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Pathways

Global transport sector: Investment opportunities and challenges on the road to net zero

Part 1 | May 2024

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Executive summary

This is the first paper in a two-part series in which we examine the outlook for the global transport sector as it attempts to transition to a net zero world. This paper focuses on road transport and shipping, while the second paper will examine aviation and discuss the opportunities and risks for investors.

The transport sector emitted 8 gigatonnes (Gt) of CO_2 in 2022, or 21.7% of total energy-related carbon emissions globally. A significant reduction in emissions from the transport sector is, therefore, a necessary condition for the achievement of net zero ambitions more broadly. Road transport accounts for the bulk of emissions from the sector (73.8%) while shipping (11.2%) and aviation (9.8%) are the other major contributors (Figure 2).

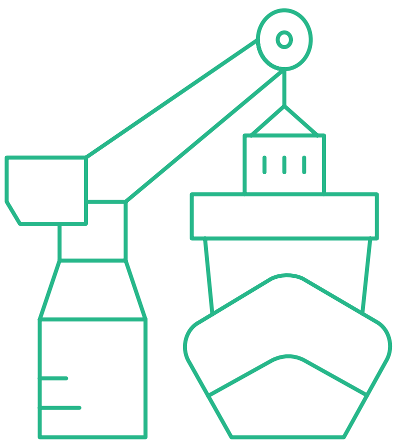
The electrification of passenger vehicles (PVs) is proceeding rapidly but currently not rapidly enough for the segment to reach net zero by 2050. However, we see good reasons to be hopeful that penetration will accelerate, as the total cost of ownership is likely to tip in favour of electric passenger vehicles around 2030 (based on our calculations), and a ban on sales of internal-combustion-engine cars goes into effect in 2035 in many markets.

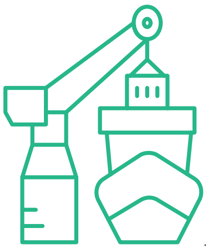
Electrification of commercial vehicles (CVs) is more challenging, for a range of technical and economic reasons. For light commercial vehicles (LCVs), penetration is actually proceeding rapidly – indeed more rapidly than it occurred for PVs in their early stages. In our view, it is reasonable to expect penetration for the CV segment to follow a similar trajectory to that of PVs, albeit with a lag of roughly four years.

Heavy commercial vehicles (HCVs) can require huge batteries – the Tesla Semi's battery likely weighs around four tonnes – given the vehicles' weight and range requirements. The payload loss that this implies significantly undermines the economics of electric models in this segment, although the lower cost of fuel offsets this loss somewhat. Payload exceptions for electric models can make a material difference in this sector and are something governments may increasingly consider.

Shipping is probably the most difficult transport subsector to decarbonise. The industry's intent is there, but the workability and cost effectiveness of different options remain a question. In our view, in the medium to long term, ammonia and carbon capture will likely be the winners, considering their cost trajectory and scalability.

Introduction: The global transport sector in context





The transport sector is one of the biggest emitters of CO_2 globally, producing 8 Gt of CO_2 in 2022,[1] or 21.7% of total energy-related carbon emissions[2] (Figure 1). Road transport accounts for the bulk of transport sector emissions (73.8%), with shipping and aviation the other two main contributors (Figure 2). Moreover, growth in transport volumes is closely linked to gross domestic product (GDP) growth, so by 2050, transport sector CO_2 emissions could be as large as 12.6 Gt[3] if efficiency gains are not accelerated or CO_2-producing energy use is not curtailed.

Figure 1:
Global energy-related CO_2 emissions by major sector (% of total)

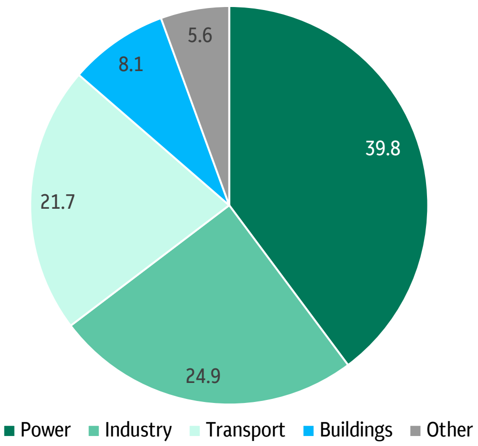
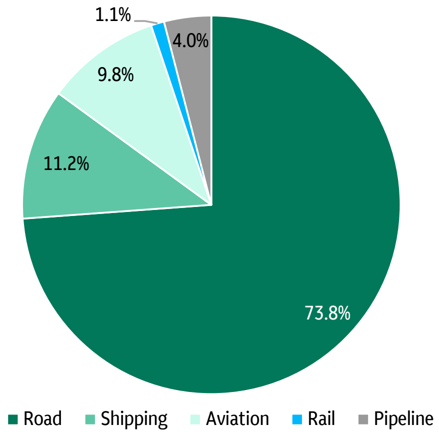


Figure 2:
Transport sector emissions by sub-sector (%)



Source: International Energy Agency (IEA), "CO_2 emissions in 2022" March 2023, IEA, "Global CO_2 emissions from transport by sub-sector in the Net Zero Scenario, 2000-2030," June 2023. Charts are for illustrative purposes only.

