Energy Tradewinds

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Energy Industry Report

The Al-Attiyah Foundation

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INTRODUCTION

ENERGY TRADEWINDS

The aviation and shipping industries are widely considered to be hard-to-abate sectors. Some technological solutions, and fuel sources to decarbonise these sectors have been developed but require urgent implementation if emission targets are to be met. Evolving regulations and standards introduced by governing bodies, the International Civil Aviation Organisation (ICAO) and the International Maritime Organisation (IMO), aim to bring new energy-efficient technologies and alternative sustainable fuel sources to commercial readiness and drive the maritime and airborne energy transition. What are the opportunities for maritime and aviation in a post-pandemic world? And how will existing policies on carbon neutrality evolve in the shipping and aviation sectors?

Energy Industry Report

This research paper is part of a 12-month series published by The Al-Attiyah Foundation every year. Each in-depth research paper focuses on a prevalent energy topic that is of interest to The Foundation's members and partners. The 12 technical papers are distributed in hard copy to members, partners, and universities, as well as made available online to all Foundation members.

EXECUTIVE SUMMARY

- Aviation and shipping account for 17% of global oil consumption and are responsible for 3.6% of greenhouse gas emissions. On a business-as-usual case, primary energy use in aviation and maritime will grow 0.8% annually by 2050[i], and be one of only two sectors where oil use continues growing (plastics/petrochemicals is the other).
- Maritime and aviation are considered "hard-to-abate" sectors because of their economic importance and the limited technical and commercial maturity of low-carbon alternatives, particularly for long-range transport.
- The International Maritime Organisation's policy on greenhouse gas reductions from shipping follows on its successful mandating of low-sulphur fuels.
- Technical efficiency gains, electrification and hybrid-powered ship engines in short-range roles, and fuel switching to LNG, biofuels, methanol, hydrogen and ammonia, will drive the energy transition in the maritime shipping sector.
- The prices of these fuels and their availability will be a decisive factor in the choice of fuel and propulsion technology that is utilised in shipping fleets. Other factors such as new infrastructure and its adaption costs, technological maturity, and the willingness / ability to pay a premium for low carbon fuels could also play an important role.
- The ICAO-CORSIA is a global market-based, carbon offsetting mechanism that allows airline operators to purchase credits to offset the carbon emissions, which can be used to finance other sustainable and green projects.
- The price of carbon offsets will determine ICAO-CORSIA's ability to promote the uptake of low carbon, sustainable aviation biofuel.
- In the short-term, switching to biofuels will be a significant driver in abating emissions. Modifying existing aircraft designs and the deployment of new electric and hybrid-powered propulsion systems will decarbonise the aviation sector in the long-term.
- Despite various technology pathways, the high cost of production has limited the uptake of aviation biofuel. HEFA or HVO is the most common process to produce biofuels, but it costs 3x – 6x more than conventional jet fuel.
- Future production of biofuels will be primarily influenced by the choice of the input feedstock, technology, and developments in regulatory policy.

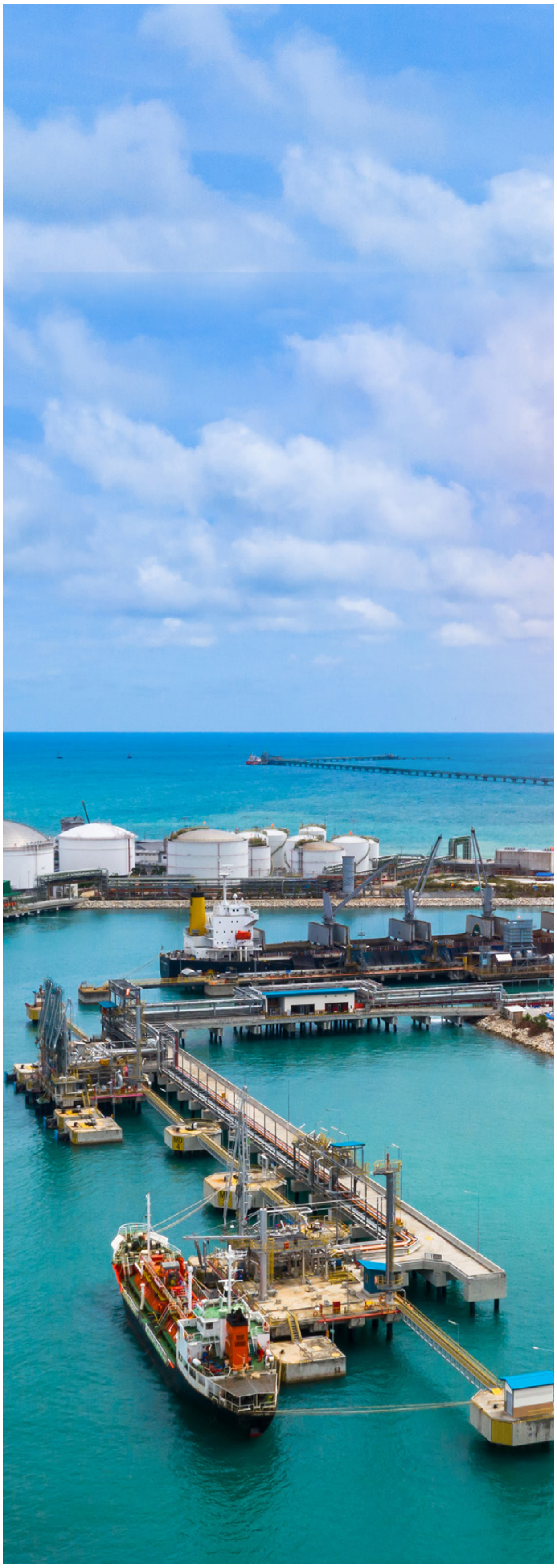
INTRODUCTION

The upward trend in maritime shipping activity and air travel is vital for the global economy but poses an increasing threat to the climate, environment, and human health. Both sectors continue to see a rise in greenhouse gases (GHG) emissions (mostly carbon dioxide and methane) and other air pollutants such as carbon monoxide, sulphur oxides (SOx), particulates and nitrogen oxides (NOx).

The maritime shipping sector is considered the backbone of the global economy and accounts for ~80% of global trade flow. In the later stages of the Covid-19 pandemic, shipping demand has even increased because of demand for physical goods. It is one of the hardest sectors to decarbonise but offers a significant opportunity for reduction in emissions of GHGs, particulates and acid gases.

Shipping is heavily dependent on fossil fuels to power its engines, specifically, bunker fuel, which is a less refined and polluting, high-carbon and high-sulphur residue. Marine gasoil (diesel) is cleaner but significantly more expensive. Alternative fuels such as liquefied natural gas (LNG) are used only to a very limited extent, mostly to power LNG carriers themselves.

In recent times, the International Maritime Organisation (IMO) has introduced various regulatory standards such as IMO 2020, in order to reduce the maritime shipping sector's environmental footprint. At the same time, shipping fleet operators and maritime regulators are also embracing new operational measures such as slow steaming, sulphur emission control areas (ECAs), better routing, and new hull designs to improve fuel efficiency. In addition to this, they are also starting to explore options for replacing conventional



marine fuel with sustainable and cleaner fuel sources such as LNG, biofuels, methanol, hydrogen, and ammonia.

