IRENA
International Renewable Energy Agency

# NAVIGATING THE WAY TO A RENEWABLE FUTURE:

## SOLUTIONS TO DECARBONISE SHIPPING

**Preliminary findings**

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# ABBREVIATIONS

| | |
|---|---|
| AD | Anaerobic digestion |
| Bio-DME | Bio-dimethyl ether |
| $CO_2$ | Carbon dioxide |
| EE | Energy efficiency |
| EEDI | Energy efficiency design index |
| EJ | Exajoule |
| FAME | Fatty acid methyl ester |
| FT | Fischer-Tropsch |
| GDP | Gross domestic product |
| GHG | Greenhouse gas |
| GJ | Gigajoules |
| EJ | Exajoules |
| Gt | Gigaton |
| $H_2$ | Hydrogen gas |
| HFO | Heavy fuel oil |
| HP | Horsepower |
| HVO | Hydrotreated vegetable oil |
| IAPP | International Air Pollution Prevention |
| IFO | Intermediate fuel oil |
| IMO | International Maritime Organisation |
| ISO | International Organization for Standardization |
| Kt | Thousands of tonnes |
| LNG | Liquefied natural gas |
| LPG | Liquefied petroleum gas |
| MARPOL | Maritime pollution |
| MDO | Marine diesel oil |
| MGO | Marine gas oil |
| MTEU | Million twenty-foot equivalent units |
| m/m | Mass by mass |
| MS | Medium sized ships |
| Mt | Megaton |
| Mtoe | Millions of tonnes of oil equivalent |
| MTEU | Million twenty-foot equivalent unit |
| $NO_x$ | Nitrogen oxide |
| ODS | Ozone depleting substances |
| OPEC | Organization of the Petroleum Exporting Countries |
| $SO_x$ | Sulphur oxide |
| SVO | Straight vegetable oil |
| SS | Small sized ships |
| TEU | Twenty-foot equivalent units |
| UNCTAD | United Nations Conference on Trade and Development |
| USD | United States dollar |
| VLS | Very large ships |
| VOC | Volatile organic compounds |

# KEY MESSAGES

- The International Monetary Fund forecasts that between 2019-2024, global GDP will grow at an average rate of 3.6% per year. Similarly, global trade volume is estimated to grow at 3.8% per year over the next five years. Under this context, in the absence of suitable mitigation policies, the International Maritime Organisation (IMO) states that greenhouse gas (GHG) emissions associated with the shipping sector could grow between 50% and 250% by 2050.

- In 2017, port container traffic amounted to 753 million twenty-foot equivalent units (MTEUs)[1] of containers, this represented a 6% growth in the container throughput between 2016 and 2017, the highest growth recorded over the last five years.

- By the end of 2018, the global shipping fleet had a capacity of nearly 2 Gt. Some 40% of this capacity was accounted for by bulk carriers, 30% by oil tankers and 15% by container ships.

- Global international bunkering for shipping accounts for 8.9 exajoules (EJ) (2017), with 82% of these energy needs met by heavy fuel oil (HFO) and the remaining 18% by marine gas and diesel oil.

- Between 2000 and 2017, the $CO_2$ emissions associated with the shipping sector grew at an average annual rate of 1.87%. In 2017, the sector was responsible for emitting 677 megatons (Mt) of $CO_2$.

- On average, the shipping sector is responsible for 3% of annual global green-house gas (GHG) emissions on a $CO_2$-equivalent basis. International shipping represents around 9% of the global emissions associated with the transport sector.

- Bulk and container carriers, as well as oil and chemical tankers, represent 20% of the global shipping fleet; together these vessels are responsible for 85% of the net GHG emissions associated with the shipping sector.

- Seven ports are responsible for nearly 60% of the bunker fuel sales around the world, with Singapore delivering as much as 22% of today's total bunkering. Accordingly, any shift towards the use of cleaner fuels should consider the needs for infrastructure adjustments at the main bunkering ports.

- Tightening regulations on sulphur oxide ($SO_x$) reductions are expected to be the key driver impacting the reduction of $CO_2$ emissions associated with the shipping sector. $SO_x$ airborne limits come into effect at the beginning of 2020; non-complying ships will face sanctions depending on their registration flag and docking ports. Yet actions taken to reduce $SO_x$ will not necessarily support the $CO_2$ reductions necessary to achieve IMO targets.

- There are three main routes for reducing the carbon footprint of the shipping sector: improve the design of the vessels themselves to reduce their specific fuel consumption; shift from fossil fuels to other alternative fuels and means of propulsion; and improve practices during docking periods by securing cold-ironing[2].

*1 TEU: Unit typically used in the shipping sector, a twenty-foot equivalent unit (TEU) is a shipping container whose internal dimensions measure about 20 feet long, 8 feet wide, and 8 feet tall.*

*2 Cold-ironing: Refers to turning off vessels' auxiliary engines during shore-side operations in the port area by plugging the vessels into an electricity source offered by the port authority, thus reducing airborne emissions during docking periods.*

- A shift from heavy fuel oil (HFO) to a clean fuel would require many actions and considerations, including:
    - » Adjustments to the refuelling structure in around 100 ports (these account for 80% of global freight).
    - » The replacement/retrofitting of around 25 000 ships.
    - » If ammonia were picked as fuel at 18.6 gigajoules/t ammonia, 8.9 exajoules (EJ) bunker fuel would translate into 480 megatons (Mt) of ammonia – twice today's global ammonia production volume.
- To achieve the IMO target of halving $CO_2$ emissions by 2050, alternative fuels will be needed, based on renewable sources and production methods, to provide low- or even zero-carbon solutions.
- Alternative fuel options all have different advantages and disadvantages, and there is no consensus on which option is best. The fuel price and its availability will likely be the decisive factors in the choice of fuel/propulsion technology. Bunker costs can account for 24-41% of total costs (with these also including container, administrative and cargo handling costs). Other decisive factors also include infrastructural adaptation costs, technological maturity and sustainability issues (e.g. food security), as well as the willingness and ability to pay a premium price for low-carbon products.
- Some alternative fuel options, like biofuels, are ready to be used, require little to no adjustments to existing infrastructure and can have a considerable, immediate impact on emissions reduction, even as blends.
- Considering the current state of technology, electric ships powered by batteries are viable for short distance applications, e.g. ferries travelling up to around 95 km.
- Various solutions are under discussion, with no clear winner to date. On the one hand, there are various advanced liquid and gaseous biofuel options, while on the other, there are hydrogen and hydrogen derivatives, such as methanol, ammonia and power-to-liquids applications.
- In general, alternative fuels are not yet economically competitive. As their adoption grows and technology improves, however, they are expected to become competitive in the medium- to long-term.
- Any action focused on reducing GHGs by cutting down on the use of liquid fossil fuels must consider the total life cycle emissions of the alternative renewable options. This is because upstream emissions might limit or even offset the overall reductions achieved through the use of alternative fuels.

# INTRODUCTION

The present analysis explores the impact of maritime shipping on $CO_2$ emissions, the structure of the shipping sector, and key areas that need to be addressed to reduce the sector's carbon footprint. Furthermore, this International Renewable Energy Agency (IRENA) paper reviews the principal, existing policy frameworks that address GHG and airborne emissions. It also looks at the potential clean fuels and renewable-based means of propulsion that can shift historical emissions trends. Overall, this initial framing analysis lays the groundwork for further work to help to create a carbon-free maritime sector.

To fully decarbonise all modes of transport, three different approaches are needed. The first approach is to avoid inefficient or unnecessary travel or transport. The second is to shift transport modes to the more efficient modes, and the third is to improve the technologies to make them more efficient and less polluting (IRENA, 2018). These approaches are further explored throughout the document to shed light on the technology pathways that have the largest potential to reduce the environmental impact caused by the emissions of shipping sector.

At present, maritime shipping represents 80-90% of international trade. With global GDP expected to grow an average of 3.6% per year between 2019-2024, global trade volume could also grow at a similar annual rate i.e. 3.8% over the next five years. Therefore, if no action is taken promptly, demand for marine fossil fuels – and thus the associated carbon emissions – will continue to grow steadily. This would challenge the decarbonisation targets set by the IMO and other private groups and make them impossible to achieve. In fact, in the absence of suitable mitigation policies, the GHG emissions associated with the shipping sector could grow between 50% and 250% by 2050 (IMO, 2015).

Sea transport is less carbon intensive than other forms of transport, on a $CO_2$ per tonne-km basis. Yet, due to the large volumes of freight and long distances travelled, the shipping sector has a significant impact in terms of climate change. In 2017, international shipping accounted for 677.25 Mt of $CO_2$; thus, 3% of all annual global $CO_2$ emissions are associated with this key sector of the world's economy. If the shipping sector's emissions were compared to the national $CO_2$ emissions of the largest economies, this sector would be the sixth largest country in the world for $CO_2$ emissions (Balcombe et al., 2019).

Given the importance of the role that the shipping sector has in reducing global GHG emissions, in April 2018, the IMO established a target of halving the 2008 level of carbon emissions by 2050 (IMO, 2018). At the same time, private stakeholders, including one of the largest shipping operators in the world, announced their intention to achieve complete decarbonisation of their operations by 2050. This would be achieved through the deployment of carbon neutral vessels, starting as soon as 2030.

There is no clear-cut path to decarbonisation. Cutting $CO_2$ emissions in half is therefore likely to require a combination of approaches, including the use of alternative fuels, upgrading of onshore infrastructure, and reducing fuel demand by improving operational performance. The shipping sector is in a strategic position to tackle climate change and could play a leading role in the transition to a zero-carbon economy. Large scale deployment of low-carbon fuel infrastructure in the shipping sector could also create the necessary momentum to decarbonise other sectors.

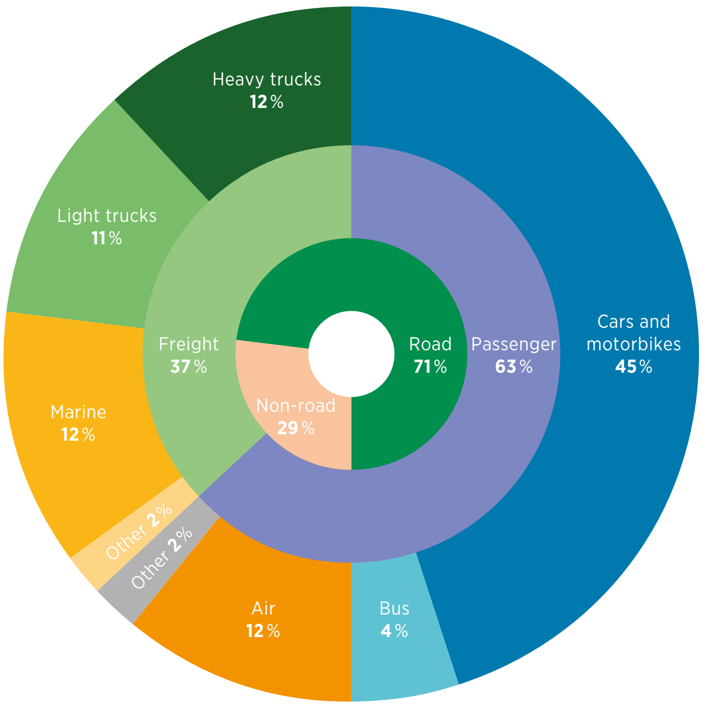
# SECTORAL ANALYSIS

## The transport sector

Some 50% of all liquid fossil fuel consumption is associated with the transport sector. Globally, the sector registered an oil consumption of 2 523 million of tonnes of oil equivalent (Mtoe) with energy usage in the transport sector accounting for approximately 30% of global energy consumption across all end-use sectors (IEA, 2019). A further disaggregation indicates that within the transport sector, marine freight is responsible for 12% of total energy consumption (EIA, 2016).

