



International
Chamber of Shipping

Shaping the Future of Shipping

Catalysing the fourth propulsion revolution



The urgent need to accelerate R&D
to deliver zero-carbon shipping by 2050

Catalysing the fourth propulsion revolution

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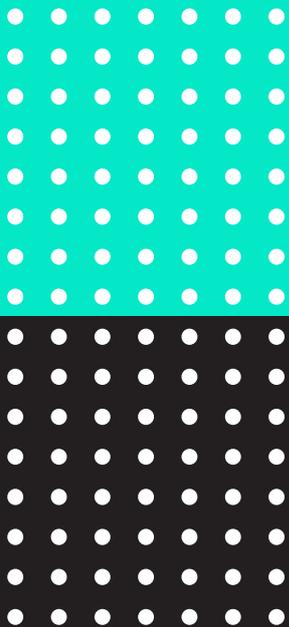
Cover image: Oceanbird, the wind powered cargo vessel (www.oceanbirdwallenius.com).
Courtesy of International Windship Association.



The International Chamber of Shipping (ICS) is the global trade association representing national shipowners' associations from Asia, the Americas and Europe and more than 80% of the world merchant fleet. Established in 1921, ICS is concerned with all aspects of maritime affairs particularly maritime safety, environmental protection, maritime law and employment affairs. ICS enjoys consultative status with the UN International Maritime Organization (IMO) and International Labour Organization (ILO).

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Executive summary

After a long history of wind, coal and oil-fuelled ships, a fourth propulsion revolution is needed if shipping is to decarbonise completely and achieve the stringent greenhouse gas reduction targets established by the International Maritime Organization (IMO).

The challenge is enormous: to move cargo across the oceans, ships require huge amounts of energy and an entirely new generation of fuels and propulsion systems will need to be developed. However, many of the potential zero-carbon fuels such as ammonia and hydrogen present serious operational challenges. In addition to the safety issues that will need to be addressed, they also have low energy density meaning that ships will have to carry much more fuel. The global shipping fleet will need to be modernised and new fuel supply networks developed.

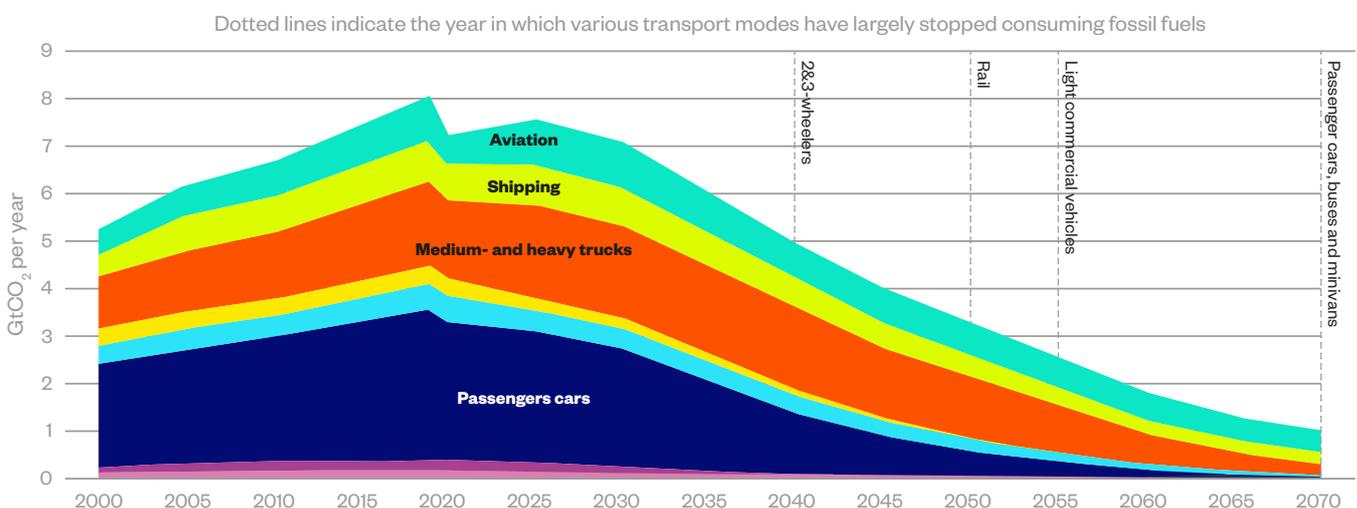
More immediately, zero-carbon technologies can only be introduced if there is a huge increase in global research and development (R&D) spending. Shipowners are prepared to catalyse this by proposing the creation of a US\$5 billion research

and development (R&D) fund aimed at identifying one or more technical pathways that can lead to the introduction of zero-carbon ships across the maritime sector by 2030 and beyond.

Trillions of dollars of investment will rely on the success of such initiatives to identify the zero-carbon technologies of tomorrow. To address the climate crisis we need to act now.

The industry has proposed a US\$5 billion R&D fund to identify pathways to zero-carbon ships by 2030 and beyond

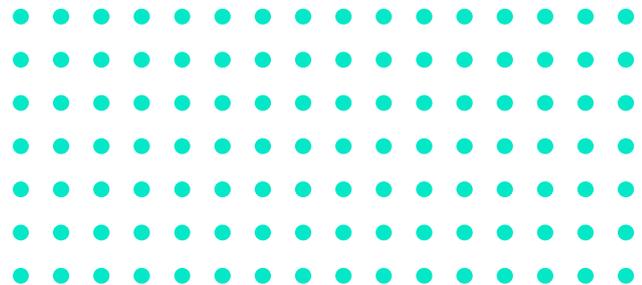
Global CO₂ emissions in transport by mode in the Sustainable Development Scenario, 2000–2070