The aviation sector contributes US$ 3.5 trillion, which accounts for 4.1% of global GDP[ii]. Over the last decade, air transport saw a massive increase in emissions due to a general trend towards longer flights and larger aircraft, as well as increased domestic and regional travel in emerging markets such as China and India. Low-cost carriers expanded their fleets and started to offer trans-continental flights that further increased emissions.

The aviation sector is considered to be one of the hardest sectors to decarbonise. Beyond the continuing strong growth in air travel, the aviation value chain is highly competitive with tight profit margins that range between 6% - 8%[iii]. In 2019, fuel made up 23.7% of operating expenses for the global airline business[iv]. Aircraft manufacturers, regulators and operators are extremely risk-averse due to their adherence to safety protocols and the high consequence of failure. New aircraft, even evolutionary ones such as the A380 rather than radically new types, take decades to introduce: the A380 programme was announced in 1990 but entered service in 2017 at a cost of €18 billion. Manufacturers and airlines consequently continue to be hesitant towards revolutionary, cleaner, and greener aircraft designs. Air travel requires cold tolerance, a high-power output and energy-dense fuels to limit weight and allow reasonable operational ranges, which also limits the sector's options in fuel switching.

However, in October 2016, the International Civil Aviation Organisation (ICAO) introduced a carbon offsetting scheme, which allows airline operators to buy carbon credits to neutralise their air travel emissions, and will mandate this after 2026. In addition, the aviation sector continues to explore avenues to boost fuel efficiency through improved engine and aircraft designs, and the cost-effectiveness of various biofuel blends in replacing conventional jet fuel.

After the COVID-19 pandemic, the maritime shipping and aviation sector are expected to experience a greener recovery. Some degree of inertia in addressing the climate change challenge by both sectors will continue. However, stricter enforcement of regulatory initiatives and standards by IMO and ICAO have opened exciting opportunities for the technology and industrial sectors in exploring efficiencies through new ship and aircraft engine designs, and for the wider energy sector in powering these fleets with renewable energy and / or other cleaner fuels.

REGULATORY DEVELOPMENTS

Over the last decade, GHG emissions from maritime transport have increased significantly as cargo volumes increased. Prior to IMO's initial proposal, in 2011 the organisation took a practical step by making it mandatory for ships to comply with the Energy Efficiency Design Index (EEDI), an indicator that measures the energy efficiency of ship engine designs and auxiliary equipment used across shipping fleets. The metric assesses a ship's gCO2 / tonne-mile emissions based on its engine design.

In 2018, IMO adopted an initial strategy for abating carbon emissions across the shipping sector.

The strategy was in alignment with the Paris Climate Agreement and the United Nations (UN) 2030 Agenda for Sustainable Development Goals, and envisaged an overall reduction in carbon emissions by the maritime shipping sector by 50% by 2050[v]. More importantly, the strategy outlined three levels of ambition,

- the reduction of carbon intensity of ships through the implementation of additional phases of EEDI for new shipping fleet,
- the reduction of carbon emissions intensity by international maritime shipping by 40% by 2030, compared to 2008 levels, with additional efforts to achieving 70% reductions in carbon emissions intensity by 2050.
- to peak GHG emissions by the maritime shipping sector as soon as possible.

Prior to these targets, IMO had been looking to regulate the emissions of various air pollutants such as SOx, NOx, ozone-depleting substances, volatile organic compounds, and waste from shipboard incineration, particularly through the adoption of Annex VI – Prevention of Air Pollution from Ships standard in 1997.

Before the introduction of MARPOL Annex VI Regulation at the end of 2019, maritime fuel outside the Emissions Control Areas were limited to 3.5% sulphur mass by mass (m/m)[vi].

A comparable initiative to the IMO's initial strategy is the IMO 2020 standard, which came into force at the start of 2020, which mandated the following pathways,

- the use of fuels with a low sulphur content, <0.5% m/m,
- if the sulphur content is >0.5% m/m – maritime ships are required to install capture technologies such as an on-board exhaust sulphur scrubber,
- the use of onshore power supply during docking periods at various international port terminals.

REGULATORY DEVELOPMENTS

The IMO 2020 standard does not directly help curtail carbon and GHG emissions. There is a wider risk that these regulations encourage the continuation of investments in fossil fuels, which diverts capital flows from the deployment of carbon-neutral fuels and delays the transition to sustainable fuels across the maritime shipping sector[vii].

Ship owners have argued that the MARPOL Annex VI Regulation rather than the IMO strategy introduced in 2018 is a more effective regulation in curbing emissions given the timescales[viii]. They also argue that the reduction in SOx emissions is highly dependent on the method that is used given the detailed regulatory framework for controlling, supervising, and enforcing low sulphur content in marine fuel.

In comparison to the initiatives introduced to regulate these emissions, IMO has proposed a non-punitive measure of reducing emissions through ten market-based standards. These standards are expected to serve two purposes,[ix]

- to provide an economic incentive for the maritime shipping sector to reduce its fuel consumption by investing in energy efficient ships and technologies,
- to operate maritime shipping fleets in a more energy efficient-manner by enabling the offsetting of carbon emissions in other segments of growing ship emissions, i.e. out-of-segment reductions.

EEDI and the Ship Energy Efficiency Management Plan & Carbon Reduction Indicators (SEEMP & CII) are the main regulations that encourage improvements in energy efficiency across the maritime

shipping sector. With EEDI regulating energy efficiency standards for new ships, SEEMP & CII regulates the efficiency standards for shipping operations through various metrics such as the Energy Efficiency Operational Indicator (EEOI) as a monitoring tool[x]. Over the short / medium term, IMO is expected to tighten both standards to encourage the uptake of new energy-efficient technologies and engine designs.

Prior to the IMO 2020 regulation, the organisation introduced and enforced the Data Collection System (DCS) regulation in 2019. Under the system, ships with a total capacity greater than 5,000 tonnes are required to submit annual reports on a database system that monitors their energy consumption and carbon emissions[xi].

Similar to the IMO, the Global Maritime Energy Efficiency Partnership (GloMEEP) has also proposed specific innovative solutions for adopting renewable energy technologies and improving EEDI by fixing sails, adding wings or a kite for propulsion, deploying Flettner rotors to generate wind power, and installing solar PV panels for onboard electricity consumption.[xii]

Mostly recently, in July 2021, the IMO's Marine Environment Protection Committee put forward new policies to reduce GHG emissions[xiii]:

- From 1st January 2023, mandate calculation of the Energy Efficiency Existing Ship Index (EEXI) and the carbon intensity rating (CII), each on an A-E scale, with incentives to reach A or B, corrective plans to improve on D and E, and required improvement in CII of 11% by 2026.
- Possible introduction of a \$100/tCO2e levy on heavy fuel oil.

The European Union is also actively exploring measures to align its shipping sector with the Paris Climate Agreement. In 2015, the EU Monitoring, Reporting, and Verification (EU-MRV) regulation was enforced, which like the IMO's DCS regulation, requires ships with a capacity greater than 5,000 tonnes calling at European ports to report their energy consumption, carbon emissions, and average energy efficiency. The monitoring phase of the EU-MRV regulation began in 2018 and the database is used to track the evolution of emissions from the European maritime shipping sector, which will be used to enforce additional policies.