While energy used for road freight amounts to twice that of the marine sector, around 80-90% of internationally traded goods (i.e. 8.7 Gt) are transported by shipping, representing 9.3% of $CO_2$ emissions linked to the transport sector. Overall, as indicated in the Third IMO GHG study (2015), shipping was responsible for an average of 2.8%[3] of all annual GHGs on a $CO_2$-equivalent basis, between 2007 and 2012 (IMO, 2015).

**Figure 1:** Disaggregation of global energy consumption on the transport sector




Source: EIA (2016)

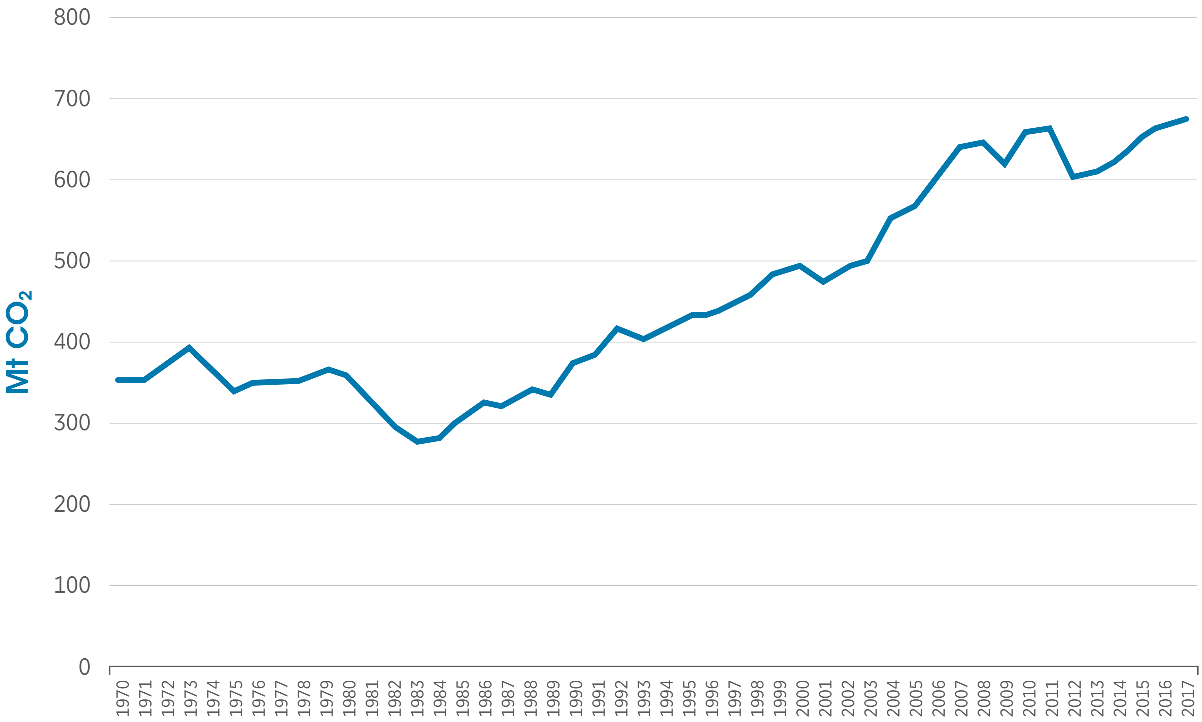
Similarly, $CO_2$ emissions associated with shipping account for around 3% of global $CO_2$ emissions. In addition, given that HFO is so widely used in shipping, the sector is responsible for approximately 15% of global annual nitrogen oxide ($NO_x$) (3.2 Mt/year) emissions and 13% of $SO_x$ (2.3 Mt/year) emissions.

Since the 1960s, airborne pollutants have been a major concern for the international community, particularly the emission of $SO_x$, a pollutant which results in harmful human health issues (e.g. respiratory complications and lung disease), as well as acid rain and ocean acidification.

*3 Basis using 100-year global warming potential conversions from the IPCC Fifth Assessment Report (AR5). IPCC (2014)*

Between 2000 and 2017, $CO_2$ emissions associated with the shipping sector increased at an average annual growth rate of 1.87%. In 2017, the shipping sector was responsible for 677.25 Mt of $CO_2$ emissions (JRC-EDGAR, 2018).

**Figure 2:** Annual $CO_2$ emissions associated with international shipping




Source: JRC-EDGAR (2018)

## The shipping sector

The shipping sector represents a substantial opportunity for $CO_2$ emissions reduction, as well as for reducing the airborne emissions of other toxic pollutants.

The sector's vessels tend to be grouped according to various criteria – mainly, type of service, size[4] and age. At present, the total number of ships in service is estimated at 90 715 worldwide, with medium sized ships (MS) the most common. This type accounts for 39 141 units, together representing 43% of the global fleet. An inner disaggregation of MS shows that the sub-sector primarily consists of general cargo (30%), oil and chemical tankers (18%), and offshore vessels (13.6%). The total number of small sized ships (SS) is comparable, with a total fleet of 33 752 units, composed of tugs (52%), general cargo (13%) and passenger ships (12%). Large ships (LS) and very large ships (VLS) account for only 11 783 and as few as 6 039 vessels, respectively. These fleets include bulk carriers, oil and chemical tankers, and container ships, which together account for 86% of the total LS and VLS types.

*4 Classification of ships by size: small ships range from 100 gross tons (GT) to 499 GT. Medium ships are 500 GT to 24 999 GT. Large ships are 25 000 GT to 59 999 GT. Very large ships are ≥60 000 GT.*

**Figure 3:** Total number of ships worldwide, by ship size

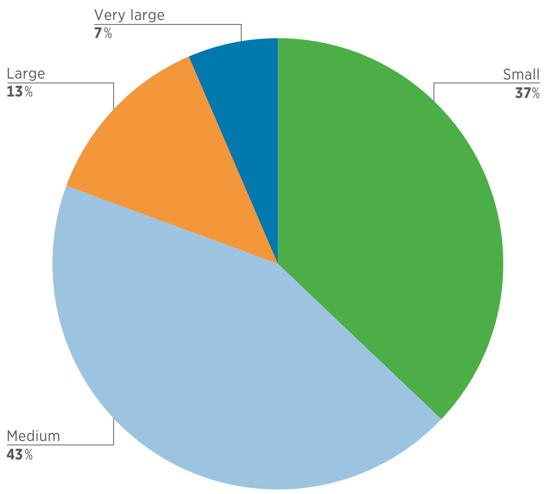
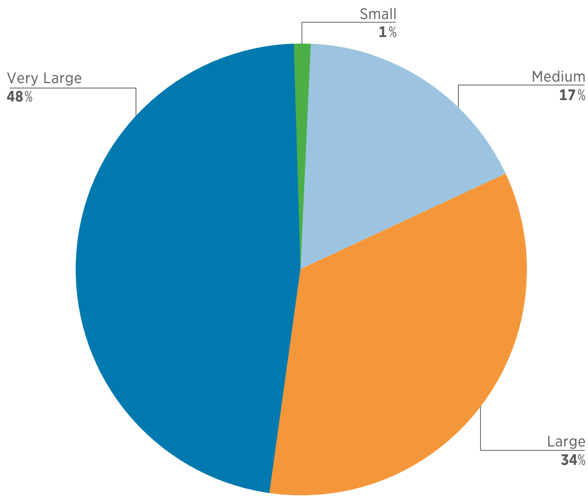



**Figure 4:** Gross tonnage of ships worldwide, by ship size

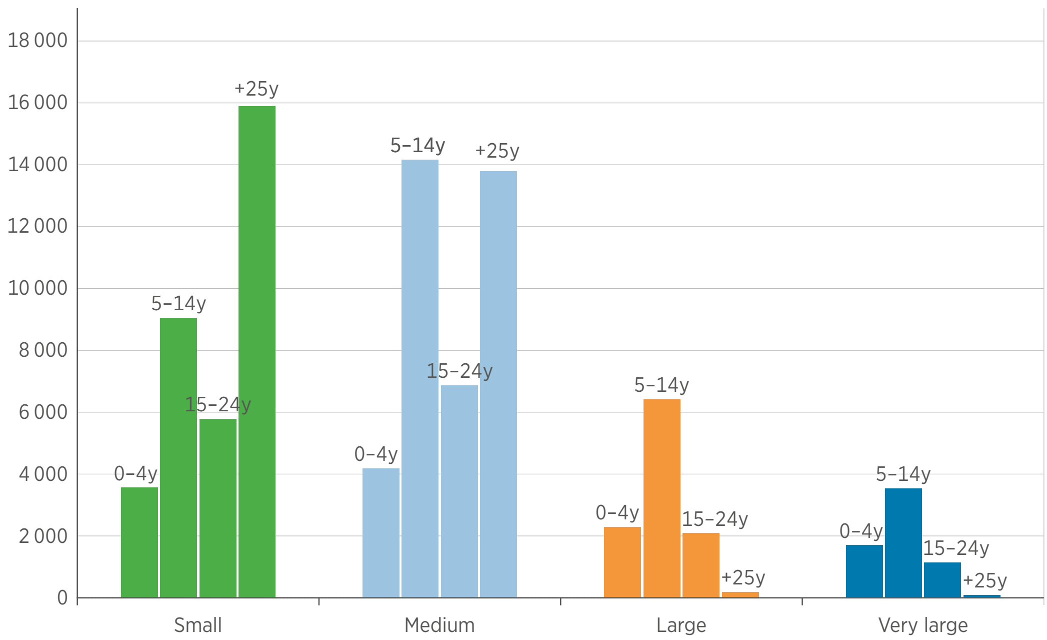



Source: Equasis (2017)

Although SS and MS ships outnumber the overall units of LS and VLS, the significance in terms of tonnage of these two latter size categories indicates that approximately 82% of global cargo by weight is linked to LS and VLS. Unsurprisingly, economies of scale in the shipping sector dictate the building and operation of larger ships. Accordingly, a substantial proportion of SS (47%) and MS (33%) ships are more than 25 years old, in their respective categories, thus nearly reaching (if not exceeding) their lifespans, while the majority of LS (21%) and VLS (26%) are relatively new, between 0 and 14 years old.