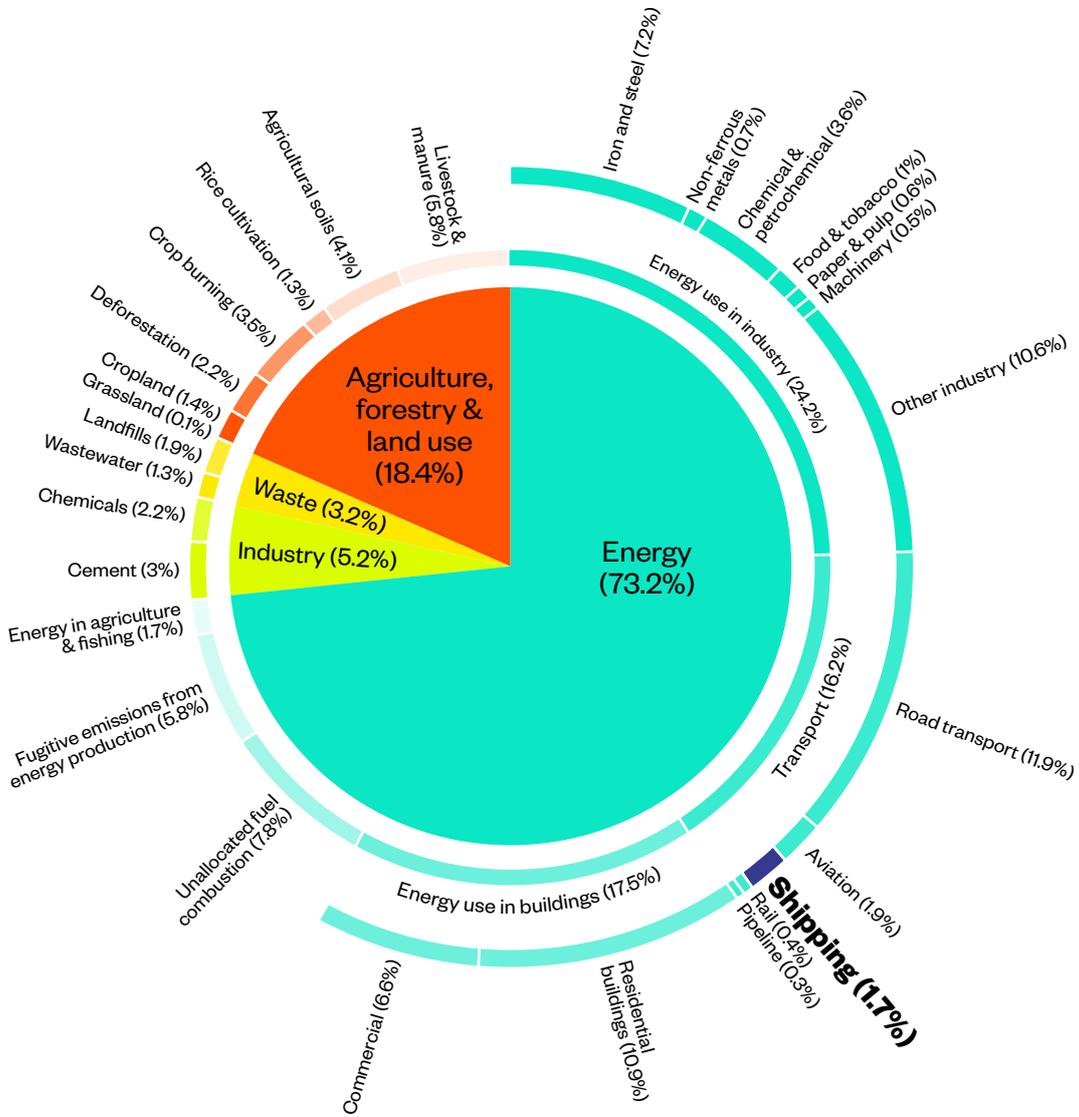
Source: IEA

Six key takeaways

- 1.** International shipping is key to the global economy, transporting about 90% of global trade volumes, using 4 million barrels of oil a day – 4% of global oil production – equivalent to over a third of the daily production of Saudi Arabia. The value of cargoes shipped by sea is close to \$7 trillion annually, more than the entire GDP of the world's third largest economy, Japan. The sheer size and scale of today's ships and the daily volume of trade they transport requires a colossal power input. The energy used by a typical container vessel crossing the ocean could provide power for 50,000 homes.
- 2.** Presently, moving such a huge amount of goods results in significant carbon emissions and the shipping industry produces 0.9 gigatonnes – 2% of the global economy's total CO₂ emissions – similar to aviation but less than the 2.4 gigatonnes of the global road transportation sector. While too high, shipping's carbon emissions are much lower than some other key industries such as the global cement industry that produces more than double the amount of CO₂.
- 3.** A fourth propulsion revolution to end the shipping industry's dependence on fossil fuels will be required but there are multiple hurdles to be overcome before full decarbonisation can be achieved. New fuels will need to be developed along with novel propulsion systems, upgraded vessels and an entirely new global refuelling network.
- 4.** Currently, zero-carbon fuels and technologies do not exist at the size and scale needed to catalyse this revolution. However, there are several promising potential zero-carbon fuels and technologies, including ammonia, hydrogen and electric batteries, but each of these pose specific challenges that require a huge amount of R&D before they can become commercially viable on a global basis.
- 5.** Ammonia and hydrogen are less energy dense compared to oil meaning that ships will consume up to five times as much fuel by volume. If the global fleet all adopted green ammonia fuel, ammonia production would have to rise by 440 million tonnes – more than treble current production – requiring 750 gigawatts of renewable energy. This means that shipping alone would consume 60% of the world's current renewable energy production of 2,537 gigawatts. The battery challenge is just as great: a typical container vessel would require the power of 10,000 Tesla S85 batteries every single day meaning that it would require 70,000 batteries in order to sail for a week.
- 6.** In order to turn the fourth propulsion revolution into reality, the industry is proposing the creation of a US\$5 billion R&D fund paid for by a levy on marine fuels, to be overseen by the industry's global regulator, the UN International Maritime Organization.



Global greenhouse gas emission by sector



Source: ourworldindata.org, Hannah Ritchie, using data in Climate Watch, the World Resources Institute (2020).



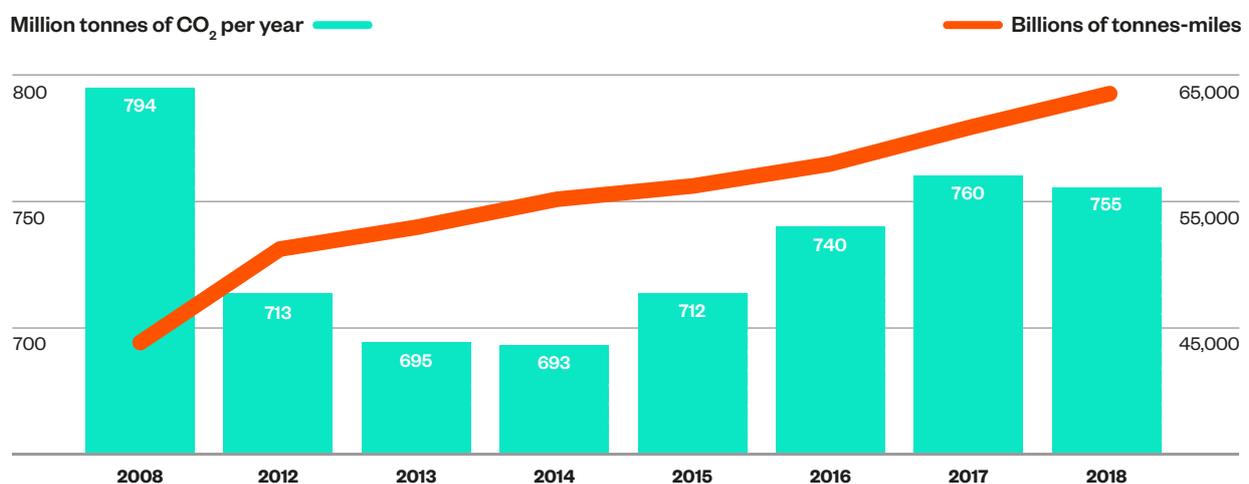
The future of shipping in a carbon constrained world: the urgent need to accelerate the transition to zero-carbon fuels and propulsion

Maritime transport forms the backbone of international trade. It is, by far, the most cost-effective way to move goods around the world. According to World Trade Organization (WTO) data, the value of global trade carried by sea is close to \$7 trillion and 90% of traded volumes are transported by way of the global shipping fleet, more than the entire GDP of the world's third largest economy, Japan. So it is not surprising that this is an industry that generates substantial carbon emissions that are similar to those of an industrialised country like Germany. Yet shipowners are keenly aware of the urgent need to aim for carbon neutrality, something that can only be done with the development of a new generation of technologies and new zero-carbon fuels.