REGULATORY DEVELOPMENTS

In early 2020, the European Parliament approved the European Green Deal, which is focused at making Europe a net-zero emitter of GHG emissions by 2050. Despite calls for covering the maritime shipping sector under the EU Emissions Trading Systems (ETS), it is so far excluded[xiv]. This is due to the fear that adding the EU shipping sector in the ETS would threaten ongoing trade negotiations and existing trade patterns with countries outside the EU. There was also a reluctance by non-EU shipping companies to pay carbon tax to support an EU economic recovery plan.

However, the European Commission is expected to introduce a gradual phase-in period for maritime companies by 2023 and 2025, which will require full compliance with emissions caps by 2026[xv]. Ship owners will have to buy permits under the ETS if their ships pollute, otherwise they will face possible bans from EU ports.

As various regulations aimed at decarbonisation are introduced, the private sector is also aligning strategies through frameworks such as Poseidon Principles and Getting to Zero Coalition.

Poseidon Principles is a framework for integrating climate considerations into financing decisions to promote international shipping's decarbonisation efforts. The framework was introduced in 2019 by a group of financial institutions consisting of ABN AMRO, BNP Paribas, Citigroup, Credit Agricole, Credit Suisse, and others.

And the Getting to Zero Coalition is an alliance of over 150 companies that are committed to deploying commercially viable deep-sea, zero emission ships by 2030.

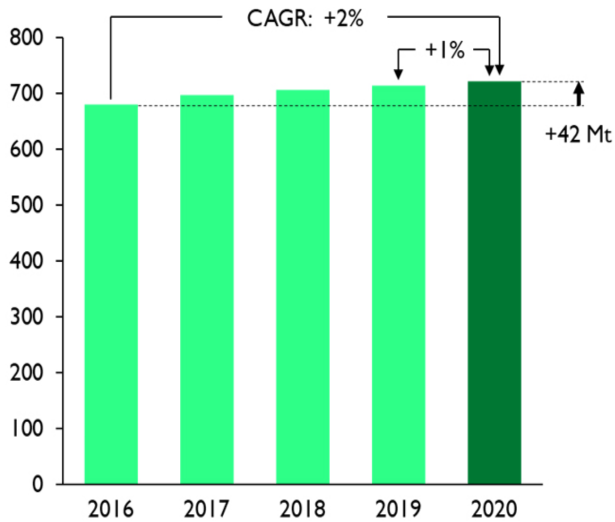
Moreover, corporates such as AP Moller – Maersk have also aligned their future business strategy to drive towards a carbon neutral business. To accelerate their transition to carbon neutral shipping, the company in 2018 set an ambitious target of net-zero carbon emissions by 2050, which it intends to achieve by fully transitioning to carbon-neutral fuels and supply chains. With an average lifeline of its shipping vessels ranging between 20 – 25 years, Maersk is also aiming for a viable carbon neutral fleet by 2030 by investing US$ 1 bn and engaging more than 50 engineers each year.

Hence, stricter enforcement of emissions regulations in combination with various private sector initiatives will continue to drive decarbonisation in shipping. The IMO's target of cutting carbon dioxide emissions by 50% by 2050 has created an opportunity for the energy value chain to capitalise on an industry-wide scale up of sustainable alternative fuels based on renewable sources and production methods.

ENERGY EFFICIENCY AND FUEL SWITCHING

The maritime sector currently emits 721 Mt of carbon dioxide annually, and this has increased by 42 Mt over the last five years at 2% / year. Shipping is responsible for 2.5% of global GHG emissions[xvi].

Figure 1: Carbon Emissions from International Shipping Units: Million of tonnes (Mt) CO2. Source: International Energy Agency (IEA)

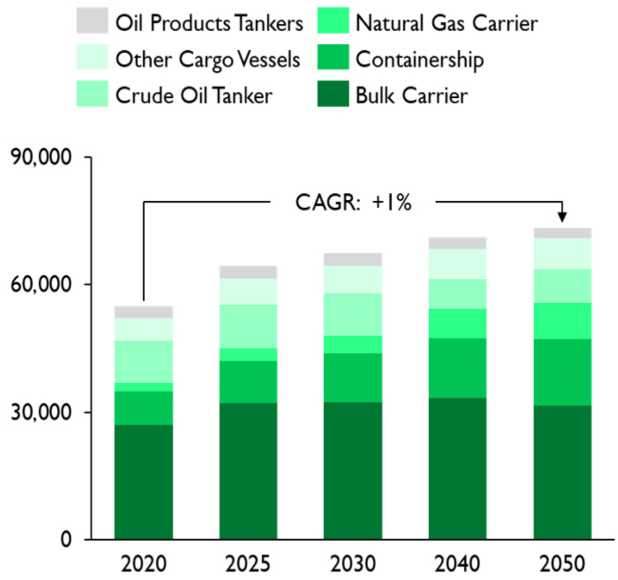


Maritime shipping transport is considered to be one of the most hard-to-abate sectors. The industry is commercially highly competitive, and fuel is a major part of costs. Ships have relatively long lives so capital turns over slowly. Safety and reliability are paramount. And energy-dense fuels are required for long voyages to minimise refuelling stops. Fuels have to be compatible with most engines and readily available at major ports.

In the IEA's view, increasing electrification across the short-sea segment and inland port operations, combined with the utilisation of carbon neutral fuels, will lead to emissions declining to 600 MtCO2e by 2050, accounting for about 3.5% of global GHG emissions by then.

Currently, maritime shipping transport is dominated by bulk carrier shipments (mostly coal, grain, iron ore, alumina/bauxite and phosphate, also timber and steel products[xvii]), which account for 49% of total maritime tonne-miles, followed by crude oil and oil product cargoes totalling 23%.

Figure 2: Global Maritime Vessel Trade by Carrier Units: Gigatonne Nautical Miles (Gt-nm). Source: DNV GL



As global GDP doubles by 2050, global maritime activity is projected to increase by 1% / year to 73,313 Gt-miles by 2050 with bulk carrier shipments accounting by then for 43% of the total maritime activity[xviii]. Other segments such as LNG and LPG carriers and containerships will also follow a similar trend, with the exception of oil and oil products shipments that will decline by 1% / year by 2050 (within the bulk segment, coal will also fall sharply). Carriers of hydrogen and related products, notably ammonia, are likely to be a growth sector from very small levels today.