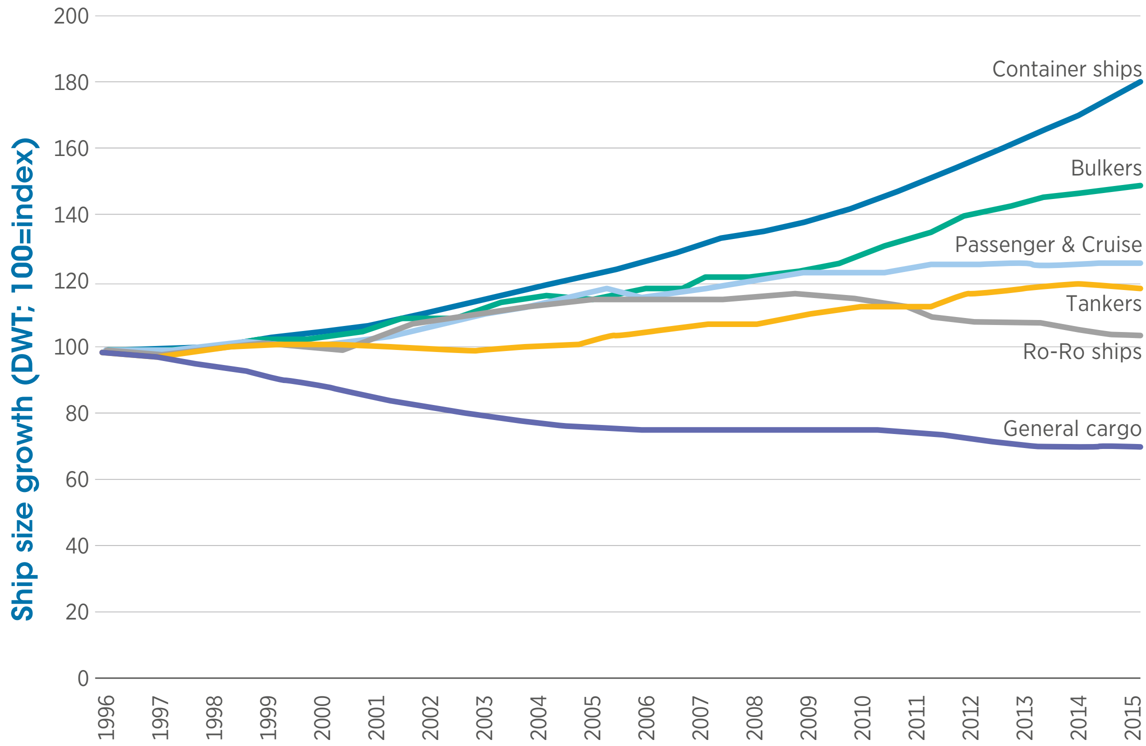
The key motivations for building larger ships greatly depend on the application of the vessel. Since larger ships need less energy to move a given amount of freight over a given distance, vessel size can reflect the aim of shipping manufacturers and owners to maximise profits by becoming more efficient, particularly with bulk carriers, container ships, and oil and chemical carriers.

**Figure 5:** World fleet: total number of ships, by age and size




Source: Equasis (2017)

**Figure 6:** Ship size development of various ship types



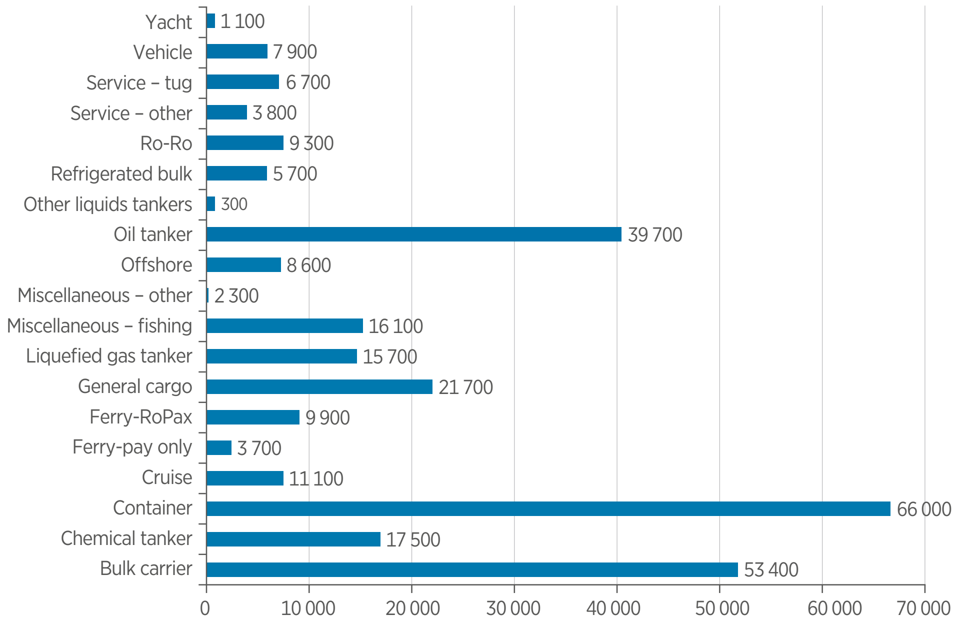

Source: ITF (2015)

In terms of fuel requirements, there has been a slow, but continuous, tendency for these to evolve over the years. The 1920s witnessed a switch from coal to diesel, and the 1950s saw a move from diesel to HFO. Lately, there has been increasing interest in moving towards cleaner fossil fuels, specifically liquefied natural gas (LNG). This has been motivated by a need to comply with increasingly tighter regulations and emissions reduction targets related to airborne pollutants and GHGs.

While LNG is cheaper than HFO, the main barrier to switching from HFO to LNG is the upfront costs linked to the retrofits required. As a result – and given that the main driver to switch from one fuel to another is compliance with SOx reduction regulations – there is a tendency at present to switch from HFO to distillate fuels, like marine gas oil (MGO) and marine diesel oil (MDO). While the use of distillate fuels would support the reduction of sulphur emissions (Balcombe et al., 2019), in fact, to achieve IMO GHG emission reduction targets, the shipping sector will eventually need to shift from fossil-based LNG to renewable fuels and alternative propulsion means.

Subsequently, and given the need to reduce the carbon footprint of the shipping sector, the interest in using cleaner fuels and propulsion means (e.g. biofuels, methanol, hydrogen, electric propulsion and nuclear) has caught the attention of the shipping industry. While the potential for cutting the carbon footprint varies from fuel to fuel and needs to be analysed on a life cycle basis, the main barrier is the economics associated with each fuel and propulsion means.

**Figure 7:** Annual fuel consumption by ship type in 2012 in thousands of tonnes (kt)

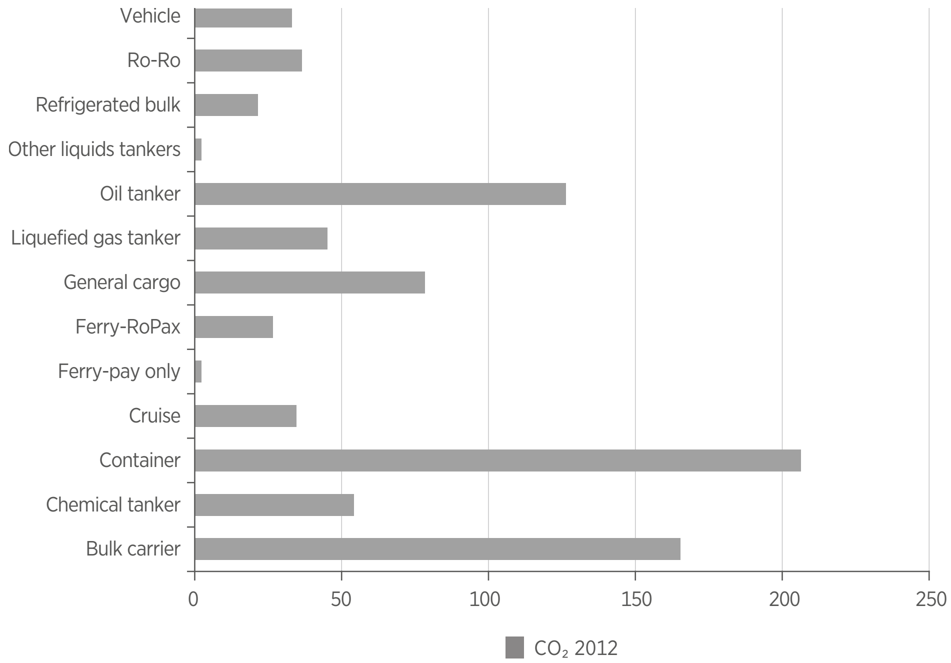



Source: IMO (2015)

A further disaggregation of the fuel needs of the different shipping categories and the specific fuel requirements of the machinery used indicates that the biggest shift needed to reduce carbon emissions must occur in the main engines – and not necessarily in the auxiliary engines and boilers. This is independent of the service provided by the vessel and indicates that container ships, bulk carriers and oil tanker engines should be the key targets.

Further evidence given in the *Third IMO Greenhouse Gas study* (2014) calls for a more systematic $CO_2$ emissions reduction agenda for the shipping sector. This is especially because in recent years, $CO_2$ trends have shown that the shipping sector's impact on climate change has not been adequately addressed.

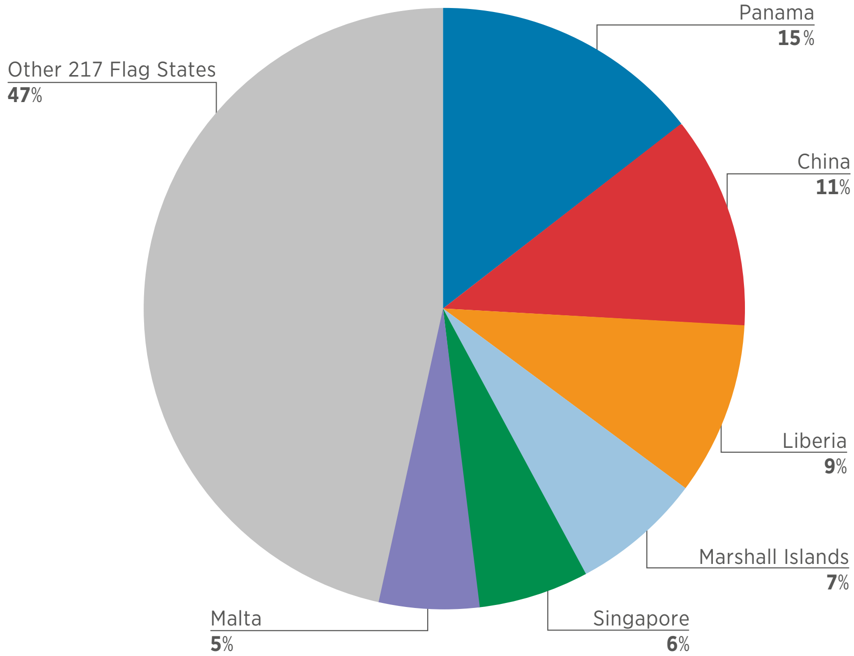
**Figure 8:** $CO_2$ emissions by ship type, 2007-2012 (Mt)




Source: IMO (2015)

The overall characteristics of the shipping sector and a breakdown by category shows that 85% of $CO_2$ emissions in the sector come from large ships, specifically container carriers, oil tankers and bulk carriers. The high level of GHG emissions linked to these vessels is also heavily influenced by the high number of miles they travel. Together, these three classes of ship account for 55% of global shipping emissions. Similarly, in terms of flag registration, 75% of vessels (on a dead-weight basis) are registered in nine locations, with Panama (17.5%), Marshall Islands (12.4%), Liberia (12%) and China (9.4%) at the top of the list. Consequently, 63% of the overall shipping emissions come from vessels with flags from six states: Panama (15%), China (11%), Liberia (9%), Marshall Islands (7%), Singapore (6%) and Malta (5%) (ICCT, 2017).