1. IEA, "CO_2 emissions in 2022."
2. IEA, "CO_2 emissions in 2022." According to Our World in Data, a further 4.31 Gt came from land use change. Adding this to the 36.8 Gt of energy-related emissions (as estimated by the IEA) gives a total of 41.11 Gt of CO_2 emissions. Note that Our World in Data estimates CO_2 from fossil fuels to be 37.15 Gt (slightly different from the IEA estimate) for a total of 41.46 Gt.
3. Based on a regression of the relationship between global GDP growth (measured in market exchange rate terms) and transport sector emissions from 1990 to 2019, combined with forward estimates of global GDP based on International Monetary Fund (IMF) and Macquarie Asset Management projections.

The decarbonisation of this weighty and GDP-sensitive sector will involve profound changes to the type of energy we consume, the relative cost of different modes of transport, and the structure of the sector and its supporting infrastructure. What does all this mean for investors, particularly real-assets investors? What opportunities do these tectonic shifts present? And what assets could be stranded, or at least have their useful lives shortened, by the coming changes?

The electrification of road transport is clearly a big part of the story. The technology has matured beyond the threshold for desirability in premium car segments and further cost reductions by 2030 and beyond are expected to make electric vehicles (EVs) appealing for entry-level consumers.[4] If the electricity generation sector is decarbonised in tandem,[5] this could go a long way to reducing emissions from passenger cars and light-duty vehicles (LDVs) generally. But will EV sales in this segment rise fast enough and far enough for it to decarbonise by 2050? What about heavy-duty vehicles (HDVs) – can they be electrified given the different power and range requirements?

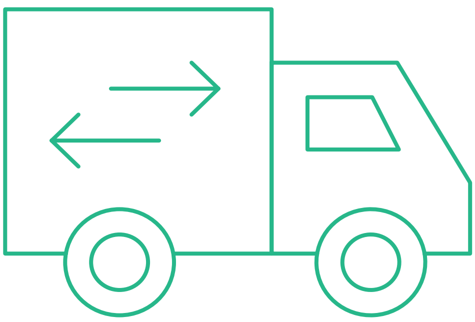
Aviation and shipping are inherently harder to decarbonise. In the aviation sector, sustainable aviation fuel (SAF) appears likely to play a sizeable role in reducing emissions, while the shipping sector is exploring methanol and ammonia as sustainable fuel substitutes. But alternative fuels, even combined with efficiency gains, are unlikely to be sufficient to achieve net zero in these hard-to-decarbonise subsectors. Direct air capture (DAC), which is likely to become significantly cheaper over time as the technology matures and scales, has underestimated potential, in our view.

This paper is the first of a two-part series that aims to unpack these issues and answer these questions. It lays out our views on how the global transport sector is likely to evolve over the next 30 years and what the implications and opportunities are for investors. This paper focuses on the two largest subsectors from an emissions perspective – road transport and shipping – while the second paper will examine aviation and discuss the implications for investors.

The first section of this paper examines road transport, focusing on the outlook for light- and heavy-duty vehicles. The second section focuses on shipping, which may be the most challenging of the transport subsectors to decarbonise. A range of potential options are emerging, and our aim is to understand which of these are likely to gain prominence (and the scale and first-mover advantages that may flow from that) and what it all means for the sector's likely path ahead.

4. At the time of writing, Tesla had just announced significant price cuts for its vehicles in the US, China, and Germany.
5. For more details, see our Pathways paper, "Decarbonisation of electricity generation: The foundation stone for achieving net zero", June 2022.

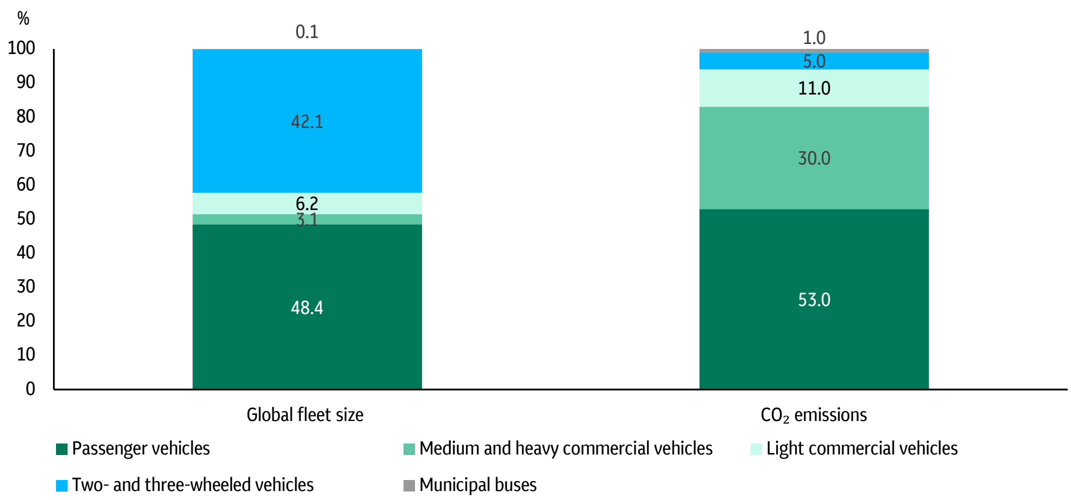
Road transport: Electrification is happening, but not fast enough