While a range of potential technological pathways have been identified, no single technology or zero-carbon fuel is ready for widescale implementation. Indeed, almost all are in their infancy and need extensive further development. In order to overcome this challenge, the industry needs to invest heavily in increased R&D and is calling for the creation of a US\$5 billion International Research and Development Fund, paid for by the industry via a mandatory levy on maritime fuel.

Overall, shipping is the least energy-intensive way to carry goods: despite the size of its share of total freight transport activity, it is responsible for about one fifth of the energy used for freight transport and just 8% of total transport energy use. At present, the

International shipping CO₂ emission estimates compared to growth in maritime trade (2008–2018)



Sources: Fourth IMO GHG Study and UNCTAD based on data from Clarksons Research

A large cargo ship with a black hull and a red bottom is sailing on a clear blue ocean under a bright sky with scattered white clouds. The ship is viewed from an elevated angle, showing its deck with various structures and equipment. The text is overlaid on the left side of the image.

Shipping's emissions are lower than in 2008 but decarbonisation is only possible with zero-carbon fuels

vast majority of energy used in shipping relies heavily on oil-based fuels and is highly carbon intensive. According to the International Energy Agency (IEA), in 2019 maritime shipping consumed 221 million tonnes of oil-based derivatives, mainly heavy fuel oil and diesel, the daily equivalent to almost 4 million barrels per day of crude oil or more than a third of the daily oil production of Saudi Arabia.

Carbon emissions from shipping in 2019 totalled 710 million tonnes – equal to one-fifth of total CO₂ emissions from freight transport, almost 10% of total transport emissions and around 2% of the world economy's total emissions. Even though this is high and needs to be reduced other industries have a substantially bigger carbon footprint. The global cement industry, for example, emits 2.8 billion tonnes, more than three times more than the shipping industry.

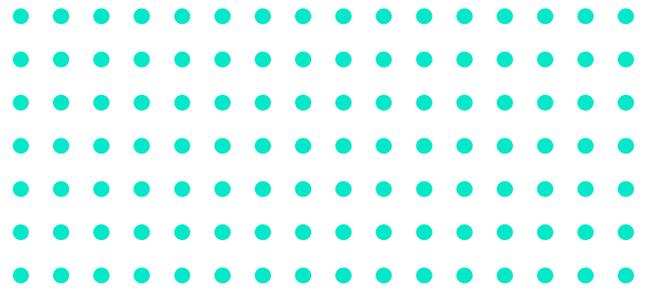
The shipping industry accepts that it needs to reduce its carbon footprint. The global industry regulator, the International Maritime Organization (IMO), has set an ambitious target of global emissions in 2050 being half of what they were in 2008 and with the clear objective of eliminating all greenhouse gas (GHG) emissions soon after. It is estimated that achieving this target might cost around a trillion dollars over the next 30 years, a significant but not unrealistic cost in

view of the bunkering infrastructure that would need to be rolled-out globally. By comparison, the IEA put global investments in energy in 2018 alone at US\$1.85 trillion.

Despite the high costs, the shipping industry itself is committed not just to the delivery of the ambitious CO₂ reduction targets already agreed by IMO Member States but the complete decarbonisation of international maritime transport as soon as possible after 2050.

In recent years, in advance of the introduction of zero-carbon propulsion, a number of interim measures have been identified to reduce the industry's carbon footprint including radically improved ship designs, increased operational energy efficiency measures and the introduction of lower-emission fuels such as liquefied natural gas (LNG). In parallel, shipowners have made major strides in improving the fuel efficiency of their fleets leading to significant cuts in GHG emissions. Fuel is, by far, a ship operator's greatest cost meaning there is a huge economic incentive to do so.

Such measures, while not sufficient in themselves to achieve complete decarbonisation, have already had a substantial effect. The latest IMO study on the sector's GHG emissions, published in August 2020,

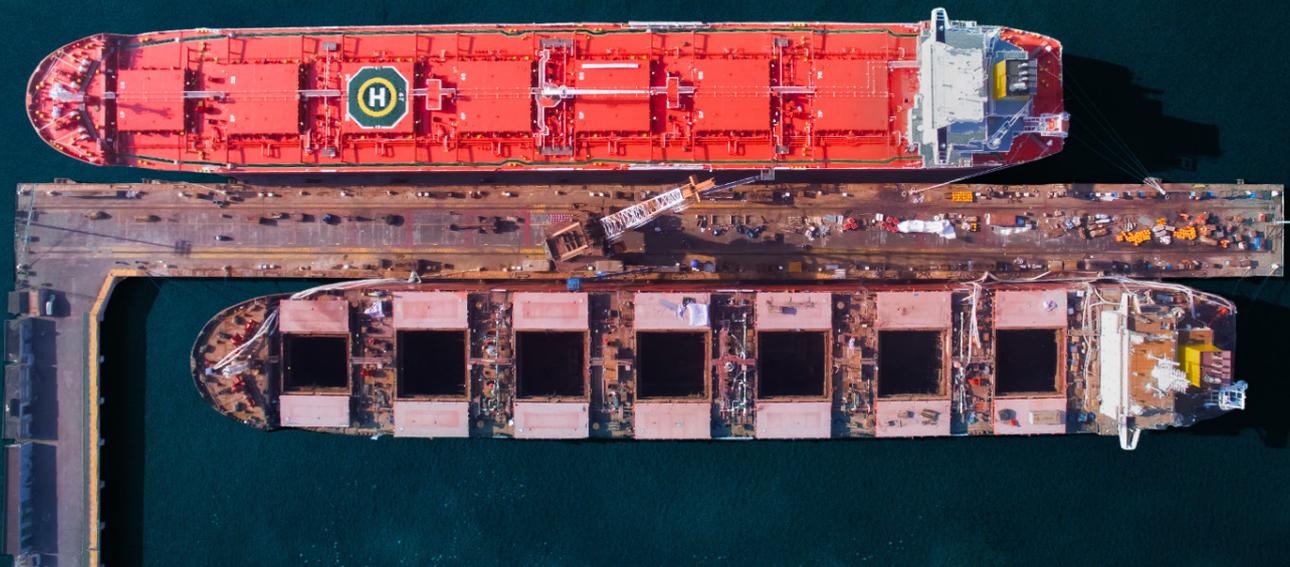


says CO₂ emissions from shipping in 2018 (prior to any contraction in trade caused by COVID-19) were 7% lower than in 2008. Overall, international shipping emissions remain below 2008 levels – the baseline year agreed for the IMO GHG reduction targets set for 2030 and 2050. This decrease came despite a 40% increase in maritime trade during the same ten-year period and represents a carbon efficiency improvement, as an average across the global fleet, of about 30% since 2008 – a significant achievement.