**Figure 9:** Share of $CO_2$ emissions by flag state, 2013 2015



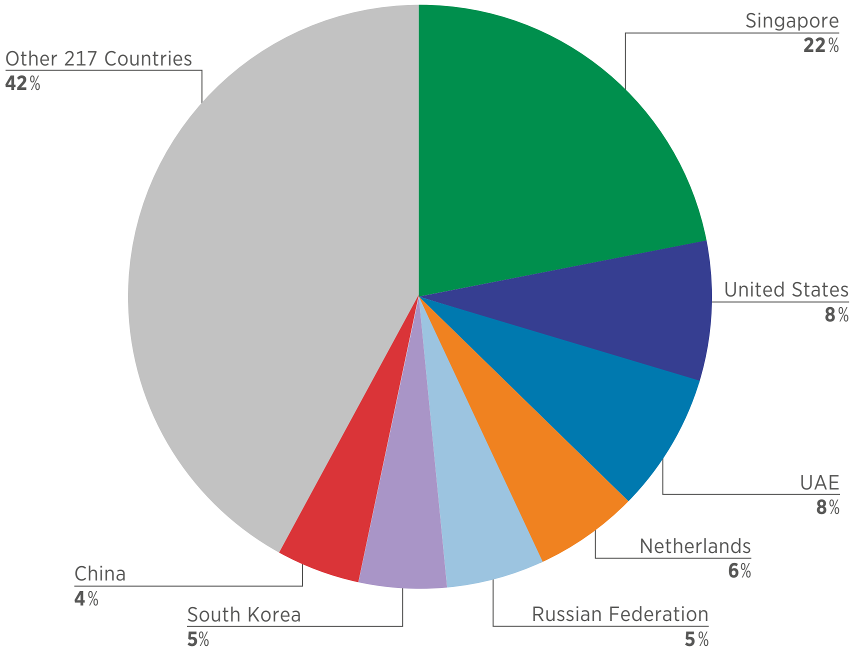

Source: ICCT (2017)

## Ports and bunkering

In 2017, global international bunkering for shipping totalled 8.9 EJ (IEA, 2019). Out of this, 82% was accounted for by HFO and the remaining 18% by gas/diesel oil. Notably, demand for bunker fuels is closely related to the intensity of economic and trade activity (OPEC, 2016). In recent years, seaborne trade has therefore risen significantly. Between 2015 and 2016, trade activity (tonne-miles) grew by 3.41%, while between 2016 and 2017, trade activity grew by 5% (UNCTAD, 2018). As mentioned above, latest data from the IMF (2019) shows that these trends are expected to continue, with expectations of global GDP growth at 3.6% per year between 2019-2024, potentially boosting trade volume by 3.8% per year over this same period. Subsequently, bunkering in the shipping sector is likely to grow progressively in the years to come.

Considering the expected growth in trade in the coming years – and thus the increasing energy needs of the shipping sector – a shift towards a cleaner maritime transport industry will require changes not only in the vessels, but also in the supply infrastructure. In this regard, seven ports are responsible for nearly 60% of all bunkering sales globally, with as much as 22% of the today's bunkering concentrated in Singapore alone.

**Figure 10:** International shipping bunkering by country, 2017




Source: IRENA analysis, based on IEA (2019)

The assets of ports themselves are divided into terminal infrastructure and operational equipment, with bunkering part of the operational side.

While bunkering is linked to the direct emissions of the shipping sector, any shift toward a cleaner sector which incorporates renewable energy sources will require important changes to port terminal infrastructure and operational equipment (see Table 1), as well as daily operational practices.

**Table 1:** Description of the main infrastructure and equipment in ports

| Infrastructure and equipment | Key asset | Function |
|---|---|---|
| **Terminal related** | Docking areas | Areas where ships can remain from between one hour to a maximum of three days. |
| | Bunkering | Processing and infrastructure linked to fuel supply of ships. The method may be one of three types: i) truck-to-ship; ii) ship-to-ship; or iii) shore-to-ship. |
| | Cold-ironing | Refers to the supply of power to ships during the docking period; generally, allows the ship to turn off the auxiliary engines and thus reduce fuel consumption and emissions. Peak power for medium-large ships varies between 6 MW for container carriers and 15 MW for cruise ships. |
| **Equipment** | Cranes | Enable the loading and unloading of cargo, a service generally provided by the port operator. An activity mostly powered by diesel generators and power directly supplied by the dock. |
| | Tugboats | Relatively small vessels with large engines i.e. ~5 000 horsepower (HP); responsible for pushing ships towards the assigned docking site. |
| | Dredging vessels | Vessels responsible for ensuring adequate water depth in the port area. |

Source: IEA-ETSAP (2011)

While port operations also result in GHG emissions, bunkering is the main factor affecting the emissions of the shipping sector. As previously mentioned, bunkering is generally grouped according to the fuel supply method, where the infrastructure linked to this activity is not necessarily owned by the port operator and could be facilitated by different means (e.g. truck-to-ship, ship-to-ship or shore-to-ship).

The advantage of truck-to-ship is that infrastructure investment for the port operator is lower. But due to quayside traffic caused by bunkering trucks, cargo operation and passenger handling can be negatively affected.

Ship-to-ship is, at present, the most common method applied for bunkering of HFO, MGO and MDO, but its effectiveness depends on the size of the port, which dictates the maximum capacity of the bunkering vessels.

Shore-to-ship is a suitable method in ports with uniform and long-term fuel demand; yet, depending on port design and traffic influx, it may lead to slow bunkering operations due to the efforts that need to be taken by the ships to reach the supply terminal.

Considering the current infrastructure and its compatibility with biofuels, switching from HFO, MDO and MGO to biofuels (e.g. straight vegetable oil (SVO), hydrotreated vegetable oil (HVO), fatty acid methyl ester (FAME), etc.) would not require major changes to the storage and bunkering infrastructure, nor in the supply methods.

Further reductions in the overall carbon footprint of the shipping sector can be achieved by addressing the operational practices and fuel usage in the key ports.

In this, securing and enforcing the cold-ironing of electricity in ports should be a priority. For this purpose, ports should secure adequate shore-side infrastructure, including upgraded connections to the national grid, while ships may also need the incorporation of a step-down transformer and additional switching boards. Clearly, the overall reduction in carbon emissions this would produce would also depend greatly on the power generation mix of the country hosting the port, however. The carbon footprint related to a port's operation could also be reduced by enhancing the deployment of distributed renewable energy in key anchorages, such as Jurong, Jebel Ali, South Louisiana, and Rotterdam.

## Policy and regulatory framework

In alignment with the Paris Agreement and the United Nations 2030 Agenda for Sustainable Development and Sustainable Development Goal 13, which states: "Take urgent action to combat climate change and its impacts", in April 2018 the IMO adopted an initial vision for reducing the shipping sector's GHG emissions.

This states that these need to fall urgently, by at least 50% by 2050, compared to 2008. More specifically, the vision sets three levels of ambition (IMO, 2018):

1. **The carbon intensity of ships to decline through the implementation of further phases of the energy efficiency design index (EEDI) for new ships.**
   This to be reviewed with the aim of strengthening the energy efficiency design requirements for ships, with a percentage improvement for each phase to be determined for each ship type, as appropriate.

2. **The carbon intensity of international shipping to decline.**
   The reduction of $CO_2$ emissions by at least 40% by 2030, compared to 2008 and as an average across international shipping. Efforts to be pursued towards making this 70% by 2050.

3. **GHG emissions from international shipping to peak and decline.**
   To peak GHG emissions from international shipping as soon as possible and to reduce total annual GHG emissions from the sector by at least 50% by 2050, compared to 2008. At the same time, efforts to be made towards phasing GHG emissions out altogether, as called for in the vision, as a point on a pathway of $CO_2$ emissions reduction, consistent with the Paris Agreement's temperature goals.

While the establishment of targets for reducing GHG emissions in the shipping sector is relatively recent, since 1960, and particularly with the adoption of Annex VI – Prevention of Air Pollution from Ships in 1997, the IMO has been working on regulating the airborne emission of $SO_x$, $NO_x$, ozone depleting substances (ODS), volatile organic compounds (VOC) and shipboard incineration. The underlying objective of this has been to tackle the detrimental impact of these pollutants on human health and the environment.

More recently, the IMO has taken significant steps in limiting $SO_x$ emissions. As indicated in MARPOL[5] Annex VI regulation 14, by 31 December 2019, all fuel-oil shipping operating outside Emission Control Areas must be limited to 3.50% mass by mass (m/m). Starting in January 2020, this requirement will be further tightened to 0.50% of the "fuel oil used on board", a term that includes the emissions from main and auxiliary engines, as well as from boilers.

To achieve these ambitious targets, the IMO suggests the following paths:

- Use a compliant fuel oil with low sulphur content (<0.50% m/m).
- If exceeding 0.50% sulphur content, use an equivalent cleaning means, e.g. exhaust sulphur scrubber.
- Replace the use of high sulphur fuels with alternative fuels, e.g. LNG, methanol and others.
- Use onshore power supply during docking periods.

From the perspective of a ship owner, considering the emissions reduction timescales for sulphur and $CO_2$, the key driver that could result in a reduction of GHG emissions for the shipping sector is the MARPOL Annex VI regulation and not necessarily the IMO strategy on reduction of GHG (IMO, 2018). Furthermore, given that the regulatory framework for controlling, supervising and enforcing low sulphur content in fuel is more thorough, GHG emission reductions are likely to depend greatly on the method for reducing sulphur emissions applied by the ship owners. In this regard, the responsible party for controlling the sulphur limit depends on the flag state of the ship. Hence, developing countries such as Panama, Marshall Islands and Liberia must have the necessary means and skills to control compliance with the sulphur limit and issuance of the International Air Pollution Prevention (IAPP) certificate. Similarly, sanctions need to be set by the flag state and/or port state, depending on the situation.

