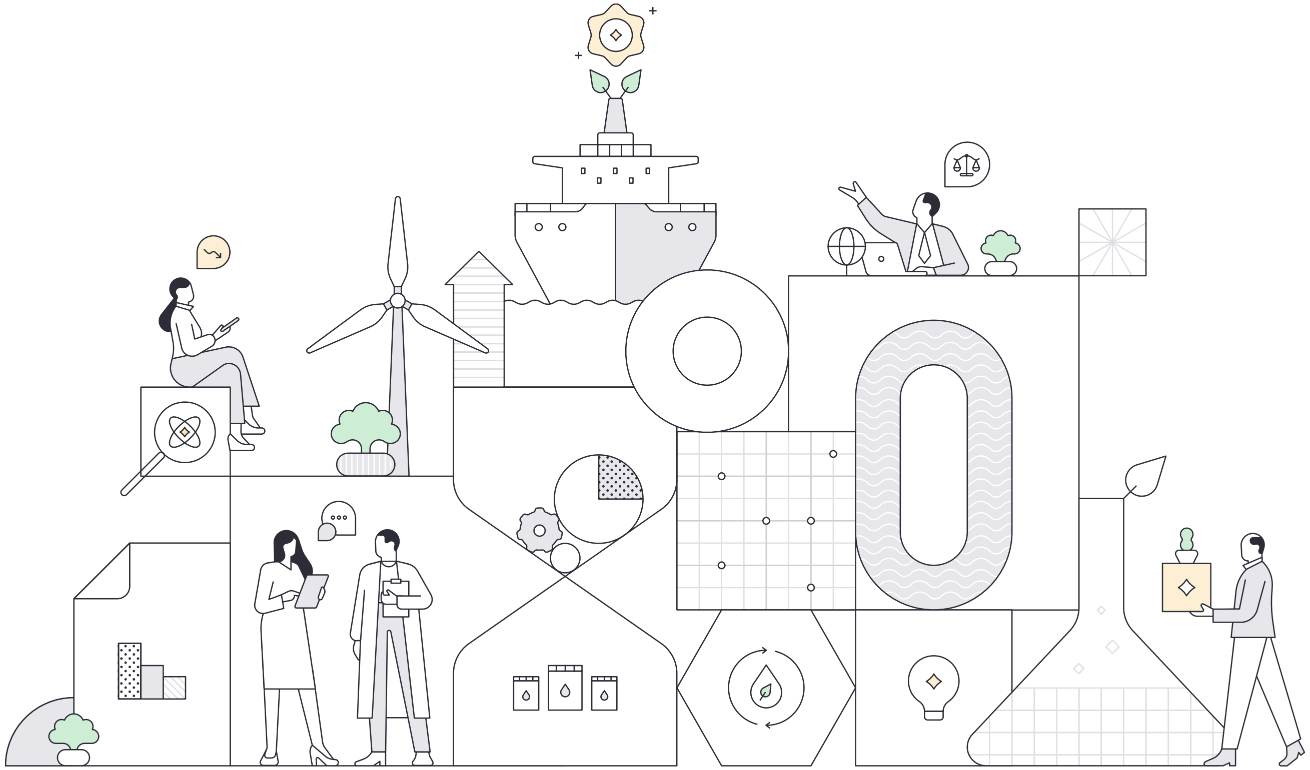
We show the world it is possible

Industry Transition Strategy
October 2021



Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping

We show the world it is possible!

It is high time for real climate action. IPCC's recent 'Physical Science Basis' report about the climate was called a 'CODE RED for Humanity' by the UN Secretary General Guterres and it is widely acknowledged across nations, regions and sectors that the climate crisis is caused by human influence. There is a global *case for change* with a strong sense of urgency as the window of opportunity to act in time is closing.

Shipping is a large global sector and a central player in multiple global systems. As part of all major supply chains, other sectors and countries depend on the shipping industry to decarbonize but at the same time they strongly influence our ability to do so. It is a daunting challenge, but we can't let the complexities and risks paralyze us. As individuals, as leaders and as a responsible shipping sector, we must all play an active role. Fortunately, many frontrunners are now acting – the big question is how we make this initial action ignite a sector-wide transformation towards truly sustainable operations at sufficient scale and speed.

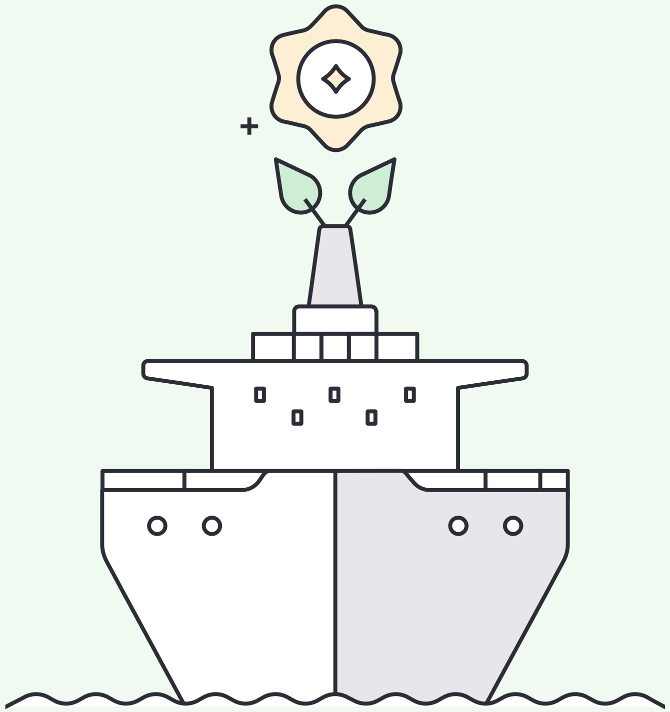
As the challenge is systemic, and no individual organization can drive the transition on its own, the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping was established as an independent player in the eco-system to help accelerate the transition through collaboration. With our partners we facilitate the development of feasible transition pathways, as presented in this Industry Transition Strategy, and then help enable these pathways to materialize.

A key objective of this strategy is to further strengthen the platform for collaboration by proposing a framework for the transition narrative and summarizing what we know today. The strategy is underpinned by deep multi-disciplinary analysis about energy, fuels, technologies, financial instruments, economics, and regulatory measures and it is our ambition to continue this open collaborative process to co-create the transition narrative from the highest global level and to the most detailed atomic level. We hope this common framework across the governing disciplines of finance, technology, energy, and policy will help a broad range of stakeholders engage and collaborate effectively on our common mission of decarbonization.

This significant task of strategizing on sector level will evolve throughout the transition. We will remain determined to expand and deepen the collaboration with the determined and courageous leaders of the maritime eco-system to turn this strategy into real climate action.

Enjoy the reading!

Bo Cerup-Simonsen, CEO



Content

Executive summary

Zero carbon shipping can become reality by 2050

Zero carbon shipping is indeed possible by 2050 with right cross-sector collaboration, industry leadership and effective global regulation

Today, The Path We Are On leads to more emissions

Commitment levels to make green transition are on the rise in the maritime industry. However, even if all ongoing and planned efforts succeed, the maritime industry emissions may increase by ~20% by 2050

First movers are critically important

Public and private action in the short term is possible and critically important, to demonstrate that decarbonization is possible. First-mover opportunities can be leveraged before global regulation is in place

Industry leadership can't drive the transition alone

First movers in the maritime industry have clearly demonstrated their willingness to go green. But, realization of current ambitions will only result in <10% emissions reduction vs. 2020, at notably high cost

Transition pathways are many, driving complexity

Several fuels can replace fossil fuels used today to drive decarbonization. Moreover, there are various technological options to use these fuels onboard. This means there is no 'one size fits all' approach driving decarbonization

Cost gap fossil vs. alternative fuels is wide

Alternative fuels' production is ~2-8x costlier than the price of fossil fuels. Such a wide gap cannot be closed by technological progress alone. Additional industry measures are needed to bridge the cost gaps

Industry action and global carbon pricing can close gaps

Besides reduced cost of fuels, improved customer's willingness to pay, reduced cost of green financing, increased energy efficiency adoption combined with a global policy on carbon levy can pave the way for the transition

It matters how a carbon pricing is designed

A global carbon price in the range of USD 50-150/tCO_2-eq can support both developing countries; and early adopters of alternative fuels if revenue is earmarked and recycled back to the industry

Several alternative fuel options will co-exist

Industry action and policy can narrow the fuel pathways to decarbonization. However, irrespective of the pathway to zero, several alternative fuel options will co-exist as part of the fuel mix

Actions in four key areas is needed in next decade

Maritime decarbonization requires: (1) industry-wide energy efficiency adoption; (2) alternative fuel scale up; (3) a well-designed global carbon levy; and (4) support to the first movers

Preface

A Transition Strategy

This Transition Strategy is the first of its kind produced by the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (also referenced to as the Center in this document). In the coming years we will publish similar strategic documents to articulate how we view the transition towards zero-carbon shipping and provide our recommendations based on the latest research and knowledge. Our views and conclusions will change over time as new technologies mature and regulation changes.

This Transition Strategy document reflects Center-produced analyses based on publicly available data, industry data provided by the Center's partners and output from NavigaTE – the techno-economic model developed by the Center.

Our aim with this strategy is to:

- Provide a science-based, independent perspective of what it takes to decarbonize the maritime industry by 2050
- Outline the relevant levers within technology, regulation and financing that will have the greatest positive impact on the transition
- Point at immediate actions that will help unlock and accelerate the transition
- Motivate and engage maritime industry participants, regulators and investors to take responsibility and start acting now

Additionally, we hope that this document can be a steppingstone for the maritime industry to engage in projects that not only focus on achieving net-zero by 2050, but trigger action today and in the near-term.

Targeting net-zero emissions

The Paris Agreement is a landmark in climate change as it is the first binding agreement bringing countries together to a achieve a climate neutral world by 2050. More specifically, it is a legally binding international treaty on climate change – entered into force on 4 November 2016 – with a goal to limit global warming to well below 2°Celsius and preferably to 1.5°Celsius, compared with pre-industrial levels.

The essence of the Paris agreement is that countries have committed to reduction targets, but certain sectors such as maritime transport were not addressed. It is expected, however, that maritime transportation will be included in the future version of the Paris agreement. If the maritime industry is to contribute to a sustainable future pathway, emissions must fall precipitously, despite an increase in global trade and demand for transportation. In this strategy paper we explore the core challenges and opportunities for the maritime industry followed by actions and scenarios of what it will take to continue to be a thriving industry while reaching net-zero emissions.

Glossary

Alternative fuels Alternative fuels are derived from sources other than petroleum; some are derived from renewable sources. Often, they have a lower environmental impact than fossil-based hydrocarbons.

Biofuels Fuel category, generally in liquid form, produced from biomass. Biofuels currently include biomethane from wet waste or agricultural waste, hydrothermal liquefaction crude from biomass, bio-methanol, and biodiesel from canola or soybeans.

Biomethane Biomethane is a near-pure source of methane produced either by "upgrading" biogas (a process that removes any CO_2 and other contaminants present in the biogas) or through the gasification of solid biomass followed by methanation. May be used as a blend or substitute for natural gas and LNG.

Bio-methanol or renewable methanol Bio-methanol is produced from biomass. Key potential sustainable biomass feedstocks include forestry and agricultural waste and by-products, biogas from landfill, sewage, municipal solid waste (MSW). Differs from e-methanol which is produced by using CO2 captured from renewable sources (bioenergy with carbon capture and storage [BECCS] and direct air capture [DAC]) and green hydrogen, i.e., hydrogen produced with renewable electricity.

Bio-oils Bio-oil is a category of biofuels that can be obtained from thermochemical conversion of biomass, via pyrolysis and hydrothermal liquefaction. For example, hydrothermal liquefaction crude.

Blue fuels Fuel pathway that utilizes natural gas as a feedstock, emissions are abated via carbon capture

Carbon capture storage or CCS Carbon capture and storage (CCS) is the process of capturing and storing carbon dioxide (CO_2) before it is released into the atmosphere. CO_2 can be captured using different methods. The main ones are post-combustion, pre-combustion and oxyfuel. Once the CO_2 has been captured, it is compressed into liquid state and transported by pipeline, ship, or road tanker.

Carbon dioxide equivalent or CO2 equivalent, abbreviated as CO2-eq The amount of carbon dioxide (CO_2) emission that would cause the same integrated radiative forcing or temperature change, over a given time horizon, as an emitted amount of a greenhouse gas (GHG) or a mixture of GHGs. There are a number of ways to compute such equivalent emissions and choose appropriate time horizons. Most typically, the CO_2-equivalent emission is obtained by multiplying the emission of a GHG by its global warming potential (GWP) for a 100-year time horizon. For a mix of GHGs it is obtained by summing the CO_2-equivalent emissions of each gas. CO_2-equivalent emission is a common scale for comparing emissions of different GHGs but does not imply equivalence of the corresponding climate change responses. There is generally no connection between CO_2-equivalent emissions and resulting CO_2-equivalent concentrations.

Carbon foot print This is the lifecycle GHG emissions of a product, organisation or nation. Different to LCA in that it doesn't consider impacts such as global warming potential.

Carbon free fuels Fuels with no carbon atom e.g., hydrogen and ammonia. However, this doesn't mean they are emission free.

Carbon neutral A state of balance between CO_2 emitted into the atmosphere and CO_2 removed from the atmosphere. Also referred to as Net Zero in some literature.

Electrofuels or e-fuels Electrofuels or e-fuels are advanced fuels, often produced with hydrogen that is obtained from the electrolysis of water using renewable electricity to power the process. The term e-fuels are referring to the process of fuel production rather than the fuels itself.

Green fuels Fuel pathways which are considered renewable from a life cycle perspective.

Life Cycle Assessment Life cycle assessment (LCA) is a methodology for assessing environmental impacts associated with all the stages of the life cycle of a commercial product,

Low Carbon Fuels In the context of the Low Carbon Fuels Standard. Low carbon fuels are fuels with a declining carbon intensity score. Fuels that score below the carbon intensity benchmark are referred to as Low Carbon Fuels.

Net Zero *See definition for Carbon Neutral.*

Tank-to-Wake pathway Steps necessary to combust a fuel in a ship's tank.

Well-to-Tank pathway Combination of steps necessary to turn a resource (elementary flow) into a fuel and bring that fuel to a vessel. Each fuel can be produced from a single or several resources as the source of primary energy.

Well-to-Wake pathway Combination of steps from production of fuel to transporting and consuming the fuel in ship operations.

Zero-emissions Zero-emissions refers to an engine, motor, process, or other energy source, that emits no waste products that pollute the environment or disrupt the climate.

Zero-carbon fuels Fuels that do not include carbon as part of their molecular composition e.g., hydrogen (H_2) and ammonia (NH_3).

The Path We Are On

Already today we see brave first movers across the maritime eco-system starting to act and initiatives stand ready to be launched. Industry leadership is gaining momentum, particularly within the car carrier and container segments. Many shipowners have announced ambitious decarbonization targets and have started ordering the first vessels that are alternative fuels ready.

The flow of news, new regulation and announcements of projects can give an impression of a shipping industry well underway to decarbonize. However, this is not the case.

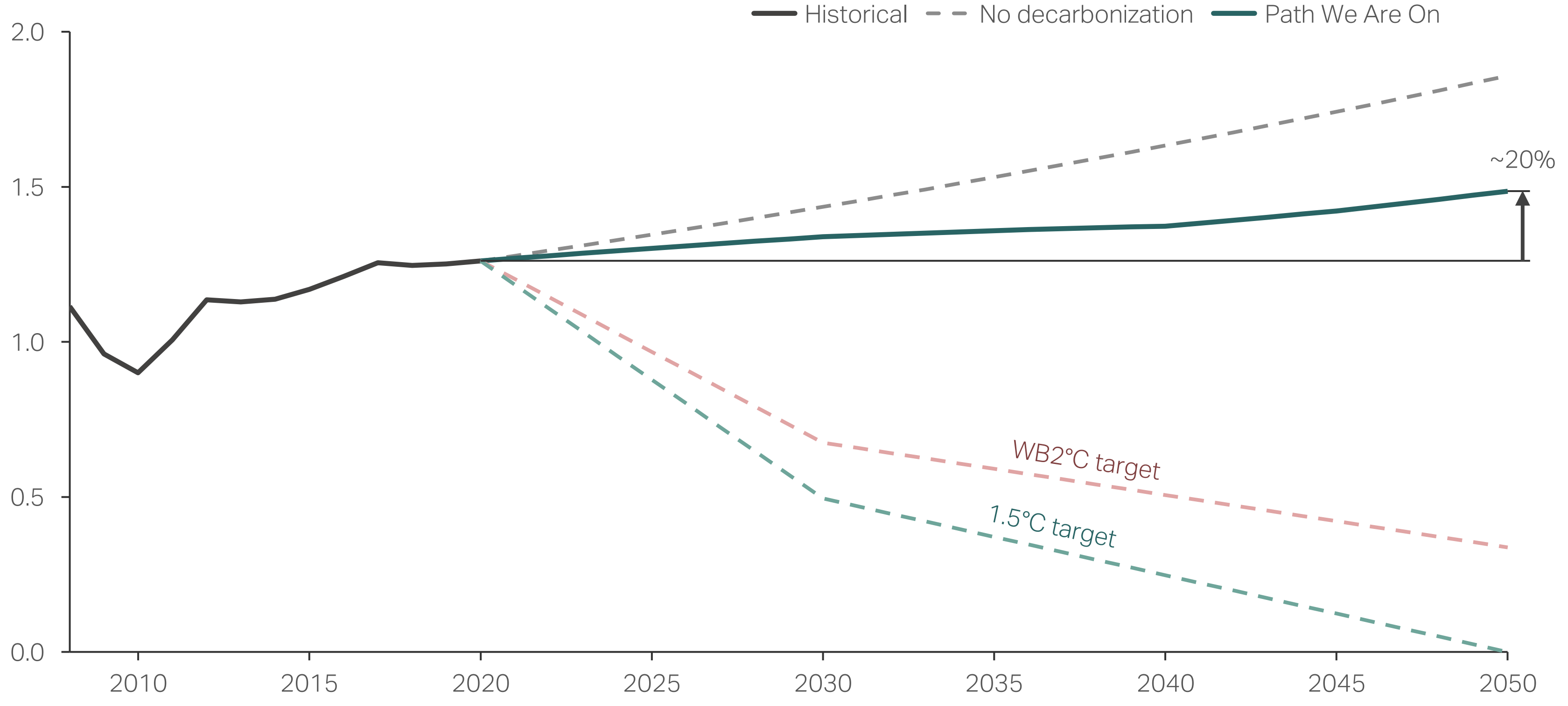
In this chapter we describe our current path towards a zero-carbon future, summing up the combined effects of the planned decarbonization activities and show how far they will take us. By assessing the documented and confirmed efforts planned, and adding other factors like growing world trade, evolving maritime fleet composition, high but continuously declining renewable electricity prices, recently tightened energy efficiency regulation by the International Maritime Organization, and more we come to the surprising conclusion that: The Path We Are On leads to growing green house gas (GHG) emissions between 2020 and 2050.

We do not take hoped-for initiatives like future implementation of market-based measures or drastic changes to consumer behavior towards green transportation into account. We are providing a snapshot of the real action and confirmed plans we see today across the industry.

We are heading for an increase in maritime GHG emissions despite current industry-wide efforts

Current decarbonization efforts are outplayed by growing trade and large fuel cost differences

WTW Maritime emission pathways[1]
$GtCO_2$-eq/year



Current maritime abatement actions are insufficient.

Growing trade volumes (1.3% CAGR trade growth), technological developments and existing industry-wide CO_2 abatement initiatives will not create enough traction for shipping to deliver what is needed to meet the Paris Agreement targets[2]:

- A **well below 2°C** (WB2°C) above pre-industrial levels"; targeting ~25% emissions reduction 2010-2030 and reaching net zero by 2070
- An **ideal 1.5°C target:** ~45% emissions reduced by 2030 and reaching net zero by 2050

The **no decarbonization** pathway reflects status quo on today's fuel mix and current energy efficiency measures towards 2050.

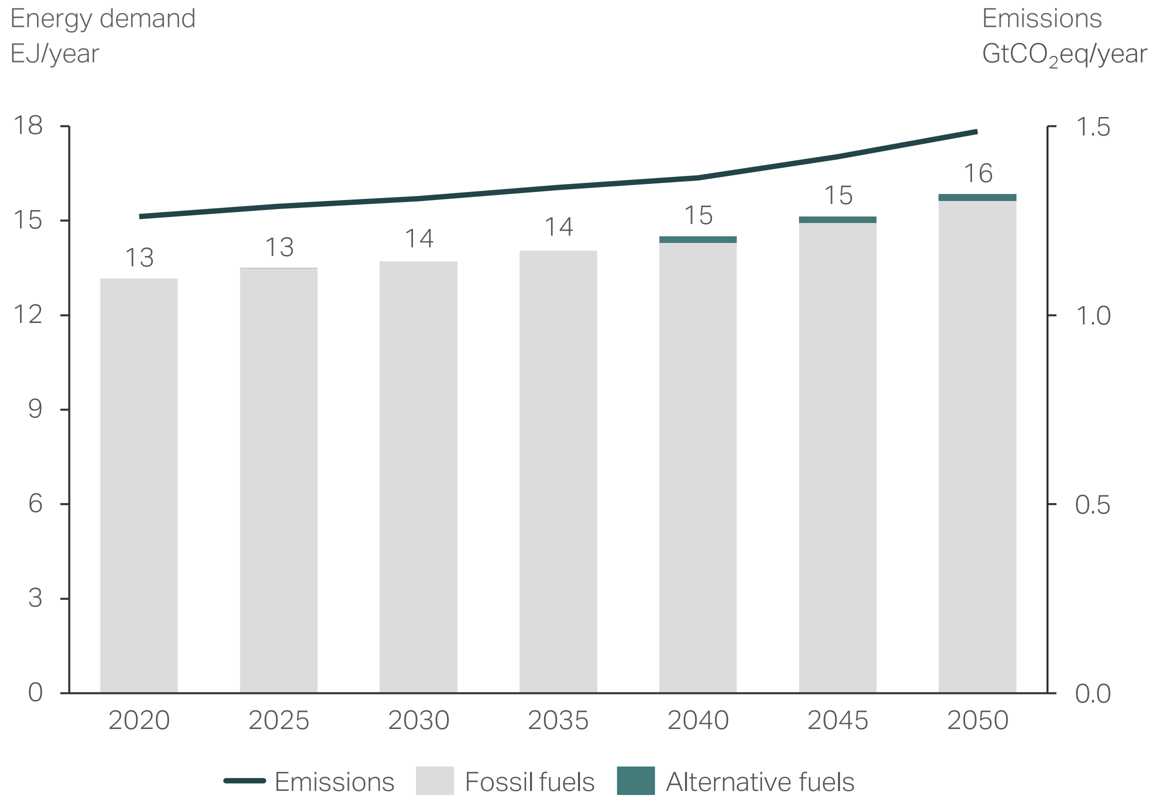
Sources: IMO, IEA, Clarksons and Techno-economic model MMM Center for Zero Carbon Shipping
1 WTW = well to wake.
2 Referencing the IPCC, 2018: Summary for Policymakers, In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related 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.

The Path We Are On will mean energy demand is met by only 1% of alternative fuels

Underlying assumptions (excerpt)[1]

Global trade growth	Average 1.3% p.a. between 2020 and 2050
Vessel retirement rate	Avg. 4% annually of global fleet with scrapped vessels replaced by same vessel size/type
Renewable electricity cost forecast[2]	Globalized avg.: 2030 – USD 47/MWh; 2035 – USD 41/MWh; 2040 – USD 37/MWh; 2050 – USD 33/MWh
Oil price development[3]	2025 – USD 470/ton LSFO (~11 USD/GJ) 2030 – USD 450/ton LSFO (~11 USD/GJ)
Biomass costs[4]	2030 – USD 50-94/ton; 2035 – USD 50-99/ton; 2040 – USD 50-103/ton; 2045 – USD 50-108/ton
Finance costs	7% WACC for building and owning vessels; 5% for fuel facilities
Emissions	Direct emissions along each step from well-to-wake across fuel value chain
Energy efficiency (EE)	Business measures: payback period of <2 years activates EE investment for newbuilds Regulatory measures: Current agreed EEDI, EEXI, CII provisions modeled for new and existing vessels

The Path We Are On will mean an increased overall energy demand

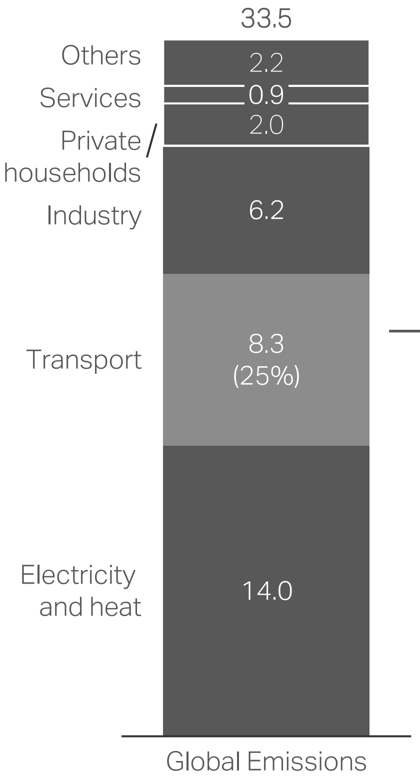


Source: Techno-economic model MMM Center for Zero Carbon Shipping
1 A longer list of key assumptions can be found in Appendix A2
2 Include balancing costs; 3 Forward 10-year curve extrapolated ; 4 Cost ranges included because of different types of sustainable biomass (e.g., Organic waste, sustainable forestry)

The maritime share of 3% of global emissions risks growing, as other sectors decarbonize at a faster pace

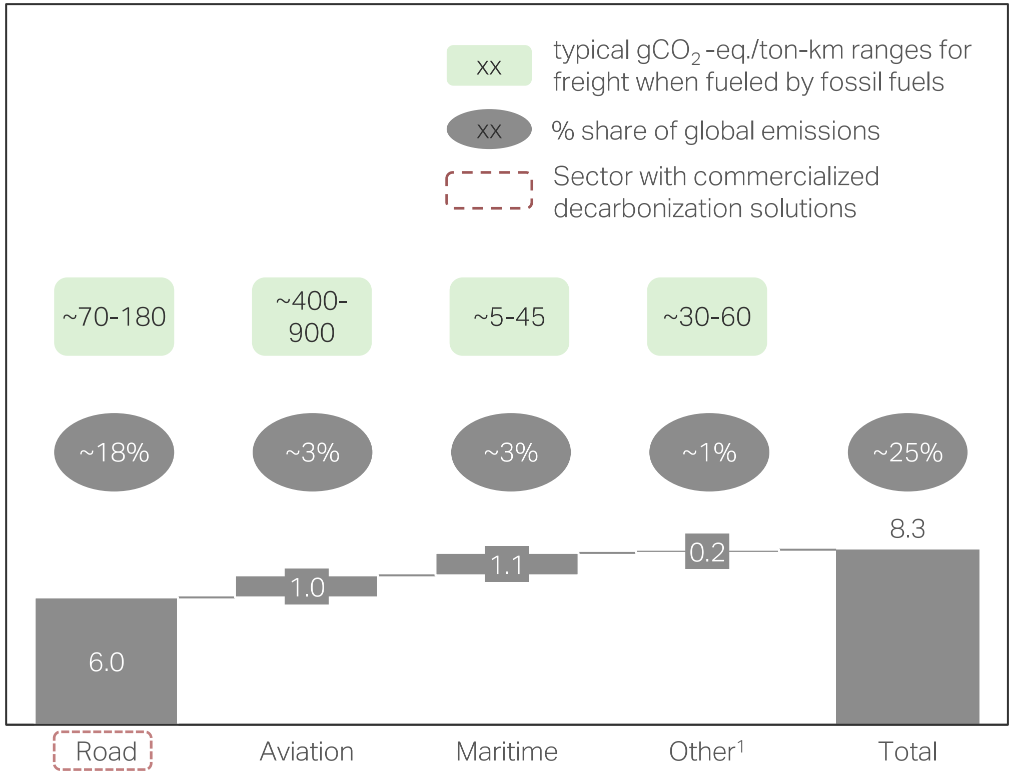
Global emissions, 2018

$GtCO_2$-eq/year (tank to wake)



Transport sector specific emissions, 2018

$GtCO_2$-eq/year (tank to wake)



The transport sector accounts for 25% of global emissions and is dominated by fossil fuels.

Shipping has the least emissions intensity in terms of CO_2-eq/ton-km for freight transported. But the maritime industry's enormous scale makes it a noticeable contributor (3%) to global emissions.