The shipping industry is keenly aware that the existing suite of possible measures to cut carbon emissions is not enough to achieve the IMO targets. Even using conservative estimates for trade growth, a 50% total cut in CO₂ by 2050 can only be achieved by improving carbon efficiency of the world fleet by around 90%. This will only be possible if a large proportion of the fleet is using commercially viable zero-carbon

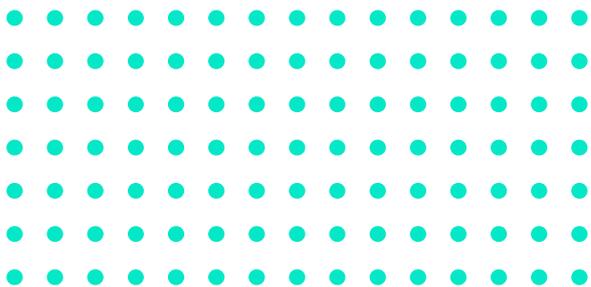
fuels. While not impossible, this will not be easy to achieve as most of these potential zero-carbon fuels are not yet at a sufficient level of technological readiness for application at sea, and will require new propulsion systems that cannot easily be retrofitted into existing ships. But rewards are high: if the 50% target is achieved, with a large proportion of the fleet using zero-carbon fuels by 2050, the entire world fleet would also be using these fuels very shortly after, making the industry’s goal of 100% decarbonisation an achievable aspiration. To reach that point, however, there will have to be major investment in maritime R&D to develop alternatives to using fossil fuels.

The vast majority of energy used in shipping today relies on oil-based fuels and is highly carbon intensive



Existing pathways point to promising alternative fuels and new technologies

For most of the last century, the technology used by ships has been internal combustion engines and steam turbines using fossil fuels resulting in large emissions of carbon. Oil has major advantages, being energy-dense and easy to handle. Its drawback, however, is the massive amount of carbon emitted during production and combustion, and as shipowners commit to tackling the climate emergency, both fuels and propulsion technologies will have to be targeted in order to achieve zero-carbon transportation of cargo. The technologies necessary to achieve these ambitious goals do not yet exist in a form or scale which is commercially viable for widespread use by international shipping, especially for transoceanic voyages that are typically in excess of 10,000 kilometres. But these ambitions can be realised if the necessary R&D investments in developing low-carbon or zero-carbon fuels and/or propulsion systems are incorporated as part of an integrated IMO strategy.



The energy needed to power one large container ship across the ocean in a single day is the same energy needed to power 50,000 homes



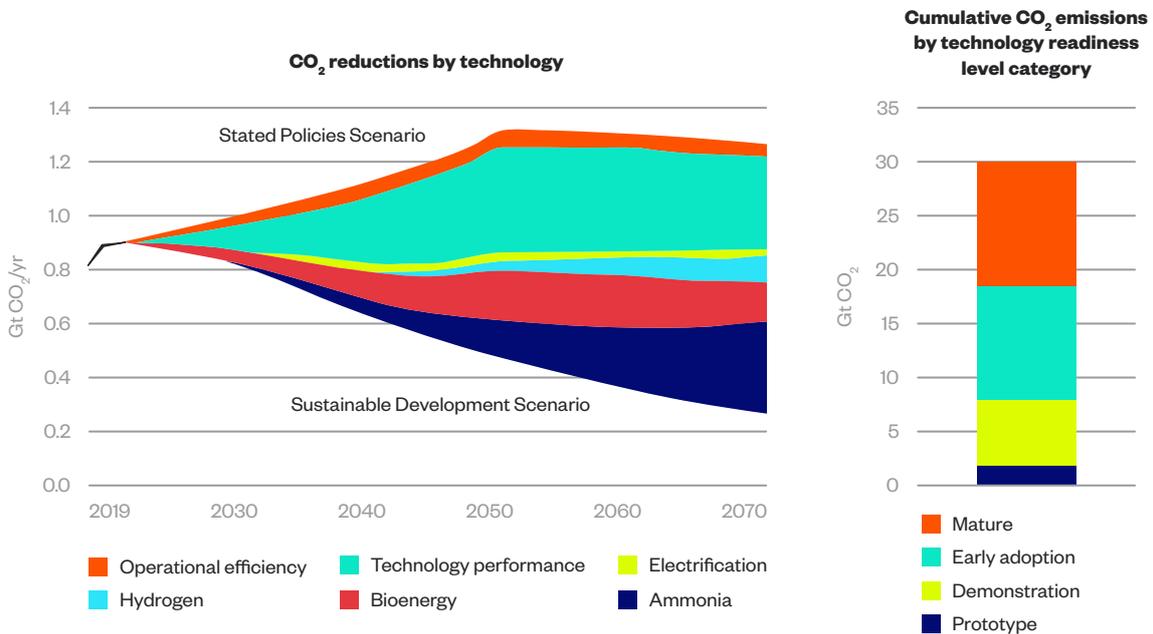
 = 500 homes

The decarbonisation challenge facing the industry is enormous. The larger ocean-going ships that provide the backbone to international trade, often travelling thousands of miles between ports, can typically have a tonnage in excess of 300,000 gross tonnage. This requires a huge amount of energy and ships need to carry very large fuel stocks for their voyages. Large container ships typically consume over 200,000 litres of fuel a day and carry over 10 million gallons in their tanks. The energy required by a large container ship travelling across the ocean on a single day could provide power for a town of 50,000 homes.

In recent years, there have been significant research breakthroughs in identifying zero-carbon fuels and technologies that have the potential to transform the shipping industry and pave the way for the decarbonisation of the global supply chain. There is a growing list of potential pathways with international organisations such as the IEA pointing to promising zero-carbon fuels such as emissions-free, hydrogen-

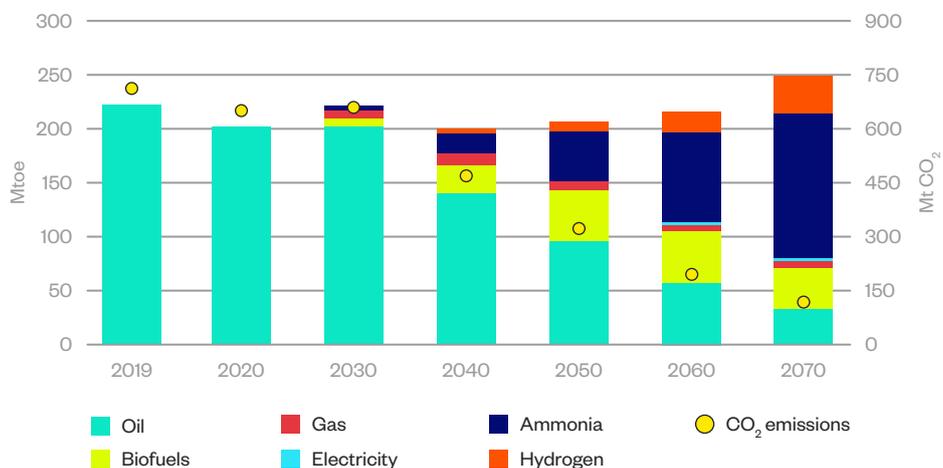
based fuels (ammonia and hydrogen) for long-range transoceanic travel, and battery electric power for coastal short-distance ships. However, most of this research is nascent, carried out in research laboratories, and a long way from being ready for commercial application. Massive investments in R&D will be required before they can be installed in a new fleet of vessels.

