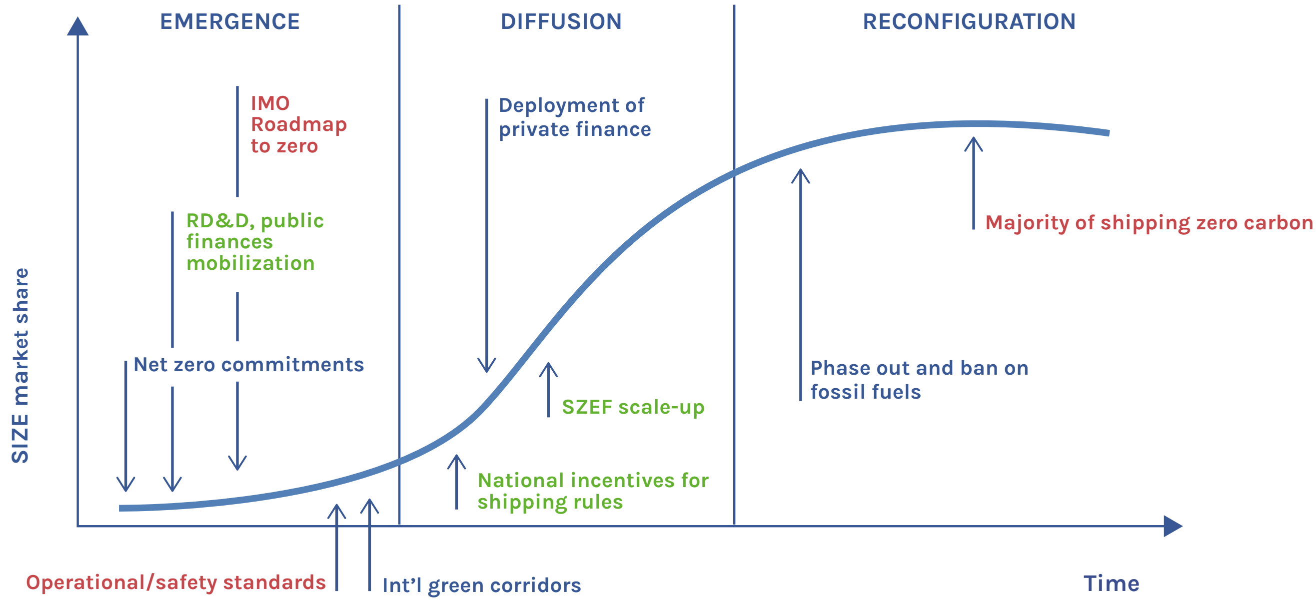
Drawing on the analysis throughout the preceding sections, and recognising the conclusion that all three scenarios considered have strengths and weaknesses, Table 5 proposes decomposed actions taken, both across different stakeholder groups, different time scales, and different levels/lever groups (e.g., national, plurilateral, and multinational) actors. This table combines the findings from this analysis with the action table produced by the High-Level Climate Champions as part of the Race to Zero in 2020.

Table 5: Table of actions needed to achieve 1.5°C-aligned and equitable decarbonisation of shipping (black – industry, green – national and plurilateral, red - multilateral).