Furthermore, maritime is a hard-to-abate sector. If maritime emissions are not reduced, the sector may be responsible for 5-8% of global emissions by 2050, as other sectors are increasingly decarbonizing at a faster pace (e.g., road transport). The consequence would likely be no access to capital markets and customers increasingly leaning towards procuring local products.

Source: IEA (2020, 2019), IMO 4th GHG Study (2020),McKinsey & Co. (2021), IPCC. (2018), all data in tank-to-wake (TTW) emissions;
1 Includes rail and non-specified transport

Three segments contribute to most maritime emissions and volumes are expected to grow towards 2050

	Global volumes, 2018		Emissions and intensity, 2020	
	Billion ton-miles	2020-50 CAGR %	$GtCO_2$-eq/year (well-to-wake)	gCO_2 -eq/ton-km
Total	58,932	1.3	1.26	~12
Bulk carrier	25,050	1.0	0.24	~5
Tanker	14,090	0.1	0.28	~11
Container	13,046	2.4	0.29	~12
Gas carrier	2,987	2.3	0.08	~15
Other cargo	2,146	2.2	0.09	~22
RoRo/Car carrier	607	2.0	0.06	~52
Ferry	135	2.0	0.06	~223
Cruise	130	4.0	0.04	~115
Others[1]	740	2.3	0.12	~89

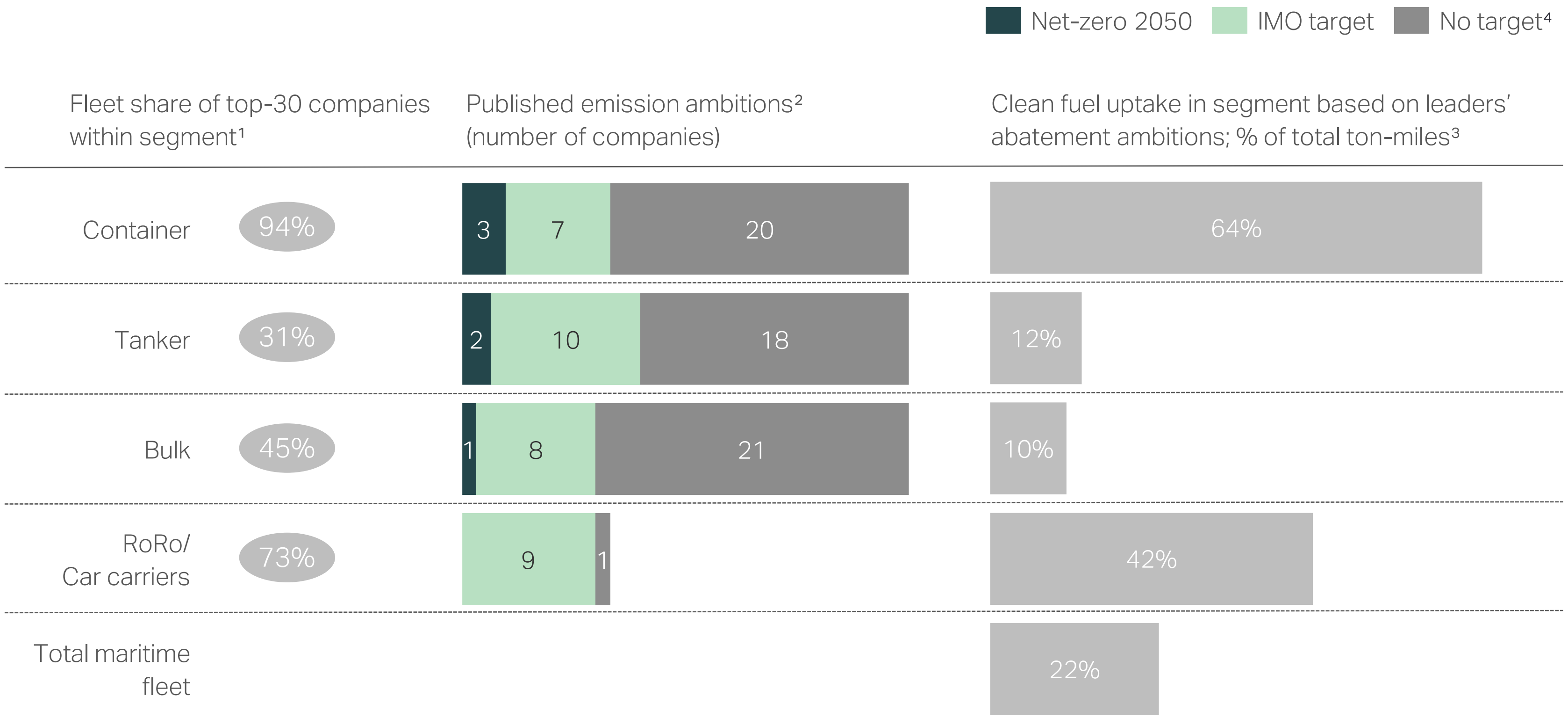
Supported by a positive World GDP outlook and historic data, maritime volumes are expected to continue to grow. Three segments - bulk, tanker and container - account for ~90% of industry volume and ~65% of emissions, making them the key focus areas for future emission reduction pathways.

Growth will not be stable. Technological disruptions, population growth, macro-economic, environmental and geopolitical events will continue to impact trade and challenge the maritime industry with some vessel segments being more impacted than others. For example, a global push for CO_2 abatement will most likely mean less oil and coal transported, growing populations will most certainly increase demand for container cargo and regionalization or pandemics such as CoVID-19 will affect global trading patterns.

Source: IMO 4th GHG study (2020), McKinsey&Co. (2021), Clarksons (2021), Techno-economic model MMM Center for Zero Carbon Shipping
1 Others include offshore, tugs and non-specified ships
2 Exports of goods and services (% of GDP) | data (worldbank.org)

Bold first movers are paving the way with declared net-zero targets by 2050

Industry leaders' ambitions may lead to increased uptake of alternative fuels by 2050



Source: MMM Center for Zero Carbon Shipping, Shipowners' websites

1 Analysis is limited to the largest emitting marine segments and RoRo/Car carriers. Industry leadership is defined by the top 30 largest shipowners within each segment, measured in TEU or DWT. Though, for RoRo/car carriers we only include the top 10.

2 Based on industry leaders' publicly available abatement statements found in annual and/or sustainability reports, as of June 2021.

3 Building on The Path We Are On scenario, but now also assuming that shipowners will reduce CO_2 emissions in line with their official ambitions, no matter how costly such a switch to zero-carbon fuels will be.

4 The No Target group also includes one shipowner stating to have a "Green Transition Strategy" but without specifying any tangible targets and one shipowner having a target of "reducing CO_2 emissions by 10% in 2020 -2025".

5 IMO target equals a 50% reduction in tank-to-wake emissions vs 2008. Numbers have been recalculated to match WTW emission reductions.

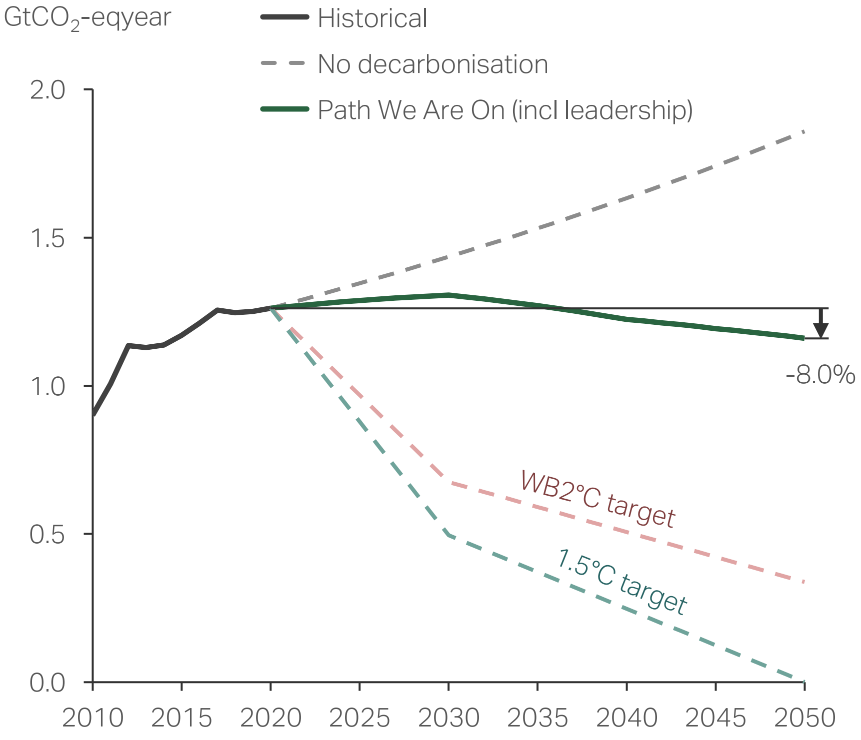
As of June '21, three leading container shipping firms have publicly announced plans to be net-zero by 2050. Although it may not sound like a lot, these account for >30% of the global container fleet, making this a significant segment impact. If we also add the companies that use IMO emission targets[5], the first mover leadership may lead to 64% fossil-free container trade by 2050.

Bulk and tanker segments also increasingly commit to IMO targets. But these segments are more fragmented and only point to a ~10% change. Additionally, most large RoRo/car carriers also aim for the IMO target, strongly influenced by the automotive industry's head start in CO_2 abatement.

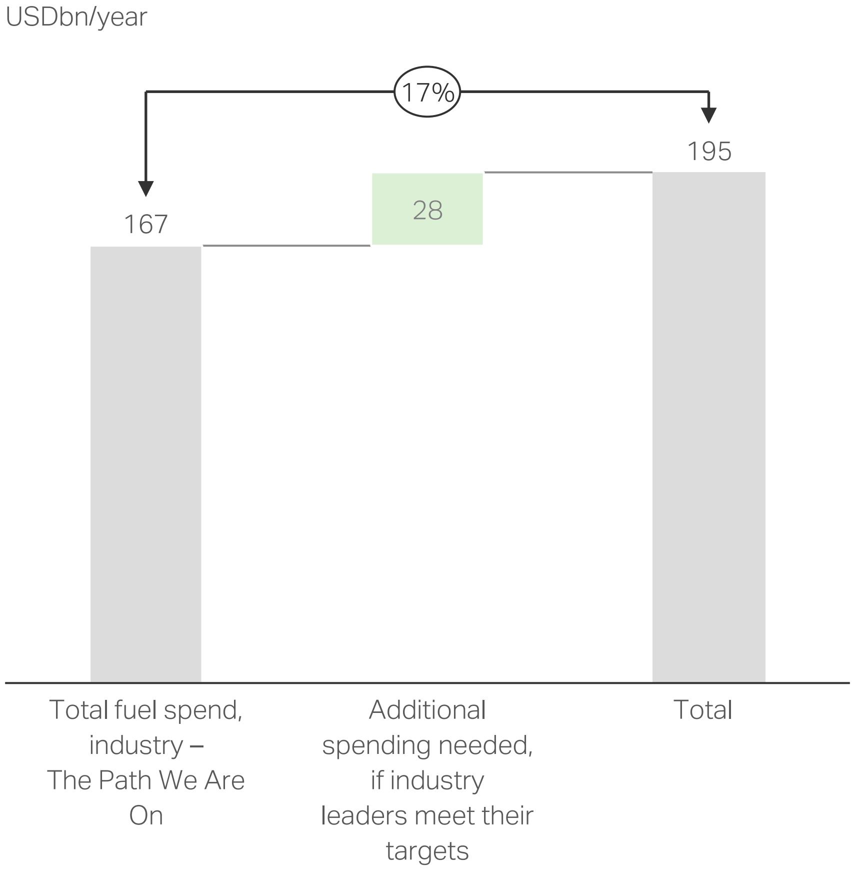
If emission reduction ambitions are all delivered on, at least 22% of global ton-miles would be transported on zero-carbon by 2050.

Industry leadership can lead decarbonization efforts provided the bold few are willing to carry the cost

Emissions if leadership ambitions are realized



Estimated global fleet fuel spend in 2050



Industry leaders' decarbonization targets pointing to ~22% of the global ton-miles running on alternative fuels by 2050 is a great commitment, potentially reducing global emissions by 8% compared with 2020.

But it will come at a high cost. If first movers are not supported by regulation or customers' willingness to pay the green premium for zero-carbon transportation, the choice of sailing on alternative fuels would lead to an additional USD 28 bn in yearly fuel spend (+17%) for the industry taken on by these leaders.

As a reference example, in 2020 the top 11 carriers publicly reporting financials had a combined net profit of USD 10 bn.[1] Industry leaders may not be able to absorb the additional cost.

Source: Techno-Economic model MMM Center for Zero Carbon Shipping

1. With many shipowners are currently enjoying their best quarters in shipping history, significantly raising profits. Though, several carriers having lined up year-on-year losses during the last five-year period. Blue Alpha Capital. Estimated profits increase to USD15.8 bn in 2020, and a more modest USD7 bn in the previous five-year period, if also including approximations of non-reporting carriers such as MSC). For more details, see Q4 20 most profitable in container shipping history, but 2021 will be better - The Loadstar

The challenge

In chapter #01 we outlined that the current decarbonization efforts are not sufficient to bring the maritime industry to what is needed to meet the Paris Agreement targets. More is needed faster.

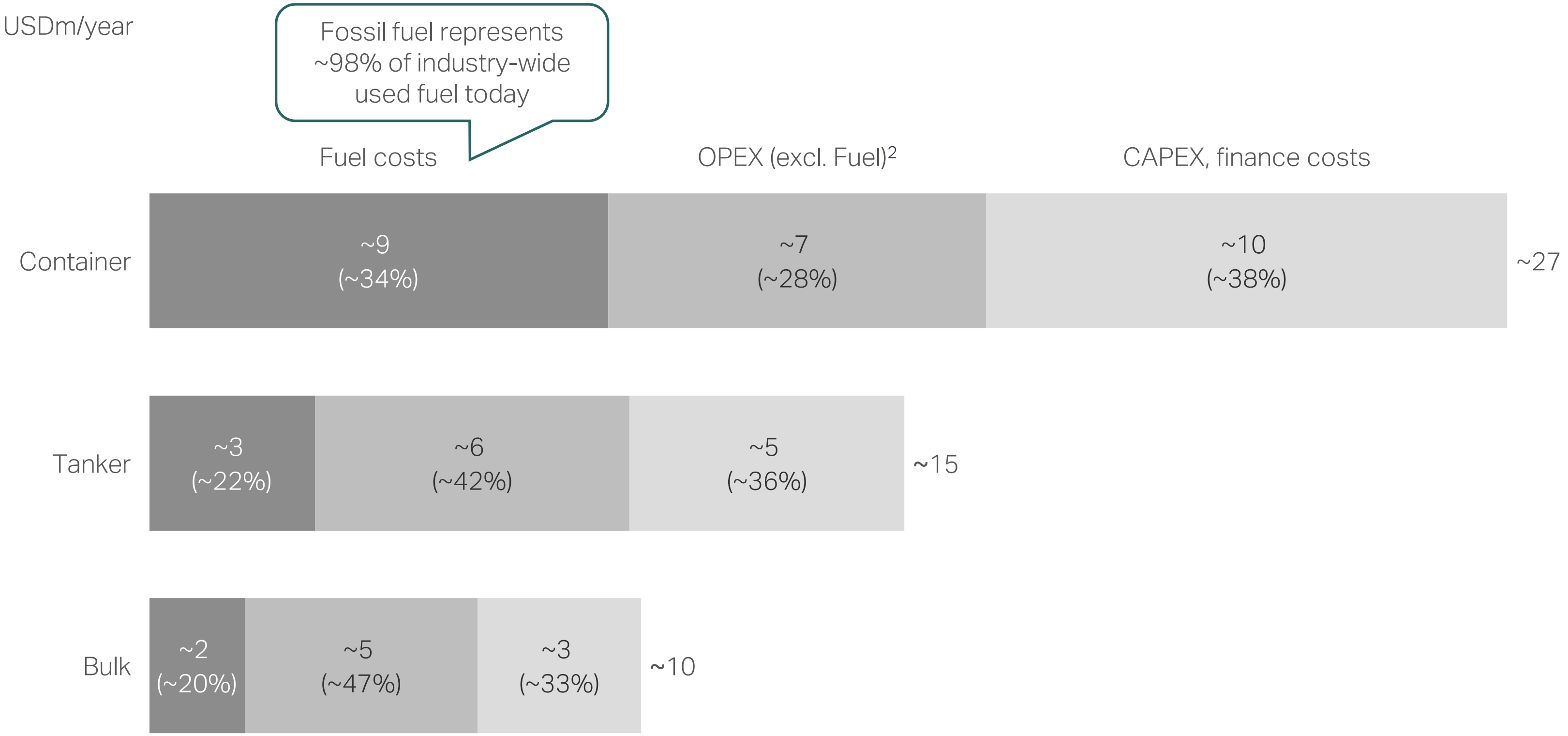
In this chapter we look at why that is not necessarily an easy task.

The maritime industry faces a dense matrix of challenges on its journey towards zero-carbon which will delay or even prevent the transition if they are not mitigated. Firstly, the maritime industry is a highly complex, global and decentralized sector with more than 100,000 commercial vessels. Secondly, the current cost gap between conventional fossil fuels and alternative fuels is very large leaving few financial incentives to make the switch. And even if shipowners wanted to, the supply chains of alternative fuels is not yet ready for global distribution to accelerate the transition.

Getting supply chains in place at the required scale points at the third major challenge: the dependency on technologies that do not yet exist or exist at low readiness level. Investing in these technologies is risky due to the lack of consensus in the industry around a common fuel pathway going forward.

Fuel represents ~20-35% of total annual costs with almost the entire industry consumption being fossil-based

Total cost of ownership for various vessel types[1] in 2020



Source: Techno-Economic model MMM Center for Zero Carbon Shipping
1 Typical vessels refer to: Container- 8,000 TEU capacity; Tanker - LR2 85-125k DWT; Bulk carrier - Panamax 70-99k DWT ; All vessels are assumed to have a 25-year lifetime. Typical operational profiles have been assigned to each vessel type.
2 Maintenance, crew, port call fees and other operating costs not including fuel costs

Shipowners and managers understand the importance of looking beyond purchase price and considering the total cost of ownership (TCO) of their vessels. Acquisition costs, operation and personnel costs all factor into the full expense of owning and operating a vessel.

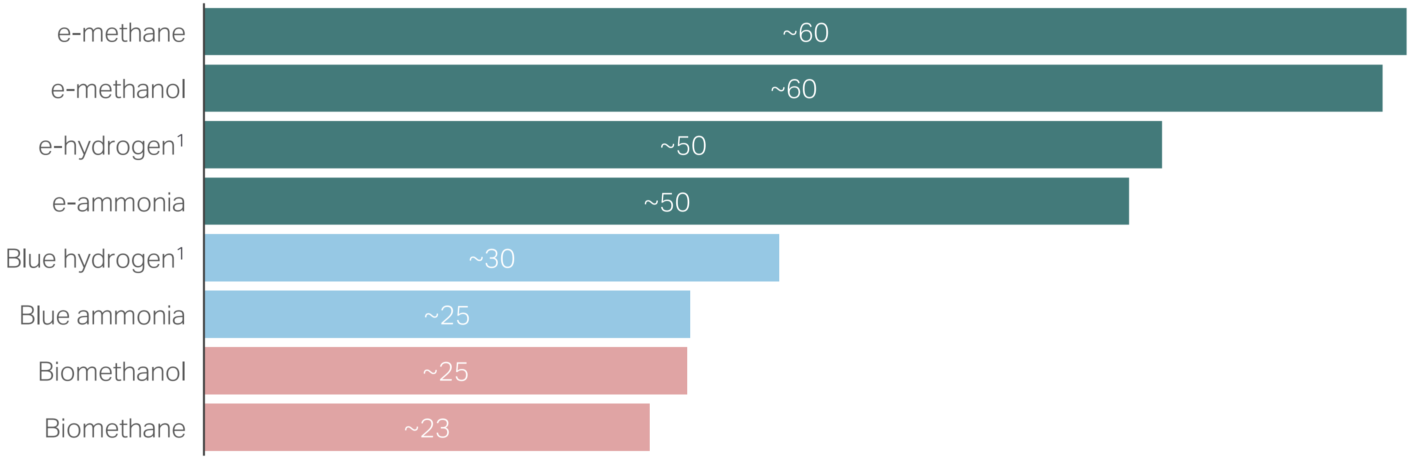
In maritime, fuel is a significant proportion of the overall cost. Firstly, there is the direct fuel purchasing cost and secondly, the quality of fuel affects cost related to vessel maintenance and performance.

Maritime fuel costs make-up 20-35% of annual TCO, with container vessels having the highest proportion of fuel cost.

With low prices and already established supply chains, fossil fuels are tough competitors to beat...

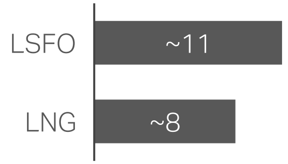
Estimated production price, 2025

USD/GJ



Estimated production price, 2025

USD/GJ



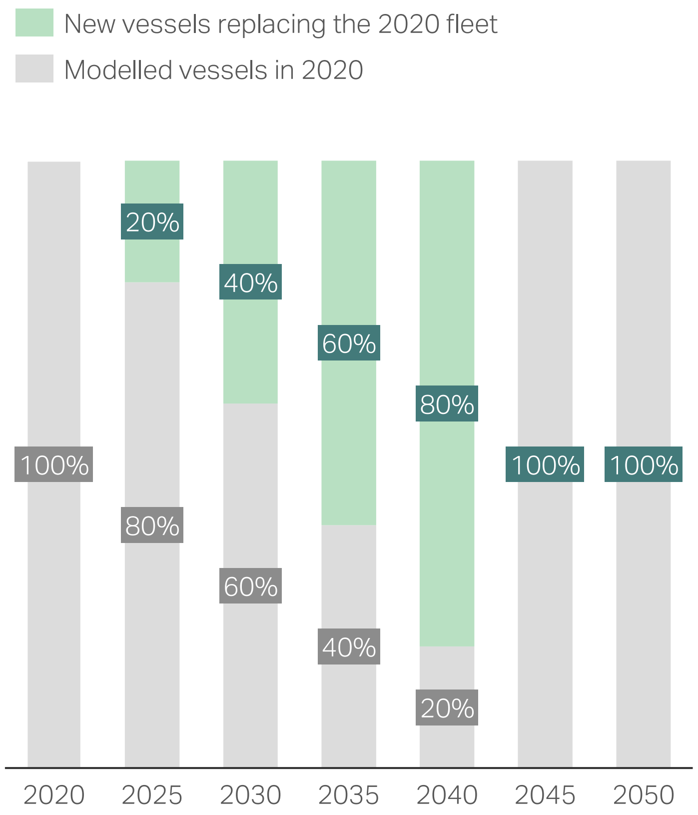
Source: Techno-Economic Model (NavigaTE) MMM Center for Zero Carbon Shipping
1 Liquefaction of hydrogen is considered; Bio-oils are only commercially available after 2025.
2 Actual fuel prices will be subject to various external factors including but not limited to supply/demand imbalances, local carbon pricing initiatives and subsidies.

Current operational complexity challenges the path towards decarbonization

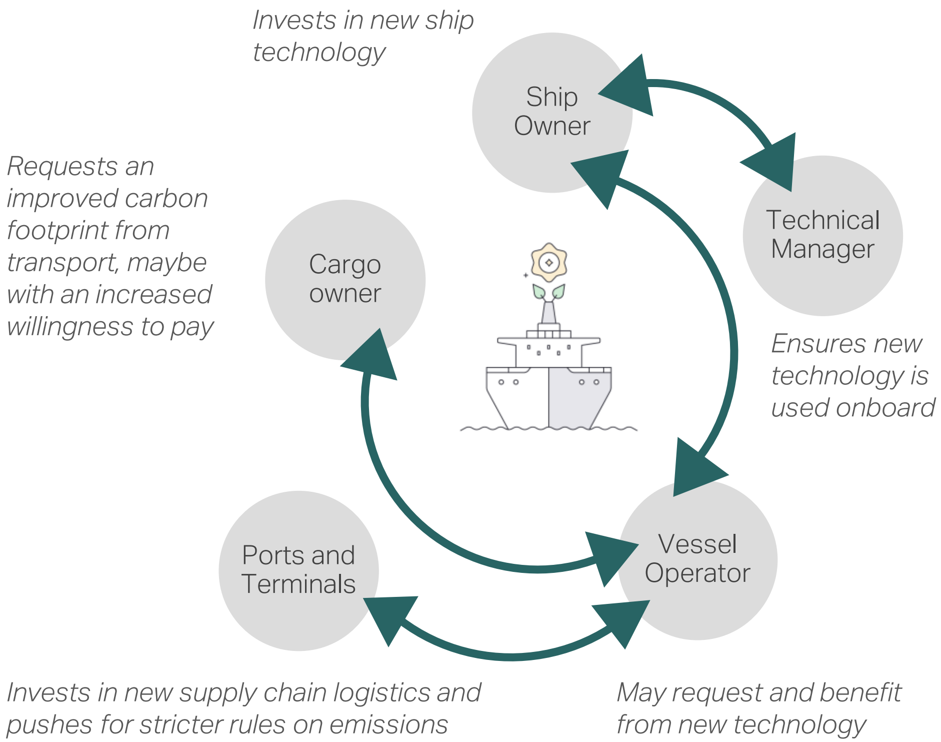
- Fossil fuels (e.g., LSFO) are among the cheapest refined crude oil products. The production costs of alternative fuels are ~2-8x of fossil fuel prices
- Global logistics and infrastructure supporting these fossil fuels are very well established and competitive, whereas those for alternative fuels are almost non-existent
- Moreover, high specific energy content for fossil-based fuels in comparison with alternative fuels (e.g., e-ammonia) means the fuel logistics to support a given energy demand will be more costly
- The global nature of the maritime industry means there is an inherent complexity stemming from different regulatory regimes – local, regional, international challenging the uptake of alternative fuels
- Regulatory regimes combined with a vast number of business participants (e.g., shipowners, charterers) further adds complexity
- Most alternative fuels are not used as a maritime fuel today. In lack of a formalized marketplace for these alternative fuels, estimated future production costs of alternative fuels are compared with future price outlooks of fossil fuels[2]

...and the current fleet composition and industry structure challenge the decarbonization path even further

Natural replacement of existing fleet[1]



Complex commercial structures



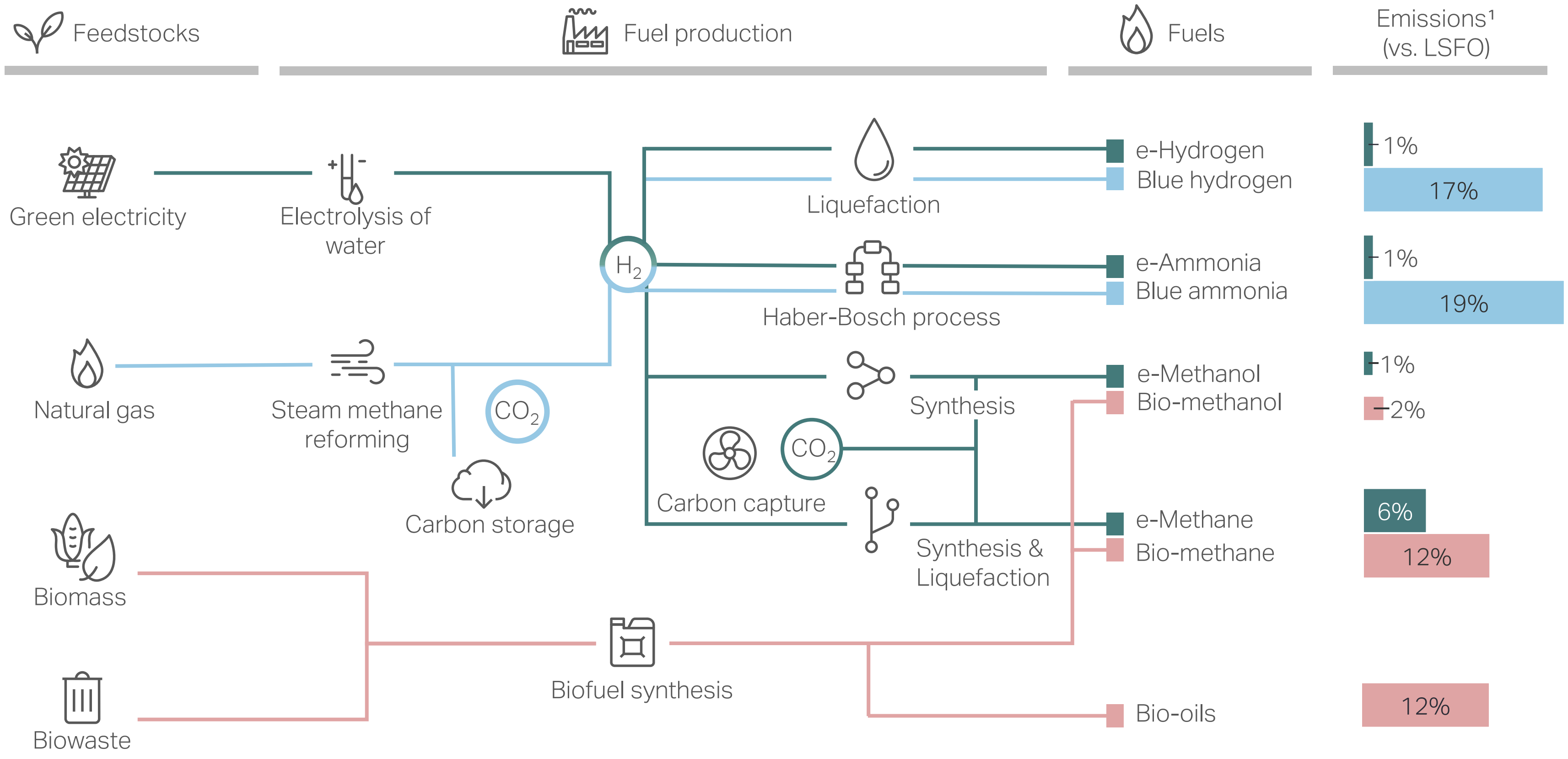
Source: MMM Center for Zero Carbon Shipping
1 Illustrating the impact of an expected vessel lifetime of 25 years and a 4% yearly scrap rate of fleet.. New vessels is the number needed to maintain the same fleet size as per 2020

Decarbonization via fleet replacement takes time; a ship's average lifetime is ~25 years. Key drivers of global fleet replacement are current age distribution, global trade capacity needed, vessel scrap prices and the concept of total cost of ownership (TCO). Thereby, retrofitting the existing fleet with new and existing technology may accelerate the transition beyond the natural replacement rate.