Global CO₂ emissions reductions in shipping by mitigation category (left) and technology readiness level (right) in the Sustainable Development Scenario relative to the Stated Policies Scenario, 2019-70

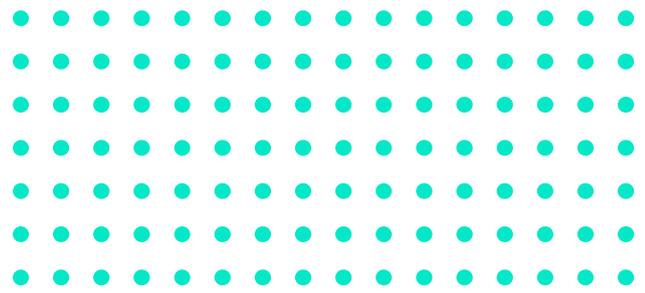


Source: Energy Technology Perspectives 2020, IEA.

Global energy consumption and CO₂ emissions in international shipping in the Sustainable Development Scenario, 2019-70



Source: Energy Technology Perspectives 2020, IEA.



The choice of the optimum future fuel will be driven by a range of considerations including the energy density (the amount of energy stored in a given fuel per unit volume), whether the fuel is fully ‘green’ (some fuels can be emissions-free when used but generated carbon during their production), the need for new propulsion systems and the availability of a global re-fuelling infrastructure. The likely outcome is that there is no single winner. Instead, the future of the global maritime fleet will likely see a number of new classes of vessels each with different zero-carbon fuel and propulsion systems focused on different market segments. The multiplicity of potential pathways represents an added challenge

for the industry as each technology option needs to be comprehensively researched before reaching the required technology readiness level or being discarded as inappropriate for further development. A recent report commissioned by the International Chamber of Shipping (ICS) suggests there could be as many as 200 early-stage R&D projects needed to result in just 20 vessel-ready demonstration projects.

The future global maritime fleet will likely see a number of new propulsion systems





**In recent years,
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carbon fuels and
technologies**

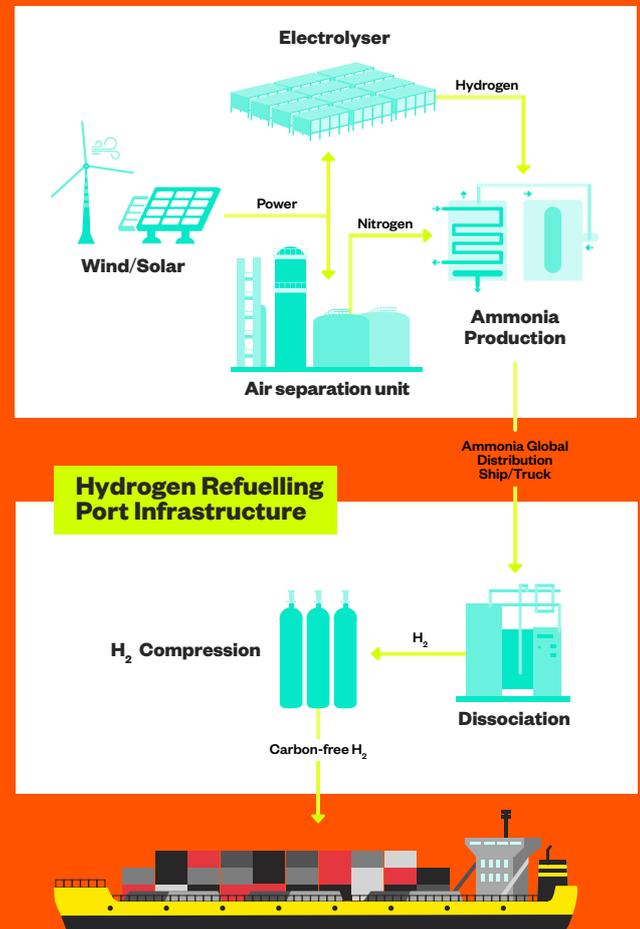
Ammonia

Green ammonia is one of the most promising low-emission fuels with the IEA predicting that its use for shipping will reach 130 million tonnes by 2070, almost twice as much as was used worldwide for fertiliser production in 2019. Nitrogen oxides – the only greenhouse gases emitted by the combustion of ammonia – could be eliminated by installing catalytic systems. Ammonia has multiple advantages including the fact that it can be used in an internal combustion engine. Already, MAN Energy Solutions, a subsidiary of the German carmaker, plans to have its first commercial ammonia-fuelled engine ready by 2024.

Ammonia is widely produced as a solid for the fertiliser industry but is currently made from natural or liquid petroleum gas which release large amounts of carbon during the production process. Green ammonia can be manufactured using renewable energy in a reaction process that uses hydrogen and nitrogen without the release of any carbon. However, in order to be used as a fuel, the ammonia would have to be stored as a liquid solution and a new bunkering network would have to be developed able to handle safely a new fuel that has very toxic properties. Furthermore, its energy density is relatively low which would mean that ships would have to carry more than twice the amount of fuel to cover the same distance compared to a diesel-power vessel.

According to Britain's Royal Society, 250 gigawatts of renewable energy would produce enough green ammonia for a third of the global fleet. If the entire fleet used ammonia, the power required would be 750 gigawatts – 60% of the current global renewable energy production of 2,537 gigawatts.

A recent study by the Danish catalyst company Topsoe forecasts that the cost of green ammonia from solar and wind energy will be \$21.50–45.70 per gigajoule in 2025, dropping to \$13.50–15.00 in 2040. By comparison, fuel oil today is priced at \$12.50–15.00 per gigajoule. Ammonia can be mixed with the existing fuel mix, enabling its use to be increased steadily.



Saudi Arabia recently announced a \$5 billion, 4-gigawatt green ammonia plant to be operational by 2025. The plant will generate four gigawatts of renewable power from solar and wind to produce 650 tonnes per day of hydrogen and 1.2 million tonnes per year of green ammonia. The hydrogen produced is being targeted for commercial trucks. Major R&D will be needed before either ammonia or hydrogen can be used as a zero-carbon fuel for ships. However, Saudi Arabia is located at the centre of the main Asia-Europe shipping lanes meaning that ships could provide a major source of demand for these zero-carbon fuels.