Efficiency improvements will be achieved through logistical and supply chain management measures, as a result of various

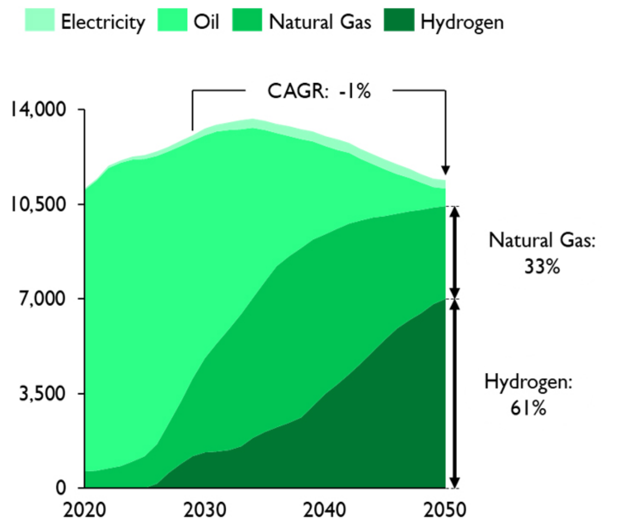
digitalisation initiatives, smart sensors and algorithms, and efficient fleet designs utilised by the maritime shipping value chain.
As result of this, energy efficiency gains are expected to outpace the growth in global maritime activity, especially between 2035 – 2050.

At the same time, there are also other significant untapped opportunities to reduce carbon emissions from shipping cost-effectively. These include technical and operational measures, such as slow steaming, weather routing, contrarotating propellers, and propulsion efficiency devices, which could enable fuel savings[xix].

Unlike for ground transport, the potential for electrification in the maritime sector is constrained to the short-sea segment (for example ferries, offshore supply vessels) and inland port operations, because of the unfeasible size of batteries required on-board for long journeys.

Therefore, the uptake of alternative carbon-neutral fuels such as biofuels, methanol, hydrogen, and ammonia is essential for achieving the IMO's GHG emissions reduction goals by 2050 and are the only current practical way for the maritime shipping sector to achieve full decarbonisation. On-board carbon capture and storage (CCS) is a possible complement, in a similar way to the use of SOx scrubbers to meet IMO fuel regulations. The CO2 would then be discharged at ports for permanent storage or re-use. Several shipping companies are investigating this option[xxviii], but the CO2 to be stored on-board has about three times the weight of the fuel burnt to produce it, so limiting the ship's cargo capacity.

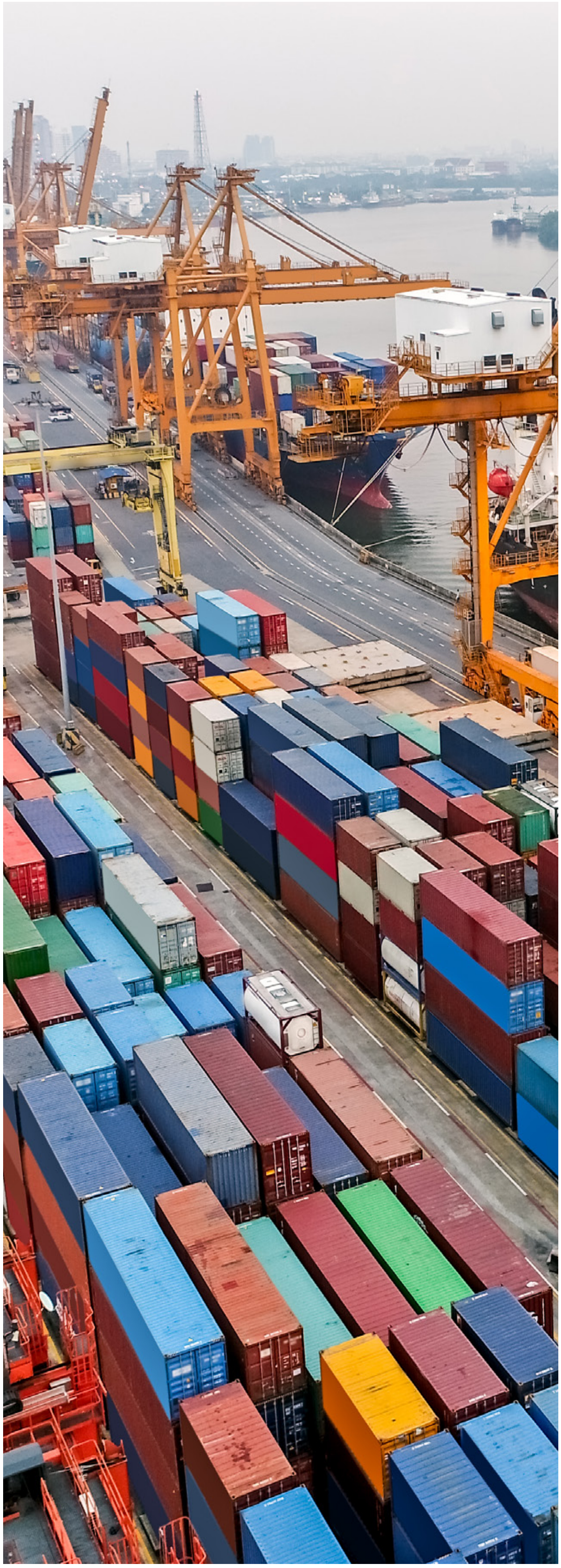
Figure 3: Global Maritime Energy Demand Units: Petajoules (PJ) per year. Source: DNV GL



At the present, oil accounts for 94% of the fuel mix and is expected to decline by 9% / year by 2050 to 6% of total maritime fuel use. Demand for low/non-carbon fuels such as ammonia and hydrogen is projected to increase by 35% / year by 2050 and will account for 61% of the fuel mix. Hence, the maritime value chain's main challenge over the next decade will be to prepare for this decarbonisation pathway.

The speed of transition to carbon-neutral fuels will have major implications for the shipbuilders and maritime fuel supply chains. For example, shipbuilders are planning for fuel flexibility across their new fleet designs, which could ease the transition and minimize the risk of investing in stranded assets. This is an important part of shipowners' portfolio management, but they have to see the regulations, carbon costs or customer pull that will justify the additional up-front expenditure.

Fuel suppliers are also providing continued support to R&D initiatives to develop carbon-neutral fuels and are considering supply chain buildouts to various global shipping ports and terminals.



ALTERNATIVE FUELS IN THE SHIPPING SECTOR

The maritime shipping sector is increasingly seeking cleaner fossil fuels such as liquefied natural gas (LNG) as a way to comply with strict regulations and emissions reduction targets. Compared to HFO, LNG cuts CO2 emissions by 20%, NOx by 90% and SOx by close to 100%. However, GHG savings are limited by methane slip from engines, as methane is itself a powerful greenhouse gas. Reducing methane slip and NOx simultaneously is challenging, but new injection systems and others are hoped to cut methane slip to 1 g/kWh, at which level LNG would save 23% of total GHGs versus HFO[xxi]. Although LNG is cheaper than heavy fuel oil (HFO), the main barrier to fuel switching is the cost of installing retrofits with LNG-powered engines and tanks. LNG-powered vessels today are primarily LNG carriers themselves. The availability of LNG at major bunkering ports is improving but is also a constraint.

As a result, there is a stronger tendency to switch to marine gas oil (MGO), a fuel similar to diesel, or low-sulphur fuel oil (LSFO). These fuels reduce SOx emissions but do little or nothing to cut carbon footprint. Indeed, the desulphurisation process in refineries as currently carried out may mean these fuels have higher life-cycle carbon footprints than older fuels. To achieve deep decarbonisation, maritime shipping sector will need to move towards LNG, and eventually to renewable fuels, and alternative propulsion modes such as biofuels, methanol, hydrogen, and ammonia.