Commercial structures in the maritime industry today can also be seen as an impediment to decarbonization. Lack of mutual attractiveness to save fuel and cut emissions do not incentivize everyone in the business model. This often slows down adoption of new and capital-intensive projects. Current business model also doesn't emphasize on the cleverness of vessel routing, and Just in Time principles among others, which could be used as operational tweaks unlocking the emissions reduction potential.

The diversity of alternative fuel options makes it difficult to agree on a common pathway...

Overview of different fuel production pathways



Source: MMM Center for Zero Carbon Shipping
Note: Only key processes are included; For bio-methane, methane slip emissions from the choice of engine technology and upstream production is considered based on technology readiness in 2030.
1 Relative comparisons to LSFO emissions of 96 gCO2-eq /MJ (direct emissions well-to-wake) by 2030

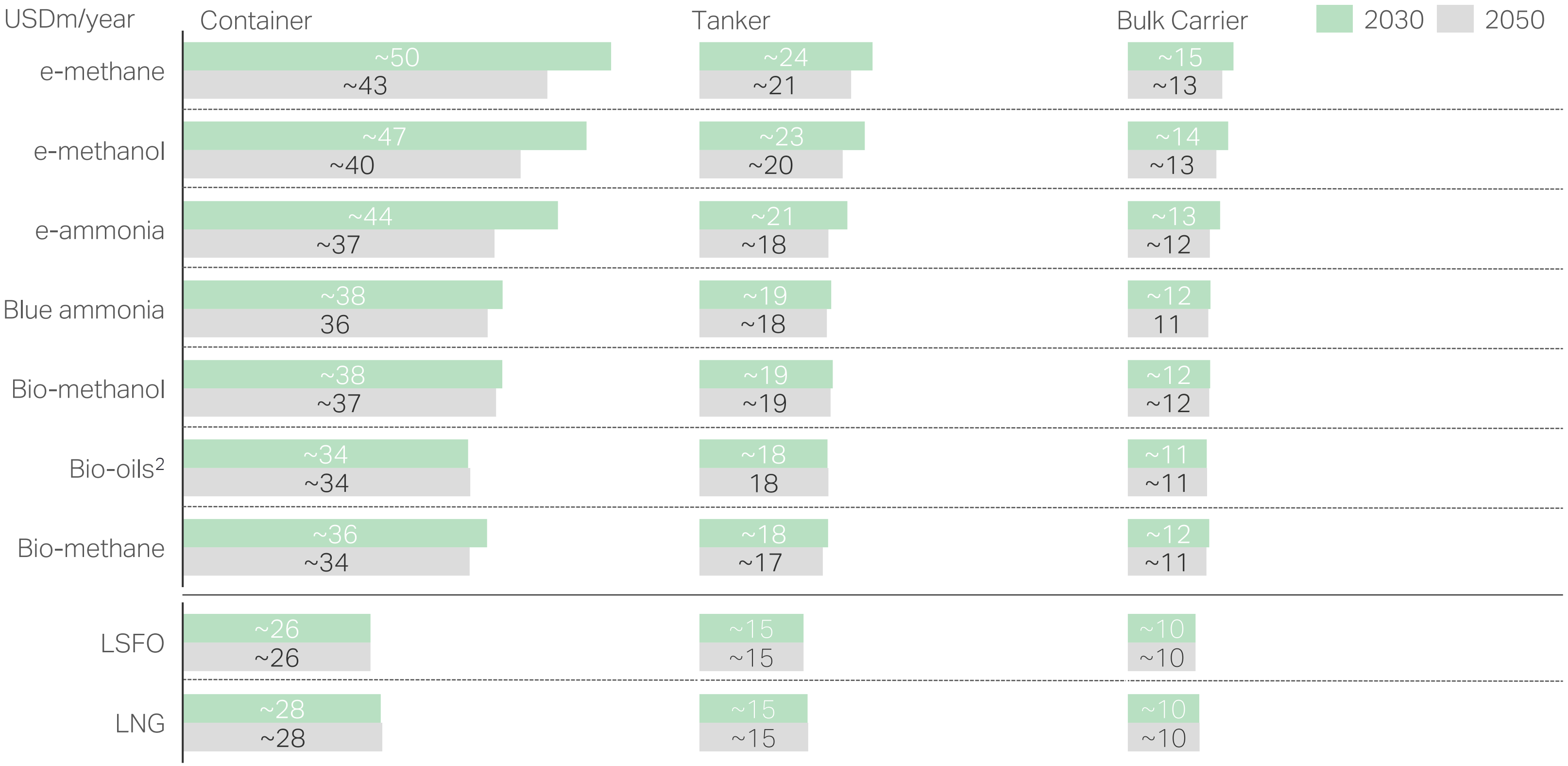
Currently, we have at least five candidate groups for future wide use alternative fuels: hydrogen, ammonia, methanol, methane and bio-oils.

Each group in turn contains different types of fuels, distinguished depending on the feedstock and fuel production processes used. Renewable energy is used to produce e-fuels, fossil feedstocks are used as a basis to produce blue fuels, while bio-oils include a range of techniques that convert biological material into an oil-like substance.

Based on the technological advancements and maturity outlooks of fuels in 2030, our analysis suggest that the emissions footprint of these fuel types may range between 1% and 19% of the comparable LSFO emissions. Methane slip in upstream production processes of blue hydrogen, blue ammonia and bio-methane is factored in based on the technology maturity levels forecasted for 2030.

…and based on future cost projections, shipowners' TCO continues to be higher when sailing on alternative fuels

Path We Are On: estimated total cost of ownership across various vessel types[1]



Source: Techno-Economic model MMM Center for Zero Carbon Shipping
Note: Hydrogen is not considered fuel suitable for deep sea shipping because of immaturity in safe usage, storage and conversion of hydrogen as an onboard fuel.
1 Typical vessels refer to: Container- 8,000 TEU capacity; Tanker - LR2 85-125k DWT; Bulk carrier - Panamax 70-99k DWT ; Typical operational profiles have been assigned to each vessel type;
2 Uses Pyrolysis Oil availability and cost projections.

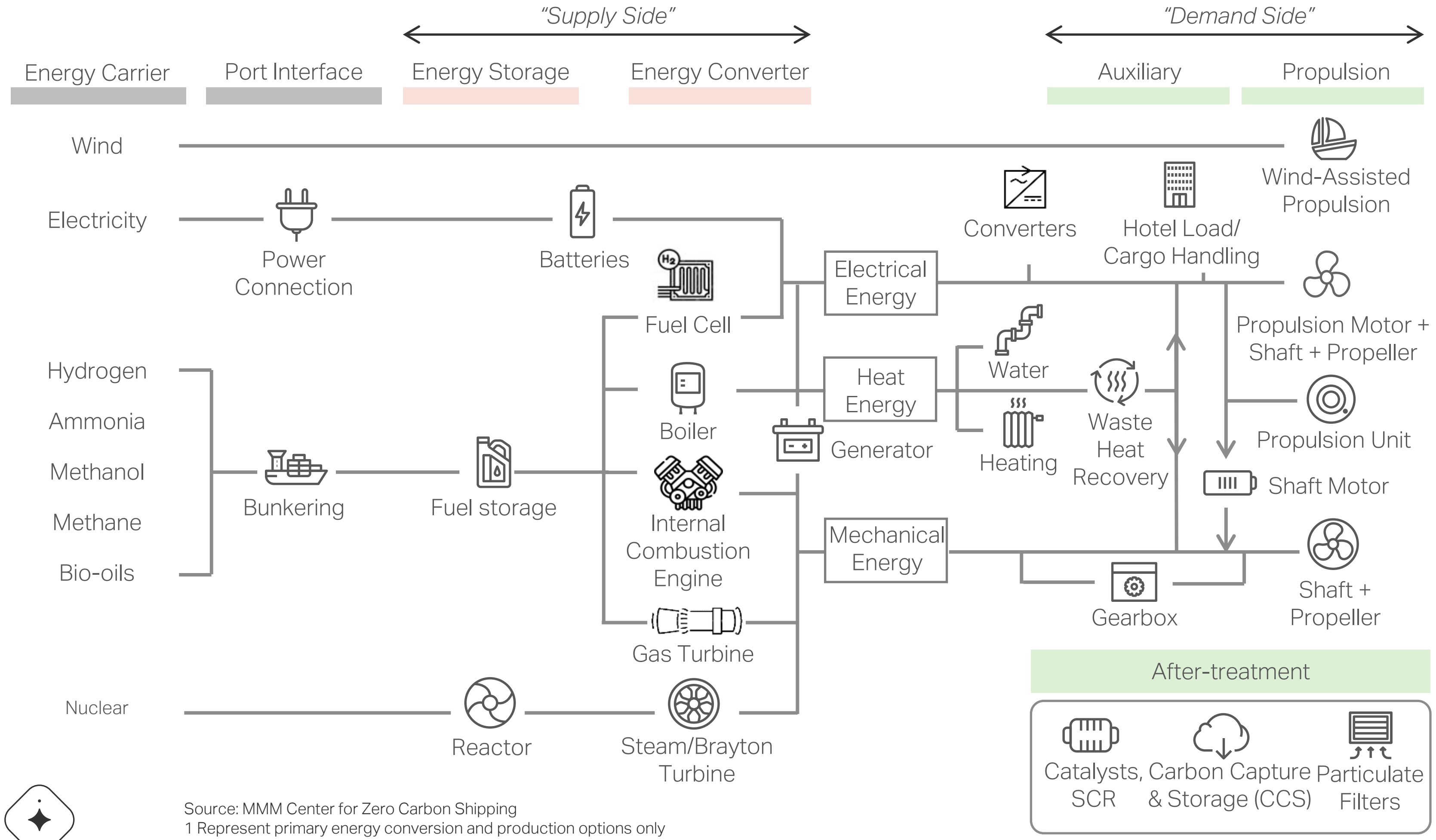
Combining our knowledge on fuel costs proportion of the annual TCO with future fuel cost projections, the analysis shows a TCO gap of up to 2x between vessels running on fossil and on alternative fuels through 2050.

Based on the large cost differences among the three segments, a conclusion could be that segments with the least TCO impact could front-run the transition. However, as the ship owners are largely competing only within their respective segments, and some segments trade in low-margin products and markets, even smaller TCO changes could impede the efforts for transition.

Across segments, vessels running on e-fuels have the highest TCO in comparison with other alternative fuels. Likewise, vessels running on blue fuels may have comparable TCO levels with bio-fuels.

Moreover, onboard energy demand can be met in different ways, thus further complicating things

Maritime energy conversion and propulsion options[1]



Source: MMM Center for Zero Carbon Shipping
1 Represent primary energy conversion and production options only

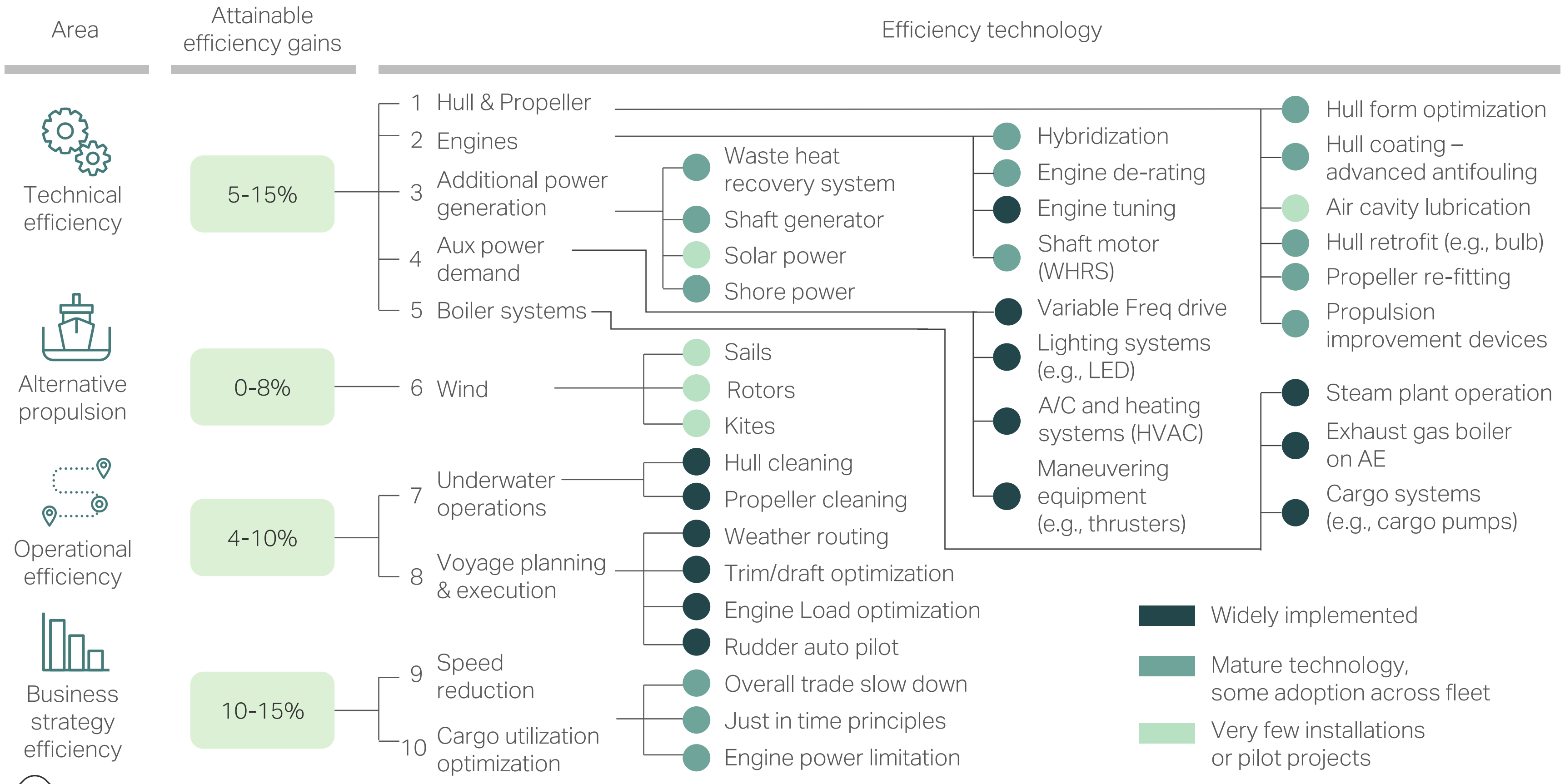
Performance requirements for every vessel is unique based on type, size and operational profile.

To fulfil these unique requirements, there are multiple onboard vessel solution pathways including different energy and fuel configurations, main vessel technologies, energy efficiency initiatives and power and propulsion concepts. Vessel owners need to evaluate the options and decide what they believe is best for their vessel.

In addition to the standard newbuild vessel design, vessels can be designed to be prepared for other fuels or retrofitted with different or new technologies throughout a vessel's lifetime. This adds another layer of decision-making complexity especially with high uncertainty regarding the main future fuels.

Ship efficiency technology is available, but not fully utilized across the industry

Overview of energy efficiency technologies and potential attainable efficiency gains[1] for world fleet

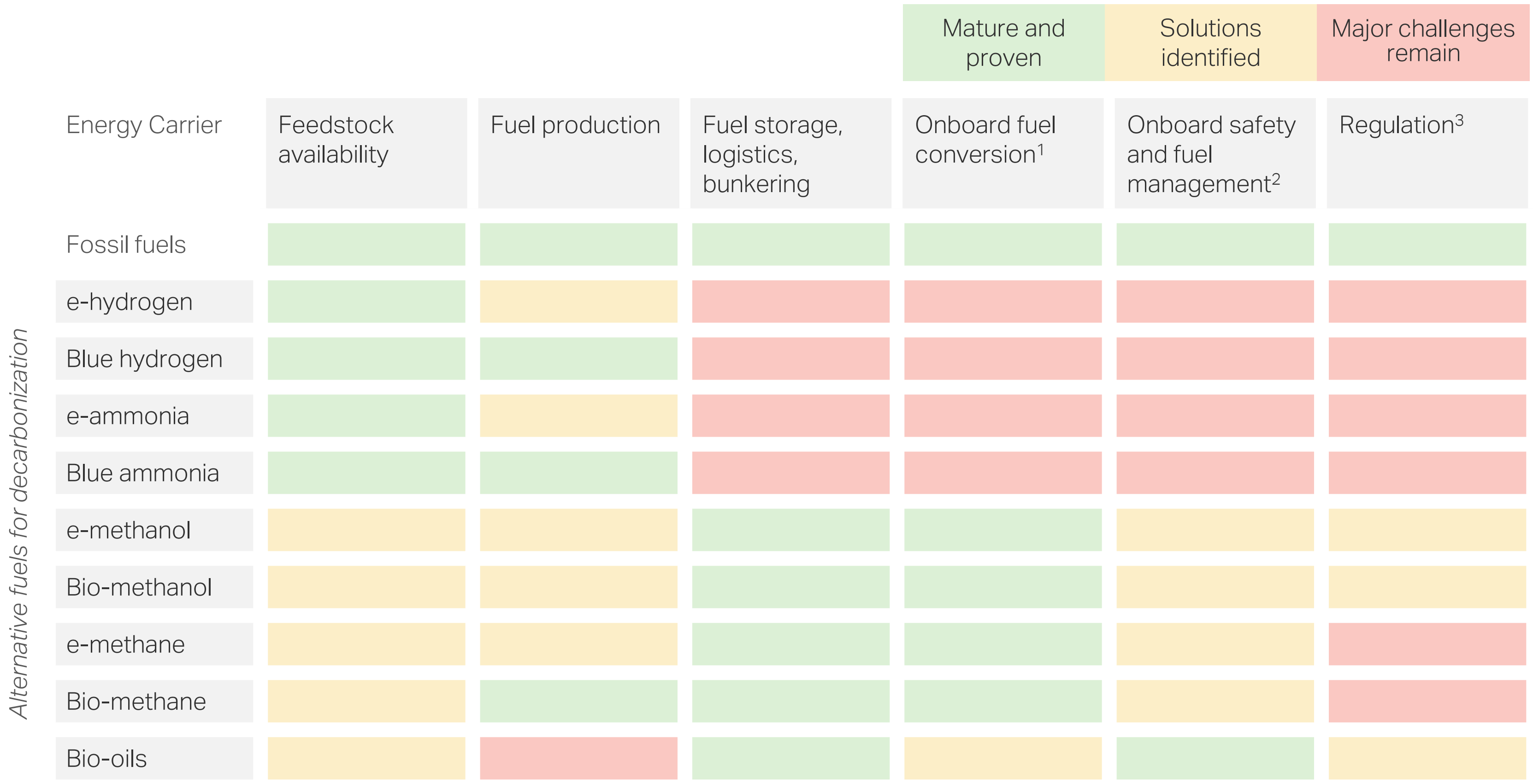


Source: MMM Center for Zero Carbon Shipping
1 Energy efficiency gains for individual ship types can be different. Attainable energy efficiency gains included above provides a global fleet perspective

Over the past decade, high bunker prices have been the main driver for the adoption of energy efficiency measures across the world fleet. Very often this was limited to low hanging fruits requiring little investment and quick returns. Expanding on existing energy efficiency measures by also recognizing their importance in reducing emissions, industry can increasingly share and adopt engineering best-practices. This can be further supplemented by accelerating the development of new radical onboard energy efficiency concepts.

Digitalization will also play a key role in reducing the energy demand on board vessels and fleets, with continuous optimization of vessel operations and smart business strategies on the trading patterns.

Decarbonization options using alternative fuels have varying maturity levels and challenges in the early years of transition



Source: MMM Center for Zero Carbon Shipping
Note: Emissions reduction impact from direct electrification of ships and nuclear-powered vessels is not modeled in NavigaTE 1.0
1 Considers onboard fuel supply and storage, fuel conversion and emissions control systems
2 Considers fuel toxicity, flammability and explosiveness
3 Includes regulatory framework supporting onboard regulatory aspects, and market mechanisms supporting adoption

Summarizing the knowledge, it can be expected that the future fuel pathways will include more options than known today.

Each of the known fuel and technology pathways are in theory possible, but each have challenges in terms of scalability, cost and technology maturity, including technical safety.

Finally, although the primary energies and fuels are made available, mature and proven, it is important to note that these will be in competition, when the sectors and nations of this world simultaneously progress through the green transformation.

What does it take to carve a path to zero in 2050?

In the previous chapter we outlined the many challenges in The Path We Are On to a zero-carbon maritime world in 2050. One of the challenges is that the eco-system wants to act but do not know where to start. This results in a 'wait-and-see' game, where all wait for others to act and hopefully be able to tag along.

In this chapter, we show the world that it is possible to choose a Path to Zero. We have identified Critical Levers in five different areas that the different participants in the maritime value chain can resonate with while recognizing the role they play in the transition. Though, with a forecasted emissions decline of ~20% compared to today's levels (a ~40 percentage points decline compared to the Path We Are On), we also recognize that more industry efforts will be needed to reach Paris climate targets. This points to the need for regulators, companies and end-consumers to act decisively. No one participant can carry the burden of the transition on its own.

This chapter illustrates how significant carbon pricing structures, regulation of energy efficiency on vessels and support to first-mover initiatives, can be used as the impactful extra efforts the industry needs to carve a path to zero in 2050. The road to zero emissions will likely include combinations of fuel pathways. The mix may be determined by factors such as primary energy availability, safety, cross-sector competition, regulatory standards and technological maturity.

No matter the path, the maritime industry energy demand will be met by a mix of alternative fuels, and never by one single winner alone.

Activating critical levers across five categories can drive emissions reduction for the maritime industry

1 Policy and regulation

- Policy and regulation can supplement, steer and accelerate transition to zero-carbon shipping.
- National and regional regulation is of great importance, but we need global regulation. IMO can level the playing field by introducing maritime **CO_2 pricing and tighter energy efficiency regulations.**

2 Tech advancements on ship

- There is potential to increase global adoption of energy efficiency technologies and best practices.
- Existing efficiency technologies are technically mature but not universally adopted. Unlocking these existing solutions could happen with better sharing of operational best practices, and broader acceptance of longer investment payback periods. Additionally, **new efficiency solutions** may become commercially viable for deep sea shipping.

3 Energy & fuel advancements

- Accessibility and availability of alternative fuels will **be largely dependent on scaling** of known, but not yet commercially scaled, technologies. This progress is needed to accelerate the decarbonization journey of the maritime industry.

4 Customer demand/pull

- Consumers are increasingly conscious about their carbon footprint. End-product-buyers are willing to change purchasing habits to meet new sustainability demands, while corporates increasingly focus on reducing scope-3 emissions.
- The pace of maritime decarbonization will increase if more consumers **demand zero-carbon transportation and become willing to pay a premium.**

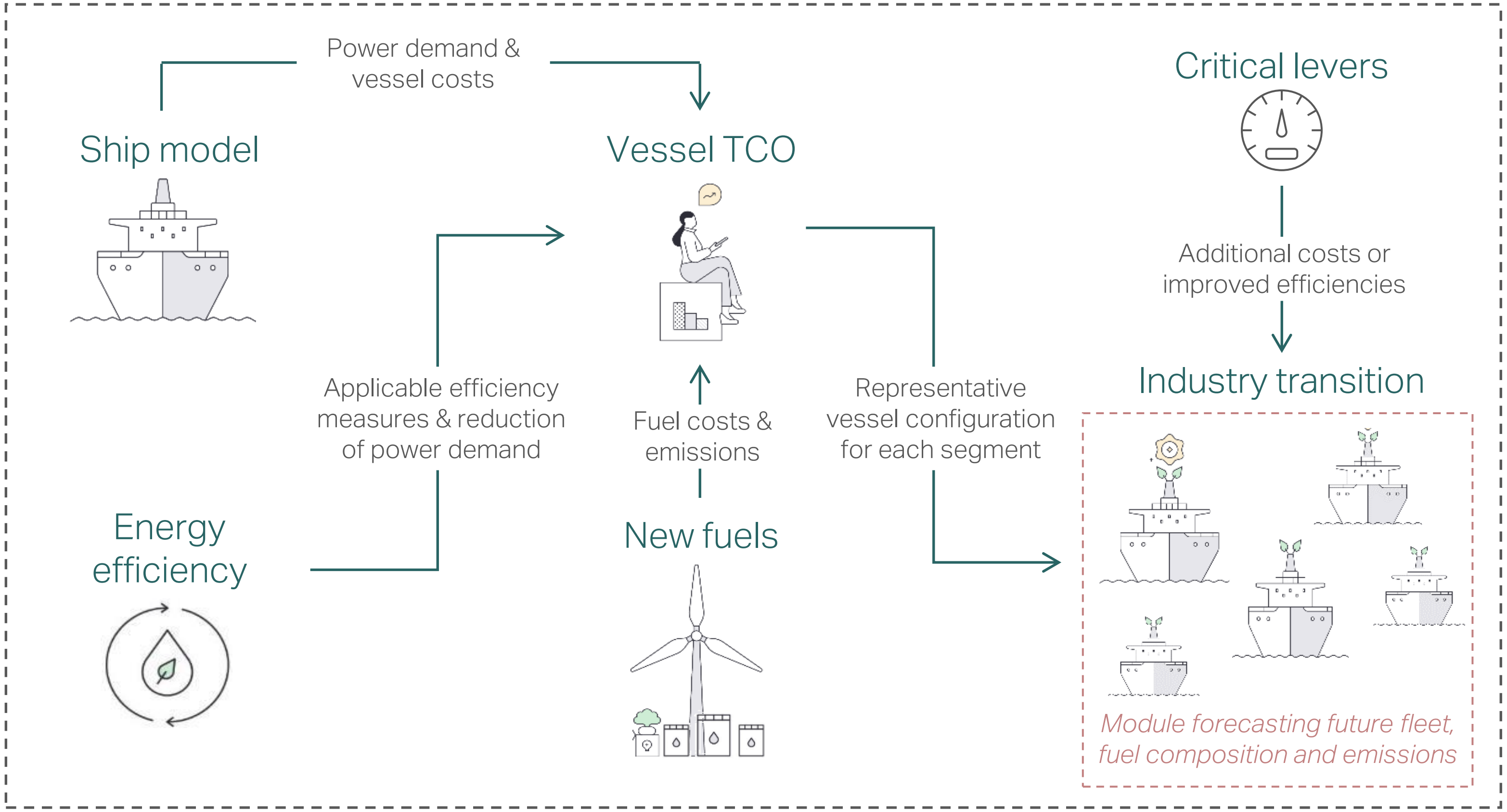
5 Finance sector mobilization

- Green and sustainability–linked financing is already widely used by other industries and is now gaining momentum in the maritime industry as well.
- The finance sector can steer and accelerate the transformation by **lowering finance cost** to finance asset and infrastructure development supporting decarbonization.