	Key actions needed to decarbonise shipping	By 2022	By 2025	By 2030	By 2035	By 2040
Policy	Multiple nations make domestic and plurilateral commitments to decarbonise shipping	[green]				
	Multiple G20 governments commit to funding for RD&D and pilot projects related to zero-emission shipping	[green]				
	Leading countries publish 1.5°C aligned decarbonisation plans for domestic shipping, with aim to fully decarbonise by end of 2030s	[green]	[green]			
	Leading countries set production targets for zero-emissions fuels (intermodal usage)		[green]	[green]		
	International agreements on zero-emission shipping route creation (at least 3 global and 3 regional routes)	[green]	[green]			
	Most national governments completely phase out fossil bunkers in domestic shipping				[green]	[green]
	Intensified effort at IMO to agree long-term measures for shipping (e.g. market-based measures and non-market-based measures)	[red]				
	IMO Clarify feasibility of retrofitting existing fleet	[red]	[red]			
	IMO require new ships to be zero-emission ready, e.g. “GHG Reduction Plan with zero emission propulsion capability”		[red]	[red]		
	IMO adopt measures in EEDI, efficiency, other GH gasses & a roadmap to zero	[red]	[red]			
	IMO adopt guidelines to estimate well-to-tank GHG emissions and regulation/ incentives for zero-emission fuels	[red]	[red]			
	IMO agrees comprehensive decarbonisation strategy and net-zero by 2050 target	[red]	[red]			
	Global agreement on gradual phase out and ban of fossil bunkers					[red]
	Classification societies adopt robust "zero-emission ready" guidelines	[black]				
	Classification societies research and set operational and safety standards	[black]	[black]			
Finance	Increase transparency in ship finance, improve standard usage, and adopt more stringent Environmental, Social and Governance standards	[black]	[black]			
	Develop risk-sharing framework (e.g. for first movers) and longer maturities for ship finance (e.g. green bond markets)	[black]	[black]			
	Mobilise industry and finance support for large scale demonstration projects	[black]	[black]			
	Rapid deployment of investments on international routes in key countries		[black]	[black]		
	Mobilise government support (in key nations) for large scale demonstration projects	[green]	[green]			
	Increasing public finance (i.e. grants, loans) for zero-emission pilots and RD&D	[green]	[green]			
	Key nations provide financial incentives for creation of zero shipping routes (e.g. subsidies, grants, reduced levies)		[green]	[green]		
	Other countries ramp up financing for large scale demonstration projects		[green]	[green]		
	Spread of finance schemes and market-based mechanisms for shipping globally			[green]	[green]	[green]

	Key actions needed to decarbonise shipping	By 2022	By 2025	By 2030	By 2035	By 2040
Demand	Freight purchasers commit to price premium for zero-emission shipping					
	Shipowners, charterers and freight purchasers conduct feasibility studies for mid-term SZEF demand with potential producers					
	Container freight purchasers participate in system demonstrations					
	Market/commercialise zero-emission shipping to end customers					
	Freight purchasers commit to use zero-emission shipping by 2040					
	Broad coalitions commit to achieving 10 decarbonised deep sea routes by 2030					
	32 developed nations decarbonise domestic shipping to 30% by 2030					
	Leading countries issue domestic shipping tenders with zero carbon clauses and set out plans for inter-modal zero fuel usage					
Technology/ Supply	Key shipping industry actors commit to net-zero by 2050 and adopt Science Based Targets					
	Cross-industry collaboration to develop smaller zero-emission ships					
	Scale up green hydrogen supply and reduce electrolysis costs					
	Develop small scale green zero emission fuel production facilities [in leading countries]					
	Public-private collaboration to scale up affordable renewable energy [in leading countries]					
	Public-private collaboration on large-scale zero-emission demonstration projects [in leading countries]					
	Public-private collaboration to scale up green zero-emission fuel production [in leading countries]					
	Development of first "Green Corriodors" for zero-emission shipping					
	Shipping companies commit to buying zero-emission propulsion ready vessels					
	Large-scale demonstration projects demonstrate viability of zero-emission shipping					
	Majority of international shipping is fully decarbonised					

Figure 25: Select actions plotted by transition phase.