Global maritime shipping is yet to use biofuels extensively. They offer lower pollution, lower life-cycle carbon footprint (when produced sustainably), reduced engine maintenance, and are quite compatible with existing engines and fuel storage and distribution systems. However, their cost is relatively high, and availability limited.

Most marine diesel ship engines can be powered by biofuels such as straight vegetable oil, hydrotreated vegetable oil, fatty acid methyl ester, Fischer-Tropsch diesel, and pyrolysis oil with minimal / no modifications necessary, depending on the fuel blend. Studies suggest reduced engine lifespan due to carbon build-up – the exception is hydrotreated vegetable oil (HVO), which is able to mitigate these problems given its low oxygen content, high fuel efficiency, and lower contaminants. Therefore, a switch to HVO would not require major changes to current storage and bunkering infrastructure or logistics. In contrast to HVO and other biofuels, the adoption of bio-ethanol incurs significant costs relating to new engines, storage, and bunkering facilities at ports.

In this scenario, bio-LNG and specifically methane from anaerobic digestion could replace conventional LNG, which enhances the reduction of carbon dioxide emissions.

Nonetheless, there are two factors that hinder the uptake of biofuels. Firstly, biofuels are twice as costly as fossil fuels. If they are to become an important fuel source for the sector, supplies of biofuel feedstock will compete with other sectors such as aviation and agriculture. In this case, waste biofuels would be a suitable option. Secondly, if biofuels replace conventional marine fuels, current production levels are insufficient to meet demand. Therefore, there must be a substantial increase in their production capacity.

Alternatives to biofuels are methanol, hydrogen, and ammonia, which can also replace conventional marine fuel.

Until recently, methanol had a limited use in the maritime sector and is mostly used in fuel cells in smaller vessels. In 2019, there were eleven cargo ships of 50,000 tonnes that were operating on methanol through dual-fuel engines[xxii].

Although methanol is extensively used across many sectors and there is significant industrial experience, methanol production costs are significantly higher than those for conventional marine fuel, which makes it difficult to implement on a large-scale. It also has a lower energy density, requiring about 2.5 times more storage capacity than traditional fuels. However, methanol is a competitive option where the sulphur limit is 0.1% and where ships would have to be retrofitted with an on-board exhaust scrubber. Ship operators have experienced a 30% reduction in fuel costs from methanol-powered ships in comparison to MGO with a sulphur limit of 0.1%. It is a liquid, making it easy to store, and is also low polluting if spilled. Methanol is mostly made today from natural gas, reducing emissions by about 10% versus fuel oil[xxiii], so is not carbon neutral. However, it could be produced from biomass or from 'green' hydrogen and atmospheric CO2. Its best applicability is probably in medium-range scheduled services.

Another emerging energy carrier is hydrogen. Most hydrogen currently used is produced from fossil fuels without carbon capture ('grey' hydrogen). Hydrogen produced from fossil fuels with carbon capture ('blue' hydrogen) is often seen as a feasible medium-term solution given the current high production cost of production from renewable sources (green hydrogen).

Hydrogen produced through electrolysis when synthesised with carbon monoxide can also be used to produce methanol, or when synthesised with nitrogen can produce ammonia.

Hydrogen can power a fuel cell and given an internal combustion engine, it can be combusted by itself or collectively with conventional marine fuels through a dual-powered fuel engine. Hydrogen eliminates carbon dioxide and SOx emissions, and reduces NOx emissions to negligible levels.

Currently, the use of hydrogen in shipping is minimal. The development of new infrastructure for hydrogen would imply heavy costs, which could be reduced by repurposing / adapting to the current natural gas transmission and distribution network.

ALTERNATIVE FUELS IN THE SHIPPING SECTOR

And finally, ammonia is another low carbon fuel. Ammonia has an energy content of 18.6 GJ / tonne, which is ~50% that of conventional marine fuel, making it comparable to biofuels and a possible energy carrier. Typically, ammonia has been used to produce solid nitrogen fertilisers such as urea and ammonium nitrate. Now, as noted, it can be produced from green or blue hydrogen for use as a fuel for ships, power plants and other engines. Ammonia can be carried in ship tanks with moderate refrigeration (larger LPG ships are refrigerated to -30 to -48°C, and ammonia would likely be carried in the same multi-purpose vessels[xxiv]). Due to these logistical advantages, ammonia looks like a more attractive method of using hydrogen in shipping, rather than running directly on liquefied hydrogen.

Similar to hydrogen and considering the overall lifecycle emissions, the reduction in emissions is dependent on the mode of production (grey, blue or green). Ammonia used to power fuel cells does not emit carbon dioxide, SOx or NOx. But when combusted it can emit NOx depending on the temperature of ignition, which might prompt use of a selective catalytic reduction system[xxv]. Ammonia is toxic to both humans and marine life, and safety measures continue to be explored.

While there is no active application of ammonia in the maritime shipping sector, the technology continues to be developed. An example this is a dual-powered fuel engine that runs on ammonia and LPG, which is expected to be available by 2022[xxvi].

As ammonia-based technologies further develop and renewable electricity generation costs decline, ammonia could become cost competitive in the longer term.

In general, alternative fuels such as biofuels, methanol, hydrogen, and ammonia, could power maritime shipping fleet. Currently, there is no consensus on which is the best option. The prices of these fuels, operational convenience, and availability will likely be the decisive factors in the choice. Other factors such as new infrastructure / adaptation costs, technological maturity, and the willingness to pay a premium for low-carbon products could also play an important role.

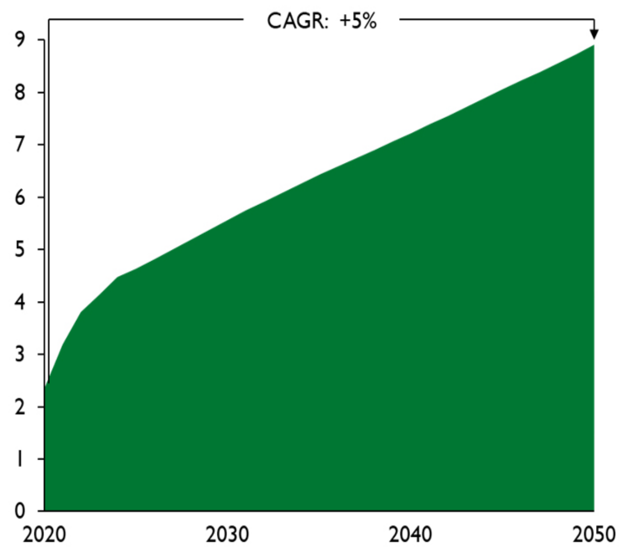
THE ICAO – CORSIA CARBON REDUCTION STANDARD

Prior to the pandemic, the aviation sector was the fastest growing form of transport with demand increasing at about 4% / year, and projections estimating that the sector's emissions could increase to 2.1 Gt / year by 2050[xxvii].