Source: MMM Center for Zero Carbon Shipping

Emissions reduction impact is analyzed using our techno-economic modelling tool – NavigaTE

NavigaTE: co-developed with Center Partners and independently assessed by Third party



The NavigaTE model consists of input from several modules translated into an Industry Transition model.

Variables input builds on external data sources (where available) as well as trusted assumptions and forecasts stemming from projects, data and analysis from Center Partners and the Center itself.[1]

The industry Transition model builds on key input from the TCO module and the critical levers:

- The TCO model enables ship level comparison of fuel and energy efficiency setup across ship types, sizes and over time based on the ship model, energy efficiency and new fuels
- NavigaTE is based on the principle that a vessel owner will shift to the fuels with the lowest TCO for the vessel ownership and operation, therefore the fuel cost becomes a key factor
- The Critical Levers can change a key assumption such as the cost of renewable electricity for fuel production and the regulatory efficiency demands or adding an emissions levy

Modelling constraint: forecasted costs of fuels, as well as critical lever outlooks, are based on trusted methods, data and assumptions of high quality but they are still uncertain.

Source: MMM Center for Zero Carbon Shipping, NavigaTE white paper (2021)
Note: Access and information on NavigaTE available here: www.zerocarbonshipping.com.
1. Individual partner data is aggregated and anonymized.

Positive, yet realistic, outlooks have been used when analyzing impact from critical levers

1 Policy and regulation

- IMO members can reach consensus on a **carbon pricing** scheme starting in 2025. Inspired by current EU ETS pricing levels we use 2020/21 **average of ~USD 50/ton CO_2 as benchmark**
- Further regulatory tightening of **energy efficiency measures** continues. Specifically, we model **continuous efficiency improvement and successful regulatory enforcement on new designs in an EEDI phase 4 post 2030 and a continued tightening of carbon intensity during operations (CII) until 2030.**

2 Tech advancements on ship

- Shipowners look for business cases with **further efficiency penetration of known measures**. Balanced between environmental and commercial necessity, investment pay-back periods may be extended from today's average of 2 years to 10 years.
- **New solutions development** in e.g. shipbuilding, propulsion, smart shipping, analytics, robotics, sensors etc., in conjunction with an increasingly skilled workforce may give significant energy efficiency improvements all the way up to 2050.

3 Energy & fuel advancements

- Energy & fuel advancements to scale the production and drive cost-down of different fuel types can drive decarbonization.
- For e-fuels, dedicated renewable energy access is available. We model a scenario where **renewable electricity costs continue with significant declines towards** 2050.
- For biofuels, technological advancements continue, however supply will be **constrained** by **biomass availability** and **cross-sector competition**

4 Customer demand/pull

- Customer willingness to pay (WTP) differs across products; the closer the end-user to the supply chain, the higher WTP premium. In maritime terms, this would imply more appetite to pay green premiums in some vessel segments (e.g., containers) than others.
- Each sector is thus modelled separately but weighed together by segment size. Our outlook suggests maritime customers paying an average **green premium of 12% on 50% of total global ton-miles** in 2050

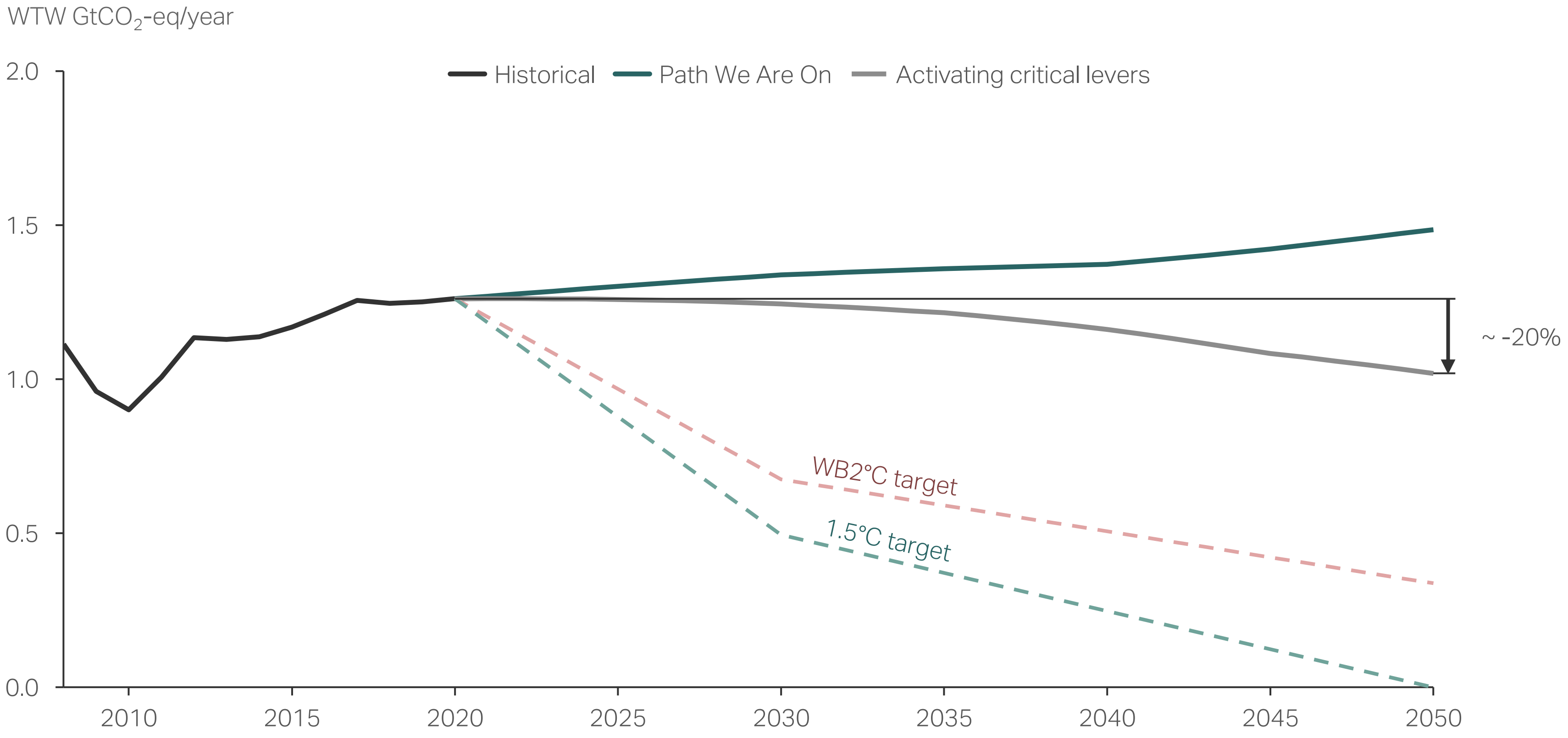
5 Finance sector mobilization

- Major financial institutions are reallocating own- and customer portfolios with the aim to reduce carbon footprint. Applied to the industry weighted cost of capital (WACC) at 7% we add discounts for green financing, rewarding those having clearly defined abatement targets. We use an **average discount up to 250 basis points (2.5%) in 2050** for vessels sailing on alternative fuels.

Source: MMM Center for Zero Carbon Shipping.
Note: These projections and outlooks are subject to significant uncertainty, predominately linked to the evolution of global environmental regulation and enforcement, global trade developments and the cost and competitiveness development of alternative fuels. More information on each individual lever is presented in the Deep-dives section.

The analyses suggest emissions decline, but more efforts are needed to reach Paris climate targets in 2050

Emissions reduction impact, when all critical levers are activated together



Source: NavigaTE

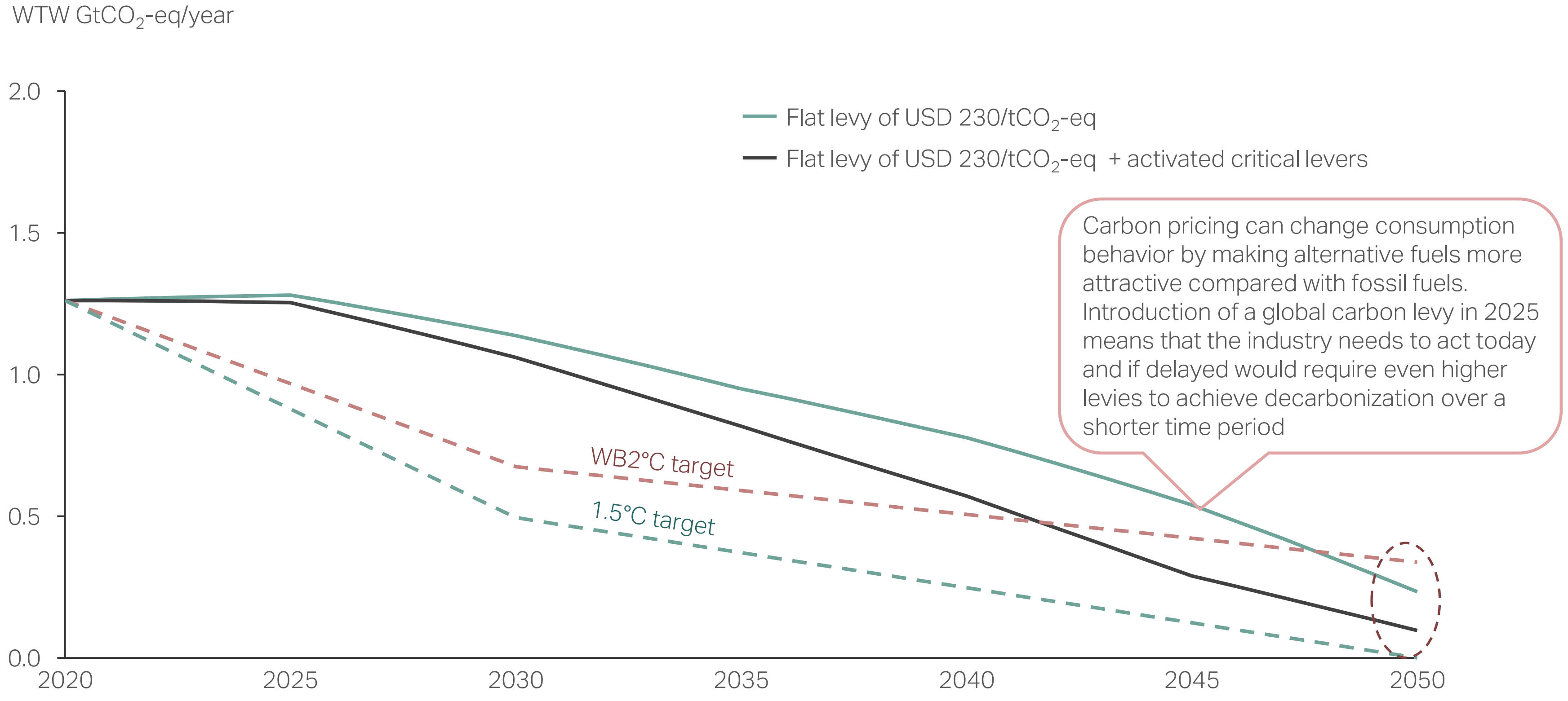
Evaluated one by one, there is no single critical lever which by itself leads to the emissions impact needed for maritime to become net-zero by 2050. An impact will be achieved when all levers are activated (~20% compared to 2020), but effects are still far from the targets of the Paris accord.

More specifically, the 2050 abatements will be just about a quarter of what it takes to reach the well below 2°C pathway and one-fifth of what it takes to be carbon neutral. Accelerating the transition and bringing the maritime industry towards net zero carbon will require much more than what we have modeled as probable and realistic outlooks on the critical levers.

On the following pages we will further explain on what it takes to carve the path(s) to zero in 2050.

Global carbon pricing can be an effective regulatory measure on a Path to Zero

Introducing a significant flat global levy by 2025 can take us to net-zero in 2050



Source: NavigaTE

1 When introducing a levy, the authorities sets the price of carbon and the resulting market forces determine how much of emissions are reduced. While in an ETS scheme the government caps total emissions and issues permits to emit up to that amount. Businesses can trade the permits, so the market determines the price of carbon. Ultimately, the schemes differ if it is price, rather than the cap, that determines the level of emissions There are positive elements and negative elements to both schemes and neither scheme is proven to be better than the other.

2 Consisting of 31 ETSs and 30 carbon taxes and covering 46 national and 32 subnational jurisdictions. Read more in State and Trends of Carbon Pricing, World Bank (2020) and Getting real on meeting Paris climate change commitments , IMF, Lagarde & Gaspar (2019).

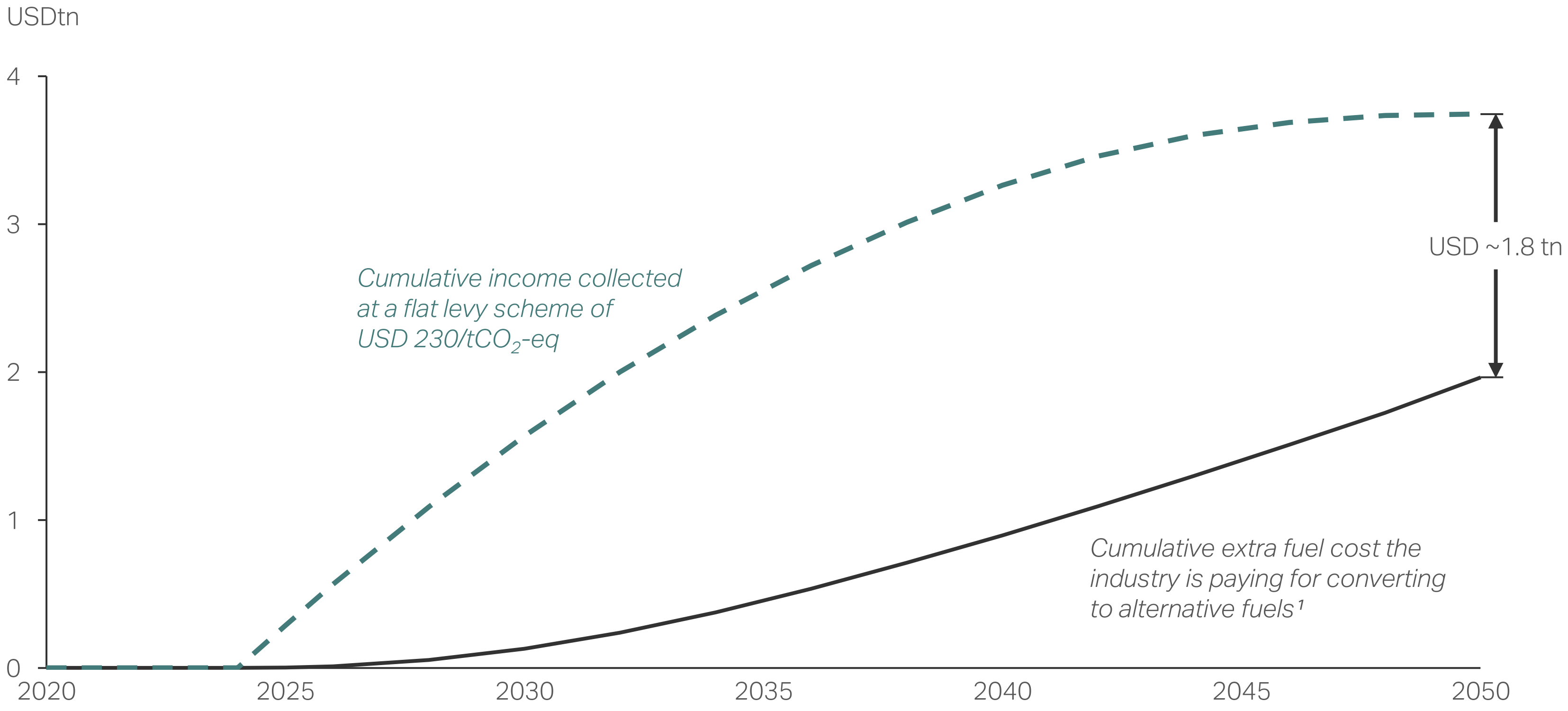
Emission levies and emissions trading schemes (ETS) are based on a simple logic: a price on carbon helps shift the cost back to those who emit, and who can act to reduce it.[1] 61 schemes are now in place or scheduled globally, covering about 22 percent of global emissions. A good progression, but far from enough and largely not including the maritime industry.[2]

In our analysis we limit the research to focus on the impact of emissions levies as such solutions currently stand out as the most debated and analyzed global carbon pricing option (e.g., by IMO, World Bank and industry itself).

Based on the consideration of anything less than 0.1 $GtCO_2$-eq qualifying as net zero emissions our analysis shows that a flat levy of USD ~230/tCO_2-eq by 2025, in combination with activated critical levers, results in the abatement needed towards 2050.

Collected revenue from a flat carbon levy will be much higher than what is required to bridge industry's fuel cost gaps

Accelerated excess cost to the industry can reach USD 1.8 trillion



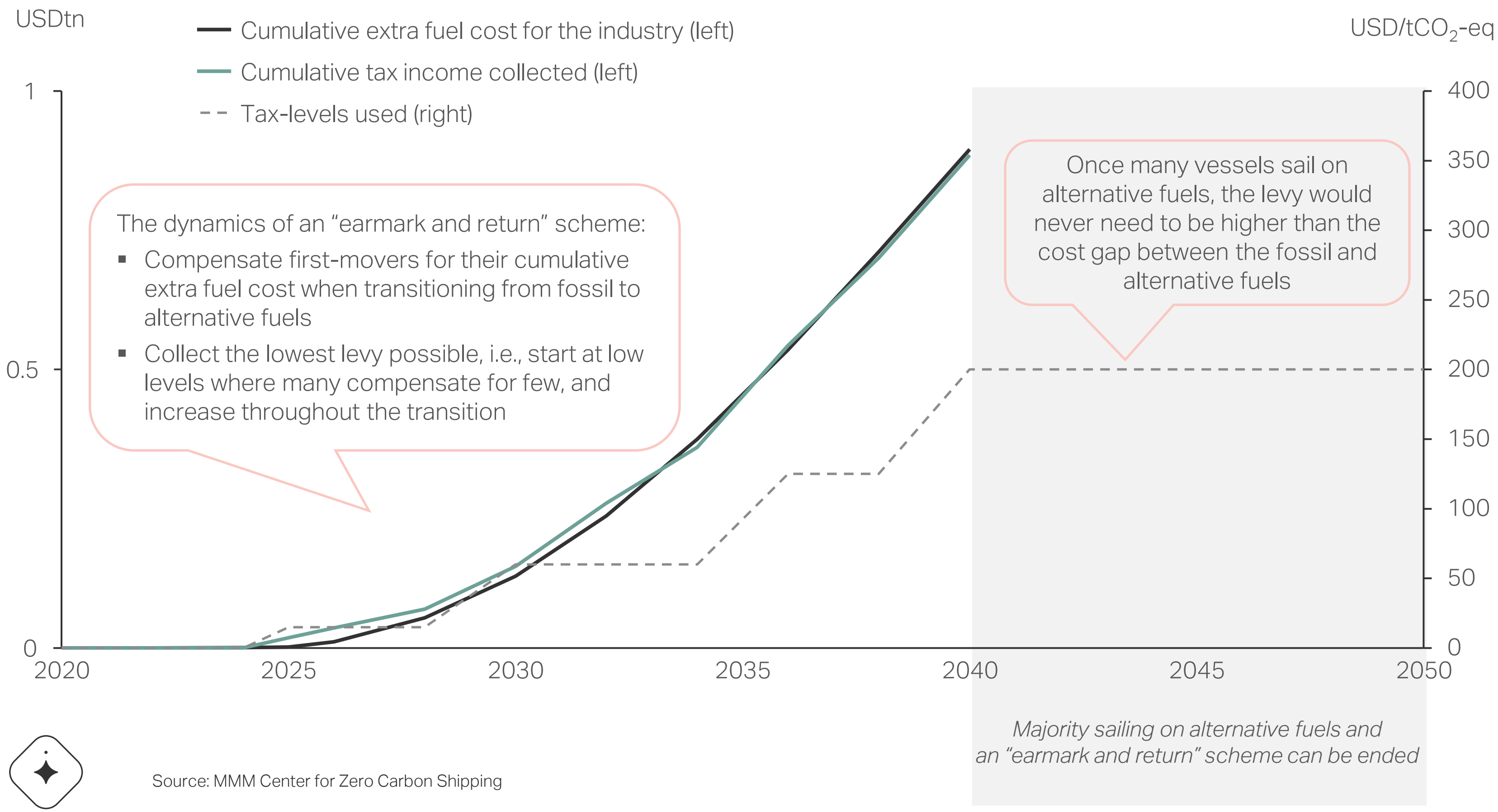
Source: MMM Center for Zero Carbon Shipping
1 Measured as the cumulative fuel cost difference the industry needs to pay converting to alternative fuels, compared to if they continued to sail on fossil fuels.
2 Note that the ~ USD 230/tCO2-eq levy is based and modeled on current outlooks (global trade growth, fuel and electricity prices, fuel availability, development on critical levers etc). Significant changes in these variables will thus directly also impact the levy level needed to reach a Path to Zero.

A flat levy of ~ USD 230/tCO_2-eq sufficiently penalizes fossil fuel usage by bringing costs up on par with the alternative fuels.[2] With most vessels operated on fossil, the cumulative CO_2-eq income collected from a levy will quickly grow large while tapering off further into the transition (green dotted line).

At the same time, opposite logic follows on the cumulative industry fuel costs when transitioning from fossil to alternative fuels: at first only a small number of first-movers carry an extra fuel cost when using the more expensive alternative fuels. The more vessels that switch to alternatives, the larger becomes the cumulative cost that the industry is paying to become carbon neutral (black line).The difference between the two lines thus signals the inefficiency arising when using a flat levy, and where a significant extra cost is added on the industry.

Lower carbon pricing levels can achieve the same result, if income is earmarked and returned to the industry...

Theoretical explanation of the dynamics of an “earmark and return" CO2-eq pricing scheme



Source: MMM Center for Zero Carbon Shipping

One of the benefits of a flat levy is its simplicity; it will remain the same every year. Though, opponents argue that it places an excessive burden on the industry forcing it to pay more than what is needed to secure a transition. In a revenue neutral scheme authorities instead earmark the income collected and return it back to early adopters (i.e., instead of mainly using a pricing scheme to penalize the use of fossil authorities now also encourage the use of alternative fuels by choosing to compensate the first-movers willing to run on such more costly fuel types).

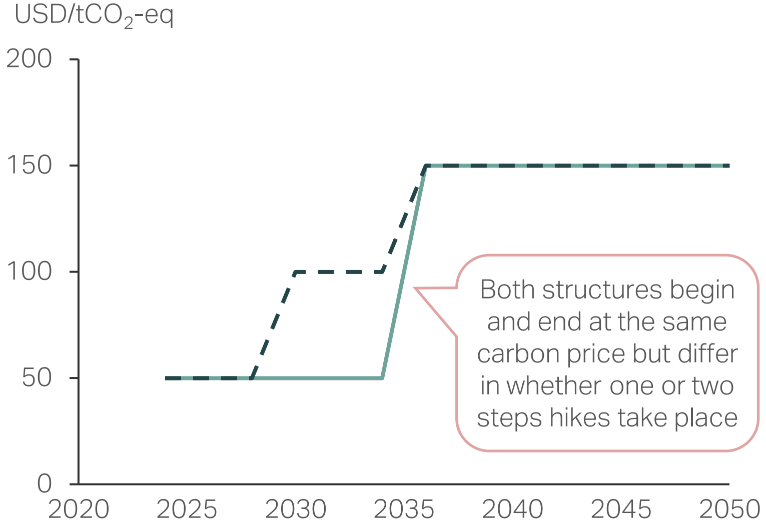
Based on such earmark and return logic, the levy needs just to be large enough to cover the fuel cost difference that the industry faces when switching to alternative fuels. Hence, it can start at much lower levels (many compensating the few) and then be increased over time to secure that the levy income from the fewer fossil fueled ships always can compensate for the extra costs of the (many) alternative ones.

Additionally, once most of vessels run on alternatives, a compensation to first-movers will no longer needed. Instead, a flat levy that closes the cost gap between fossil and alternative fuels can be collected.

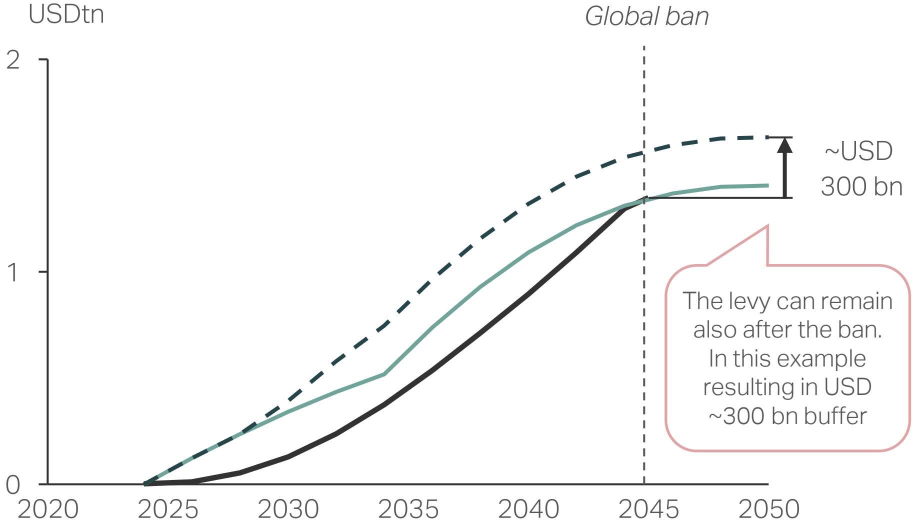
... and sequencing such pricing schemes with a ban can motivate levies in the range of USD 50-150/tCO_2-eq

Sequenced pricing and ban can level the playing field for industry participants and nations

The regulator can start by imposing an “earmark and return” global carbon levy system...



...and then follow it up with a global ban on fossil fueled vessels once majority of the fleet has transitioned to alternative fuels



An earmark and return scheme should aim at being stable, predictable and easily administrated. E.g., a simplified scheme with a levy growing with one or few hikes.[1]

Clarity on how long an “earmark and return” scheme will continue can be created by introducing a fixed end date for the scheme and a ban on new fossil fueled vessels. Such system would:

- Compensate first-movers
- Send a clear regulatory signal that fossil fuels are not part of the future
- Avoid the risk of switching back to fossil fuels once the return scheme ends
- Allow collection of extra income (i.e., a buffer) that in turn may be used to level the playing field[2] by funding developing countries, accelerating retrofits, building infrastructure, R&D, etc

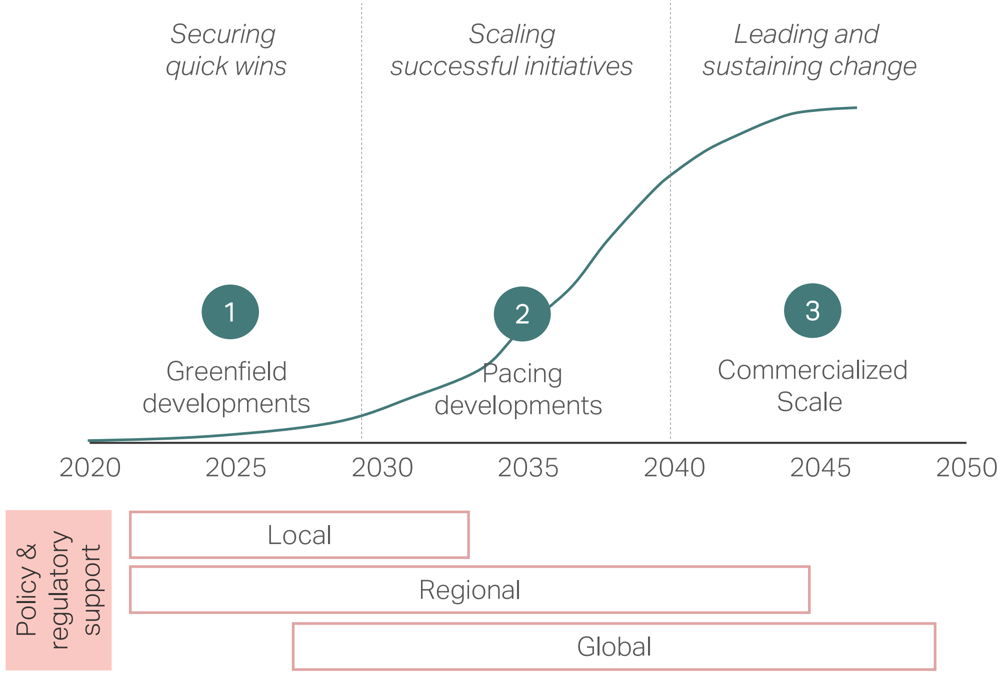
Source: MMM Center for Zero Carbon Shipping

1 This setup also addresses other key abatement considerations such as: price on emissions needing to be raised over time to reflect the growing damage expected from climate change, then sending a signal to emitters that they will need to do more to reduce emissions.