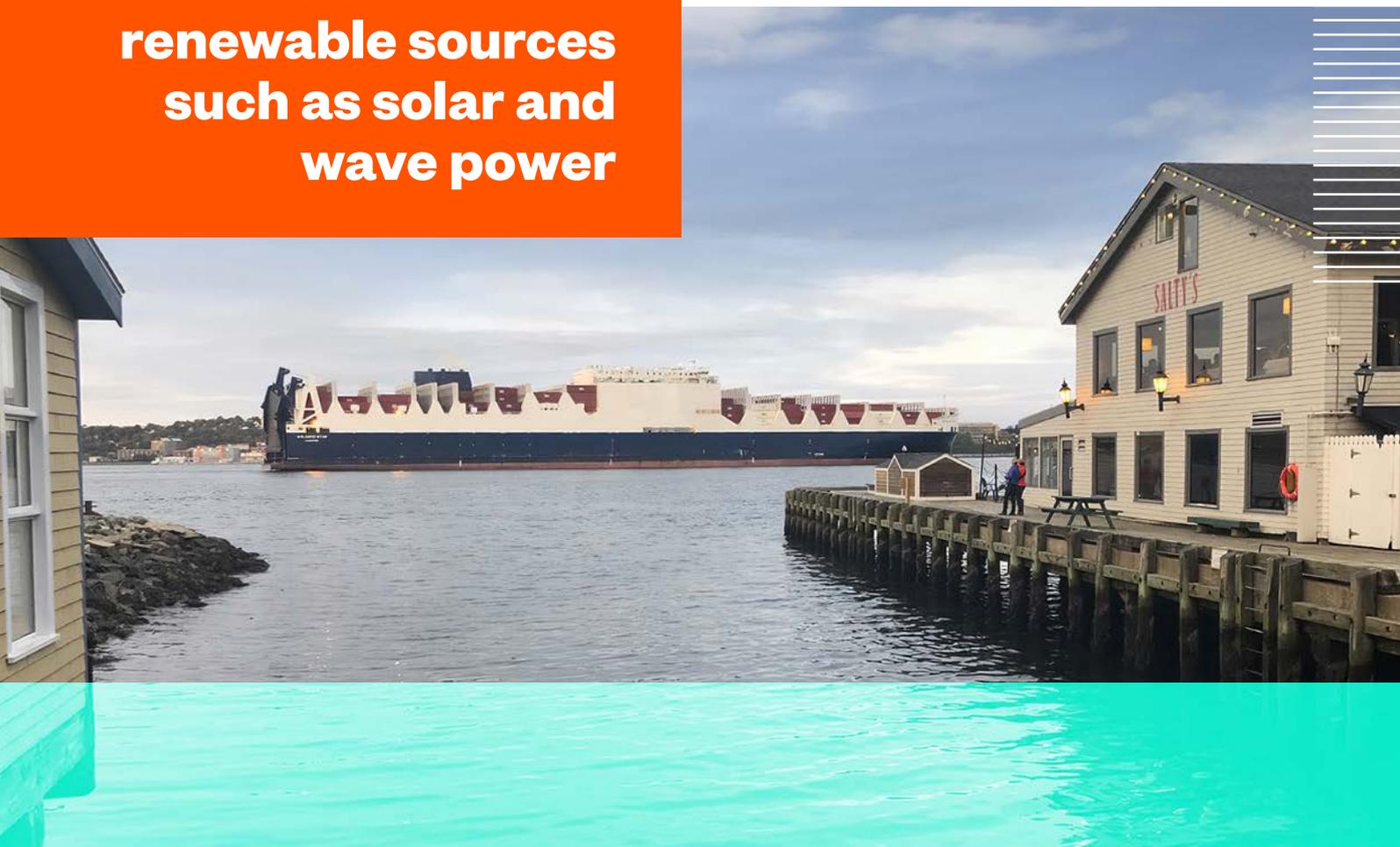
Hydrogen

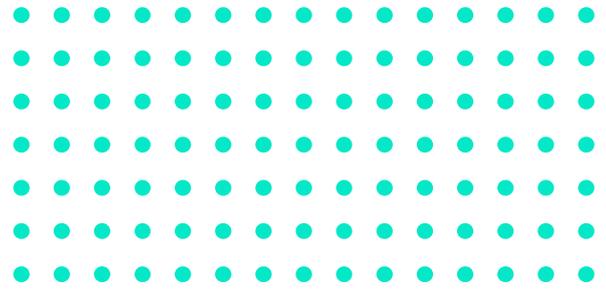
Hydrogen as a fuel is attractive because it emits no carbon or other pollutants when used. At present, most commercially available hydrogen is made from fossil fuels in a process that emits a large amount of carbon, effectively negating its green credentials. However, research is underway to develop energy efficient processes for producing green hydrogen from water via thermochemical processes using renewable energy. For renewable energy producers such as wind and solar, the production of hydrogen by electrolysis is an attractive

opportunity to store and transport surplus energy, thereby stabilising the energy output of their power plants.

The energy density of hydrogen gas is relatively low, and it would need to be liquefied and stored under pressure to be viable as a fuel, creating a transportation and storage challenge. A unit of cooled liquid hydrogen has less than half the energy of diesel and requires more than double the space to store it. Furthermore, an appropriate bunkering infrastructure will also be needed. The IEA notes that the role of hydrogen as a fuel for large vessels is more limited than ammonia due to the high costs of hydrogen storage and its lower energy density. Nonetheless, it predicts hydrogen use could reach 12 million tonnes in 2070, equivalent to 16% of 2019 global maritime bunker demand and 16% of today's global hydrogen use.

Hydrogen for shipping will need to come from renewable sources such as solar and wave power





Existing hydrogen manufacturers can produce ‘blue’ or low-carbon hydrogen by capturing and storing the carbon emitted during the production process. Already, Norwegian company Equinor is leading a project to develop one of the UK’s – and the world’s – first at-scale facilities to produce hydrogen from natural gas in combination with carbon capture and storage (CCS). Oil and gas companies producing hydrogen close to their oilfields can store the carbon in the underground reservoirs from which the gas was produced.

Another potential approach to produce carbon neutral fuels involves chemically processing green hydrogen together with carbon or nitrogen to produce gaseous or liquid fuel. Carbon-based synthetic fuels have properties similar to the fossil fuels used today but the fact that they use captured carbon means that they are technically carbon neutral.

Shipping companies are already working on hydrogen-fuelled vessels. Belgian shipping company CMB recently teamed up with ABC Engines to develop the world’s first dual-fuel hydrogen-diesel engine. The joint venture called Behydro has developed a diesel-hydrogen engine that will be able to provide up to 10 megawatts of power. BeHydro has already received its first order for 2 x 2 megawatts dual-fuel engines that will be installed on board the HydroTug. This vessel is the very first hydrogen tugboat in the world and will be deployed by the Port of Antwerp, using a mono-fuel hydrogen engine that will be ready by the second quarter of 2021. However, there is a huge difference between a 300 gross tonnage tugboat that can be refuelled daily and a large 236,000 gross tonnage oceangoing container ship, illustrating the major scale of the challenge and the need for an accelerated R&D programme.



Fuel cells and batteries

Rather than being combusted as a fuel, hydrogen can be used in fuel cells that turn the chemical energy from hydrogen into electricity through an electrochemical reaction. Fuel cells are considered a potentially promising zero-carbon technology that could be capable of powering ships sailing short distances, as well as supporting auxiliary energy requirements of larger vessels.

Using batteries to power electric engines in ships is still in its infancy but advances in chemistry and technology could eventually mean that even large ocean-going ships could be powered by batteries using renewable sources of energy. However,

achieving this will be a major challenge: a typical large container vessel would require the power of 10,000 Tesla S85 batteries every single day meaning that it would require 70,000 batteries in order to sail for a week.

The current view is that purely electric vessels will only be economically viable for short-distance trips, but this could be changed with increased R&D. The shipping industry is likely to be a big beneficiary of advances in the electric car industry. Much research is already underway to increase the watt-hours per kilogram (Wh/kg), the unit of measurement commonly used to describe the density of energy in batteries. Existing batteries that Tesla uses in its Model 3 are an estimated 250 Wh/kg but some companies believe that they will soon be able to achieve batteries of 1,000 Wh/kg. Achieving increased energy density of batteries will be key.