The aviation sector emits 915 Mt of carbon emissions, 2% of global emissions and 12% of the total emissions by the transport sector[xxviii]. Over 80% of the carbon emissions are emitted over long-distance flights, i.e., > 1,500 km, for which there is no easy alternative or sustainable mode of transport. In addition, non-carbon emissions from air travel (primarily, contrails, reflective clouds formed around water vapour from flight exhausts) contribute to ~65% of the net radioactive forcing, which has a significant climate impact and is not currently addressed in any official standard[xxix].

The demand for aviation travel is a key driver of emissions. The COVID-19 pandemic had a dramatic impact on the aviation sector – with the number of passengers declining by 51% - 52% in 2020[xxx]. It is estimated that airlines lost ~US$ 84 bn in revenues in 2020, with more recent projections estimating US$ 388 bn – US$ 400 bn[xxxi].

Figure 4: Global Air Trips Units: Billion trips per year.
Source: DNV GL



However, in the long-term, it is projected that rising incomes and populations will double the demand for air travel by 2050.

Over the last decade, carbon reduction initiatives across the aviation sector were mostly limited to enhancements in aircraft operations by increasing the fuel efficiency of the new aircraft fleet by 20% with new technologies that make aircraft lighter and improve engines. Weight of existing planes was reduced by removing unnecessary cabin items. In addition to this, airport operations powered by renewable energy and navigation systems that optimised routing and flight time led to additional emissions reductions.

To tackle the aviation climate challenge, the International Air Transport Association (IATA) introduced three targets in 2009:

- an average improvement in fuel efficiency of 1.5% / year from 2009 to 2020,
- a limit on net aviation carbon emissions from 2020, i.e. carbon neutral growth,
- a reduction in net carbon emissions of 50% by 2050 based on 2005 levels.

To achieve them, the IATA introduced a four-pillar strategy, which encouraged stakeholders to improve technologies and deploy sustainable aviation fuels (SAF), implement energy-efficient aircraft operations, and modernise air traffic through infrastructure improvements. At the same time, the IATA advocated for a global market-based measure that mitigates the remaining GHG emissions.

THE ICAO – CORSIA CARBON REDUCTION STANDARD

Such a measure was introduced in 2016 at the 39th International Civil Aviation Organisation (ICAO) Assembly, which adopted the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) scheme[xxxii].

The ICAO-CORSIA is a global market-based carbon offsetting mechanism that aims to stabilise net carbon emissions starting from 2021. The mechanism was designed to operate in conjunction with efficiency improvements, innovative technologies, the uptake of sustainable aviation blends.

In its simplest form, ICAO-CORSIA allows airline operators to purchase credits to offset the carbon emissions from their flights, which can be used to finance sustainable and green projects.

Prior to the pandemic, ICAO-CORSIA's carbon offset requirement for the aviation sector was expected to be calculated against a baseline, which is defined by the average of all air travel emissions between 2019 – 2020. However, due to the disruption from the pandemic and upon recommendation from the IATA, the baseline was changed to 2019 emissions. After this change, it is estimated that net carbon emissions from air travel would be stabilised at ~600 Mt, equivalent to the carbon emissions that IATA had forecasted for 2020 prior to the crisis[xxxiii], and equal to 1.6% of the global total emissions.

The initial pilot phase of ICAO-CORSIA will be implemented between 2021 – 2023, followed by a voluntary phase between 2024 – 2026. After that the ICAO-CORSIA derived targets will be mandatory for all member countries, except for those that have applied for exemptions. Least-developed, small island, and landlocked countries that account for < 0.5%

of international revenue tonnes-kilometres are eligible for exemptions from the ICAO-CORSIA targets but may choose to voluntarily participate. The initial voluntary period covers 65 countries with 60% of aviation emissions, though excluding Brazil, Russia and India[xxxiv].

As of 2020, 88 countries have volunteered to participate in Phase I (from 2021) of the ICAO-CORSIA, which notably include North American and EU countries, Australia, Saudi Arabia, the UAE, and Turkey[xxxv]. Carbon emissions from all other flights have to be reported to ICAO and offsets will only be required for emissions for flights between volunteering countries.

It is likely that the purchase of carbon offsets and emissions reductions from ICAO-CORSIA will extend beyond the aviation sector to "CORSIA – low carbon aviation fuels", defined as a "renewable or waste-derived aviation fuel that meets the sustainability criteria"[xxxvi].

However, the price of carbon offsets will determine ICAO-CORSIA's ability to promote the uptake of SAF. Even though ICAO-CORSIA encourages airlines to use biofuels to meet carbon reduction requirements, if an airline is able to purchase offsets at a lower price than what it would pay for using biofuel to achieve a similar carbon emissions reduction, this hampers ICAO-CORSIA's ability to power air travel with SAF.

Aviation biofuel is estimated to be an attractive and economically feasible option based on an offset price of US$ 23 / tonne of CO_2[xxxvii]. Prices lower than this means that ICAO-CORSIA would offer little incentive to lower carbon emissions. Market dynamics are another challenge to price carbon offsets with the average price of offsets at ~US$ 3 / tonne of CO_2[xxxviii].

Currently, it costs US$ 1 to offset a tonne of CO_2 through the ICAO-CORSIA programme. The International Council on Clean Transportation (ICCT) and Ecosystem Marketplace, an NGO focused on carbon markets, estimates that prices are expected to range between US$ 0.7 – US$ 12 / tonne by 2035. Atmosfair, a Germany-based joint venture between Forum Anders Reisen and Germanwatch, supported by the German Federal Environment Agency, allows passengers to voluntarily offset their carbon emissions by charging them US$ 28 / tonne of CO_2. These levels are still well below the European Trading Scheme (ETS), which were around €47 / tonne ($56 / tonne) in early August 2021[xxxix].

THE ICAO – CORSIA CARBON REDUCTION STANDARD

Although ICAO-CORSIA has approved six offset programmes, to address the challenge of pricing carbon offsets, the eligibility of the various offset programmes and the types of projects that might be approved is expected to be reviewed before the end of Phase I in 2022. High-quality offsets that provide verifiable, long-term carbon reductions are likely to become scarce as other companies also purchase them to meet their own carbon neutrality goals. Carbon dioxide removal from the atmosphere (CDR) is the most secure form of offset, but costs are much higher, likely around $100-200/tonne CO2 in the longer term. For comparison, this would add $60-120 (or $160-320, allowing for the impact of contrails) to the cost of a one-way London-New York economy flight ticket.

Nonetheless, when it comes to long-distance travel there is no ready low-carbon alternative. Carbon offsetting, at least in the short-term, will continue to be viewed as an immediate and direct means to mitigate climate change impacts.

BIOFUELS IN THE AVIATION SECTOR'S FUEL MIX TO 2050

In the long-term, carbon reductions in the aviation sector will be achieved by modifying existing aircraft designs and the deployment of new propulsion systems such as electric and hybrid aircrafts with batteries that could be suitable for short haul flights with a limited number of passengers. Hydrogen or a hydrogen-based synthetic fuel could be used for long-haul or larger aircraft, but its potential remains unproven. IATA expects that short-haul hydrogen aircraft, covering about a quarter of aviation emissions, could be available by 2035 but that long-range hydrogen planes are only likely after 2050[xl].