2 How to tackle disproportionate negative impacts is one of today’s most disputed topics on carbon pricing. Recent discussions have specifically targeted questions of how to best create a level playing field for the maritime industry, and in what way any negative CO_2–eq levy impact should be measured and compensated, e.g., how differences in socio-economic progress, remoteness to main markets and transport dependency should be considered when forming emissions pricing schemes.

Moreover, recognizing first movers' efforts could serve catalytic in accelerating learning rates and cost-out potential

First-movers enable growth and development of new innovations



Source: MMM Center for Zero Carbon Shipping

S-curve pattern of initiatives highlight the fact that an industry and its products, technology and business models evolve over time. In this respect, the maritime industry will be no different from any other industry, meaning that where you are on the S-curve, as well as how you grow and shift with it, will be important.

1. Green-field developments and initiatives – recognizing first-movers with local/regional support. Green-field developments are associated with uncertainty on long-term potential. Therefore, recognition and support of these early projects improve the probability of transition pathways being materialized in the long term. Authorities can assist in this process by recognizing the importance of first-movers while also de-risking investments.

e-methanol example: A ship owner, local e-methanol producer and national/regional authorities join forces to prototype and scale decarbonization technologies

Ship owner...

- ..takes the risk by buying a new vessel
- ..signs a long-term e-methanol supply contract
- ..builds on growing no. of customers willing to pay a green premium

e-methanol producer...

- ..develops and scales proven technology; thereby driving cost-down
- ...secures long-term offtake contract for e-methanol
- ...proves commercial viability of emerging small-scale technology

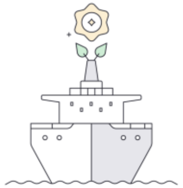
Authorities...

- ..ensure (scalable) foundation for infrastructure and operations
- ..map and address possible regulatory gaps (e.g., safety standards)
- ..(Possibly) subsidize ship owner/fuel producer

Cost-reduction and risk mitigation arising from sector-coupling opportunities

In addition, investments targeted at lowering industry's energy demand would be effective in driving the transition

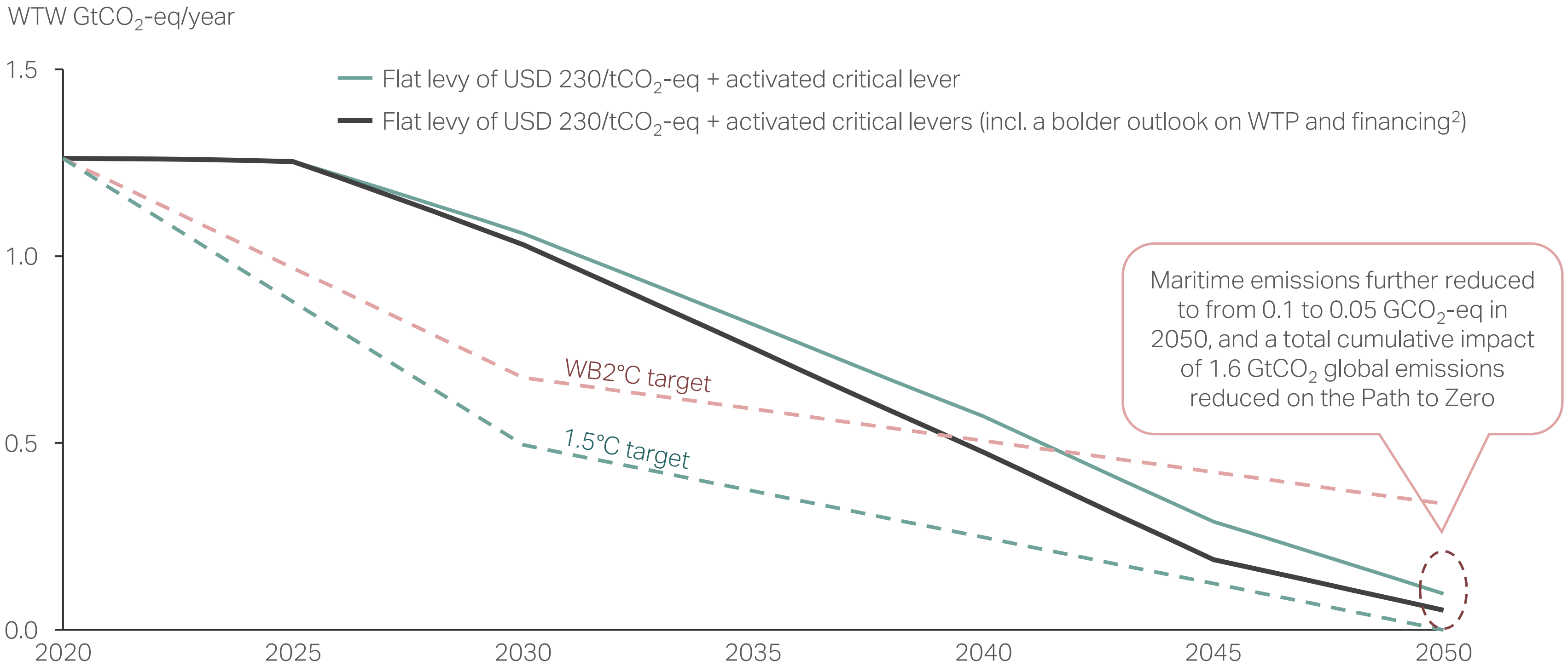
Emission savings potential if USD 20M is invested in one of three alternatives

		Using USD 20M...	Results in ...	Lifetime emissions reductions potential[2]
	Investing in **more efficient newbuilds**	... to install **air lubrication** on 10 container vessels, obtaining 4% propulsion power savings ...with expected lifetime of 25 years	**~5,300 tons/year** of LSFO saved ~16,600 tons/year of CO2-eq saved	~415,000 tCO_2-eq
	Investing in **retrofitting** energy efficiency technologies	...to install **flettner rotors** on 6 tanker vessels, obtaining 8% propulsion power savings ...with expected lifetime of 20 years	**~2,900 tons/year** of LSFO saved **~9,000 tons/year** of CO2-eq saved	~180,000 tCO_2-eq
	Securing a long-term procurement contract **buying green ammonia** to operate a ship at zero carbon	... to procure **~25,500 tons** of green ammonia over a 10-year period ...with average production cost **~42 USD/GJ** over the period	**~1,100 tons/year** of LSFO saved **~1400 GWh** of clean electricity consumed to produce the ammonia	~35,000 tCO_2-eq

Source: MMM Center for Zero Carbon Shipping
1 Emissions lifetime savings potential of investment option one - more efficient new-buildings - is assumed to be 25 years. The two other investment options assume a 20-year investment lifetime.

Higher consumer premiums and lower financing costs are effective, but industry cannot transition relying on them alone

Impact on emissions if customers' WTP is increased and green finance lending made cheaper



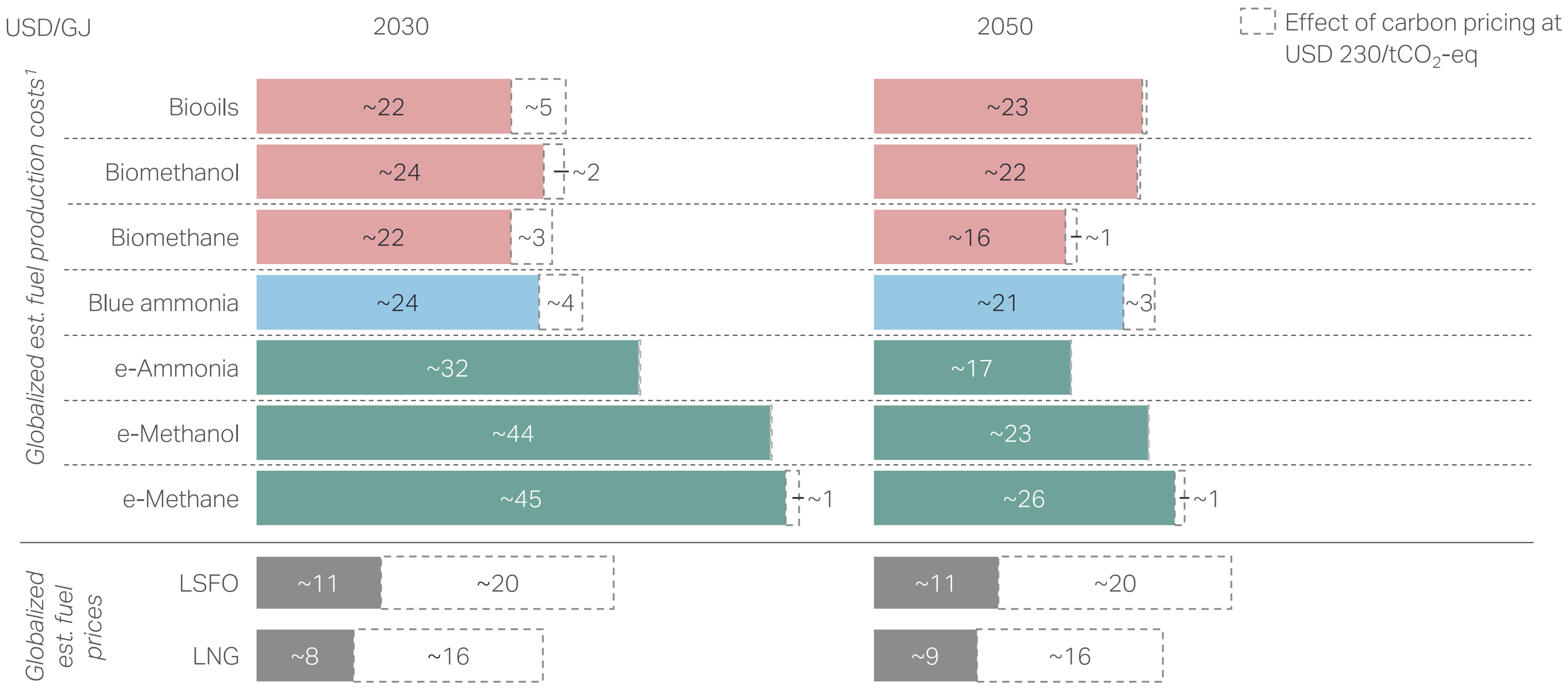
Source: NavigaTE
1 Ability gets defined by the proactiveness to reduce scope-3 emissions while capability stems from the type of product being transported (low- or high margin products) and type of customer being the receiver (the closer the end-user is to the supply chain, the higher their WTP).
2 More information on financing availability and customers' willingness to pay is found in the Deep-dive section.
3 Our more positive outlook involves customers increasing the premium paid from 12 to 25% (the will to wallet share remains unchanged, meaning that 50% of total global ton-miles have a customer premium paid in 2050), and the financing discount is increased from 250 to 500 bps).

Industry participants may flirt with an over-reliance on customers' willingness to pay (WTP) for green transportation. Customers' appetite to pay the green premium is driven by their ability and capability to pay.[1] While surveys increasingly point to consumers being willing to change their habits to reduce emissions, research shows also that surprisingly few consumers walk the talk.[2] And if they do, premiums added are not always as large as hoped for.

Our analysis suggests that a significant difference in emissions can be achieved with dramatic changes in WTP and financial costs.[3] But for the reasons above, we argue that industry should not solely rely on these critical levers to lead decarbonization of the maritime industry.

With all critical levers activated and an ambitious carbon levy, several fuel options will take part in the future fuel mix…

Global carbon pricing can lift competitiveness of alternative fuels, thereby drive wider adoption



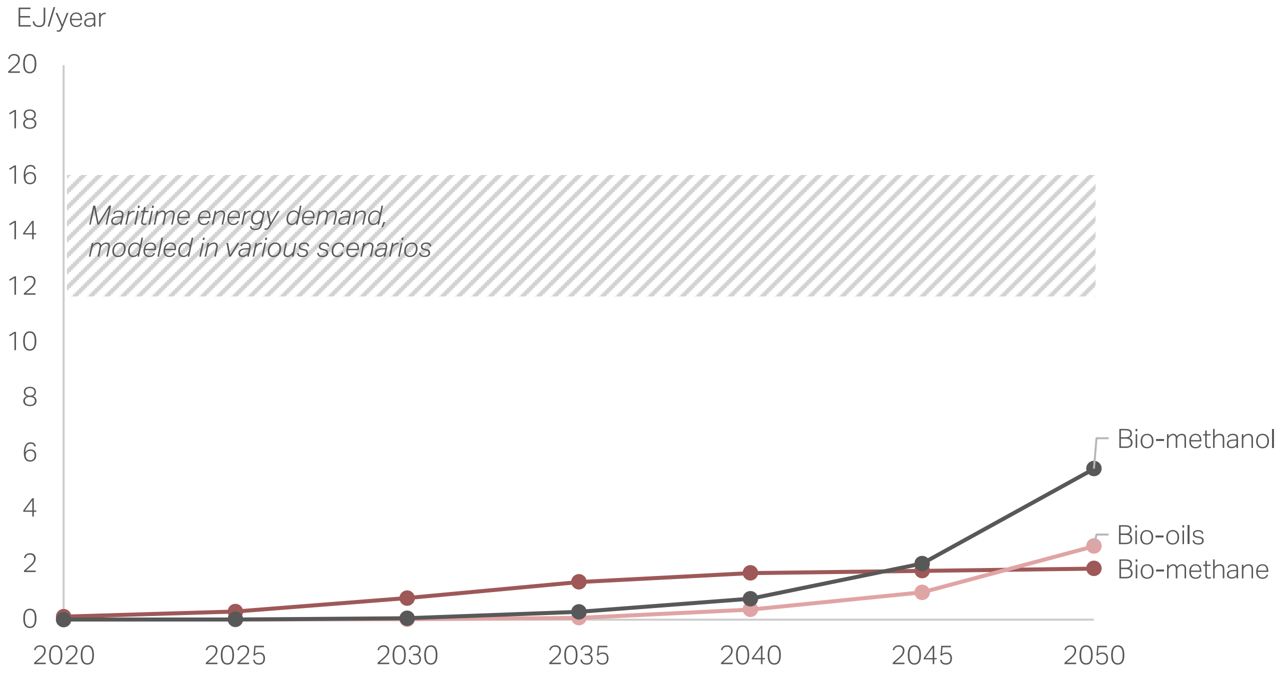
Source: NavigaTE.
1 For non-subsidized, world scale, stand-alone plants. Renewable LCoE at activated critical lever levels
2 See Appendix A3 for more details on the higher vessel CAPEX for using alternative fuels

Biofuels and blue fuels will show the lowest cost gap to fossil fuels already in 2030 and all the way to 2050. Some of the key trends and main cost drivers of the alternative fuels are outlined here:

- **Biofuels:** will be cost competitive by a large margin, but scaling constraints will affect global supply, maritime availability and price (see next slide)
- **Blue fuels:** costs for natural gas as a feedstock, carbon capture and permanent storage are key drivers. Implementation will also require establishment of global regulation to manage risks at various parts of the blue supply chain (e.g., liability of carbon storage) and to support technology investment
- **e-fuels:** reduced cost of electricity lowers production costs throughout the period. Among these fuels, e-ammonia will have the lowest cost per energy unit, likely off-setting the higher vessel CAPEX[2]. Availability of biogenic CO_2 sources will challenge the competitiveness of e-methanol and e-methane. Safe handling and operations represent a barrier for e-ammonia.

…however, biofuels' role in the transition may be constrained by feedstock availability and technology scale-up limitations

Modeled maximum boundaries for biofuel supply available for the maritime industry



Source: MMM Center for Zero Carbon Shipping
Note: See Industry Transition Scenarios- Fuel Options Position, by MMM Center for Zero Carbon Shipping (2021) for more details on future biofuel availability and constraints. Methane slip emissions from upstream production of bio-methane is addressed to prevent adverse environmental effects. It is also included where relevant in vessel technologies e.g., internal combustion engines burning methane. A global warming potential (GWP) factor of 100 years is currently used. To simulate competition with other industries we set a maximum percentage of the maximum supply of biofuels which the maritime industry could obtain. We also project that the maritime industry could benefit from a first-mover advantage gaining higher access than its current volume share. We therefore set a maximum limit where maritime market share can double from today's levels.

Almost starting from zero

- Today, global sustainable biofuel energy production sums to 1-2 EJ per year

A limit to global sustainable biomass availability

- A limited amount of biomass can be used for biofuels without compromising sustainability, food production and biodiversity
- This sets a maximum volume of biofuels available for all industries and suggests an upper limit of ~75 EJ of global sustainable biofuel production by 2050

Scaling takes time

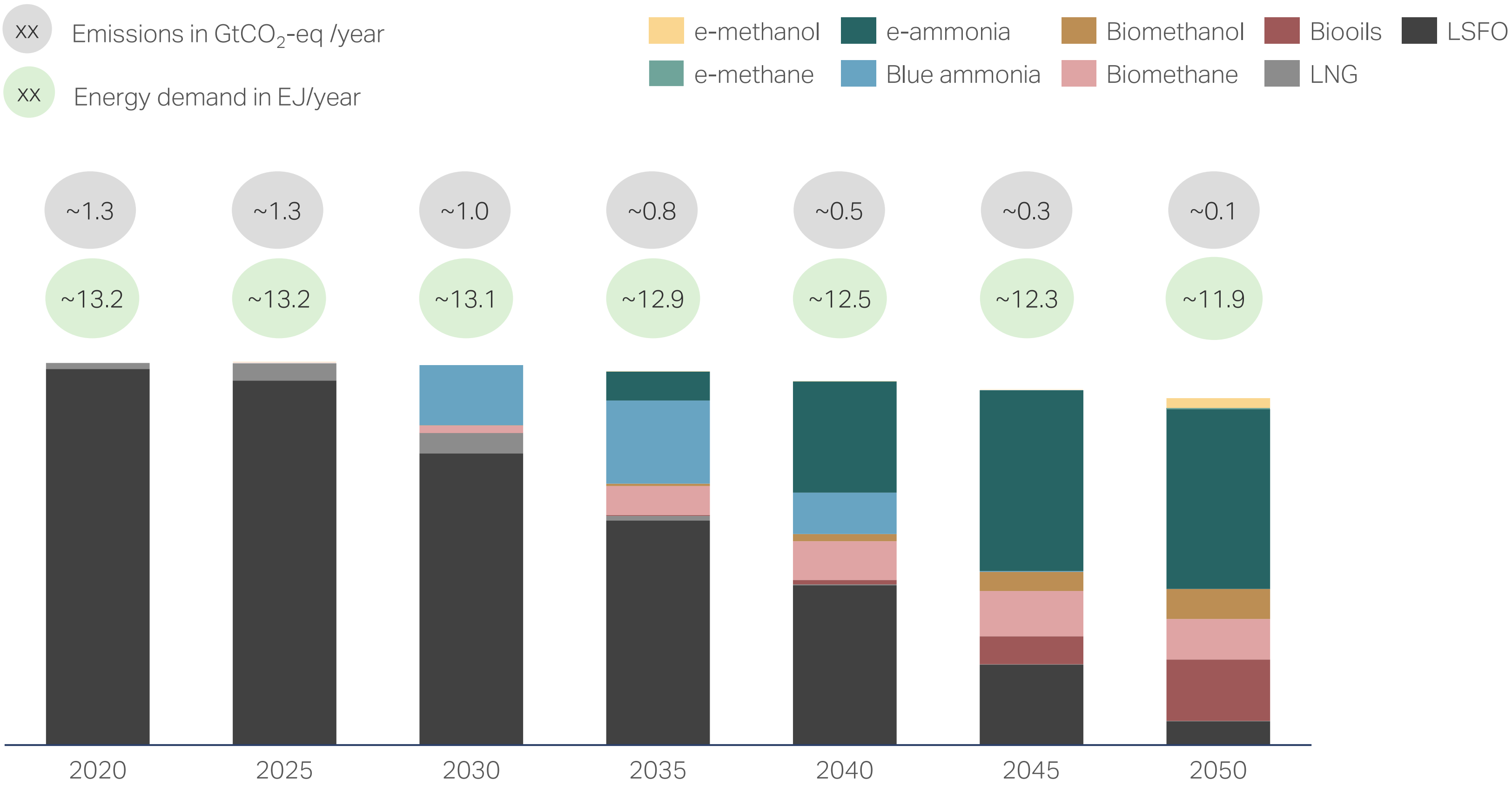
- Most biofuel value chains are still immature
- Rapid scaling is needed to support decarbonation of the global industries
- The speed of scaling will determine the timing of biofuel availability

Competition for biomass and biofuels between industries

- Many global industries are decarbonizing towards 2050
- Especially hard-to-abate sectors (aviation, cement production etc.) will be looking to biofuels for their non-electrifiable energy needs
- This creates competition for sustainable biomass and biofuels and may limit the availability of biofuels for shipping[1]

This means that ammonia may likely play a notable role while transitioning on a path to zero in 2050

Scenario: Activating all critical levers and introducing a flat global carbon levy of USD 230/tCO_2-eq



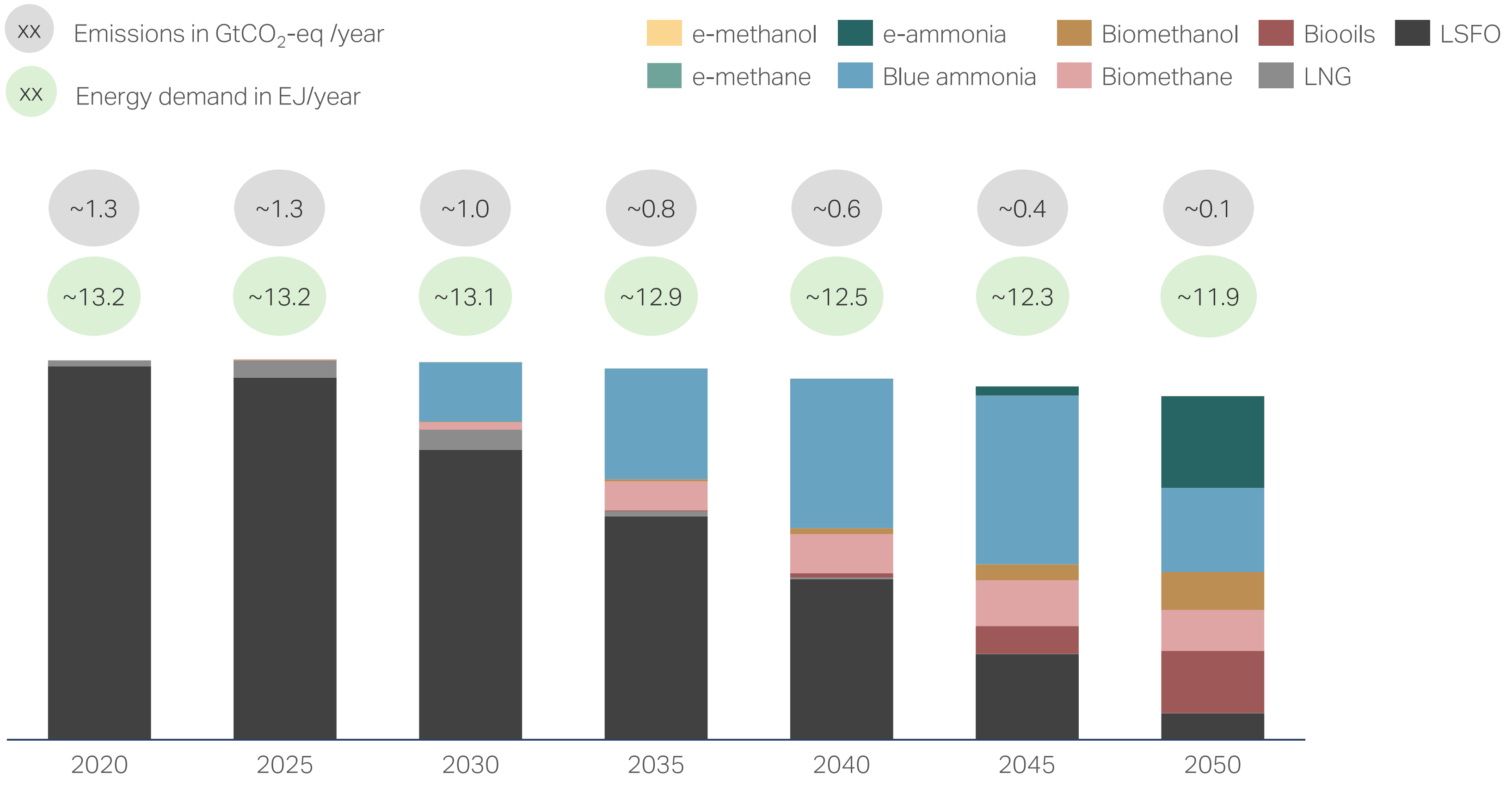
Source: NavigaTE
1 Read more about ammonia cost assumptions in Appendix A4.

Ammonia may play a central role in meeting the maritime industry's overall energy demand during the transition on a Path to Zero. Ammonia's share in the fuel composition could steadily increase from ~16% in 2030 to just more than half in 2050. This has two main reasons – firstly, ammonia may be the cheapest e-fuel (fuel cost and vessel TCO) and secondly, ammonia may be the only relevant blue fuel.

Biofuels likely play a role as their production throughput, technological maturation and supply chains reach necessary scale: bio-methane with a primary role from 2030s, and bio-methanol and bio-oils impacting the fleet mix from 2040s. Lastly, other e-fuels (e.g., e-methanol) may not play a significant role in early years of transition, because of lack of cost-competitiveness[1]

Blue fuels may play a role if they are scalable fast or if cost-down of renewables is too slow

Alternative Scenario 1: All else equal except that critical lever on renewables LCoE is not activated



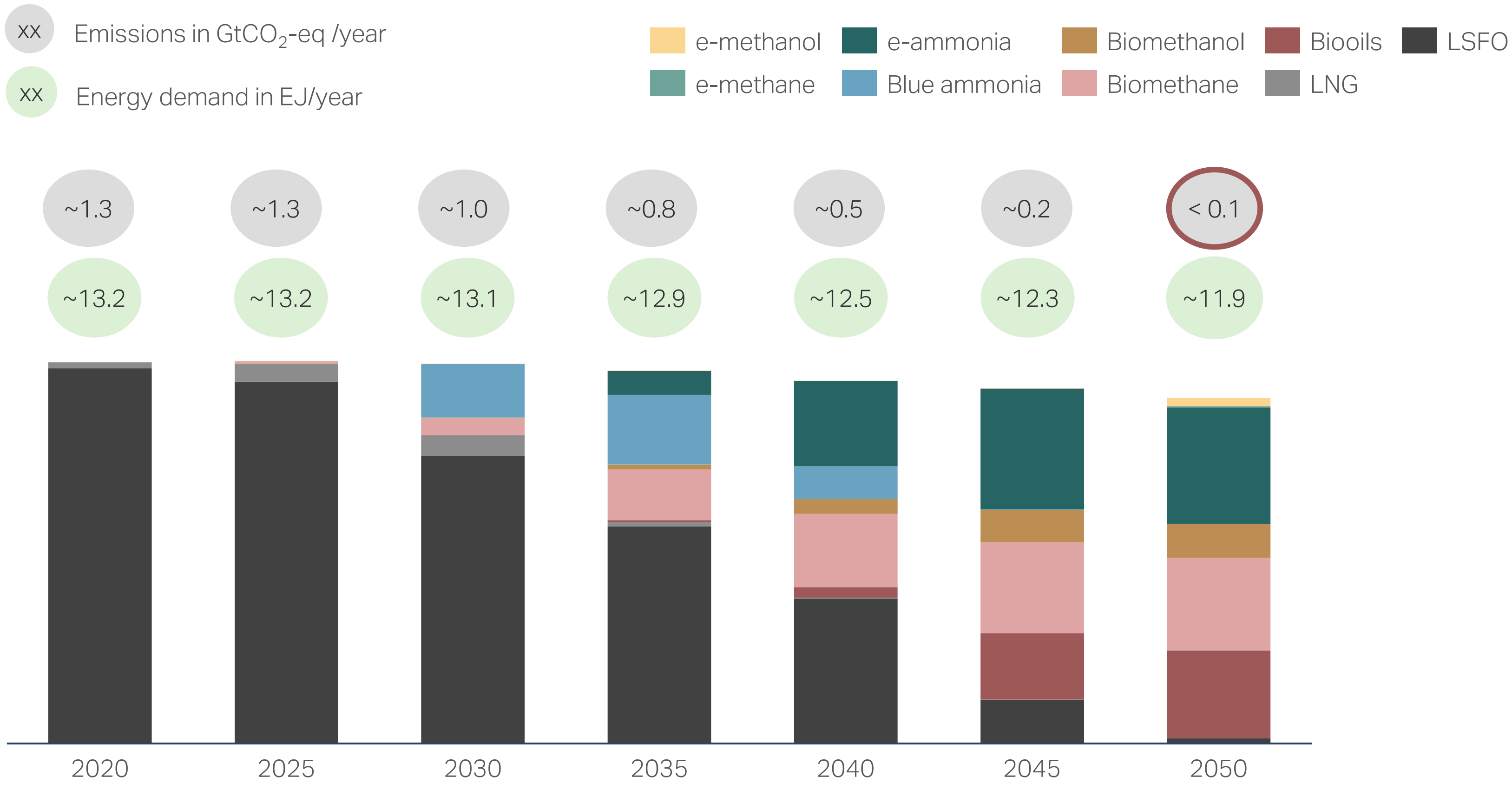
Source: NavigaTE

There are two main drivers that can make blue ammonia play a larger role in the fuel composition during the transition – (1) higher renewable energy costs making e-fuels less cost-competitive and (2) no or limited activation of accelerated scale-up of renewable energy capacity. Though blue ammonia does lead to GHG emissions, the overall emissions are below those of fossil fuels. This results in blue ammonia in the maritime fuel composition leading to lower GHG emissions in the early years of the transition.