Appendices

7. Appendix I: Modelling Assumptions and Detailed Outputs

Modelling Assumptions for the GloTraM Analysis

Global GHG Policy	Zero international and domestic emissions by 2050, attained through EEDI requirements and a carbon price from 2025 set to meet a pathway of CO2 reduction that achieves zero absolute GHG emissions in 2050.
Air Quality Policy	Agreed IMO Policies, e.g., SOx/NOx ECAs, global sulphur cap. EEXI/CII are not included.
Fuel Prices	BEIS Central Fuel Prices,[62] with NH3 and H2 produced through SMR/CCS.
Transport Demand	The RCP 2.6 SSP2 scenario was applied, a scenario used to produce the more Paris goal-aligned "Business As Usual" scenario, as used in the Third IMO GHG Study.[63]
Bioenergy Availability	For this modelling, bioenergy was assumed to not be available to shipping due to evidence of the scarcity of sustainable supply and the expectation of multiple other demands for that supply. In practice, there might be some small volume use of bioenergy and this assumption is illustrative of that small volume being so small it is not material to emissions reduction efforts or the demand for other fuels.
Fuels Available for Take-Up	HFO, MDO, LSHFO, LNG, H2, NH3, and Methanol. Low life cycle emission versions of H2, NH3 and Methanol are included. Based on the evidence at the time of modelling, a synthetic methane (low lifecycle emission version) is not included because it was not anticipated to be more competitive than the equivalent production pathway for methanol.

62 Department for Business, Energy and Industrial Strategy. (2017). *Data tables 1 to 19: supporting the toolkit and the guidance.* https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

63 Vuuren, D. (2014). *SSP/RCP-based scenarios: Implementation*, IIASA. http://www.iiasa.ac.at/web/home/about/events/8.detlef.ssps_2.pdf

The scenario modelling performed in GloTraM simulates the investment and operation decision-making of profit-maximising shipowners and operators (broken down into groups of similar ship type, size, and age profile). This stakeholder chooses from a range of options (speed reductions, energy efficiency interventions, or different fuel/machinery combinations) at each time step. Newbuild specifications are optimised for each time step with perfect foresight of fuel prices, and fuel/machinery can be retrofitted at any point as long as the commercial case can be made. Both existing policy instruments (EEDI) and a constraint on absolute operational CO_2 emissions (applied for the sake of modelling as a carbon price set at the level required to achieve a given absolute CO_2 emission at each time step and therefore CO_2 trajectory) drive each set of decisions and, in aggregate, a series of trends.

Whilst the ability to retrofit a ship is included in the modelling in GloTraM, each scenario can only take a specific set of input parameters for how a fuel option might be produced over time, and how this might result in a given cost/price trajectory and lifecycle emissions profile. In practice, there can be multiple characterisations of fuel production pathways for any one “molecule”, and different fuel production specifications may be suited to different roles across the ship type/size age categories modelled.

8. Appendix II: First Mover Potential by Route and Ship Type

Table 6: Top 10 countries/clusters with good or strong H2 potential, and highest shares of fuel consumption on intra-cluster shipping activity.

	tot_route_hfoe_kt_year	reduction_potential %	Most_common_ship_type
Greece	481.0	0.2	Ferry-RoPax
China	456.0	0.19	Ferry-RoPax
Italy	305.0	0.13	Ferry-RoPax
Japan	295.0	0.13	Ferry-RoPax
USA and Puerto Rico	294.0	0.12	Bulk carrier
Norway	283.0	0.12	Ferry-pax only
Republic of Korea	267.0	0.11	Bulk carrier
Spain	248.0	0.11	Ferry-RoPax
France	173.0	0.07	Ferry-RoPax
Russia	145.0	0.06	Chemical tanker
Total top 10	2947.0	1.24	

Table 7: Intra-cluster first movers, specifics per ship type.

	size_range_ standardised	capacity_unit	tot_route_ hfoe_kt_year	reduction_ potential_%	No_vessels
Ferry-RoPax	10000-19999	gt	2632.0	1.12	936
Oil tanker	0-4999	dwt	346.0	0.15	294
Bulk carrier	0-9999	dwt	339.0	0.14	218
Service - other	0-+	gt	334.0	0.14	884
Chemical tanker	0-4999	dwt	319.0	0.14	215
Ferry-pax only	300-999	gt	268.0	0.11	639
Ro-Ro	5000-9999	dwt	152.0	0.06	40
Offshore	0-+	gt	118.0	0.05	159
General cargo	5000-9999	dwt	107.0	0.05	181
Container	0-999	teu	104.0	0.04	79
Total_top_10			4719.0	2	3645