The time required to manufacture and test such aircraft designs combined with the long-life expectancy of aircraft, in excess of 20 years, will result in slow fleet replacement with the uptake of new propulsion systems expected to be seen in significant quantities only after 2040.

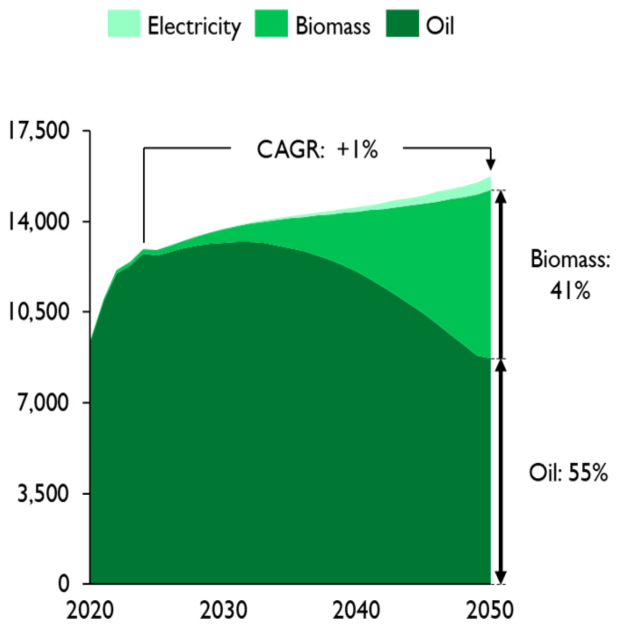
In the medium-term, solutions to decarbonise are relatively limited as air travel is highly dependent on energy-dense fuels. With designs of the aircraft fleet currently in operation, this also limits the range of alternative and sustainable fuel types that could replace conventional jet fuel. Contrail formation can be reduced by better weather forecasting and re-routing to avoid the conditions that encourage contrail formation. Alternative fuels that produce less soot also eliminate the nuclei for contrails[xli].

In the short-term uptake of sustainable biofuel blends will be a significant driver in abating carbon emissions.

The IATA's target of cutting carbon emissions by 50% by 2050 is estimated to require >100 billion litres / year of aviation biofuel, and if the Paris Climate Agreement's goal of limiting the global temperature increase to less than 2°C is to be achieved, then it is estimated that >200 billion litres / year of aviation biofuel will be required by 2050[xlii]. This requires an investment of ~US$ 5 bn / year in biofuel production up to 2050, which varies based on the technological mode of production, the jet fraction of the biofuel blend produced, and the procurement of feedstock.

BIOFUELS IN THE AVIATION SECTOR'S FUEL MIX TO 2050

Figure 5: Global Aviation Energy Demand Units: Exajoules (EJ) per year .Source: DNV GL



ICAO has carried out a study that assesses the complete replacement of conventional jet fuel with aviation biofuel based on the currently available feedstock and technology scenarios. The complete replacement of 460 – 730 billion litres of conventional jet fuel will require the development of 170 new large-scale biorefineries / year with an estimated investment cost of US$ 15 bn – US$ 60bn / year[xliii].

Nevertheless, it is estimated that sustainable biofuel blends will account for 41% and electricity will account for 3% of the total aviation fuel mix by 2050. This is mainly a result of energy efficiency gains achieved through the modification of existing aircraft designs, the deployment of new electrified / hybrid propulsion systems with battery storage systems, combined with the successful outcome of decarbonisation targets by ICAO-CORSIA.

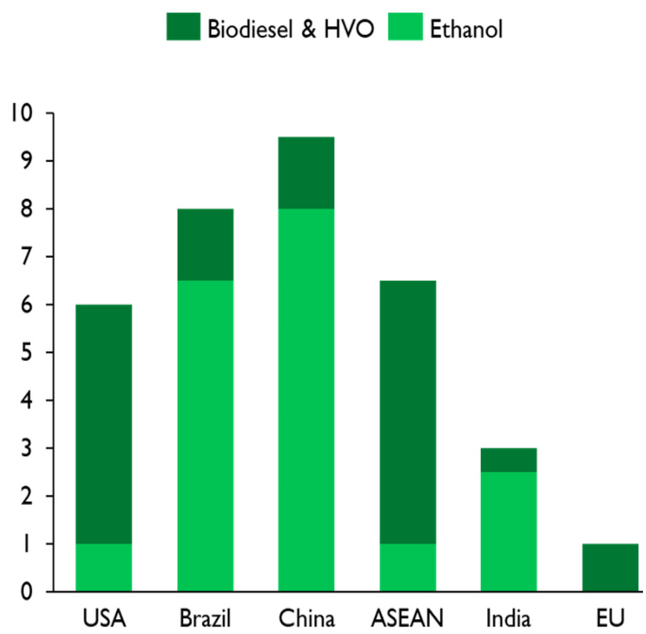
SUSTAINABLE AVIATION FUELS

Despite continuing improvements in fuel efficiency, in the short-term carbon neutral growth in the aviation sector can only be achieved through purchases of carbon offsets through the ICAO-CORSIA standard. Scaling up the supply of aviation of biofuel or other synthetic fuels will be essential to achieve early reductions in carbon emissions by 2030 and deep reductions by 2050. Over time, synthetic aviation fuel blends produced from green hydrogen could serve as a replacement – currently production is very limited, and costs are high.

At present, aviation biofuel is mainly produced through the hydrotreatment of fats, oils, and greases such as used cooking oils. These oleochemical / lipid feedstocks are also known as hydrotreated esters and fatty acids (HEFA) or hydrotreated vegetable oils (HVO).

There are two production facilities under development in the US that will produce large-scale aviation biofuel – Red Rock Biofuels with a planned capacity of 56 million litres / year and Fulcrum Bioenergy with 40 million litres / year. Both facilities will use biomass gasification and Fischer-Tropsch synthesis to produce a blend with a jet fraction of 40%. Other US-based companies such as Gevo produce aviation biofuel from corn biomass and LanzaTech's LanzaJet process uses fermentation of waste carbon gases to produce ethanol for alcohol-to-jet blend.

Figure 6: Growth in Biofuels Production Units: Billions of liters.
Source: International Energy Agency (IEA)



One of the advantages of biofuels is that several technology pathways also allow the production of low carbon diesel or gasoline fractions that can be used for other applications. As of now, eight pathways have received certification by the American Society for Testing and Materials (ASTM) allowing aviation biofuel to be co-processed or blended with petroleum-derived jet fuels.

Despite these technology pathways, the high cost of production has limited the uptake of aviation biofuel. It is estimated that fuel costs account for ~30% of the total operating expense incurred by an airline[xliv]. And a large quantity of aviation biofuel is currently produced from HEFA or HVO, which cost 3x – 6x more than conventional jet fuel depending on the current cost of petroleum jet fuel and the lipid feedstock[xlv].

Therefore, it is more favourable for refineries to sell liquid products as renewable diesel rather than separating the aviation biofuel fraction from renewable diesel. However, the implementation of an effective regulatory policy could drive further investment in the production of aviation biofuel as well as renewable diesel by fractionating liquid products into two separate fuel blends: aviation biofuel and renewable diesel.