However, there remains two specific challenges impeding blue ammonia adoption – (1) lack of industry standards for proven permanence of Carbon Capture and Storage (CCS); (2) mitigation of upstream methane emissions to eliminate harmful environmental impact.

Biofuels could be widely used if production capacity is scaled up faster than expected

Alternative Scenario 2: All else equal combined with doubling of bio-fuels supply for the industry



Source: Clarksons (2021), NavigaTE

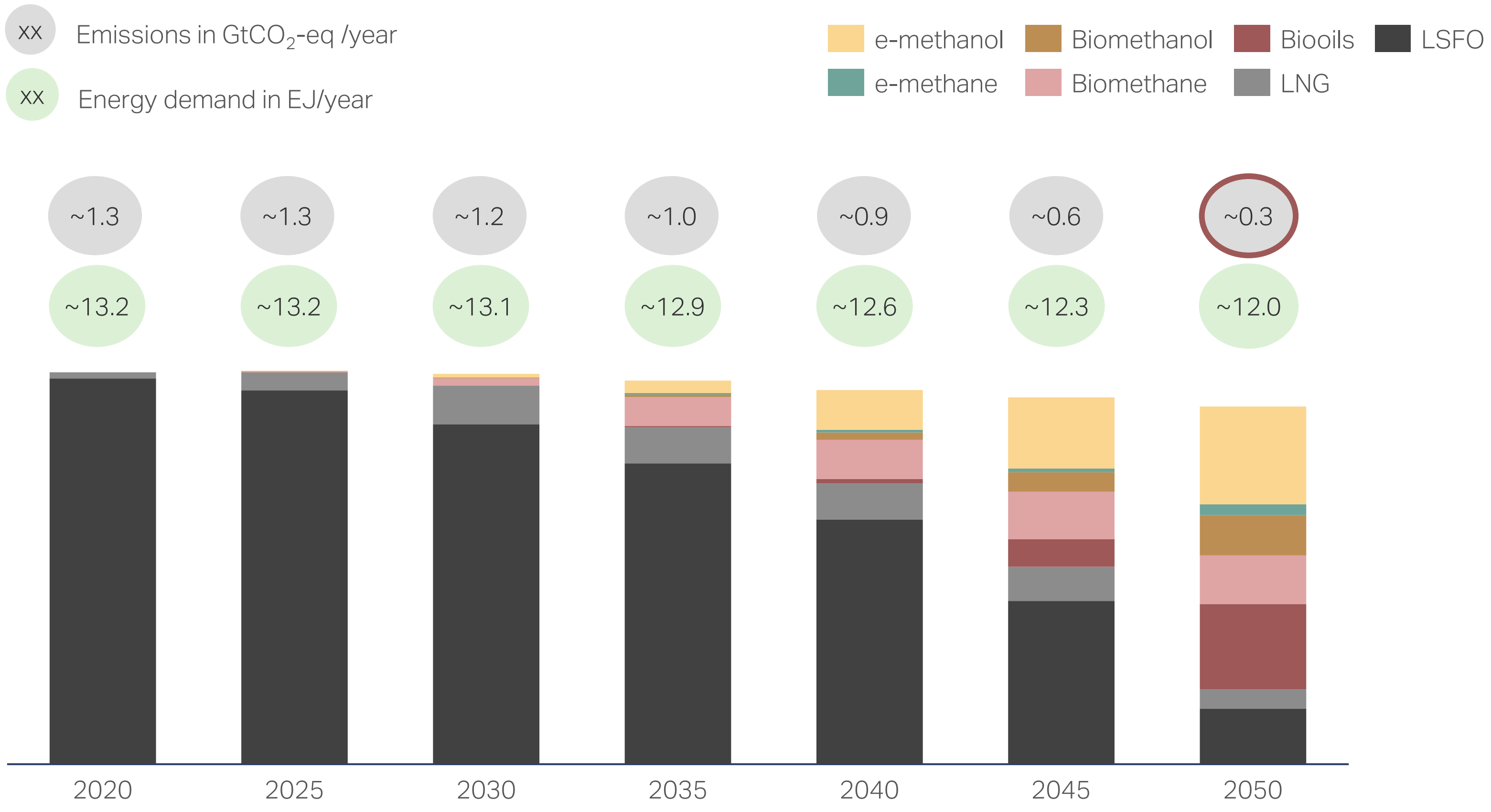
1 Methane leakage from biogas production must be mitigated. Bio-methane trading certificates will be required for reaching commercial scale

Biofuels availability for the maritime industry may not be limited by their cost-competitiveness but more likely by their availability at scale. Consequently, if supply could increase twice as much of projected biofuels available to the maritime industry, emission would further reduce to below 0.1 $GtCO_2$-eq /year. In a global maritime fuel composition context this scenario will result in a steadily increasing share of bio-methane and more bio-oils in later years of the transition.

In 2020, ~1500 bn ton-mile traded on LNG fueled assets and the LNG fleet grew by ~5% y/y to just below 600 vessels. This means that the newbuilds from 2020s will still be operational by 2050. Seen in isolation the potential utilization rate of these ships may fall if LNG demand wanes. However, these vessels can also sail on bio-methane[1] thus securing their long-term deployment.

Additionally, if ammonia is not accepted as a safe marine fuel, then other fuel options would drive the transition

Alternative Scenario 3: All else equal except that ammonia is not classified as a safe marine fuel



Source: NavigaTE

If ammonia does not meet the safety standards for storage, handling and operations onboard, overall maritime emissions may well increase.

This would result in a fuel composition where almost half of the fuel mix is supported by biofuels and a third by e-fuels such as e-methanol and e-methane.

As previously argued, the Center does not consider any global maritime emission level above 0.1 $GtCO_2$-eq in 2050 qualifying as net zero emissions. Notably, the ~0.3 $GtCO_2$-eq/year emissions is not in line with the abatements needed to follow a Path to Zero. Further regulatory focus in the form of even higher emission levies than those discussed earlier and/or tighter energy efficiency regulation thus seems to be justified in a scenario where ammonia is not accepted as a safe marine fuel.

In summary, success in four areas is needed to make the transition happen

A level playing field with global regulation

Global regulation is critical in order to ensure a level playing field, inspire investor confidence and accelerate technological developments. For example; a carefully designed global carbon pricing structure has the potential to create a level playing field for industry participants and nations.

Energy efficiency support across the value chain

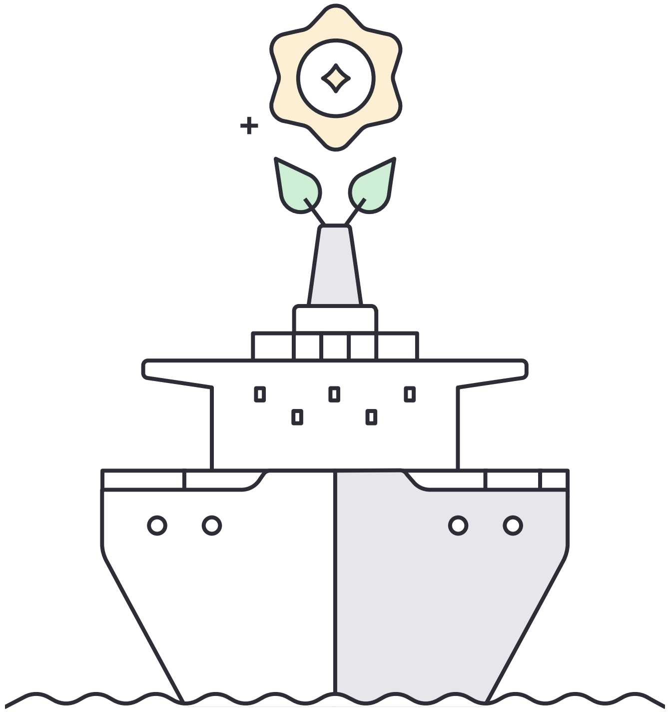
Energy efficiency deployment is needed to reduce overall industry energy demand. Focus on energy efficiency can maximize primary energy conversion to new energy carriers. To exploit EE's potential industry should focus on resolving current challenges preventing wider adoption, tightening of regulation and foster new EE technology innovation.

Support to first movers

The green transition may be costly and uncertain. Industry needs a blueprint, such that industry participants can embark on the green transition. This means that first movers along the value chain need support enabling investments, allowing innovation of solutions that drive technology cost-downs and risk reductions. Establishing a framework that captures system integration, new partnership structures and financial incentives may create a scalable platform.

Competitive alternative fuels for maritime at scale

Decarbonization requires alternative fuels. Production and supply chains of such fuels need to mature through technology innovation and scaling. Also, developments of permits, licenses, standards and regulation is urgently needed. But projected production scaling also brings challenges that may not be solved by business alone. Authorities and industry need to take action to ensure sufficient renewable energy and alternative fuel production for the maritime industry.



What needs to happen in the next decade?

While we are targeting a decarbonization of the maritime industry by 2050 it is evident that significant achievements must be made already within this decade to get the transition on track. This is challenging as we are highly dependent on new and unknown technologies, unavailable fuel types and regulation which is not yet in place.

Challenging but not impossible. In this chapter we focus on the actions the industry can take already now to demonstrate and accelerate the transition towards a decarbonized maritime industry. Because not all is new – there is plenty to gain from scaling what we know works while developing the future solutions and incentives that will take us the rest of the way towards net zero.

We are heading into a complete transformation of an entire business system, and it will require a certain culture of collaboration and innovation to succeed. Leaders across the eco-system need to participate and act. Together we can leverage industry resources and competence by creating, testing, coordinating, and producing sustainable solutions at scale, the better the odds for our industry to become the global decarbonization catalyzer the world needs.

The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping will take real climate action and lead collaboration and innovation projects where outcomes will be made widely available to the benefit of the entire industry. In this final chapter of the Industry Transition Strategy, we take a step in this direction by calling for action in four defined areas, point at specific activities and outline what we as a Center will focus on to move things forward. We see this document as the beginning of the journey where we want to leverage the collaboration platform to continually shape visions, objectives and actions together within the eco-system. It is the initiation of a strategizing process rather than a final strategy.

Together we can show the world it is possible!

In summary, success in four areas is needed to make the transition happen

A level playing field with global regulation

- Design and quantify global market-based measures and their impact
- Encourage regional and national regulatory measures as scalable platforms for a global regulation
- Develop and implement safety and environmental standards for alternative fuels
- Establish common vision and methodology for end-to-end life cycle analysis

Energy efficiency support across the value chain

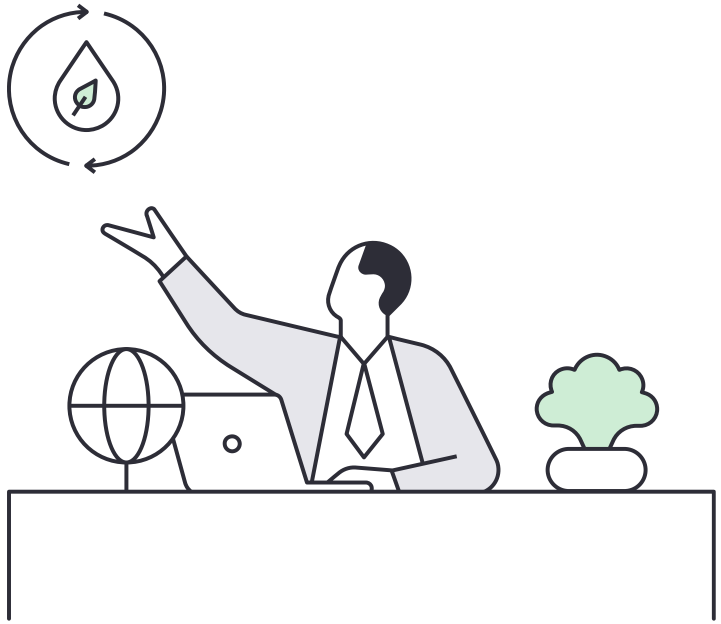
- Create transparency and baselines for current shipping operations
- Launch and test new commercial structures enabling wider energy efficiency adoption
- Tighten energy efficiency regulation for new build and existing fleet
- Advance industry best practices and enforcement in ship design and fleet operations

Support to first movers

- Initiate and formalize a regulatory framework to support industry-wide efforts led by first movers
- Showcase first-mover solutions and build scalable sustainable solutions of future
- Implement green corridors, and large demonstration projects
- Facilitate cross-sector development to harvest synergies by driving sector-coupling initiatives

Competitive alternative fuels for maritime at scale

- Mitigate risks and enable fuel pathways at scale
- Innovation to drive down cost
- Enable partnerships to unlock investments in scalable solutions
- Establish an industry-wide understanding of the role to be played by different alternative fuels
- Activate regulatory action to secure supply of alternative fuels needed to drive the transition



Source: MMM Center for Zero Carbon Shipping

Regulatory actions can create a level playing field for industry and nations, ensuring an effective and fair transition

Regulation must be implemented from local to global

✦ Center's active participation to accelerate the transition

On a global level, regulatory authorities should …	...establish end-to-end life cycle approach to maritime industry emissions ...review and implement a tighter EE regulation towards 2030 ✦ ...discuss, conduct impact analyses and establish a global framework for MBMs ...adopt and launch global MBMs (latest by 2025)
Regional/National authorities should…	✦ ...strengthen incentives and cooperation across value chain using demonstrators ...support industry with financing and roll-out of critical infrastructure for transition ...develop and implement regulatory framework for large-scale solutions ...adopt national action plan complementing global policy making at IMO level
To create a foundation for broader execution, local authorities should..	✦ ...accelerate partnerships and involvement in demo projects across value chain ...support industry with financing and roll-out of critical infrastructure for transition

- The maritime industry needs global solutions to decarbonize by 2050 and the IMO plays a key role in ensuring this
- Market-Based Measures will play a critical role for the decarbonization of shipping and present an opportunity to enable and reward first movers and fund initiatives that support the transition (e.g., compensate developing countries, accelerate retrofits, building infrastructure and R&D)
- More ambitious regulation on energy efficiency is another critical area that will help accelerate the transition
- Regional, national and local measures will be needed, including the establishment of regional emission trading schemes and Green Corridors

Source: MMM Center for Zero Carbon Shipping

Actions supporting first movers serve as a blueprint for accelerating future solutions and de-risking investments

Support to first-movers can accelerate the transition

✦ Center's active participation to accelerate the transition

To enable first-mover actions, authorities should...	...develop strategies and establish policy framework for first-movers ✦ ...shape and support existing initiatives accelerating transition pathways (at global, regional and national level)
To transition the entire value chain, there is a need to...	✦ ...demonstrate near-term market mechanisms supporting first-mover initiatives ...conceptualize and implement best practice business models enabling first-movers
Developing regional and/or global Green Corridors could...	✦ ... establish a blueprint for making commercially viable business cases ...establish required steppingstone for scaling-up alternative fuel supply chains ...enable developing models for deep sea commercial operations

Source: MMM Center for Zero Carbon Shipping

- Enabling first movers present an opportunity to show the maritime industry participants and adjacent industries (e.g., energy) that the decarbonization of shipping is possible and commercially viable
- This requires incentives and frameworks to assess, support and realize first-movers
- Developing Green Corridors are instrumental in activating industry participants across the value chain. Such projects could be used as industry references to develop blueprints for new business models and identify the maritime industry's inter-dependencies

Further business-driven adoption of energy efficiency is needed

Energy efficiency (EE) enforcement is critical

Center's active participation to accelerate the transition

To create a foundation for broader implementation of known EE levers there is a need to…

- …assess current industry penetration of known EE levers
- …conduct gap analysis, explaining the role of known EE levers in decarbonization
- … test new commercial structures with focus on sharing costs and benefits originating from known EE levers (including best-practice sharing)
- …strengthen enforcement of EE regulations
- …improve industry transparency and monitoring of EE measures

To build future energy efficiency momentum there is a need to…

- … drive innovation to develop new EE options (technology and operation) and pursue demonstration projects
- ….engage in dialogue with regulatory authorities to mature new technology options and co-develop future EE regulations

- Energy efficiency is a critical element in industry transition, and will be of significance even when the industry adopts alternative fuels
- As a starting point, the industry could benefit from an assessment of the emissions reduction potential in existing EE technologies and digitalized operations to pave the way for wider adoption
- Policy and regulation review and extension beyond the existing timelines is needed, with a view to improve visibility and drive enforcement
- Lastly, there are new technologies emerging (e.g., fuel-cell) as new fuel options become available. These should mature and qualify based on emissions reduction potential

Source: MMM Center for Zero Carbon Shipping

Alternative fuels must achieve cost-down and wide availability during next decade

Dedicated production and large-scale availability of alternative fuels need to be secured

Center's active participation to accelerate the transition

For alternative fuels, there is an urgency to…

- … clarify fuel pathways with target reductions in 2030, 2040 and 2050
- …describe and apply LCA methodology to quantify emissions intensity
- …develop dedicated large-scale renewable power for the maritime industry
- …develop large-scale e-fuels and bio-fuels production plants
- …demonstrate bunkering and logistic solutions for alternative fuels
- …define and formalize onboard safety and fuel management standards
- …secure regulatory approval on fuel specification and operational safety standards

For wider adoption of alternative fuels, the industry should …

- …test and qualify new scalable commercial models balancing long-term supply-demand
- …introduce market mechanisms (e.g. green certificates) and use them to de-couple physical and traded markets for alternative fuels for the industry
- …standardize commercial models supporting adoption of different alternative fuels

Source: MMM Center for Zero Carbon Shipping

- The development and adoption of alternative fuels are critical elements in an accelerated industry transition
- For alternative fuels to play that pivotal role, key challenges to resolve are – production and availability at scale, safe onboard use and documentation of reduced emissions intensity from an LCA perspective. Moreover, the alternative fuels need new market mechanisms (e.g., green certificates) enabling new commercial models
- Regulatory considerations on stand-ards and safe operations must be addressed as part of an accelerated scale-up of alternative fuels and the necessary infrastructure

The Center has kicked off three programs to accelerate the ambitions towards 2030 and realize the transition

	Advancing alternative fuel pathways	Realizing energy efficiencies	Enabling first movers
Program objective	- Identify technological, regulatory and commercialization gaps for introducing alternative fuels and propose solutions - Assess LCA of alternative fuel pathways - Align and advice industry on decarbonization pathways using alternative fuels and accelerate establishment of required standards and regulations	- Quantify emissions reduction potential by energy efficiency along the value chain - Illustrate digitalization's role in driving energy efficiency through voyage optimization - Influence policy makers in articulating energy efficiency's decarbonization role, port-vessel-interaction, fleet composition, voyage and trade optimization - Accelerate new technology development on-shore or onboard	- Drive, shape and support existing and upcoming first mover initiatives - Identify and develop scalable solutions - Conceptualize and execute best practice business models - Demonstrate market mechanisms and critical levers accelerating first movers - Help establish the regulatory environment needed for first movers (e.g. Green Corridor)
Project examples	- NoGAPS 2- demonstrating green ammonia fueled vessels - Methanol dual fuel vessel – demonstrating a methanol fueled vessel - Ammonia safety study – quantitative assessment for regulatory guidance and safety standards for ammonia fueled ships - Green fuels optionality study – conversion of new and existing ship designs to use green fuels	- SOFC4Maritime – developing and demonstrating concept for solid oxide fuel cell (SOFC) power system - Energy efficiency position paper; describing state-of-the-art, baselining current emissions and energy efficiency, discussing opportunities for industry wide reduction of energy usage - Role of digitalization in driving energy efficiency through optimized operations	- Singapore ammonia bunkering feasibility study – developing and demonstrating the concept of ammonia bunkering - MAGPIE – Port of Rotterdam ammonia bunkering demonstration - Mission Innovation – a public-private partnership to promote Zero Emission Shipping

Source: MMM Center for Zero Carbon Shipping
Note: The Center's efforts contributing towards developing effective regulations go across all programs

Deep dives: Critical levers

In this deep-dive section we highlight five critical areas and the associated critical levers needed to accelerate a maritime Path to Zero. The following slides describe each lever and the role they can play in driving further maritime emission reduction. Short one-pagers are used to explore and explain their critical nature, their linkages between cause and effect, and what we consider to be positive but realistic outlooks based on successful activation.

The deep-dives are structured as follows:

1. Policy and regulation
   - 1a/ Carbon pricing
   - 1b/ Energy efficiency regulation
2. Technological advancements on ship
   - 2a/ Wider adoption of existing energy efficiency technology on vessels
   - 2b/ New energy efficiency technologies becoming technologically available
3. Energy and fuel advancements
4. Customer demand/pull
5. Finance sector mobilization

1a | Introducing global carbon pricing to limit emissions

IMO agrees on a global carbon pricing scheme starting in 2025

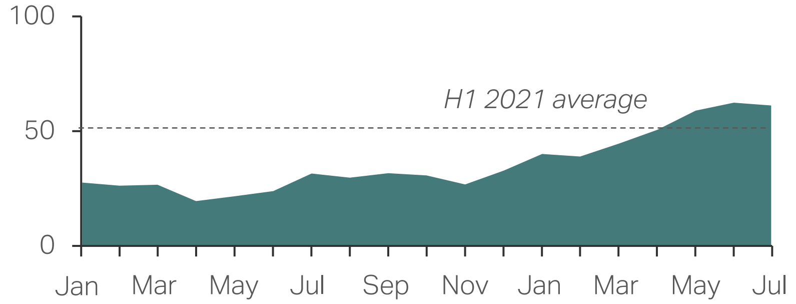
- **Rationale**
  In many countries, and for many emission-intensive industries, CO_2 or CO_2-eq pricing is increasingly used to ensure and speed up decarbonization. In the maritime industry, several shipowners and industry organizations have called for a global emissions levy. Many believe that a global solution is both a desirable and necessary step to close the fuel cost gap for first-movers.

- **The Path We Are On**
  IMO is expected to discuss market-based measures, but no clear roadmap is defined yet. *Modelling in NavigaTE:* no global emissions levy is added to the model.

- **Possible outlook (if activating critical levers)**
  IMO members reach consensus on a CO_2 pricing scheme starting 2025. However, as the price and possible compensation schemes will be up for tough negotiations it is still too early to say at what levels an agreement is realistic. *Modelling in NavigaTE* : For modelling purposes we argue that IMO is likely to be inspired by current pricing schemes and that a realistic scenario therefore could reference the H1 2021 average of the EU ETS carbon trading price at ~USD 50/ton CO_2-eq . Further elaborations on the CO_2-eq pricing levels needed to reach the Paris climate targets are instead included later in this document.

- **Inputs for NavigaTE modelling**

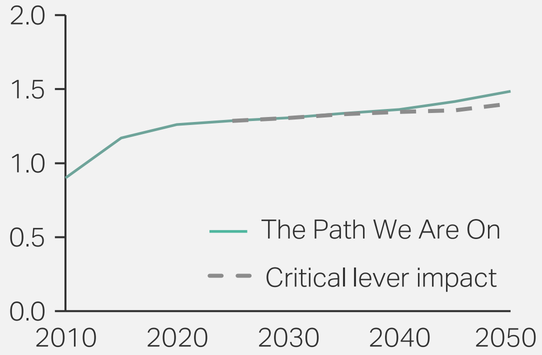
EU ETS CO_2 futures prices[1]
2020-2021 prices, USD/ton CO_2



- **Risks and opportunities**
  Risks: Uncertainty on regulators sense of urgency, room for maneuver and bargaining power. Opportunities: there is already a significant discussion and call-outs made by regulators, business and academia argue for much higher levies than USD 50 being needed. Other notable actions are e.g., an ETS system became operational in China in 2021, plans of a gradual extension of the EU ETS to the maritime industry starting in 2023, and some shipowners publicly demanding a levy in the range of USD 50-150/t CO_2-eq to secure a decarbonized industry by 2050.

Standalone reduction potential

WTW, $GtCO_2$-eq/year



The carbon pricing of USD 50/tCO_2-eq is not enough to bridge the large cost gaps between fossil fuels and the more expensive alternative fuels with low emissions intensity (e.g., e-methanol). However, introduction of levy at this level would close the cost gap to bio-crudes resulting in limited emissions reduction. The emissions reduction is estimated to be ~85 Mt CO_2-eq/year in 2050.

Source: MMM Center for Zero Carbon Shipping, NavigaTE
1 Carbon Price Viewer - Ember (ember-climate.org). Prices recalculated from EUR to USD.

International political support for a global maritime CO_2-regulation by 2030

Global political support for decarbonization is key

As previously highlighted by other swing factors, there are currently several technological and financial solutions that can accelerate the maritime decarbonization journey. However, most of them are too costly to motivate an individual business case. To close the price gap, initiate and upscale solutions as well as encourage other needed regulatory measures, the transition largely depends on global political support. Strong political will and a global agreement on the introduction of Market-Based Measures (MBMs) well in advance of 2030 are key to accelerate the change sought and achieve synergies from all other swing factors.

Reaching global political consensus at IMO is difficult

Current negotiations at the IMO on the decarbonization of shipping are faced with both political and structural challenges; delegates are split on fundamental questions concerning the political content and ambitions.

So far, discussions focus on CO_2 intensity, not absolute CO_2 reductions. To date, it is difficult to see how the IMO will overcome these challenges and be able to reach consensus on ambitious absolute reduction targets by 2050 and global Market-Based Measures supporting them.

How to reach global political consensus?

As long as global consensus on the pathway to zero-carbon shipping by 2050 does not appear to be reachable, regional initiatives could break the ice and encourage IMO to speed up processes, including Market-Based Measures.

The Center therefore supports regional initiatives such as the EU proposals to decarbonize shipping by including an introduction of a maritime EU Emission Trading Scheme (ETS) from 2025. The ETS should be based on intra-EU traffic as well as the possibility to include traffic outside EU waters.

In a parallel track, the EU should encourage IMO regulation on global maritime Market-Based Measures. If IMO is not able to agree on ambitious global regulation, including MBM, by 2025, the EU should proceed considering further regulation beyond EU waters. Once IMO reaches consensus, regional Market-Based Measures should cease to exist in order to avoid multiple charges.

Funds generated through Market-Based Measures should also benefit the maritime sector, supporting the development of new fuels, onboard vessel solutions and infrastructure for zero-carbon shipping.

Supporting global regulation, shipping nations need to agree on a more ambitious political approach at IMO as well ambitious national regulation implementing concrete roadmaps on the decarbonization of shipping. In addition, local political support from major ports and port cities will be key in order to establish first green corridors.

Source: MMM Center for Zero Carbon Shipping

1b | Stricter regulations on new builds improves energy efficiency onboard resulting in emissions reduction

Stricter regulation can be applied to further accelerate the transition

- **Rationale**
  IMO has defined technical indexes and assigned limits to ensure continuous improvement of new designs (EEDI), existing ships (EEXI) and lower the carbon intensity during operations (CII). However, energy efficiency regulation must be further tightened in order to accelerate decarbonization.

- **The Path We Are On**
  For new building vessels, the EEDI phase 2 efficiency improvements came into force in 2020 and EEDI phase 3 in 2025, with the latter applying to all subsequent new builds entering the fleet.

  EEXI compliance will be mandatory from 2023 and will aim at bringing all existing vessels in the fleet (pre and post EEDI designs) in line with EEDI phase 2 targets. This will be a one-time adjustment to the power demand of the fleet.

  Compliance with the operational measure CII will be required for all vessels in the fleet from 2023. Reduction factors are currently only specified until 2026 and range from 1% yearly improvements between 2019 and 2022 to 2% yearly from 2022 until 2026.

- **Possible outlook (if activating critical levers)**
  An EEDI phase 4 may be applied to all new build vessels post 2030 requiring a further energy efficiency design improvement of 10%. An extension of the CII could lead to yearly improvement of 2% until 2030.