Table 8: Bilateral first movers, specific per ship departure-destination country pairings.

	tot_route_hfoe_kt_year	reduction_potential %	Most_common_ship_type
(China, China)	573.0	0.244	Bulk carrier
(Japan, Japan)	382.0	0.163	Ferry-RoPax
(USA and Puerto Rico, USA and Puerto Rico)	296.0	0.126	Chemical tanker
(Australia, China)	84.0	0.036	Bulk carrier
(United Arab Emirates, Japan)	80.0	0.034	Liquefied gas tanker
(Japan, United Arab Emirates)	80.0	0.034	Liquefied gas tanker
(Netherlands, United Kingdom)	72.0	0.031	Ferry-RoPax
(United Kingdom, Netherlands)	70.0	0.03	Ferry-RoPax
(China, Australia)	65.0	0.028	Bulk carrier
(Russian Federation, Russian Federation)	57.0	0.024	Oil tanker
Total top 10	1759.0	0.75	

Table 9: Bilateral first movers, specifics per ship type.

	size_range_standardised	capacity_unit	tot_route_hfoe_kt_year	reduction_potential_%	No_vessels
Bulk carrier	35000-59999	dwt	714.0	0.3	235
Ferry-RoPax	10000-19999	gt	687.0	0.29	81
Ro-Ro	5000-9999	dwt	365.0	0.16	25
Liquefied gas tanker	0-49999	cbm	315.0	0.13	17
Container	0-999	teu	220.0	0.09	28
Oil tanker	20000-59999	dwt	97.0	0.04	30
Vehicle	0-29999	gt	64.0	0.03	8
Chemical tanker	40000-+	dwt	60.0	0.03	16
General cargo	0-4999	dwt	25.0	0.01	20
Service - other	0-+	gt	18.0	0.01	55
Total_top_10			2565.0	1.09	515

Table 10: Summarised reduction potential of liner vessels grouped by number of visited clusters in a year.

	Grouped_by: Total_No_clusters	Reduction_potential_prc	Number_of_vessels	Proportion_of_vessels_(%)	Number_of_voyages	Proportion_of_voyages_(%)
1	Up_to 2.0	0.89	787	1.188	71562	0.026
2	3	2.05	1069	1.613	89405	0.036
3	4	1.42	521	0.786	30032	0.017
4	5	1.04	357	0.539	16569	0.012
5	5.0-15.0	2.03	537	0.81	16958	0.018
Total		7.43	3271	4.936	224526	0.109

Figure 26: Identified liner route first movers. Map showing activity of a subset of domestic only liners.

Table 11: Summary results of the liners subgroup operating in a maximum of three clusters & only one country.

	Most_common_ship_type	Number_of_vessels	Mean_voy_distance_nm	tot_route_hfoe_kt_year	prop_hfoe_yr_%	Average_No_ports
Japan	Bulk carrier	392.0	314.0	1215.0	0.517	24.0
China	Bulk carrier	460.0	643.0	1214.0	0.516	20.0
USA and Puerto Rico	Service - other	53.0	945.0	344.0	0.146	11.0
Norway	Service - other	38.0	237.0	76.0	0.032	36.0
Australia	Service - other	17.0	1245.0	26.0	0.011	7.0
United Kingdom	Service - other	22.0	315.0	19.0	0.008	7.0
France and Monaco	Service - other	7.0	153.0	4.0	0.002	13.0
Germany	Service - other	11.0	261.0	3.0	0.001	7.0
Malaysia	Service - other	4.0	1280.0	3.0	0.001	6.0
Sweden	Service - other	4.0	127.0	1.0	0.001	18.0
Total_top_10	Service - other	1008.0	552.0	2905.0	1.235	

Table 12: Summary results of the liners subgroup operating in a maximum of three clusters & only two countries.