Using batteries to help power ships is possible but still in its infancy

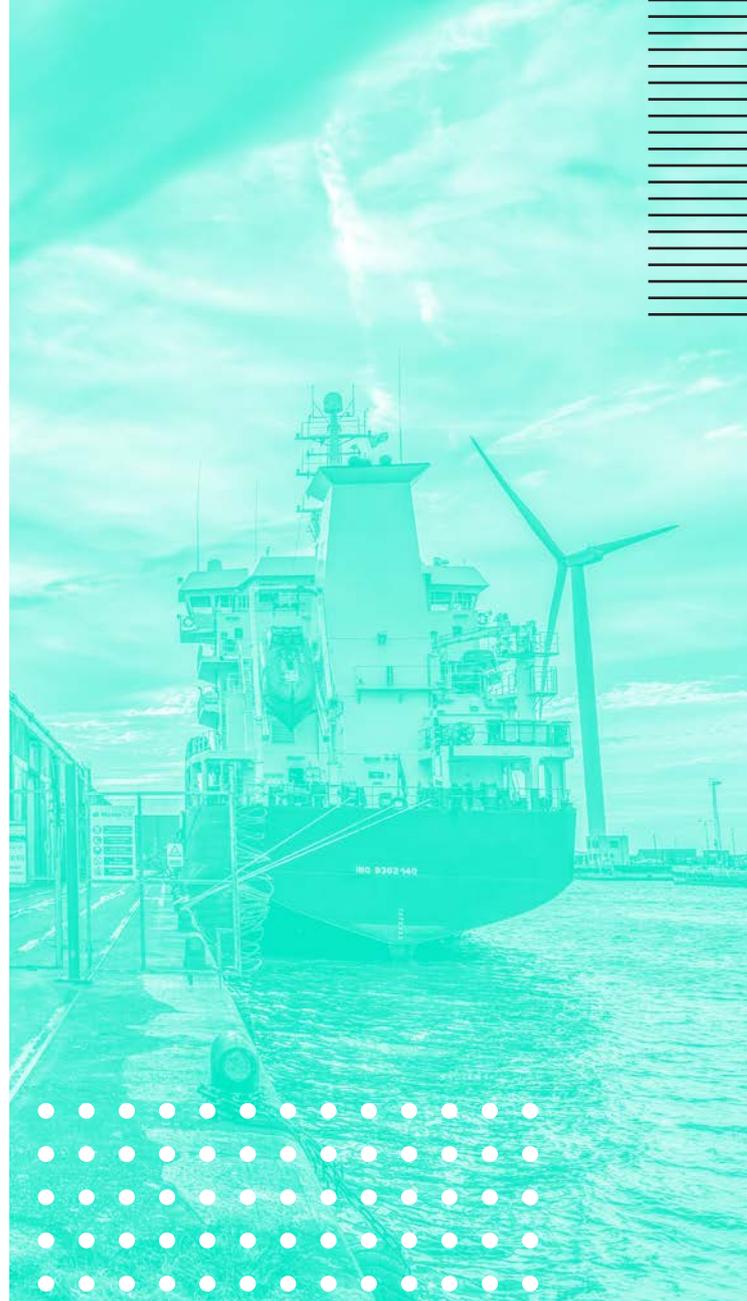


Wind

Harnessing the power of the wind, the shipping industry's oldest propulsion system, is becoming a viable option thanks to new technology. While today's modern ships are unlikely to ever be driven exclusively by the power of nature, wind-assisted propulsion could complement systems that use zero-carbon fuel. Recently developed rigid wing sails and kites as well as the Flettner rotor that use force that derives from vertical rotors, could be further developed to provide a secondary zero-carbon propulsion system for ships or even primary propulsion on some routes. Even though existing retro-fitted wind systems can only currently supply 5–10% of a ship's energy requirements, these are likely to be further optimised and hybrid wind-electric systems are potentially attractive R&D approaches.

Nuclear

Nuclear fuels are a proven technology that could be readily applied to many merchant ships in order to eliminate CO₂ emissions completely. Only a small nuclear reactor would be required, with a life of many years, removing the need for ships to refuel or carry bunkers. Russia successfully operates a number of nuclear ice breaking vessels in the Arctic. However, it is currently assumed that widespread use of nuclear fuels is unlikely to be viewed as politically acceptable by the majority of governments, due to concerns about safety and security.



Up-scaling infant technologies into adoptable solutions: the case for a global maritime R&D fund

A quantum leap in decarbonised technology similar to the switch from sail to steam over a century ago is required if shipping's current CO₂ reduction targets are to be achieved. The required carbon efficiency improvement of up to 90% is simply incompatible with the continuing long-term use of fossil fuels by commercial shipping. Already time is short as the IMO 2050 target can only be achieved with the introduction of commercially viable zero-carbon technologies in the 2030s. Furthermore, a new generation of vessels will have to be built as it will take many decades before the existing fleet is fully replaced. Ships typically have a lifespan of 20–25 years.

However, the majority of vessels constructed today run almost exclusively on fossil fuels, and it will not be possible for regulators to mandate their phase-out before 2050 unless zero-carbon fuels and propulsion systems are available on a global basis.

Such zero-carbon technologies do not currently exist in a scale or form that can be applied to large ocean-going ships and the current state of technological readiness of potentially promising solutions such as hydrogen, ammonia and battery systems will require a massive amount of investment in R&D before they can be commercially applied in the global shipping industry. Other challenges will include the anticipated need to create new land-based fuel handling and supply infrastructures as well as the need to embark on training programmes and the development of completely novel safety procedures. The size of the task, while not insurmountable, is enormous for an industry which is dependent on fossil fuels, and

Commercially viable zero-carbon ships need to appear in the 2030s



which mostly comprises small and medium sized enterprises. Furthermore, shipping companies are global transportation enterprises not technology companies. While they can support the technology development process, individual shipping companies cannot be expected to lead the necessary R&D, underlining the need for a global R&D Fund to which the entire industry can contribute.

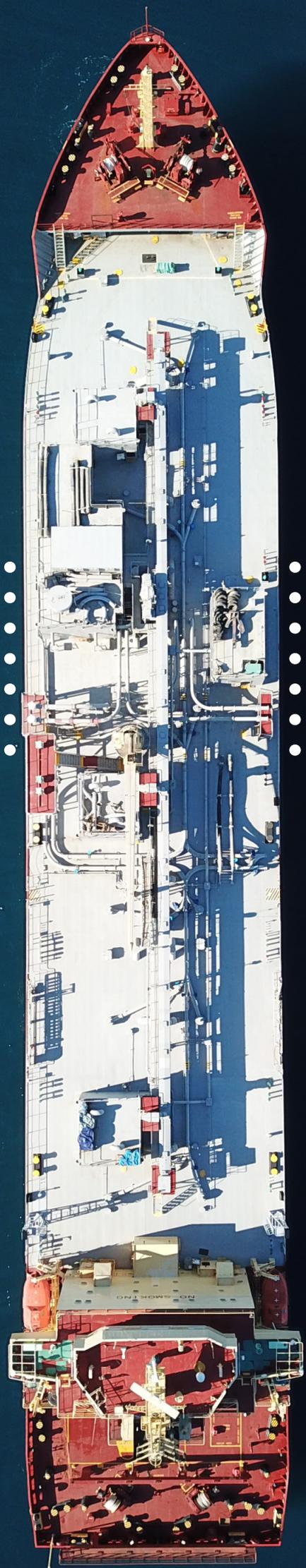
In an attempt to provide a major impetus to global R&D efforts, the global maritime transport industry has submitted a proposal to IMO to form the world's first collaborative shipping R&D programme to help eliminate CO₂ emissions from international shipping. The proposal includes core funding from shipping companies across the world of about US\$ 5 billion over a 10-year period.