In contrast to the methods of sulphur content control, the IMO has proposed a non-punitive method for reducing GHG emissions through ten market-based measures.

*5 MARPOL is short for maritime pollution.*

These serve two purposes: to “provide an economic incentive for the maritime industry to reduce its fuel consumption by investing in more fuel efficient ships and technologies and to operate ships in a more energy efficient-manner” and to “enable the offsetting in other sectors of growing ship emissions (out-of-sector reductions)” (IMO, 2019).

While the IMO Strategy on reduction of GHGs is recent, in July 2011, the IMO took more practical action to reduce $CO_2$ emissions by making it mandatory for ships to comply with the EEDI. This indicator focuses on enhancing the energy efficiency (EE) of engines, as well as of auxiliary equipment. It uses the individual ship design, expressed in grams of $CO_2$ per ship’s capacity-mile. Thus, a small EEDI indicates lower specific fuel consumption and lower $CO_2$ emissions.

The following formula illustrates how to calculate the EEDI:

$$\text{EEDI} = \frac{\text{Engine power x Specific fuel consumption x Carbon factor}}{\text{Deadweight tonnage x speed}} \quad (\text{g}CO_2\text{/ton-mile})$$

The mandatory nature of the EEDI has resulted in the identification of specific activities for improving EE across the various shipping components.

The Global Maritime Energy Efficiency Partnership (GloMEEP, 2019a) has also proposed specific actions for fostering renewable energy and improving EEDI, including: fixing sails, adding wings or a kite to support propulsion, including Flettner rotors to generate wind power, and installing solar PV panels for power generation.

# RENEWABLE FUEL PATHWAY ANALYSIS

As mentioned in the previous chapter, apart from a few exceptions, virtually all commercial shipping activities today are powered by fossil fuels. The entry into force of new emissions regulations is, however, triggering a change in fuel sources in much of the industry. Most vessels are expected to either switch to very low-sulphur fuel oils, LNG or retrofit scrubbing systems to reduce $SO_x$ emissions. Yet, these short term solutions are insufficient to achieve the IMO target of halving $CO_2$ emissions by 2050. To achieve this goal, alternative fuels will be needed, based on renewable energy sources, or renewable based production methods, to provide low- or even zero carbon solutions.

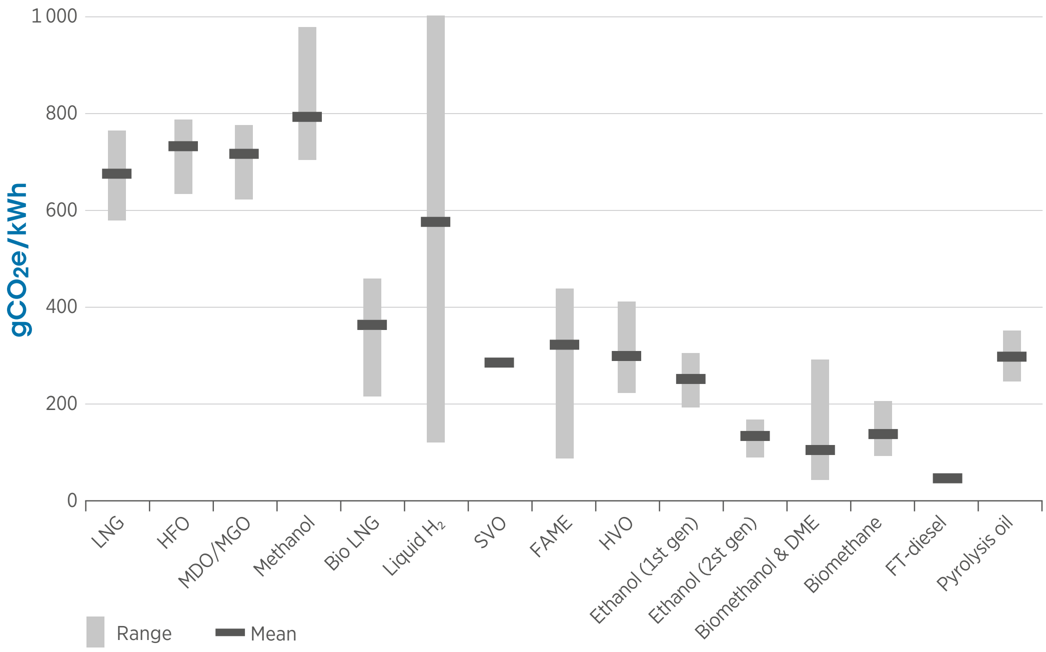
Alternatives include: conventional and advanced biofuels; other synthetic fuels, such as methanol, hydrogen and ammonia ($NH_3$); battery-powered electric propulsion; and efficiency improvements achieved through the harnessing of other renewable energy sources, such as wind and solar.

These alternative fuel options all have different advantages and disadvantages, as described in the sections below, and therefore there is no clear-cut way forward. The ultimate choice will likely boil down to the particular social, economic, technical and environmental implications linked to each fuel option (e.g. land and water availability for energy crops, food security, land use change, and the yield of the various energy crops).

Any action focused in the reduction of GHGs by cutting down on the use of liquid fossil fuels must consider the total life cycle emissions of the alternative renewable options. This is because upstream emissions might limit or even offset the overall reductions achieved through the use of alternative fuels.

Figure 11 shows different GHG life cycle emissions ranges for different fuel types. Methanol and hydrogen are noteworthy, since – depending on the production method, feedstock choice and source of electricity – their total life cycle GHG emissions can exceed those of fossil marine fuels. Ammonia contains hydrogen and nitrogen. Therefore, the life cycle emissions related to ammonia production will be similar to those of hydrogen production, albeit higher given that emissions from nitrogen production should also be considered.

**Figure 11:** Total life cycle GHG emissions per kWh of engine output for different fuels




Based on: Balcombe et al. (2019)

The energy density, volumetric energy density, and storage temperature and pressure of the different fuel alternatives also play an important role, since they have a considerable impact on the techno economic feasibility of each fuel.

For example, as shown in Table 2, ammonia has two-thirds the volumetric energy density of LNG, and therefore more storage space is needed. At the same time, methanol can be stored as a liquid at ambient temperature, while LNG needs to be kept at -62°C, which warrants considerable logistical and infrastructural consideration. Certain fuels are therefore more difficult to handle because of their special storage needs and safety considerations (e.g. hydrogen). In contrast, fuels such as methanol have characteristics closer to conventional fossil fuels, but their cost is at present uncompetitive. Therefore, in the choice of the selected alternative fuel, the implications for logistics, infrastructure and safety need to be considered.

**Table 2:** Comparison of different marine fuels

| Fuel type | LHV* [MJ/kg] | Volumetric energy density [GJ/m³] | Storage pressure [bar] | Storage temperature [°C] |
|---|---|---|---|---|
| **MGO** | 42.7 | 36.6 | 1 | 20 |
| **LNG** | 50 | 23.4 | 1 | -162 |
| **Methanol** | 19.9 | 15.8 | 1 | 20 |
| **Liquid ammonia** | 18.6 | 12.7 | 1/10 | -34/20 |
| **Liquid hydrogen** | 120 | 8.5 | 1 | -253 |
| **Compresed hydrogen** | 120 | 7.5 | 700 | 20 |

*LHV: Lower heating value
Based on: De Vries (2019)

Another important consideration is the price of fuel. At USD 350/tonne (United States dollars), bunker costs can account for 24-41% of total costs (i.e. including container, administrative and cargo handling costs) (Notteboom and Vernimmen, 2009). These shares become larger as the bunker costs increase, which means that fuel prices will likely be a decisive factor in the final choice of fuel/propulsion technology.

**Table 3:** Applicability of biofuels by type

| Biofuel | Applicability |
|---|---|
| **Biodiesels (HVO, FAME, Fischer-Tropsch [FT] diesel)** | Tugboats, small carriers/cargo ships, replacing MDO/MGO |
| **Bio dimethyl ether (bio-DME)** | Carriers and cargo ships (all sizes), replacing MDO/MGO |
| **SVO** | Carriers and cargo ships (all sizes), replacing IFO/HFO |
| **Bio-LNG** | Tugboats, LNG carriers, ferries, cruise ships, support vessels, replacing conventional LNG in gas or in dual fuel engines |
| **Bio-alcohols** | Tankers, cruise ships, passenger ships, blended with distilled fuels or in dual fuel engines |
| **Pyrolysis oil** | Carriers and cargo ships (all sizes), replacing IFO/HFO |

Source: IRENA, based on Florentinus et al. (2012)

## Biofuels

Biofuels are not yet extensively used in the shipping industry, yet they could play a vital role in its decarbonisation. Compared to fossil fuel alternatives, they offer smaller GHG, $NO_x$ and $SO_x$ emissions and they do so at relatively limited cost, due to their high technical compatibility with currently available shipping and bunkering infrastructure. Additionally, due to their biodegradability, they are safer for the environment in the case of spills, when unblended.

There are several commercial marine engine technologies that are able to operate on liquid biofuels. These can be blended with existing marine fuels, e.g. 20% FAME blends, which are widely available (IEA, 2017), and ISO 8217:2017-compliant 7% FAME blends, which are also commercially available. Some biofuels are even compatible as drop-in fuels.[6] Table 3 shows some of the main biofuel alternatives and their applicability.

Marine diesel engines commercially available today are already capable of operating with certain biofuels, such as SVO, HFO, FAME, FT-diesel and pyrolysis oil, with little to no modifications necessary, depending on the fuel and the blend. The use of these diesel-like biofuels does, however, raise some fuel-specific issues. These include reduced engine lifespan, due to carbon build-ups in the case of SVO, or in the caseof FAME, water contamination, which could lead to loss of efficiency, microbial growth[7] and fuel gelling. HVO solves some of these issues, however, due to its low oxygen content, higher fuel efficiency and longer lifespan. A switch to these fuels would not require changes to current storage and bunkering infrastructure or logistics (Balcombe et al., 2019; Hsie and Felby, 2017), making them an excellent option for the short, medium and long term.

On the other hand, the use of alcohols and gaseous fuels, such as bioethanol, bio-methanol and bio-LNG, would come with considerable cost. These are related to the adaptation requirements of operating engines, storage and bunkering infrastructure. Available commercial dual-fuel engine technologies can run on these types of fuels, however, and provide an excellent solution for new vessel orders. The next section includes more information on the necessary bunkering infrastructure and logistical adaptations.

Given the IMO's low sulphur emissions regulation, which comes into effect in January 2020, large ships such container and bulk carriers, as well as oil tankers, are likely in the short term to aim for compliance through retrofits which would enable them to switch from high sulphur fuels (e.g. HFO, MFO, etc.) to fossil fuel LNG. Such a trend would result in a reduction of $SO_x$ emissions, but would not help achieve the required $CO_2$ emission reduction.