	Most_common_ship_type	Number_of_vessels	Mean_voy_distance_nm	tot_route_hfoe_kt_year	prop_hfoe_yr_%	Average_No_ports
China, Australia	Bulk carrier	32.0	3107.0	326.0	0.139	9.0
Japan, Australia	Bulk carrier	12.0	3405.0	207.0	0.088	8.0
China, Japan	Container	28.0	577.0	185.0	0.079	13.0
Japan, USA and Puerto Rico	Container	11.0	1869.0	178.0	0.076	10.0
Canada, USA and Puerto Rico	Bulk carrier	41.0	297.0	141.0	0.06	28.0
Mexico, USA and Puerto Rico	Chemical tanker	18.0	820.0	134.0	0.057	11.0
China, USA and Puerto Rico	Container	5.0	3065.0	94.0	0.04	7.0
New Zealand, Australia	Container	7.0	956.0	41.0	0.017	9.0
France, Monaco, Italy	Chemical tanker	8.0	234.0	16.0	0.007	14.0
China, India	Bulk carrier	1.0	1140.0	1.0	0	7.0
Total_top_10		163.0	1547.0	1323.0	0.563	

Table 13: Summary of liner first movers per vessel type.

Most_common_ship_type	size_range_standardised	capacity_unit	Number_of_vessels	Mean_voy_distance_nm	tot_route_hfoe_kt_year	prop_hfoe_yr_%	Average_No_ports
Bulk carrier	60000-99999	dwt	1052.0	2300.0	5983.0	2.545	17.0
Container	0-999	teu	345.0	1028.0	4121.0	1.753	14.0
Liquefied gas tanker	0-49999	cbm	186.0	1690.0	1973.0	0.839	16.0
Oil tanker	5000-9999	dwt	307.0	966.0	1363.0	0.58	18.0
Chemical tanker	0-4999	dw	376.0	536.0	1064.0	0.452	24.0
Ferry-RoPax	10000-19999	gt	75.0	615.0	691.0	0.294	9.0
General cargo	5000-9999	dwt	341.0	767.0	643.0	0.274	24.0
Ro-Ro	5000-9999	dwt	52.0	585.0	598.0	0.254	10.0
Vehicle	0-29999	gt	42.0	1643.0	340.0	0.145	12.0
Service - other	0-+	g	298.0	765.0	260.0	0.11	13.0
Total_top_10			3074.0	1090.0	17035.0	7.246	

9. Appendix III: National Climate Plans and Linkages to Shipping

Many nations have nationally determined contributions (NDCs) for GHG reduction and climate change mitigation. However, the maritime sector is often either confined to the margins or missing entirely from NDCs.[64] [65]Since the ambition of countries' NDCs should increase over time, it is likely that countries will increasingly turn to sectors not previously considered to make further GHG reductions. Additionally, the IMO adopted a resolution in 2020, urging member states to develop and update a voluntary national action plan (NAP) focused on contributing to reducing GHG emissions from international shipping.[66] It further encourages member states to share their plans publicly on the IMO website. At the time of writing, the UK, Norway, Marshall Islands, India, and Japan have shared their national action plans on the IMO website.

Specific examples of the actions that can be expected in this decade include:

Japan: The NAP from Japan is a broad roadmap to achieving action in line with the IMO Initial Strategy by focusing on energy efficiency in the short term and promoting uptake of alternative fuels in the long term. As part of this they consider two pathways: Emission pathway I – "a fuel shift from LNG to carbon-recycled methane", and Emission pathway II – "the expansion of hydrogen and/or ammonia fuels". [67]

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64 Löhr, E., Perera, N., Hill, N., Bongardt, D., Eichhorst, U. (2017). *Transport in Nationally Determined Contributions (NDCs): Lessons Learnt from Case Studies of Rapidly Motorising Countries Synthesis Report.* Ricardo Energy & Environment & GIZ, on behalf of Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety of the Federal Republic of Germany. https://www.international-climate-initiative.com/fileadmin/Dokumente/2018/180205_GIZ-Ricardo_Transport-in-NDCs_Synthesis-Report.pdf

65 Ocean Conservancy. (2021). *Ocean-Based Climate Solutions in Nationally Determined Contributions.* https://oceanconservancy.org/wp-content/uploads/2021/01/NDC_tracker_January-2021-update.pdf

66 IMO. (2021b). *Resolution MEPC.327(75), Encouragement of Member States to develop and submit voluntary National Action Plans to address GHG Emissions from Ships.*
Lloyd's Register & UMAS (2020) Techno-economic assessment of zero-carbon fuels. London.