In order to accelerate the R&D process, the shipping industry proposed, in December 2019, the establishment of an International Maritime Research and Development Board (IMRB), a non-governmental R&D organisation that would be overseen by IMO Member States. Under the proposal, the IMRB will be financed by shipping companies worldwide via a mandatory R&D levy of US\$ 2 per tonne of marine fuel purchased for consumption by shipping companies worldwide, which will generate about US\$ 5 billion in core funding over a 10-year period.

This US\$ 5 billion in core funding to be generated from the industry contributions is critical to accelerate the R&D effort required to decarbonise the shipping sector and to catalyse the deployment of commercially viable zero-carbon ships by the early 2030s.

ICS believes that a global fund, once adopted by the IMO, can be established quickly. Other stakeholders such as energy producers, ship builders and engine manufacturers are likely to want to contribute via co-funded projects supported by this major R&D programme, potentially generating substantial additional funding for R&D for zero-carbon technologies.

In its proposal to the UN IMO, the industry set out details for governance and funding of the coordinated R&D programme, which, with the political support of governments, could be put in place by as soon as 2023 via amendments to the existing IMO Convention for the Prevention of Pollution from Ships (MARPOL).



Conclusion: zero-carbon shipping is a win-win for all

The IEA estimates that by 2070, oil and gas will be responsible for just one-sixth of total shipping fuel consumption. For that, the fourth propulsion revolution will have to have succeeded. However, this will require an enormous effort and a large amount of money. The establishment of an International Maritime Research and Development Board will be a major step in the journey towards ending the use of fossil fuel by embracing zero-carbon fuels.

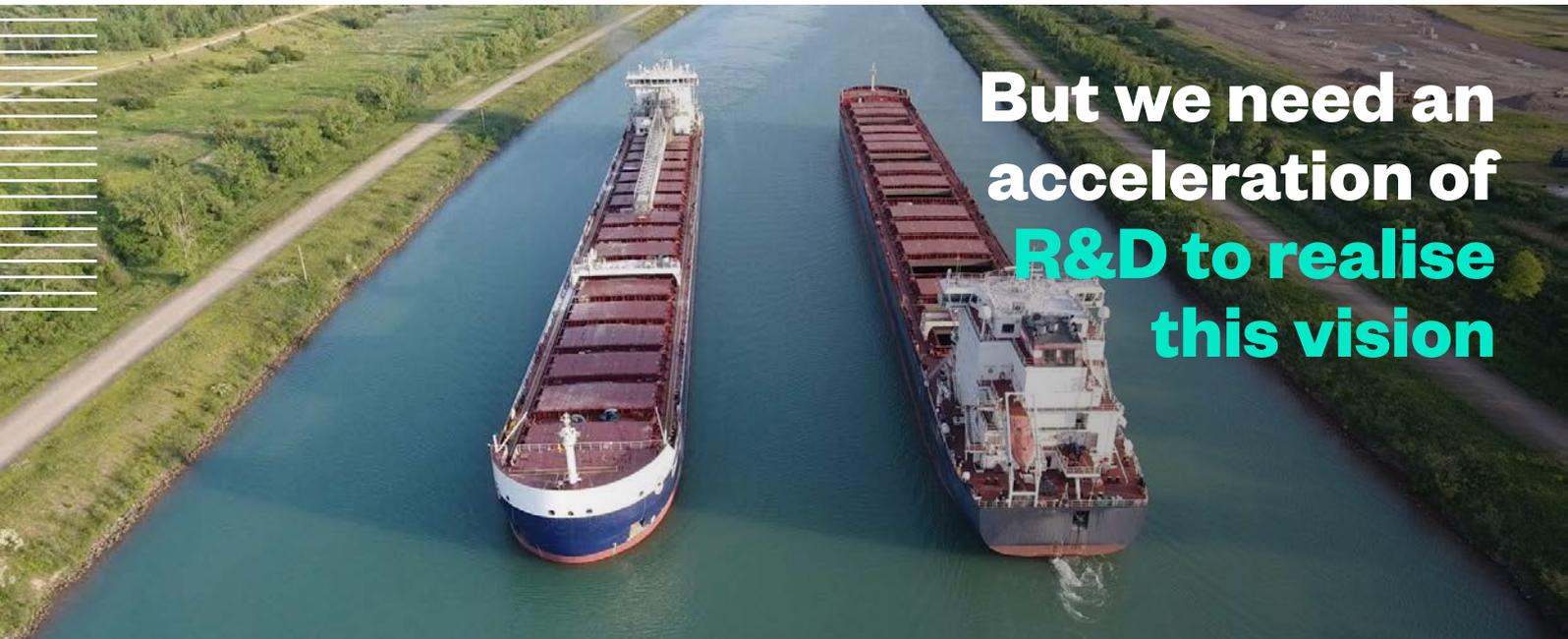
The global shipping industry has no intention whatsoever of allowing COVID-19, or its attendant economic challenges, to deflect from its efforts to achieve the IMO targets or to fulfil its responsibility to help meet the 1.5-degree Celsius climate change goal that has been set for the global economy by the Paris Agreement. Many companies have begun investing in research into new fuels and technologies, but the \$5 billion fund will provide a major boost.

This is a process in which there are winners and very few losers. In addition to the major contribution in the fight against climate change, R&D actions undertaken within the scope of the International Maritime Research and Development Board will almost certainly have wider benefits beyond the

shipping industry. For example, hydrogen fuel cells are already being tested in passenger vehicles while green ammonia is also being lined up as a fuel for airplanes. The British aircraft-engine manufacturer Reaction Engines says it is working on a fuel system in which ammonia is exposed to a catalyst that splits it into nitrogen and hydrogen, with the latter burned in the aircraft engine.

Legacy hydrocarbon producers will not necessarily lose out. Indeed, they could end up being major producers of a new generation of zero-carbon fuels. For example, Middle East oil producers could produce blue hydrogen from natural gas or methane while capturing the carbon produced during the process and re-injecting it into the oilfield geological reservoir. Likewise, they could use their abundant solar resources to make green hydrogen by electrolysis of water with renewable energy.

Shipowners themselves will be beneficiaries despite the major investments they are prepared to make. As the world moves towards a green economy, charterers will come under pressure from their clients to use ships with green credentials. Likewise, financiers will be more likely to fund green ships than older carbon emitting ships.



But we need an acceleration of R&D to realise this vision



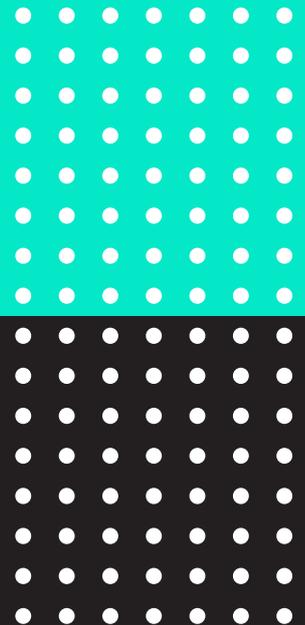
**To succeed, the fourth
propulsion revolution needs
a massive and immediate
acceleration of R&D**





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