Another challenge to total production costs is the high cost of feedstocks, which has limited the production of economically feasible volumes of aviation biofuel. Currently, HEVA and HVO is the most technically mature mode of production. However, there is a significant scope for new or expanded production capacity to produce higher volumes of renewable diesel and aviation biofuel from low carbon sources such as waste cooking oil, sunflower, soy, and rapeseed oil. It is estimated that 3.5 – 12 billion litres / year of aviation biofuel could be produced from cooking oils as feedstock with a jet fraction of 15% - 50% using HEFA ranges between 3.5 – 12 billion litres, and 85 billion litres / year of aviation biofuel could be produced from waste oils[xlvi].

The long-term prospects of aviation biofuels are dependent on their prices and feedstock availability. Prices are expected to decline in the long-term as multiple production facilities come online, technological experiences improve optimisation, and new supply chains are established.

But availability is limited by feedstock, land use, and competing requirements for biomass. A recent report by the Energy Transitions Commission estimates that about 30-50 EJ/ year of sustainable biomass would be available

after material use[xlxvii], well below figures from the International Energy Agency of 110 EJ/year and the International Renewable Energy Agency of 150-250 EJ/year. At an average aviation fuel energy density of about 43 MJ/kg, 30-50 EJ is equivalent to 860-1435 billion litres. This is more than the 460-730 billion litres of aviation fuel forecast to be required, but it would consume about half of the available sustainable biomass, leaving little for shipping, ground transport, plastics or other uses.

It is still unclear if or when aviation biofuel will achieve cost parity with conventional jet fuel. The upcoming review of carbon credits offered by ICAO-CORSIA in 2022 will have a significant role to play in creating market demand that enables the further development of aviation biofuels.

Following the review, ICAO-CORSIA could introduce an alternative way of calculating costs for aviation biofuel by deriving the specific cost of carbon abatement, in comparison to the minimum market selling price, which effectively takes into account the price of aviation biofuel relative to the reduction in carbon emissions.

In addition to costs, there is high degree of uncertainty in the future demand for aviation biofuel by 2050. Future demand is likely to be dependent on regional and international carbon emission reduction goals, the demand for air travel, and the extent to which technological and systemic options are adopted across aircraft designs and the production of aviation biofuel.

Other synthetic alternatives include fuels made from atmospheric carbon dioxide with low-carbon energy inputs. LanzaTech is investigating a commercial-scale air-to-jet facility in the UK, in partnership with British Airways and Virgin Atlantic, that would produce more than 100 million litres of jet fuel annually. Its process converts atmospheric CO_2 into ethanol and then to jet fuel . This has the advantage of unlimited feedstock. Of course, 1000-2000 such facilities would be required to meet estimated long-term total demand for SAF.

Nevertheless, to achieve early reductions in carbon emissions by 2030 and deep reductions by 2050 – SAF, including biofuels, will be essential. Aviation biofuel is currently the most certified form of sustainable aviation fuel and as synthetic forms of the fuel become available, new technological pathways could help SAF to achieve a cost-effective scale. The extent to which it is utilised by the aviation sector by 2030 will play a major role in quantifying long-term demand for the fuel by 2050.

CONCLUSION

The COVID-19 pandemic has opened the aviation and maritime shipping sectors to a more sustainable and greener recovery. Regulatory standards and initiatives introduced by the organisations, IMO and ICAO, that regulate these sectors will get stricter as they continue to align themselves to global climate initiatives and goals.

Corporations that operate global airlines and shipping fleets are also rethinking their long-term business strategies to adhere to these standards, thus driving a trickle-down effect.

These trends have opened new market opportunities for the wider industrial and technology sector in the development and deployment of new efficient ship engines, propulsion systems, aircraft engines and designs, and carbon capture technologies – in addition to exploring the deployment of fully electrified / hybrid power systems. Low- and zero-carbon fuels will play an important role in the short- and long-term, but the type of fuels will change over time and will be different between aviation and maritime.

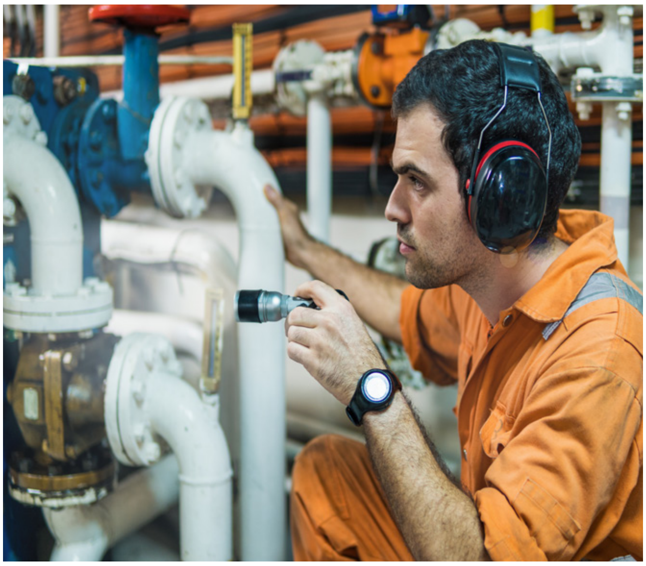
This will open up new avenues for oil & gas companies to expand their product mix with alternative sustainable fuels. These will likely be LNG in the near-term for long-range shipping, then ammonia or other hydrogen-derived fuels. For aviation, biofuels are likely to be dominant, with synthetic hydrogen-derived fuels taking a larger role later on, and electrics for short ranges.

The future use of biofuels and synthetic fuels will be primarily influenced by the choice of the input feedstock, technology, and future developments in regulatory policy. In the medium-term, biofuel will continue to be produced via the HEFA-based processes, which are relatively simple and already at a fully commercial scale.

Oil refiners have three options to capitalise on the fuel switching trend in the maritime shipping and aviation sector. Firstly, they can encourage their use through an increase in production capacity and a move into biofuel refining and blending. Secondly, they can invest in industrial and technology assets that run on alternative fuels and produce synthetic hydrogen-based fuels such as ammonia and methanol, whether from fossil fuel-based or renewable feedstocks.

And thirdly, there is a possibility that not all technologies and fuel switching options will become commercially viable for shipping and aviation. They may be delayed or fail to take off due to infrastructure and / or regulatory barriers. In this case, they can maintain demand for conventional fuel sources by investing in carbon capture technologies, including on-board capture for ships.

Nonetheless, the changing energy mix in these sectors will have profound consequences for the energy value chain and the environment.



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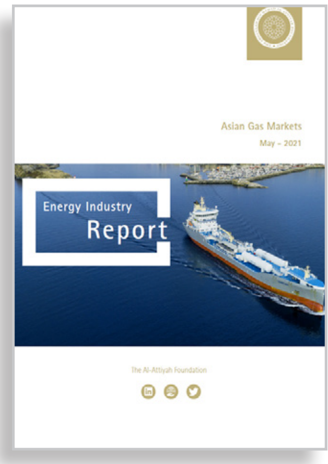

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Asia-Pacific is emerging as the key area for global gas demand growth, consuming 60% more gas than Europe. Yet the level of interconnectivity is low, and there are wide disparities in gas use, infrastructure and regulation.

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