Given the likelihood of such scenario, Bio-LNG holds tremendous potential as a transitional fuel which could gradually replace fossil LNG. This would actively enhance the reduction of $CO_2$ emissions in the shipping sector, particularly if synthetic methane from anaerobic digestion (AD) is used, harnessing waste which can then be upgraded and liquified.

Research on the life cycle airborne emissions of alternative shipping fuels shows that harnessing agricultural and animal waste and its processing through AD for further production of bio-LNG may result in an around 30% $CO_2$ emissions cut, if compared with fossil fuel LNG (Gilbert et al., 2018). The relevance of this finding has been underscored by the announcement from Gruppo EF Tecnologie, an Italian company, which is currently trying to market bio-LNG to end users and distributors and pitching the shipping sector as an important niche (Gruppo EF Tecnologie, 2019).

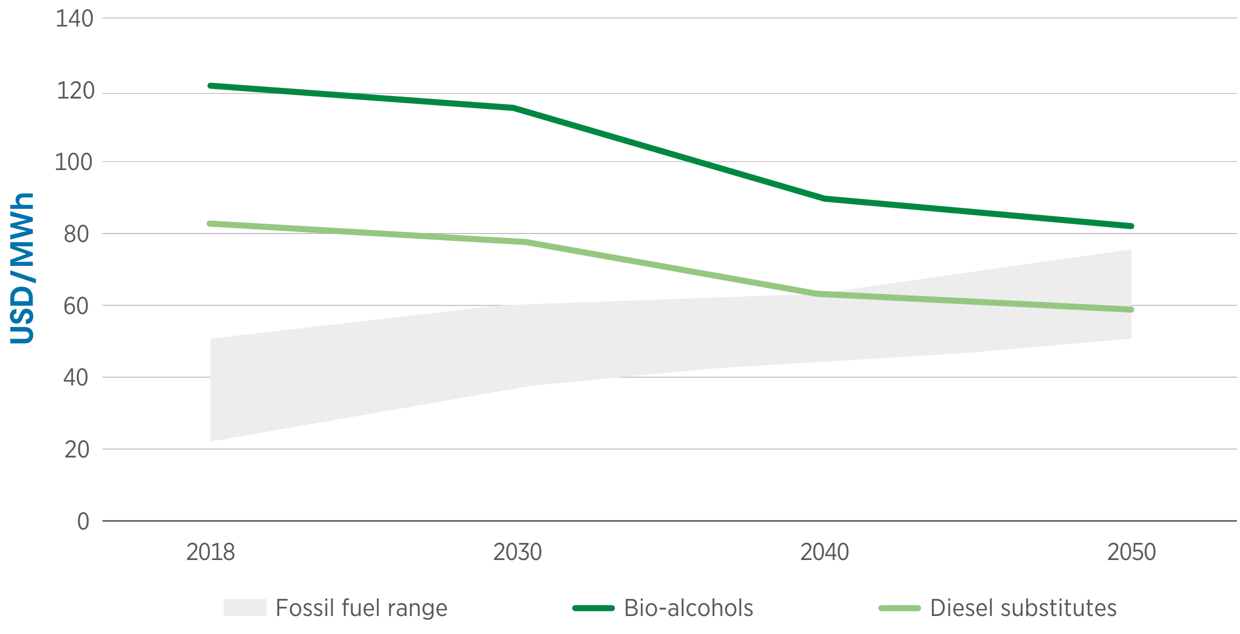
*6 A drop-in fuel is a fuel that is functionally equivalent to petroleum-based fuels.*

*7 A trial on the Maersk Kalmar ship, looking to evaluate the impact of FAME usage, did not show microbial growth to be an issue, although more research is needed on this topic (RAENG, 2013).*

Another attractive and currently available method for the production of bio-methane is the gasification of woody biomass. The GOBiGas plant in Gothenburg, Sweden, for example, produces 1 megajoule (MJ) of bio-methane by harnessing 1.54 MJ of biomass. The methane is then conditioned, synthesised, upgraded and liquified (Alamia et al., 2016).

Overall, there are three main barriers limiting the widespread adoption of biofuels in shipping, the first being cost. Presently, the cost of biofuels is roughly twice the price of their fossil counterparts. As Figure 12 shows, however, the cost of biofuels is expected to drop considerably, becoming competitive by 2040. The largest component of biofuel costs is the feedstock cost. Hence, if biofuels become an attractive energy commodity for the sector, the competition for biomass feedstock with other sectors (e.g. food and agriculture) may result in an increase in the biofuel price. To avoid these potential sustainability issues (e.g. competition for land and water, food security, etc.), second and third generation biofuels appear to be the most suitable option.

**Figure 12:** Biofuel product cost projections




Note: Product cost includes production, transport and logistics costs.
Source: Biofuel cost projections (IRENA, 2016); fossil fuel cost range (Lloyd's Register, 2019; Ship & Bunker, 2019).

The second barrier is biofuel availability. Biofuels would not be currently capable of meeting global demand, if they were to completely replace currently available marine fuels. For them to be able to cover demand in the future, there would therefore need to be a substantial increase in their production levels. This is closely linked with the third and final barrier – sustainability. If biofuel production were to be scaled up to the necessary levels needed to meet future demand, the social and environmental impact of such a scale-up would need to be managed to ensure sustainability. Secure, long-term supplies of low-cost, sustainably-sourced feedstock will be critical to the economics of biofuels. A combination of smart agricultural practices, waste and residue policies, high-yield energy crops and the reclamation of degraded or fallow land can provide both the volumes and the high-quality carbon emissions reductions that the world needs.

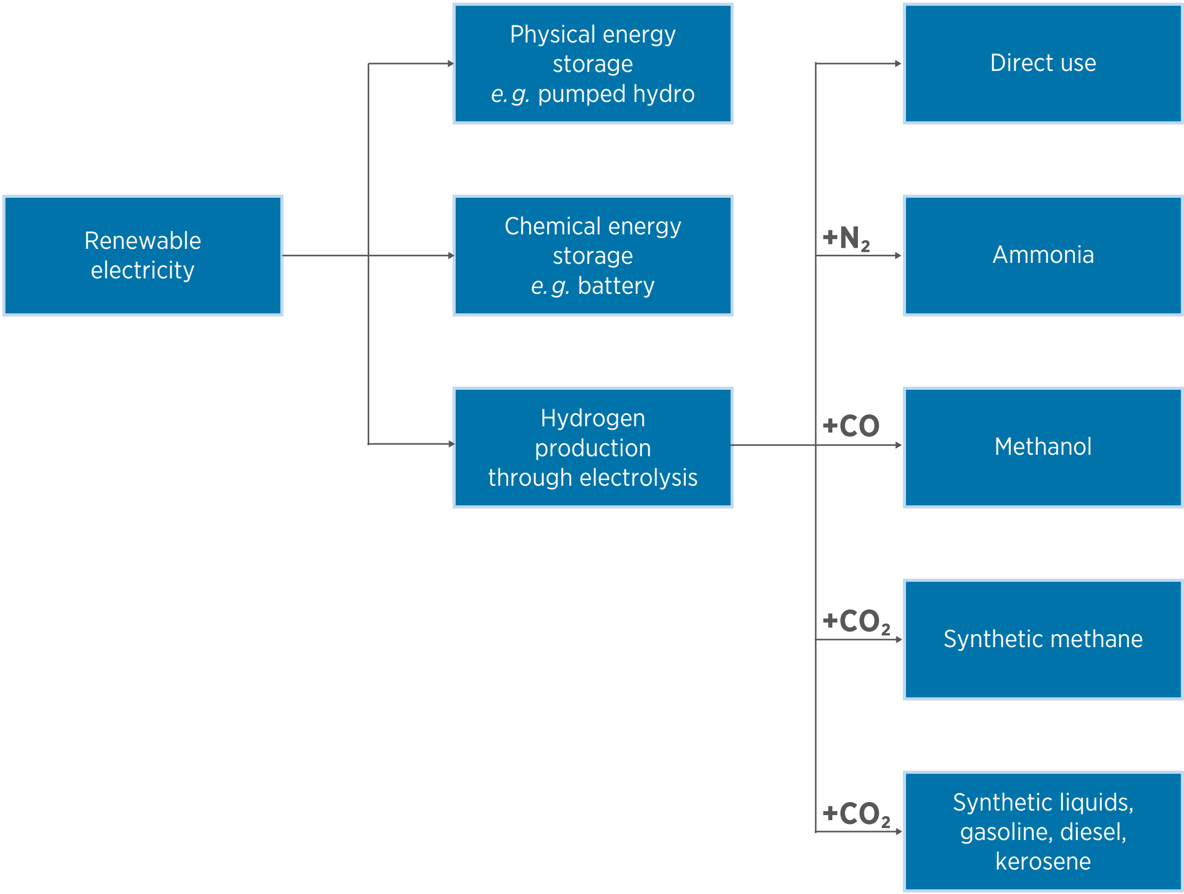
## E-fuels

### Power-to-liquids

Other synthetic fuels being considered as potential replacements for conventional marine fuels, due to their emission-reduction potential, are methanol, hydrogen and ammonia.

These and other similar energy carriers can be produced through a variety of processes, with production of synthetic fuels from electricity referred to as power to liquids (see Figure 13). Hydrogen can be produced from electrolysis and then synthesised with carbon monoxide to produce methanol, or with nitrogen to produce ammonia. These fuel products are also known as e-fuels.

**Figure 13:** Schematic representation of power-to-X routes




As the purpose of this document is to examine pathways for the decarbonisation of the shipping industry, a switch to e-fuels would only be worthwhile if the electricity used to produce e-fuels comes from renewable sources, with the carbon monoxide coming from biomass combustion/gasification processes, or the atmosphere. Otherwise, emissions are simply transferred upstream, as opposed to being reduced.

## Methanol

The majority of methanol production today is based on a mixture of hydrogen and carbon monoxide produced from natural gas or coal. Methanol produces considerably less emissions than conventional marine fuels. It virtually eliminates $SO_x$ emissions and reduces $NO_x$ emissions by 60%, compared to HFO (ITF, 2018). $CO_2$ emissions differ, depending on the feedstock used to produce the methanol. For methanol produced from natural gas, $CO_2$ emissions reductions amount to 25%, while for biomass feedstock-based methanol they are biogenic and discountable.