- **Inputs for NavigaTE modelling**

Improved energy efficiency for new builds

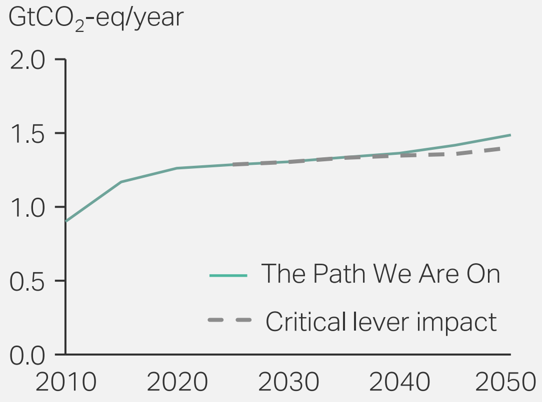
EEDI for new vessels[1]	2020	2025	2030	2050
Path We Are On	20%	30%	30%	30%
Activating critical levers	20%	30%	40%	40%

Improved y/y energy efficiency for vessels in operation

CII for existing vessels	2019-2022	2022-2026	2026-2030	2030-2050
Path We Are On	1%	2%	-	-
Activating critical lever	1%	2%	2%	-

- **Risks and opportunities**
  While the EEDI is known and Phase 1 has been implemented in new designs since 2015, the operational CII indicator has just been defined and the impact is still yet to be fully understood by ship owners and operators. Enforcement of the CII rating will be key to successfully drive the expected emissions reductions during operations. The impact of the CII also raises some questions since it is vessel and not fleet focused, is based on nominal capacity and not actual transported work, is very sensitive to the deployment or charter agreement, speed reductions may be a quick way to comply but may not reduce global emissions if more vessels are needed.

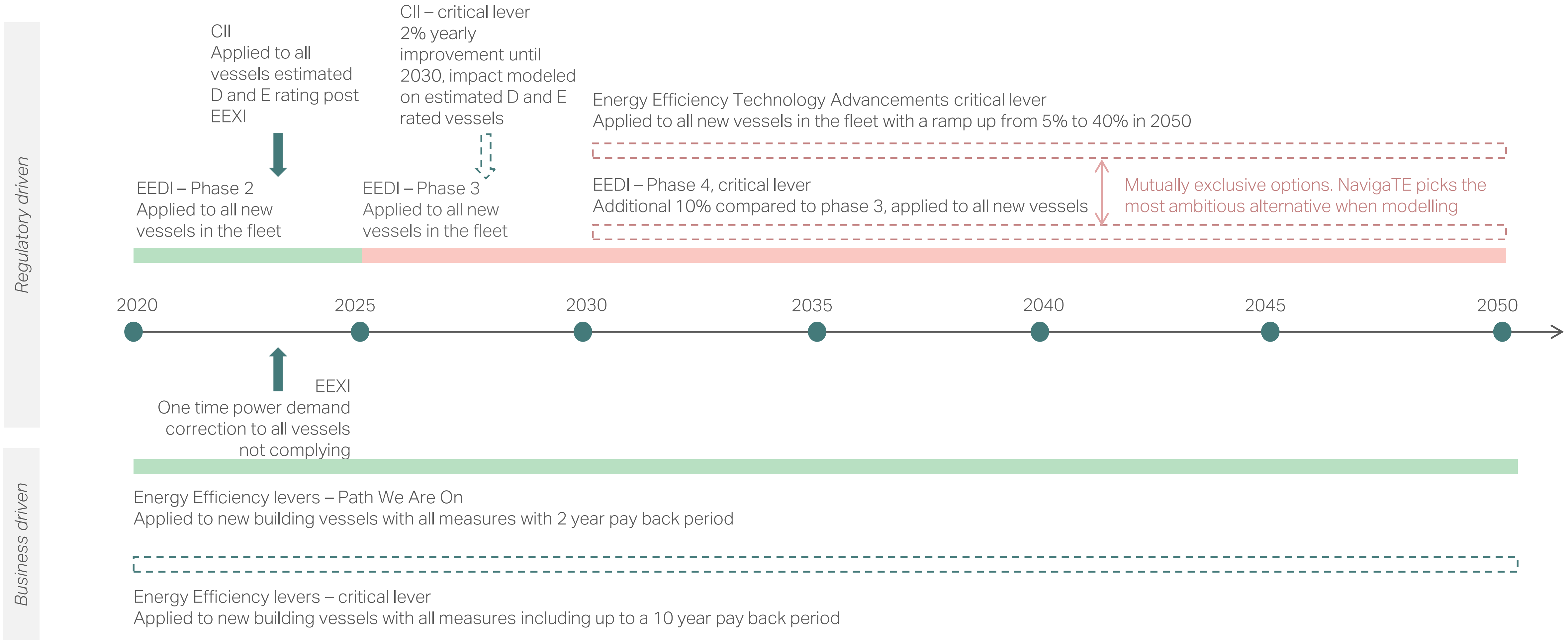
Standalone reduction potential



Strengthened energy efficiency has the most standalone emissions reduction impact in 2050 (~220Mt CO_2-eq/year). This is achieved by a lower total energy demand in the fleet due to more efficient vessels from regulatory tightening rather than transitioning to alternative fuels

Source: MMM Center for Zero Carbon Shipping, NavigaTE
1 Containerships phase 3 will be different based on ship size, ranging between 30 for the smaller designs and 50 for the largest ones

1b | Energy efficiency regulation and business driven initiatives as modeled in NavigaTE



Source: MMM Center for Zero Carbon Shipping

2a | Wider adoption of existing onboard energy efficiency technology

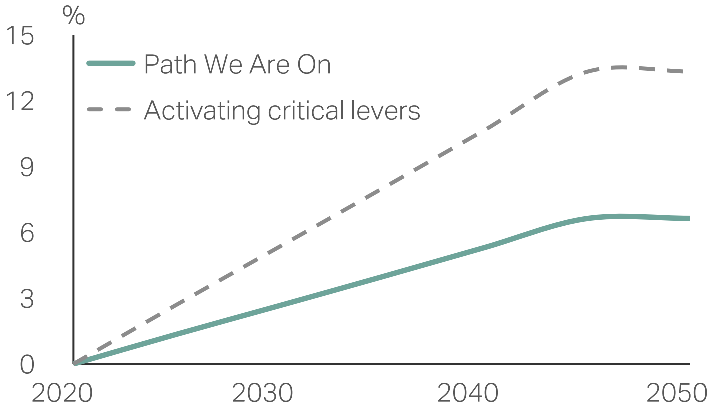
Payback periods could be extended if incentives are aligned across the industry

- **Rationale**
  Known energy efficiency technologies have been implemented onboard vessels over the past decade as they typically yield a good return on the investment. However, the adoption rate has been limited due to the misalignment on the incentives between owners and charterers. Whereas charterers pay the fuel bill, owners pay for the capex of the technology and often may forego the technology since there has not been a strong reward mechanism in terms of increased charter rates or pay back on savings. Further incentive alignment across the industry may open for longer payback periods.

- **The Path We Are On**
  Despite favorable business cases, shipowners are not fully implementing known technologies at the scale needed since the operators are the ones benefiting from the fuel savings. In addition, regulatory risk and the challenges to substantiate benefits of these installations are challenging the business cases. *Modelling in Navigate*: we include only energy efficiency business cases with payback periods of max 2 years[1].

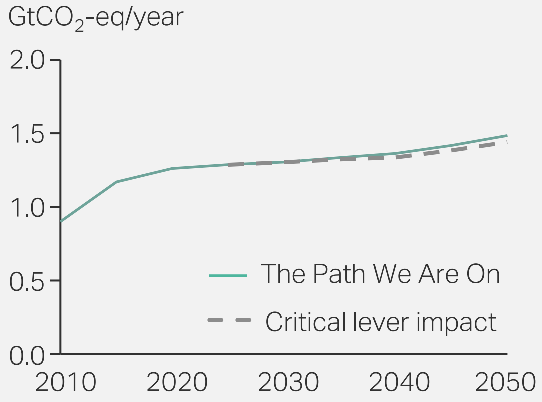
- **Possible outlook (if activating critical levers)**
  With better contractual framework for cost and reward sharing, a longer time perspective on technology investments may be adopted with business cases possibly extending from 2 to 10 years. This would imply that more costly measures but with a higher impact on energy efficiency would be more widely adopted, thus reducing overall energy demand.

- **Inputs for NavigaTE modelling:**
  Reduction of energy demand onboard vessels



- **Risks and opportunities**
  Changing the mindset and adapting new commercial agreements to share investment cost and benefits will take time and may only be accelerated through stricter regulation and increased financial incentives such as a carbon levy.

Standalone reduction potential



Shipowners can look for business cases with further efficiency penetration of known measures with longer payback periods. Such investments would reduce industry energy demand by ~7-15%, in 2050. Not as significant emissions reduction as wider EE adoption due to regulatory obligations can drive (~5 Mt CO_2-eq/year vs ~220 Mt CO_2-eq/year in 2050; Ref. Critical Lever 1b)

Source: MMM Center for Zero Carbon Shipping, NavigaTE
Acknowledged average industry standard.

2b | New technologies become commercially available, further improving energy efficiency of ships by 2050

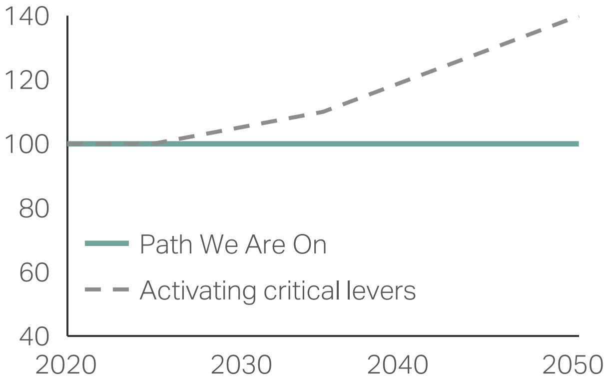
Onboard technology advancements will further reduce future fuel needs

- **Rationale**
  New developments are expected to spur from existing energy efficiency solutions as well as new (and maybe currently unknown) concepts. The drivers for these technologies are balanced between environmental and commercial necessity.

- **The Path We Are On**
  Without the development and prototyping of new technologies in the coming decade, energy efficiency will be limited to the current commercial offerings throughout the entire industry transition to zero carbon shipping. *Modelling in Navigate:* no new efficiency technology modeled.

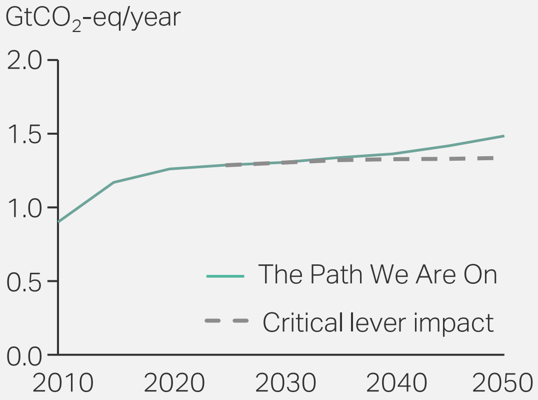
- **Possible outlook (if activating critical levers)**
  New onboard technologies may originate from advances in:
  - Reduction of hull friction with biomimetic surfaces (e.g., shark skin or passive air entrapment), going beyond current ambitions of antifouling paints
  - Improved air lubrication systems with a much broader application on vessel types and sizes, operational profiles and weather conditions
  - New concepts building on wind as primary propulsion mechanism, going beyond flettner rotors and traditional sails available already today
  - Radical improvements on battery technology, making shore power the primary energy source for short sea shipping (1 to 2 days sailing)
  - Improvement on fuel cell technology to maximize the efficiency of converting fuel to power
  - Improved cargo flow optimization and autonomous vessels given new Internet-of-Things and digitalization advancements

- **Inputs for NavigaTE modelling:**
  Energy demand reduction



- **Risks and opportunities**
  These technologies are still under development and their true potential still needs to be confirmed. Other challenges may arise with regards to scalability, safety, operation ability, etc. that may either stop the development of the solution or limit the applicability in the world fleet

Standalone reduction potential



If new energy efficiency technologies were commercially available to the industry, a wider adoption of such technologies could result in lowering of the energy demand in the industry, thus reducing emissions ~150 Mt CO_2-eq/year in 2050.

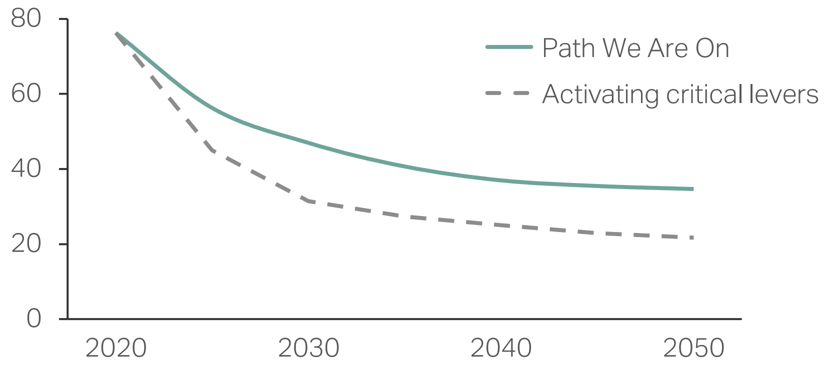
Source: MMM Center for Zero Carbon Shipping, NavigaTE

3 | Technology advancements hold the potential to drive cheaper renewable electricity availability

Cheaper renewable electricity is needed for the cost-down of e-fuels

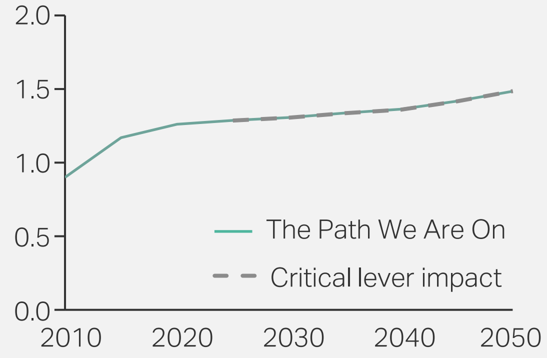
- **Rationale**
  As renewables have seen substantial cost decline in last decade and are projected to follow the same trajectory with increased levels of deployment, we explore their role in accelerating the green maritime transition.
- **The Path We Are On**
  Renewable energy has entered a virtuous cycle of falling costs, increasing deployment and accelerated technological progress. For e.g., over the past five years, costs for utility-scale solar and wind have fallen rapidly (~5-15% per year). *Modelling in NavigaTE:* The renewable cost decline continues, but at a somewhat slower rate. With economies of scale in renewable energy (led by solar photovoltaic (PV)) we are likely to see LCoE[1] levels at half of today's levels in 2050.
- **Possible outlook (if activating critical levers)**
  Even larger declines in renewable LCoE are possible if installed capacity increase more than the anticipated rate. Moreover, dedicated capacity development for maritime in renewable hot spots will prove advantageous to draw costs further down.
- **Inputs for NavigaTE modelling**

Renewable levelized cost of electricity (LCoE) & storage, *USD / MWh*



- **Risks and opportunities**
  The decline in renewable electricity price could be more modest if technology improvements are delayed, if energy demand outpaces supply, or if it becomes strategic to locate infrastructure where price is challenged (capacity factor, transmission infrastructure among others). Additionally, even though electricity is a key factor for the cost-down of e-fuels, the costs for distribution, propulsion, and storage systems also need to be considered when evaluating their competitiveness compared to fossil fuels.

Standalone reduction potential



Despite being a key component in e-fuel production, the isolated emission reduction potential stemming from decreasing renewable energy costs alone is barely visible. Like for other critical levers, the reason is again that this lever alone can not cause the big difference between fossil and alternative fuels to shrink to the point that it becomes interesting for industry to change energy source. The emission reduction potential is estimated to ~5 $MtCO_2$-eq/year in 2050 suggesting that additional impact from other levers is needed.

Source: MMM Center for Zero Carbon Shipping, NavigaTE
1. LCOE, the average net present cost of electricity generation for a generating plant over its lifetime (incl storage and infrastructure costs).

Renewable electricity drivers and key assumptions

Cost scaling of renewables infrastructure

Drivers
Solar power price has dropped due to improvements across multiple drivers: technical efficiency, production innovation, and economies of scale. Wind power costs have similarly declined due to efficiency and upscaling, which can further contribute to increasing capacity factors. Areas of improvement have included: improved O&M, longer blades, taller hubs, and advantageous siting.

A future with even lower costs
Bloomberg's low-cost scenario includes assumptions beyond the above drivers. Even today, fortuitous circumstances can minimize infrastructure costs. Concentrating installations where capacity factors are highest will decrease specific cost. Selecting locations having access to transmission (or having less need for it) lowers the required investment, as does decreasing the need for local energy storage.

For example, the low-cost scenario assumes stand-alone installations need only 25% storage capacity, instead of the 50% assumed for the mid-cost scenario.

Assumptions for calculating representative costs

Dedicated electricity infrastructure, off-grid
E-fuels for the maritime industry would need to be produced in massive quantities, and in locations suitable for marine supply. Therefore, the maritime industry would require a dedicated supply infrastructure. Despite some P2X overtures that peak hours may provide nearly free cost, the maritime industry could not rely solely on peak hours, since e-fuel production requires full-day operation.

It is assumed electro-fuel production rates must be nearly constant
Chemical-producing plants are not able to shut-down and start-up daily. Even for hypothetical plant designs which might adapt their loads, a low plant uptime means a longer payback time on investment – for a high CAPEX engineered for peak capacity. Regardless, the economics of production would be worsened due to intermittent operation.

Renewable electricity must also be supplied at constant rate
The aforementioned constraint on e-fuel production means that electricity must also be supplied at a constant rate. Therefore, intermittent power sources will require some form of load balancing, in order to achieve stable and economical plant operation. The practice of buffering– with batteries or other storage– is sometimes called "peak shaving". We assume costs of renewable energy sources production that include batteries [See details in the Center's publication "*Fuel Options - Industry Transition Scenarios*"]. In the low-cost scenario, the required buffering capacity is assumed to be half of the amount in the medium-cost scenario.

Source: MMM Center for Zero Carbon Shipping, Fuel Options - Industry Transition Scenarios (2021)

4| Customers are increasingly willing to pay a premium for zero-carbon transportation

Willingness to make positive changes

- **Rationale**
  Sustainable transportation is gaining importance as sustainability awareness is growing amongst consumers. As non-fossil fuels are more expensive than fossil fuels, it should be expected that operators will charge higher rates. Evidence is growing, and willingness to pay (WTP[1]) research indicates that zero-carbon transportation can be charged at higher rates.

- **The Path We Are On**
  Customers and WTP differ across products; the closer the end-user is to the supply chain, the higher willingness to pay a premium. In maritime terms, this would imply premiums being higher for container>dry bulk>tankers. However, with less than half of the consumers that report positive sustainability attitudes in surveys also following through with their wallets, we adjust our data accordingly[2]. Further down the supply chain, corporate WTP is growing as brands to step up on sustainability, focus on CO_2 footprint and scope 3 (supply chain) emissions. *Modelling in Navigate*: consumer WTP of each vessel segment is modeled separately, then weighed by segment size and translated to a share of total fleet, as summarized in the table.

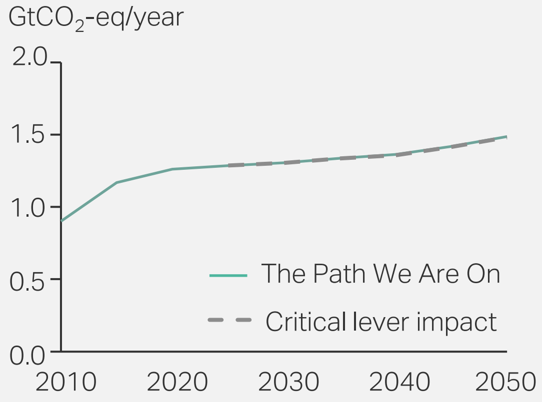
- **Inputs for NavigaTE modelling**

Weighted industry averages	2020	2030	2040	2050
Path We Are On				
Customers paying a premium on the global ton-miles transported	10%	20%	25%	35%
Premium paid	2%	5%	7%	8%
Activating critical levers				
Customers paying a premium on the global ton-miles transported	10%	30%	40%	50%
Premium paid	2%	7%	9%	12%

- **Possible outlook (if activating critical levers)**
  The gap between attitudes and behavior narrows and WTP increases slightly. The shift in consumer buying behavior reinforces the need for companies to increase their commitments to reduce carbon footprints, including zero-emission transportation.

- **Risks and opportunities**
  In case of greenwashing, end-consumers may become more skeptical about paying premiums, giving only marginal improvements from the path We Are On. Though, a more positive outlook may also be possible if customers recognize the importance of their actions for the maritime sector to reach emission targets by 2050.

Standalone reduction potential

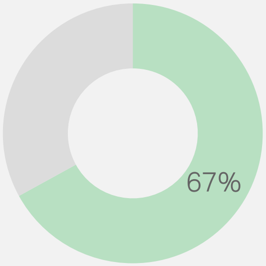


To significantly impact the abatement pathway, consumers seem to need to be willing to bear an even larger share of the transition cost. Hence, with the assumed WTP, the cost gap between fossil fuels and alternative fuels remains too large and WTP will not alone be the effect that causes the maritime industry to change energy source. The emission reduction potential is estimated to ~5 $MtCO_2$-eq/year in 2050, suggesting that additional impact from other levers is needed.

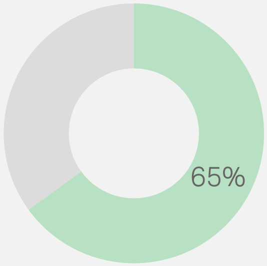
Source: MMM Center for Zero Carbon Shipping, NavigaTE
1 WTP is defined as the maximum premium a customer is willing to pay for your product or service.
2 See example: The Elusive Green Consumer (hbr.org). In NavigaTE, the consumer shares have been adjusted according to this “will-to-wallet” difference, thereby reflecting a more representative share of customers also actively acting on their WTP.

Sustainability: A mantra for retailers as well as consumers

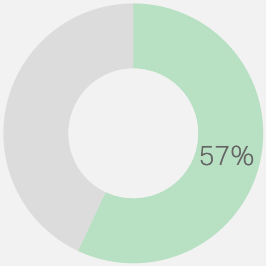
Across the globe, climate change and loss of biodiversity is considered as the **top challenge over the next decade**



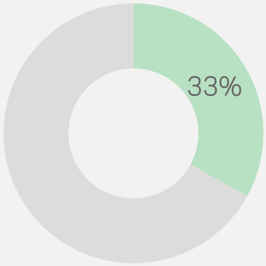
More than 6 out of 10 citizens believe their own **individual behaviour can help tackle climate change**



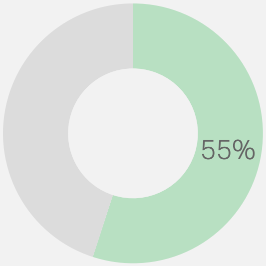
57% of consumers are **willing to change their purchasing habits** to help reduce negative environmental impact



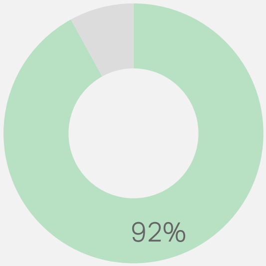
About 1/3 of consumers are **already choosing brands that do environmentally or socially good**



The share is growing. Between 2015-2019 sustainable products delivered 55% of the consumer packed goods market growth in the US...



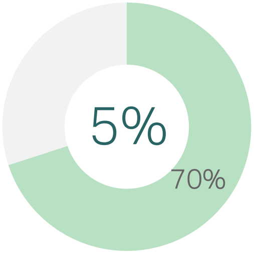
...and 92% of European retailers **expect sales in sustainable products to increase** in the next five years



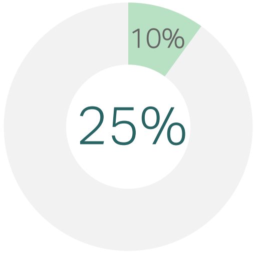
Note: Global surveys if not otherwise mentioned.
Sources: UNESCO, McKinsey, Unilever, IBM, International Trade Center, European Commission, European Investment Bank

Consumers are willing to pay more for sustainable delivery and products

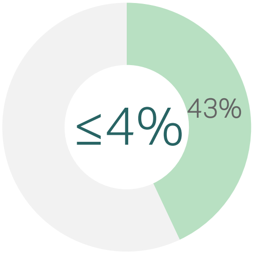
70% of consumers say they are willing to pay (WTP) a price premium of 5% for sustainable consumer goods



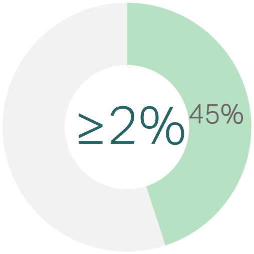
WTP decreases to only below 10% when premiums are increased [1]



About 50% of international online shoppers want sustainable delivery. 43% are also willing to pay a premium[3]

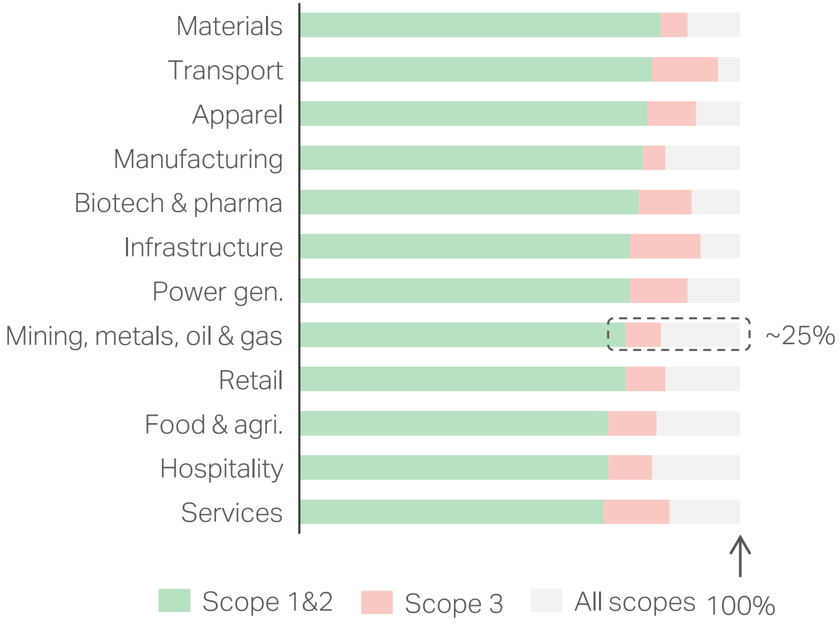


Consumers are also willing to compensate for own emissions neutral transportation[4]

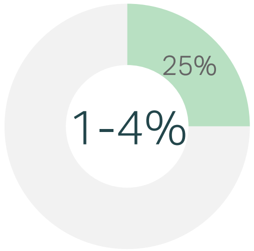


Sustainability pressure on mining, metal, gas and oil companies will increase dramatically in the coming years, as downstream players aim to reduce Scope 3 emissions[2]

Type of emission-reduction target, by industry, % share



A premium between 1-4% is expected when scope 3 targets trigger downstream players to demand low-emissions transportation



Note: Global surveys if not otherwise mentioned. Sources: BCG, McKinsey, International Post Corporation (IPC)
1 WTP also differs across product types. The 10% is an average based on packaging, furniture, automotive, building, and electronics (McKinsey Insights)
2 Study summarizing emission targets of more than 4500 companies in 2021.
3 In 2019, 43% of global e-commerce shoppers were willing to pay EUR 0.10 for carbon free delivery. With 38% of all e-commerce deliveries being valued at <EUR 25, this would correspond to a premium of 4% or less.
4 Consumers' willingness to pay for carbon neutral flights

Current WTP premiums correspond to customers' taking on abatement cost of ~USD 20/tCO_2-eq

		Steel (1 ton)	Jeans (1 pair)	Car	Beef (1kg)
Price/cost (USD/unit)	Retail/Wholesale	600	50	30000	20
	Transport	22.5	0.8	700	0.6
CO_2 amount (kg CO_2-eq/unit)	Total	1900	53	21000	30
	Transport	63	6.1	1200	0.3
CO_2 abatement cost (if priced at USD 20/t CO_2-eq)	Total	38	1.1	420	0.59
	Transport	1.3	0.1	24	0.01
Translating abatement cost to a consumer price premium (CO_2-eq offsets, %)	Total	6%	2%	1%	3%
	Transport	6%	15%	3%	1%

WTP premiums largely within currently acceptable 1-5% range

A 15% price premium may seem surprisingly high. However, as cost of transportation constitute only a small proportion of the price, the price premium corresponds to a transportation price increase of only USD 0.12 (~ EUR 0.10). Such an increase falls within the acceptable price premium expressed as WTP for 43% of global e-commerce shoppers for carbon free delivery (see previous slide)

Companies increasingly explore the opportunity of making use of customers' willingness to pay for green. Some firms see it as a way to signal commitment to sustainability, while others view it as means to raise revenue for green projects. Basis the fact that customers today seem to be willing to pay premium of ~5% for sustainable products and services, we here display some examples of what such an add-on would mean if translated to a corresponding carbon pricing level.