67 Japan Ship Technology Research Association and Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan. (2020). *Roadmap to Zero Emission from International Shipping.* https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/Roadmap%20to%20Zero%20Emission%20from%20International%20Shipping%20-%20Japan%20March%202020.pdf

India: The voluntary NAP submitted by India identifies more than 150 initiatives across different shipping sectors to support and monitor as part of the Maritime India Vision 2030. The focus of the plan is holistic and sustainable sector growth in alignment with the UN's Sustainable Development Goals. India places a particular focus on inland waterways and ports, stating that, "Indian ports have started multiple initiatives such as driving solar and wind energy adoption." This plan is not limited to environmental impact and instead is focused on sustainable economic growth.[68]

Marshall Islands: The Republic of the Marshall Islands has set a policy target of reducing its transport emissions by 16% by 2025 and 27% by 2030. As part of this plan, the Micronesian Center for Sustainable Transport (MCST) was established. The plan includes a "whole sector" approach to transport, a "whole country" approach, a strong focus on partnerships and regional leadership, and the aim of implementing local solutions while influencing international policy.[69]

Denmark: Denmark and Danish companies have consistently been at the forefront of recent action to decarbonise shipping. Companies based in Denmark are global leaders in the development of renewable energy technology, green hydrogen/ammonia production, zero emission/ready ship designs, and operation on new fuels. The government has taken a leadership position at IMO and in its NDC, as well as on wider global platforms, including leading the shipping component of Mission Innovation.

Norway: The Norwegian Government's ambition is to reduce emissions from domestic shipping and fisheries by 50% by 2030, for Norwegian ports to be emission-free by 2030 where possible, and to promote the development of low- and zero-emission solutions for all vessel categories. The plan considers possible measures and policy instruments for different vessel categories and updates on the funding of environmental initiatives, for example, in 2019 allocations to Enova via the Green Fund for Climate, renewable energy and energy efficiency measures have been increased by NOK 485 million.

68 Ministry of Ports, Shipping and Waterways, Government of India. (2021). *Maritime India Vision 2030*. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/Maritime%20India%20vision%202030.pdf

69 Micronesian Center for Sustainable Transport. (2015). *A Catalyst for Change*. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MCST_Framework.pdf

UK: UK domestic policy relating to emissions of GHGs from the maritime sector is based around the Climate Change Act 2008,[70] the most recent target of which is to reduce UK-wide emissions by 78% by 2035 compared to 1990 levels.[71] In Maritime 2050, the UK Government sets out a vision whereby zero-emission vessels are commonplace by 2050.[72] In the "Clean Maritime" plan, ammonia is suggested to be the most cost-effective alternative fuel for shipping. Additionally, as stated earlier, the recently adopted update to the Climate Change Act now includes international shipping and aviation within the UK carbon budgets.

70 Department for Transport, UK Government. (2019). *Clean Maritime Plan.* https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Clean%20Maritime%20Plan%202019.pdf

71 Department for Business, Energy and Industrial Strategy, UK Government. (2021). *UK enshrines new target in law to slash emissions by 78% by 2035.* https://www.gov.uk/government/news/uk-enshrines-new-target-in-law-to-slash-emissions-by-78-by-2035

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For the Getting to Zero Coalition

About the Getting to Zero Coalition

The Getting to Zero Coalition is an industry-led platform for collaboration that brings together leading stakeholders from across the maritime and fuels value chains with the financial sector and other committed to making commercially viable zero emission vessels a scalable reality by 2030.

Learn more at:
www.globalmaritimeforum.org/getting-to-zero-coalition