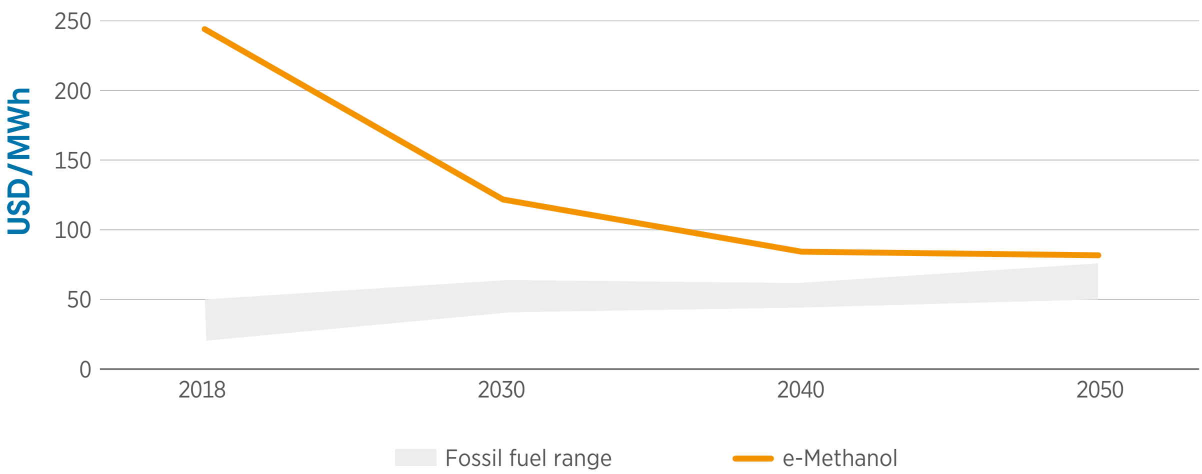
While emission reductions from the use of methanol are considerable, when using natural gas-based methanol, lifecycle GHG emissions are actually 10% higher than when using HFO (Balcombe et al., 2019).

Up to now, methanol has had limited use in the marine sector and has mostly been used in fuel cells in smaller vessels. This is changing, however, and there are now a small number of methanol-powered commercial vessels in operation, using commercially available marine engine technologies. Vessels can also be retrofitted relatively easily with methanol engines; the Stena Germanica ferry, for example, was retrofitted to operate with methanol in about four months at a cost of roughly USD 27 million. By 2016, seven cargo ships of 50 000 tonnes each were operating on methanol through a dual-fuel engine produced by MAN SE, with the number set to reach 11 by the end of 2019 (Waterfront, 2019).

Because methanol is widely available and extensively used in other industries, there is industrial experience on best transport, handling and operation practices (ITF, 2018). Methanol also offers advantages in terms of bunkering requirements, when compared to LNG – a fuel frequently considered by the industry to be a feasible option to replace oil-based marine fuels. At ambient temperature, methanol is liquid and therefore more compatible with existing bunkering infrastructure, as it can be stored in regular, non-pressurised tanks. It must be taken into account, though, that methanol occupies more than twice the space of MGO, which affects both onshore and shipping infrastructure.

For the use of alcohols, there are different bunkering scenarios, ranging from ship-to-ship bunkering to land storage tank to ship bunkering. According to Ellis and Tanneberger (2015), the conversion of a bunker barge would amount to USD 1.7 million, while constructing a methanol storage tank and associated installations would amount to roughly USD 5.7 million, which is approximately one tenth of the cost of an equivalent LNG terminal.

**Figure 14:** e-Methanol product cost projections




Note: Product cost includes production, transport and logistics costs.
Source: e-Methanol cost projections are self-produced; fuel cost projections (Lloyd's Register, 2019; Ship & Bunker, 2019)

As Figure 14 shows, given the various possible ways to produce methanol, on average, methanol production costs are considerably higher than those for the marine fossil fuels in use today. This makes the methanol option difficult to implement on a large scale. It could, however, prove to be a competitive option in emission control areas where the sulphur limit is 0.1% and where ships have to be retrofitted with scrubbing systems, or to operate on fuels with very low sulphur contents. In fact, 30% savings in fuel costs have been observed when compared to 0.1% sulphur MGO (MAN, 2014).

Meanwhile, however, another source of concern regarding the adoption of methanol as a marine fuel is its toxicity to humans.

### Hydrogen

Hydrogen is a clean energy carrier that can play an important role in the transition to zero-emission shipping.

Today, the vast majority of hydrogen is produced from fossil fuels and without $CO_2$ capture. Therefore, although this is seen as the lowest-cost solution for hydrogen production today, it is not sustainable and a different, clean hydrogen source is needed.

One option is the production of hydrogen from fossil fuels with $CO_2$ capture and storage – sometimes referred to as blue hydrogen. Some see this as a transitional solution, given the current high production costs of producing hydrogen from renewable power. The better solution, though, is green hydrogen from renewable sources, as this is the only source of zero carbon hydrogen (IRENA, 2019).

Hydrogen can be used to power a fuel cell or combusted in an internal combustion engine. In the latter case, it can be combusted by itself, or together with conventional marine fuels in duel-fuel engines. The gas provides considerable emissions benefits, compared to fossil fuel usage, as it eliminates carbon and sulphur emissions and reduces nitrogen emissions to negligible levels. Yet, as with other synthetic fuels, the source of hydrogen and its production methods are critical in terms of life cycle emissions (see Figure 11).

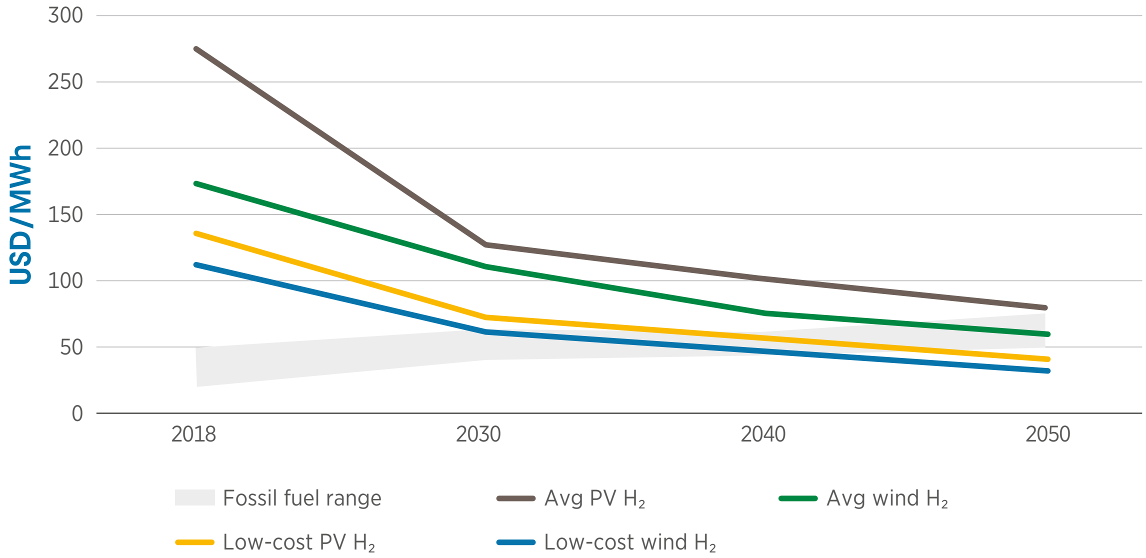
To date, the use of hydrogen as a marine fuel has been quite limited, with only a few small-scale projects undertaken. Use of the gas is, however, advancing for to certain applications. Royal Caribbean International, for example, has tested fuel cells in one of its vessels and plans to have three hybrid (LNG/$H_2$) ships operational by 2025.

Yet, as of mid-2019, substantial development was still needed before hydrogen could reach commercial scale, a fact made evident by the lack of standard design or fuelling procedures for $H_2$-powered ships and bunkers (Lindstad et al., 2015).

Liquid hydrogen has a much lower volumetric energy density than the marine fuels used today and is stored at temperatures lower than -250°C. On the other hand, the storage of compressed hydrogen requires very high-pressure tanks. The adoption of either of these technologies would require considerable changes to storage and refuelling systems, both onboard and in bunkers. An additional source of concern for hydrogen as a fuel is its high flammability, although this issue is also true for certain currently used marine fuels.

The addition of new infrastructure for hydrogen would imply prohibitive costs, although these could be reduced by repurposing and adapting natural gas infrastructure (Balcombe et al., 2019). As shown in Figure 15, today's hydrogen production cost, excluding the special needs associated with its storage, stands at 108 275 USD/MWh (3 593 – 9 180 USD/ton). Thus, current hydrogen costs are not competitive with those of the fossil fuels currently in use. Costs are expected to decrease, however, and become competitive by 2030, reaching 37 – 77 USD/MWh (1 233 – 2 566 USD/ton) by 2050 (IRENA, 2019). Factors such as competitive electricity prices being motivated by the lower costs associated with renewable generation technologies – and the need to deal with curtailment – may play key roles in reducing hydrogen's overall product costs.

**Figure 15:** Hydrogen product cost projections




Note: Product cost includes production, transport and logistics costs.
Source: Hydrogen cost projections (IRENA, 2019); fuel cost projections (Lloyd's Register, 2019; Ship & Bunker, 2019)

## Ammonia

Ammonia is a commodity with a global production volume of around 200 million tons per year. The substance is usually processed into solid or gaseous nitrogen fertilisers (e.g. urea and ammonium nitrate). Its use as a marine fuel is also now being considered, due to its emissions reduction potential.

Ammonia has an energy content of 18.6 GJ per ton, which is roughly half that of fossil fuel oil products and is comparable to biomass, making it a possible energy carrier.

As with methanol and hydrogen, when considering total life cycle emissions, ammonia's emissions reduction potential depends on the production method and on the way it is consumed. If used in fuel cells, it creates no carbon or sulphur and nearly no nitrous emissions. When combusted, however, it can produce nitrous emissions, depending on the ignition temperature (Latarche, 2019). The use of a selective catalytic reduction system might therefore be necessary, especially for emission control areas.

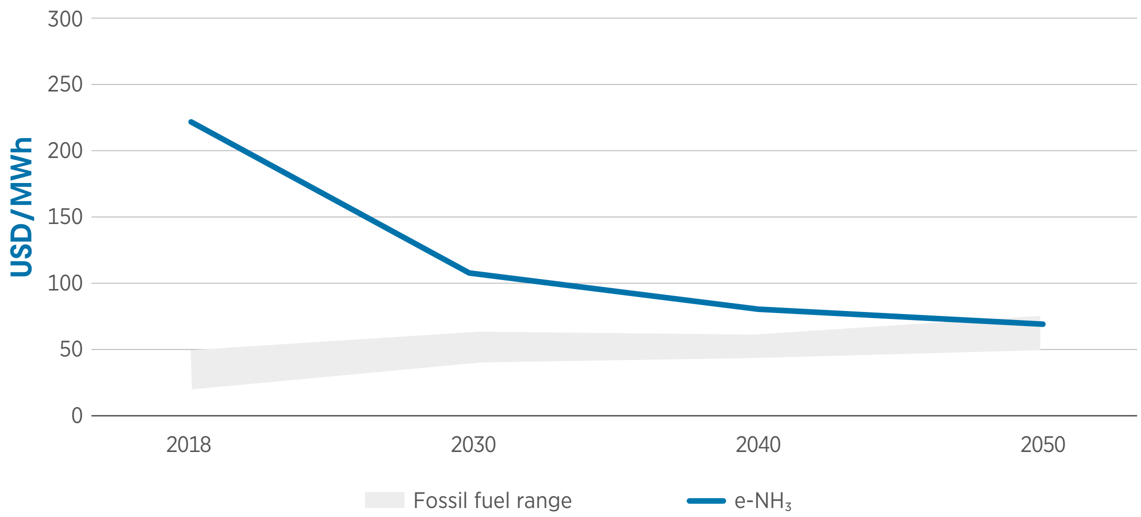
Ammonia presents some advantages compared to hydrogen technologies, though. Firstly, it does not require cryogenic temperatures or very high pressure to be stored as a liquid. Secondly, it is a widely used commodity, so there is considerable experience in its handling and transport. Bunkering and storage infrastructure would require some modification, though, given the need to refrigerate or pressurise.