Our calculations show that the ~5% - corresponds to a CO_2-eq abatement cost of USD ~20/tCO_2-eq. This price is higher than levels currently seen in most regional and national pricing schemes in place today, but still substantially lower than the global CO_2-eq price levels needed to achieve the temperature goals of the Paris Agreement.[1]

Source: World Bank (2021), McKinsey (2021), MMM Center for Zero Carbon Shipping

1 The World bank concludes that observed regional, national and subnational carbon pricing shemes (through either an ETS or a carbon levy) span a wide range, from less than USD 1-140/tCO2-eq. About three quarters of covered emissions remain priced at less than USD10/tCO2-eq. Carbon Pricing Dashboard | Up-to-date overview of carbon pricing initiatives (worldbank.org)

5| Low-cost financing is broadly available to companies that reduce emissions

Significant reallocation of capital over time

- **Rationale**
  The concept of sustainability–linked financing is now gaining momentum in the maritime industry. The financing sector has an opportunity to facilitate, steer and accelerate the transformation by providing (cheaper) financing rewarding those zero-carbon vessels or vessels targeting to become zero-carbon.

- **The Path We Are On**
  Major financial institutions are reallocating own- and customer portfolios as carbon footprint reduction is increasingly valued. Improved regulatory frameworks supported by increasing numbers of capital providers available and willing to finance the maritime transition brings scope for the right projects to be financed at a lower cost of capital.[1] *Modelling in NavigaTE*: Applied on top of the industry weighted cost of capital (WACC) at 7% we add discounts for green financing. modeled discounts build on interest rate input received from shipowners and financing industry dialogues. Rates are reduced pro-rata so alternative fuels get 100 basis points lower cost of capital (pro-rata relative to carbon content).

- **Inputs for NavigaTE modelling**

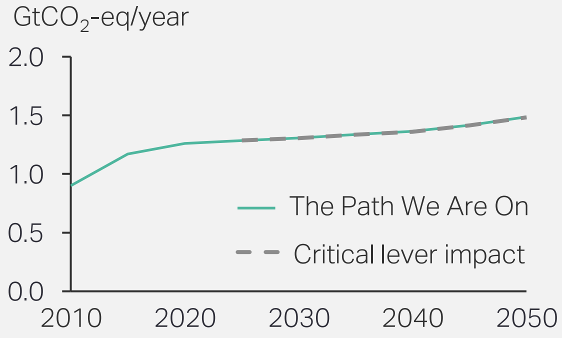
Average maritime discount levels lowering green finance cost compared to fossil fuels

	2020	2025	2030	2035	2040	2045	2050
Path We Are On	0.1%	0.5%	0.75%	1.0%	1.0%	1.0%	1.0%
Activating critical levers	0.1%	0.5%	1.5%	1.5%	1.75%	2.0%	2.5%

- **Possible outlook (if activating critical levers)**
  Medium- and long-term decarbonization plans mature in the maritime sector, resulting in both new and improved opportunities. Financing initiatives reward those targeting to become zero-emission by offering average discounts up to 250 basis points.

- **Risk and opportunities**
  Access to capital is both carrot and stick. In the stick approach the finance sector may decide against financing shipowners that don't reduce GHG emissions. The alternative approach is to partner up with shipowners e.g., by strengthening the relationship between maritime ESG scores and cost of capital. With the highest-rated ESG companies also getting significantly lower cost of capital, we may see even higher average industry discounts.

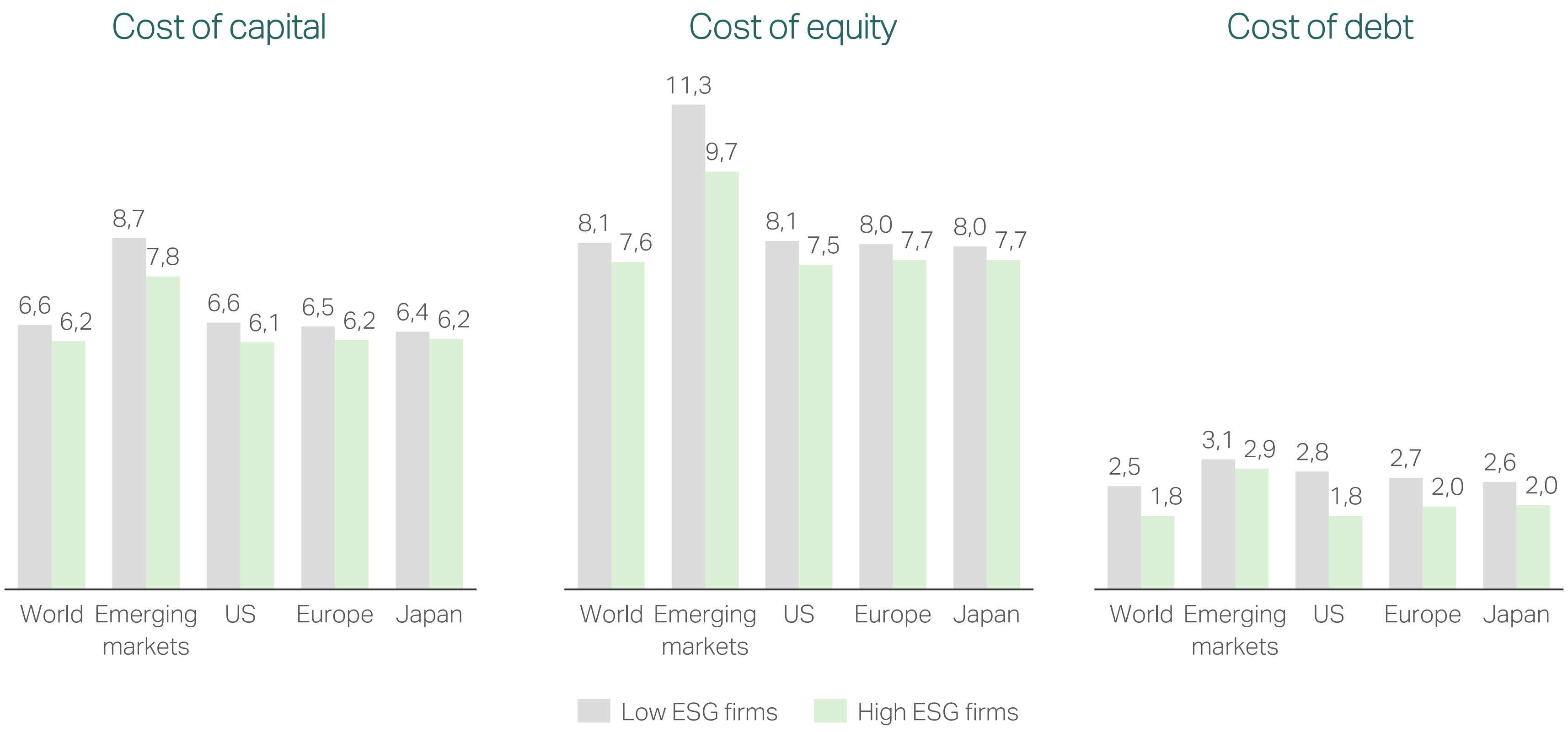
Standalone reduction potential



Available financing is a prerequisite for decarbonization to gain momentum. The fact that cost gaps between fossil and alternative fuels are significant, and that fossil fuel consumption already represents ~20-35% of the total annual costs of a vessel, financing discounts alone will have a very limited impact on emissions reduction. The emission reduction potential is estimated to ~3 $MtCO_2$-eq/year in 2050, suggesting that additional impact from other levers is needed.

Source: MMM Center for Zero Carbon Shipping, Navigate, Poseidon Principles
1.E.g., the Poseidon Principles, the LMA Green Loan Principles and the Sustainability–Linked Loan Principles create a common, global baseline to quantitatively assess and reveal whether financial institutions' lending portfolios are in line with adopted climate objectives

Cost of capital for the lowest-rated ESG companies is significantly higher than for the best-rated ones...



Source: MSCI Monthly averages reported over the period from Dec. 31, 2015, to Nov. 29, 2019. The average number of companies over the period analyzed: World (1552), Emerging Markets (960), US (538), Europe (452) and Japan (319)

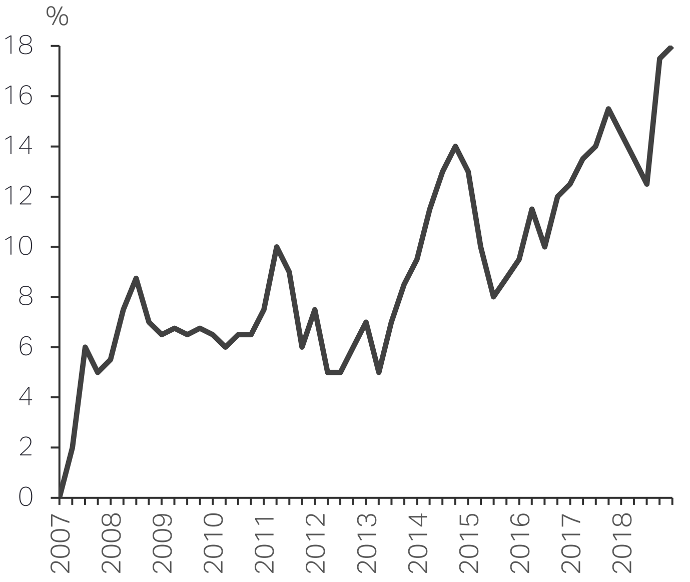
Over the past few years, integrating ESG (environmental, social and governance) criteria into investment portfolios has shifted from an exercise involving a relative handful of financial players to a mainstream focus.

MSCI data now confirms that the transition to a low-carbon economy leads to significant reallocation of capital, where companies with high ESG scores experience lower costs of capital compared to companies with poor ESG scores. This holds true across industries as well as industry sectors, strongly suggesting that those dynamics would also be applicable to a global industry such as the maritime industry.

…and financial data confirms that ESG investments are a money-making opportunity that's gaining popularity

Returns

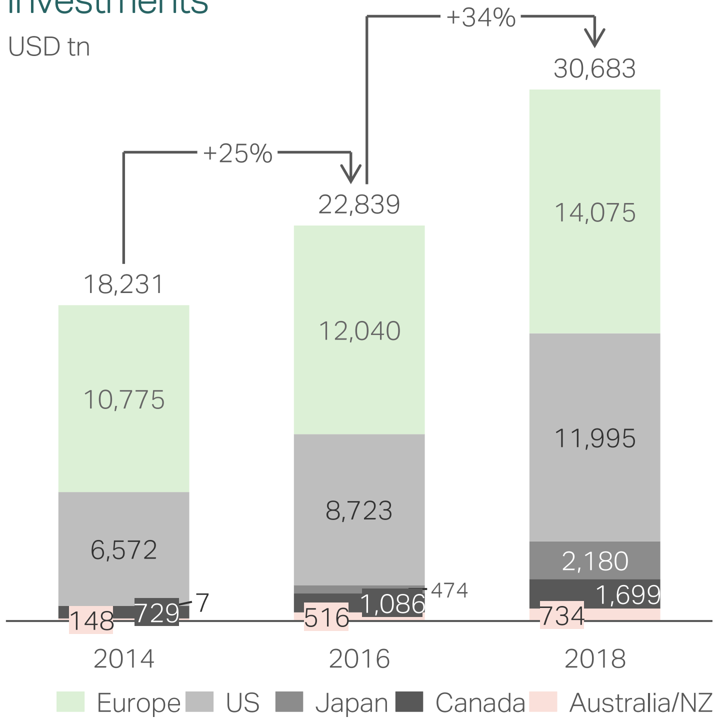
'Good news' portfolios relative to the MSCI World Index (pp)



Companies that experienced the most positive climate change news outperformed the MSCI World stock price index by 20 percentage points.[1]

Investments

USD tn

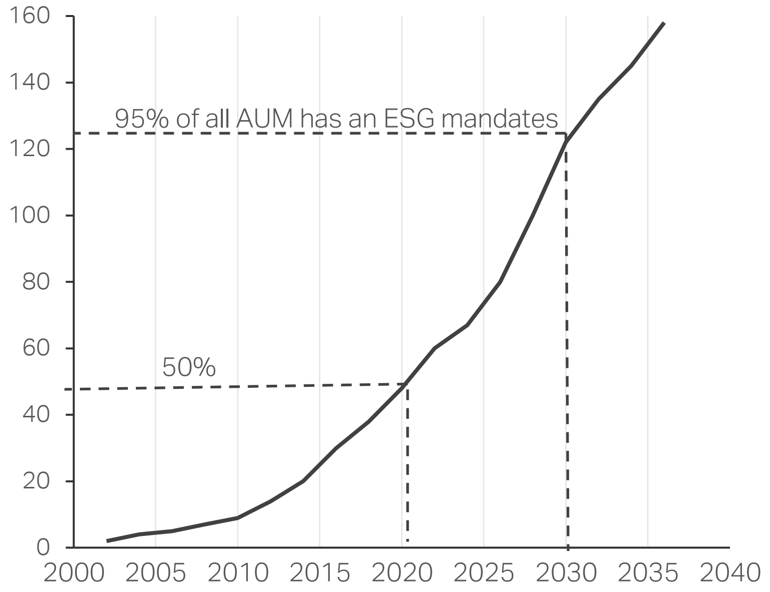


Considerable growth of global sustainable investment assets[2] …

Assets Under Management (AUM)

Global AUM falling under an ESG mandate

USD tn



…and a positive outlook means that climate change-related share price effects will likely amplify.[1]

Sources: Deutsche Bank Research, Climate change and corporates Past the tipping point with customers and stock markets, Global Sustainable Investment Alliance Report

Appendix

A1: Examples of abatement actions and initiatives in today’s maritime eco-system

A2: Key modelling assumptions

A3: CAPEX outlook if sailing on alternative fuels

A4: Ammonia assumptions

Today, across the maritime eco-system actions are taken, and initiatives stand ready to be launched

The maritime eco-system and current initiatives/actions (excerpt)

Value chain | Enablers

Maritime eco-system

Regulators & compliance
- International
- National
- Regional
- Local

- Global regulation, incl carbon pricing, to be discussed in IMO
- Energy efficiency regulation tightened
- Public support for green investments

Finance & commercial
- Ship financing
- Corporate lending
- Finance initiatives

- Using Poseidon principles and sustainability–linked financing to promote maritime decarbonization and integrate climate considerations into lending decisions

Policy
- Lobby groups
- Classification societies
- NGOs

- New coalitions and partnerships formed
- Pressure on regulators to raise ambitions, not least for the short term e.g. ,2030

Knowledge providers
- Academia
- Start-ups
- Thinktanks
- Digital services

- Reports and research showing possible pathways, risks and opportunities on maritime decarbonization
- Guidance/assistance on sustainability reporting and strategy

End customers
- Corporate customers
- End-consumers
- Customer associations

- Corporates enrolling for scope-3 reduction targets
- End-consumers willing to pay the green premium
- Use of carbon accounting and carbon footprint tracking

OEMs & suppliers
- Engine manufacturers
- System integrators
- Fuel-cell manufacturers

- Ammonia IC engine by 2024
- Scaling of fuel-cell technology
- Nitrous oxide emissions control

Energy companies & utilities
- Energy companies
- Biofuel providers
- Utility providers

- Setting scope-3 reduction targets
- Reducing/eliminating upstream investments in oil exploration
- Feasibility of converting natural gas infrastructure to hydrogen

Shipyards & ship designers
- Ship builders
- Ship designers

- Introduction of improved efficiency and zero-carbon system concepts such as ammonia fuel-cell vessel
- Wind assisted propulsion concept demonstrated as early as 2024

Ports
- Port and terminals
- Infrastructure

- Key bunkering hubs are assessing deployment feasibility and safety standards for new fuel types
- Demonstration projects involving full electrification of coastal/near sea shipping vessels

Shipowners & charterers
- Shipowners
- Ship operators
- Charterers

- Ordering of zero-carbon ready vessels
- Full scale operations using drop-in biofuels already in place

Source: MMM Center for Zero Carbon Shipping

NavigaTE: Key modelling assumptions and methodology considerations driving significant impact on model output

General

- Focus on deep sea going vessels, as they account for major share of GHG emissions. Less detailed coverage on short sea shipping vessels
- Emphasis is also on newbuilding of vessels and the model builds on two key modules: A classical Total Cost of Ownership (TCO) module and an Industry Transition module
- We consider emissions of <0.1 $GtCO_2$-eq/year as being net zero as this is less than 10% of 2020 emissions, and conventional ways (e.g., afforestation) can mitigate those emissions
- Fleet composition is based on the data from IMO 4^{th} GHG study
- Global trade CAGR is estimated at 1.3%/years between 2020 and 2050
- Scrap rate at lifetime of 25 years
- No significant change of trade route patterns, vessel sizes and vessel types has been assumed
- A 100 years Greenhouse Warming Potential (GWP) is used
- Methane slip is included in upstream production processes of blue hydrogen, blue ammonia and bio-methane and from the use of LNG as a fuel onboard

Energy & Fuels

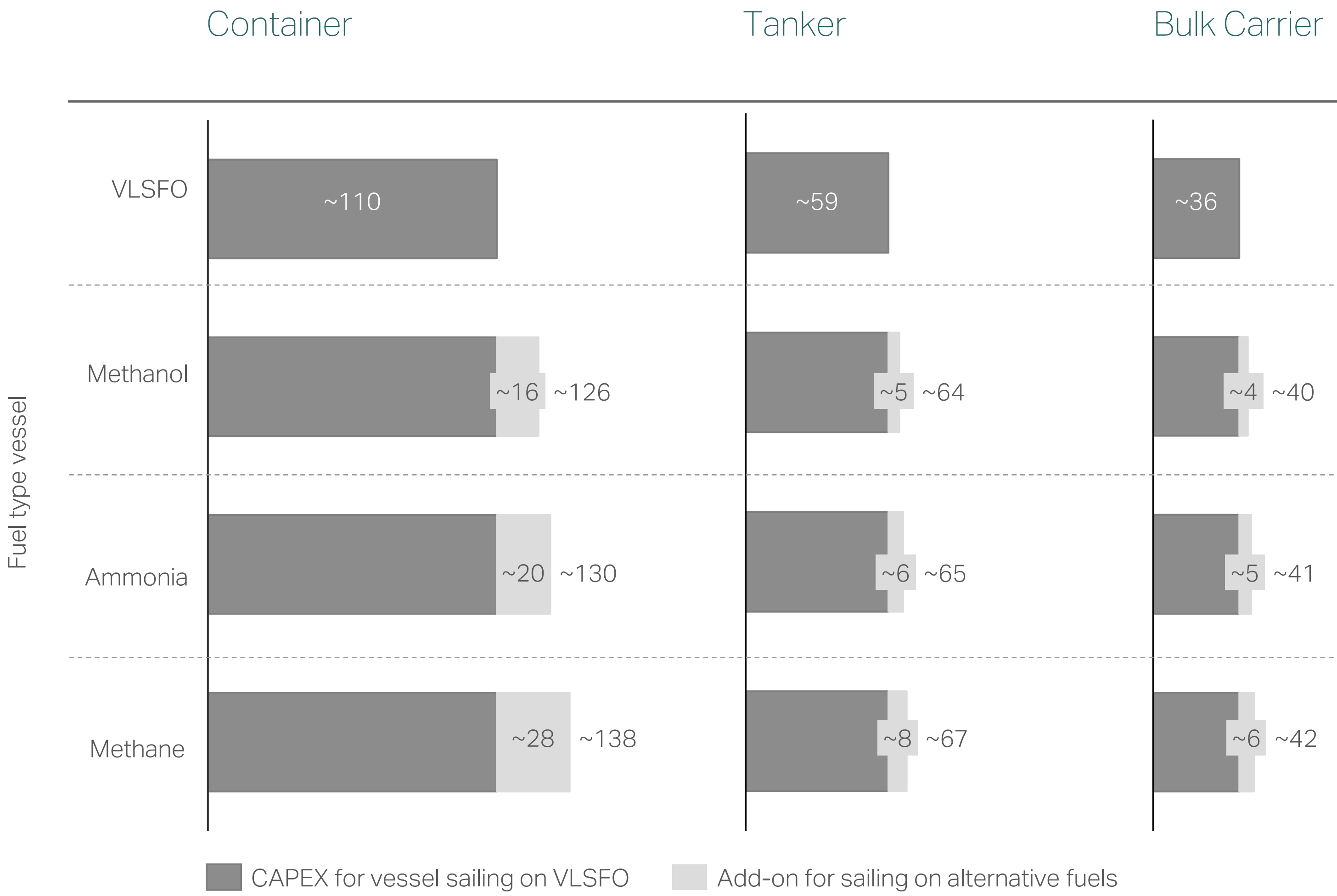
- Modelling focus is currently on identifying main pathways for oceangoing vessels that account for the majority of fleet emissions. This means that onboard electrification with batteries is not included
- A total of 21 types of fuels are assed and included: 3 types of fossil fuels and 18 alternative fuel types
- Fuel production and fuel logistics GHG footprint are added together to give the Well-to-Tank (WTT) emissions for all modeled fuels.
- Levelized cost of electricity (LCoE) from renewable sources is used. Balanced electricity supply is assumed e.g. buffering capacity is supplied by batteries
- Oil prices are modeled with forward curves as reference
- Natural gas prices are modeled as forward curves following relevant development in oil prices is used as reference
- All alternative fuel production pathways are unsubsidized
- Only sustainable biomass (forestry residue, agricultural residue and organic wet waste) is considered and included in the model
- Renewable electricity supply assumed sufficient to cover demands in base case scenario

Onboard vessel solutions

- Vessel operating profiles are defined by number of sailing days, days in port, power/speed curve and average speed, average auxiliary power use and boiler use
- The model includes several efficiency levers that can be configured
- A configured vessel will have an adjusted TCO with the additional CAPEX and OPEX of the efficiency measures together with the expected benefit on fuel consumption (power demand) of those measures
- Regulatory steered retrofits are included in the model (e.g., EEXI) while other additional retrofit of energy efficiency technology or retrofit to use alternative fuel options are not included
- Tank-to-Wake (TTW) is used and calculated based on the combustion of the fuel onboard
- Wind is not modeled as a main source of propulsion power, but instead considered as an energy efficiency initiative (i.e., as wind-assisted propulsion)
- Onboard carbon capture and storage is not considered
- Nuclear power propulsion technologies are not considered due to current safety and public perception

Source: MMM Center for Zero Carbon Shipping, NavigaTE Whitepaper (2021), Fuel Options - Industry Transition Scenarios (2021)

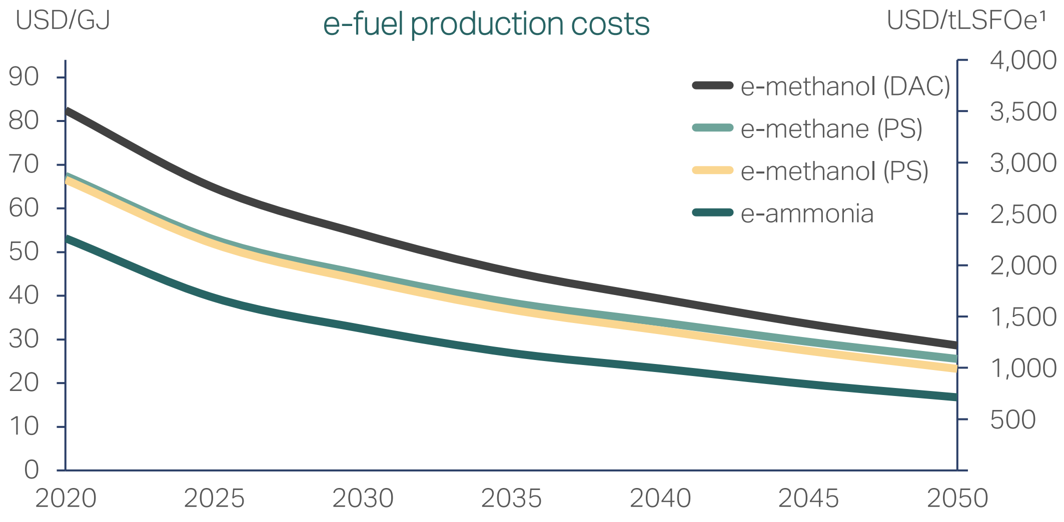
CAPEX estimate for medium-sized new builds in 2030

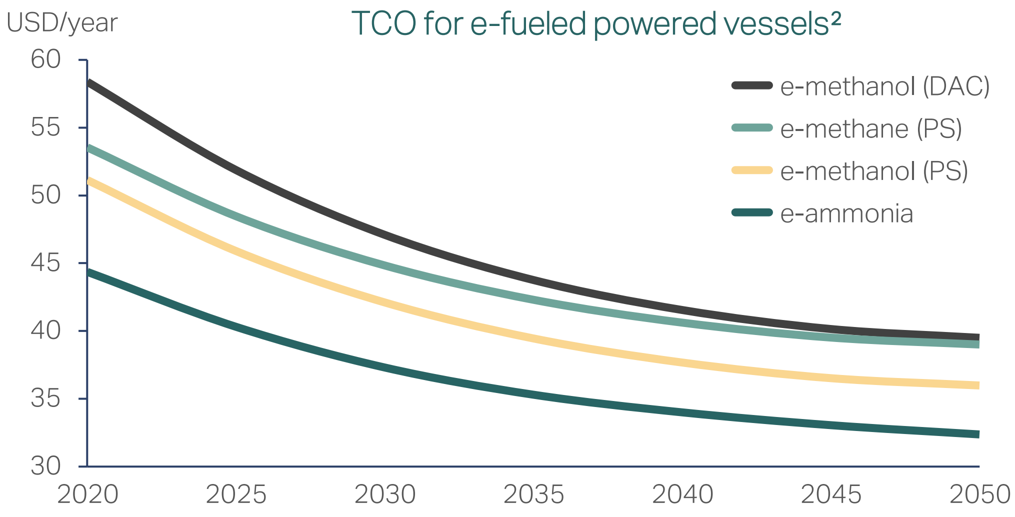


Fuel type vessel	Fuels that can be used on vessel	Key drivers to CAPEX add-on compared to VLSFO
VLSFO	▪ Compatible bio-oils	
Methanol	▪ Bio-methanol ▪ e-methanol	▪ Dual fuel engine ▪ Complex fuel supply system ▪ Tank size
Ammonia	▪ e-ammonia ▪ Blue ammonia	▪ Dual fuel engine ▪ Complex fuel supply system ▪ Tank size ▪ Cryogenic tank (-33°C)
Methane	▪ Bio-methane ▪ e-methane ▪ LNG	▪ Dual fuel engine ▪ Complex gas supply system ▪ Tank size ▪ Cryogenic tank (-162°C)

Source: MMM Center for Zero Carbon Shipping, NavigaTE
Note: CAPEX numbers for Europe

e-ammonia may be the cheapest e-fuel to produce and has the least TCO among other e-fuel powered vessels





e-fuels share a similar cost decrease due to declining electricity cost

The projected e-fuel costs depend similarly on the decreasing cost of renewable electricity prices. Extra cost differences are due to CO_2 costs and potential technology optimizations

Ammonia is the least costly energy-dense e-fuel

Ammonia is made from N_2 feedstock, which is readily available and may be cheaper to obtain than the carbon-neutral CO_2 that is needed for carbon-based fuels. However, ammonia has slightly lower energy density than the carbon-containing options, and it faces significant safety and regulatory hurdles

e-methanol and e-methane may be produced with similar costs

If ammonia should fail to overcome the barriers to its implementation, the next most cost-effective e-fuels are e-methanol and e-methane. These two options have very similar costs of production, but their effective total costs of usage depend on ship storage and consumption: bunkering, onboard storage, operational characteristics, and shipping route. As with ammonia, both methane and methanol require more space onboard than LSFO: e-methane requires cumbersome cryogenic storage, and e-methanol is less energy-dense. All considered, e-methanol is likely the more cost-effective option for a larger portion of the fleet, although e-methane may still find use

Source: NavigaTE
1 LSFO equivalent (1 ton LSFO equals ~42 GJ of energy.
2 Typical container vessel (~8,000 TEU) with a 25-year lifetime and a representative operational profile, low-cost scenario for electricity prices, and all energy efficiency levers with <10 years payback on