While there are no active ammonia applications in shipping, the technology continues to be developed. A dual-fuel engine capable of running on ammonia and LPG is currently under development and could be available as soon as 2022 (Laursen, 2018).

Still, the cost of producing ammonia-based fuels and making them safe for marine use needs to be explored further. Apart from the cost of adapting infrastructure, ammonia is toxic to both humans and aquatic life. Considerable safety measures must therefore be taken.

As Figure 16 shows, ammonia production costs are currently much higher than those of conventional marine fuels. As ammonia technologies continue to develop and are more frequently used, while renewable electricity costs continue to drop, ammonia technologies could become more competitive in the long term. Although, at present, the production cost of ammonia appears to be higher than that of hydrogen, given that ammonia does not have special storage needs, the overall capital cost for using ammonia is likely to be more attractive than the direct use of hydrogen.

**Figure 16:** e-Ammonia product cost projections




Note: Product cost includes production, transport and logistics costs.
Source: e-NH3 cost projections are self-produced; fuel cost projections (Lloyd's Register, 2019; Ship & Bunker, 2019)

## Battery stored renewable electricity

This option consists of electric engines powered by electricity stored in batteries onboard ships. Electric engines provide an advantage in terms of efficiency compared to internal combustion engines. At the same time, the costs of renewables and batteries are dropping dramatically. Indeed, in recent years, battery technology has been advancing rapidly, leading to better performance and cost reduction. Hence, batteries are becoming attractive in new applications – particularly lithium-ion batteries, which have an energy density eight times higher than conventional storage technology, such as lead acid and nickel cadmium.

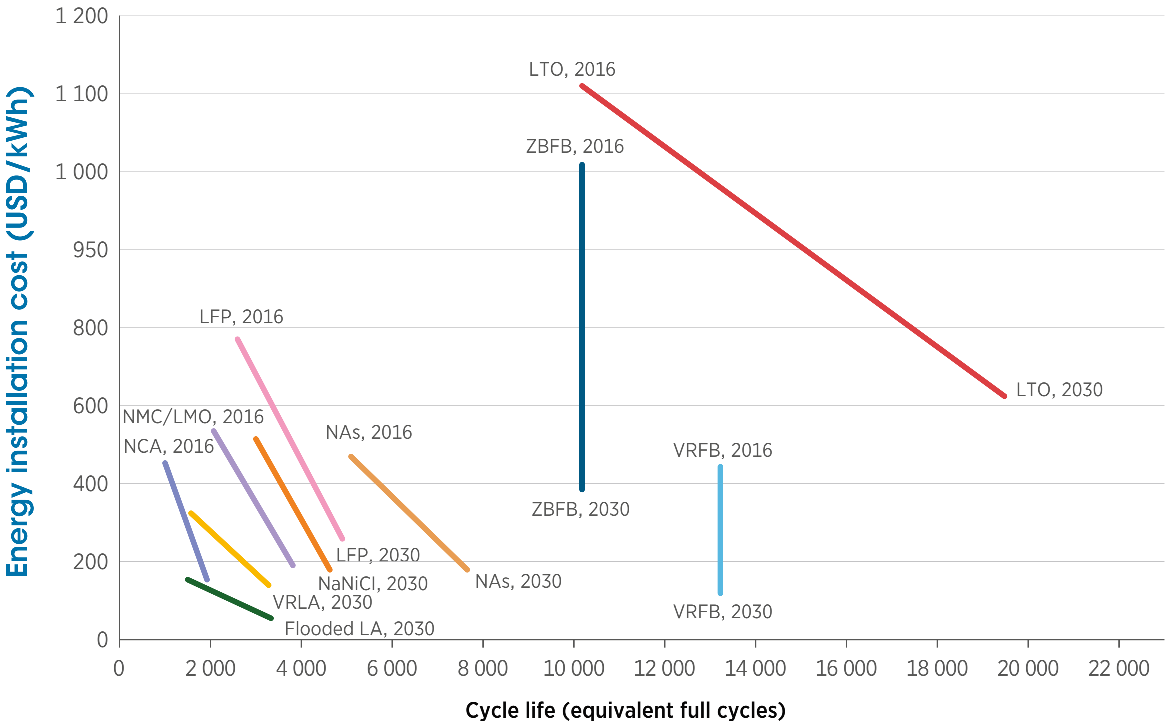
Shipping is one of the new segments where batteries could enable zero-carbon propulsion. Nonetheless, there are concerns over their use. These include the flammable nature of the lithium-ion electrolyte and the detrimental performance and fire hazards caused by high and low temperature operation. The inclusion of lithium-ion storage in vessels must therefore involve a robust battery management system, coupled with thermal management components (e.g. temperature sensors and a cooling system), adequate ventilation to avoid flammable and toxic gases, and fire protection and heat dissipation units in the battery bank chamber.

Further considerations related to full electric propulsion include the convenience of having an onboard AC/DC converter, or of locating the converter at an on-shore charging station, if the type of service offered by the vessel is limited and repetitive (DNV GL, 2016).

An example of fully electric vessels can be found in Sweden and Denmark, where ABB have converted two ships, the Tycho Brahe and Aurora, into fully electric ferries. At a cost of USD 31 million, the overall battery power stands at 4.6 MWh for each ferry – a figure comparable to 5 350 battery cars. Together the ferries can accommodate 1 175 passengers and 240 cars over a route of 4 km, which takes approximately 20 minutes. For this purpose, the battery banks need to secure 1.2 MWh of charging every time the ferry is at Helsingør and Helsingborg ports, with each charging taking five and nine minutes, respectively (ITF, 2018). Similar efforts have been announced by Stena Line (2018). The Swedish company has indicated that the 92.6 km ferry route between Frederikshavn in Denmark to Gothenburg in Sweden will be covered by a fully electrified vessel, with a 50 MWh battery bank. This will subsequently establish a zero airborne emissions route.

At present, for full electric propulsion to be economically viable, the weight of the battery should be comparable to that of a conventional fossil fuel system. With the current state of technology, therefore, fully electric vessels are generally unable to travel more than around 95 km, with such solutions viable for relatively small vessels. As battery technology progresses, however, the energy density and the cycle life of batteries should increase, whereas the cost of battery storage technologies, including lithium-ion, should gradually fall. Figure 17 shows the expected drop in costs in stationary battery technologies for year 2030, yet, considering that car batteries cost a fraction of what stationary batteries cost, in a shipping context this may be rather conservative. In the long-term, all these findings coupled with the experiences from Nordic countries, promise to make full electrical propulsion economically attractive for bigger vessels engaged in services that require to travel longer distances.

**Figure 17:** Energy installation costs and cycle lifetimes of battery storage technologies, 2016 and 2030




LA: Lead-acid | LFP: Lithium iron phosphate | LMO: Lithium manganese oxide | LTO: Lithium titanate. VRFB: Vanadium redox flow battery | NaNiCl: Sodium nickel chloride flow battery | NaS: Sodium sulphur | NCA: nickel cobalt aluminium | NMC: nickel manganese cobalt | VRLA: Valve-regulated lead-acid | ZBFB: Zinc bromine flow battery

Source: IRENA (2017)

## Wind and solar applications

Wind power has historically been an important part of the shipping sector. Given the size and weight of today's commercial vessels, however, wind alone cannot provide the thrust needed to move the full load of a large ship. A similar argument can be made for solar power, where the area needed to create enough power to move a load of thousands of tons would simply be too large.

Nowadays, the roles of wind and solar technologies in the context of shipping are therefore more related to enhancing efficiency by reducing fuel consumption. $CO_2$ emissions reductions provided by wind and solar technologies in shipping have been calculated to be up to 32% and 12%, respectively (ITF, 2018).

Wind propulsion can be categorised under soft-sail, fixed-sail, rotor, kite and turbine technologies, with kite and rotor technologies being the more mature varieties. Flettner rotor installation costs are around USD 1-3 million, while kites go from USD 0.2 to USD 3.4 million. Solar panels can meet the demand of auxiliary systems and can be installed on vessels at a price of USD 2 800/kW to USD 3 400/kW (GloMEEP, 2019b).

Barriers to the adoption of these technologies include surface availability and cargo space limitations for wind, while for solar PV technologies, environmental salinity can be an issue.

# OVERVIEW AND OUTLOOK

Global GDP is expected to grow at an average rate of 3.6% per year between 2019 2024. At the same time, the volume of global trade is expected to grow at a similar pace – i.e., 3.8% over the next five years. Meanwhile, in 2017, container throughput showed its highest growth since 2012, signalling rapid growth in the shipping sector. At its current rate, the sector's GHG emissions could see growth between 50% and 250% by 2050, if no mitigation measures are taken.

In the absence of specific measures aimed at reducing $CO_2$ emissions, tighter regulations on sulphur oxide ($SO_x$) emissions are expected to be one of the key indirect drivers of the sector's $CO_2$ emissions reduction. Yet, given that current observable trends focus on reducing $SO_x$ emissions by either switching to low-sulphur fossil fuels or installing onboard scrubber systems, the shipping sector will need to shift to carbon free fuel alternatives in order to achieve the IMO's emission reduction targets.

To reduce the shipping sector's carbon footprint, the design of vessels themselves must be improved to cut their fuel consumption, along with shifting from fossil fuels to other fuels and means of propulsion. Practices for vessels in port are also in need of improvement globally.

Under the standing regulatory framework – and given current carbon prices – clean fuels are not economically competitive. Thus, fuel price and availability will likely be the decisive factors in the choice of renewable fuel/propulsion technology. Other key, decisive factors will include the infrastructural adaptation costs of ships and ports, technological maturity and sustainability issues (e.g. food security). Also decisive will be the willingness and ability of shipping companies to pay a premium price for low-carbon products.

As the adoption of clean technologies grows across sectors, technology improves, renewable fuel costs fall and regulation becomes more favourable, however, carbon-neutral options are expected to become more competitive in the medium- to long-term. All these developments will require a global effort, however, involving the co operation of both private and public stakeholders.

With this report as a first step, IRENA aims to support the shipping sector's key stakeholders by providing a rigorous knowledge base on how renewable energy can contribute to decarbonising maritime transport – thus paving the way to carbon-free maritime shipping by 2030.

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