The decarbonisation of road transport is overwhelmingly about the decarbonisation of passenger and commercial vehicles (light, medium, and heavy), with the PV and CV subsectors accounting for 94% of global road transport sector emissions in 2022 (Figure 3). Two- and three-wheelers are a significant share of the global vehicle fleet (42.1%), but they account for a very small share of emissions (5%). Buses remain a small part of the market, however measured.

Two- and three-wheelers' limited emissions are due to their relative fuel efficiency and low average kilometres driven, although the relatively high level of electrification in this segment (26.1% of the global fleet is electrified) also helps. CVs are the inverse, accounting for only 9.3% of the global fleet but around 40% of total transport sector emissions (Figure 3). This is a function of the fact that CVs are driven more kilometres – for example, CVs racked up an average of 17,814 kilometres in 2022, whereas PVs averaged 13,297.[6] But it is also due to greater CO_2 emissions per kilometre travelled – PVs on average emit 194 grams of CO_2 per kilometre travelled, whereas CVs emit 573 grams per kilometre.[7]

Figure 3:
Global road transport subsectors by share of the total fleet and CO_2 emissions (2022)



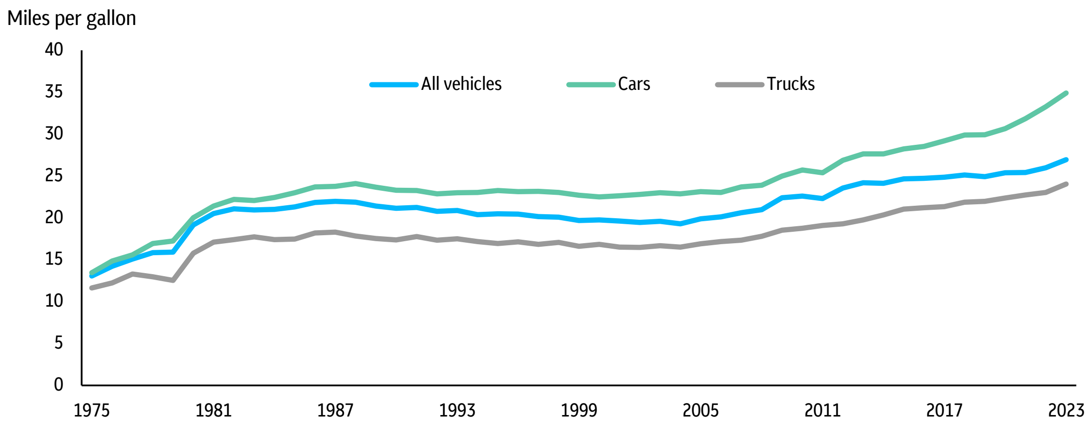
Source: Bloomberg New Energy Finance (BNEF), "EV Outlook 2023", pages 17, 28, April 2024.

6. BNEF, "EV Outlook 2023", page 30-31.
7. BNEF, "EV Outlook 2023", pages 17 and 30-31.

Fuel efficiency: Helpful in limiting emissions, but not a path to net zero

Figure 4 below shows the history of fuel efficiency in the US for both cars and trucks. Since 1975 the US car fleet has seen an increase in miles per gallon of 159%, or 2% per year. A large proportion of these gains came in the immediate aftermath of the sharp rise in the price of oil in the 1970s as the higher cost of fuel incentivised, and government action on fuel efficiency compelled, improvements. Legislation in 2007 that further raised fuel efficiency standards, and an acceleration of that increase in standards by the Obama administration in April 2009, has also had an impact, with further significant gains in fuel efficiency seen since then.[8]

Figure 4:
Fuel efficiency in the US



Source: US Environmental Protection Agency, April 2024.

Similar trends have been observed in the European Union (EU), where fuel consumption per 100 kilometres driven by new cars fell by 1.9% per annum between 2000 to 2021,[9] and a 1% annual reduction was achieved by all LDVs between 2005 and 2019.[10] But overall, efficiency gains occur only slowly by the standards of the speed required to reach net zero by 2050 and can never take you all, or even most, of the way there.

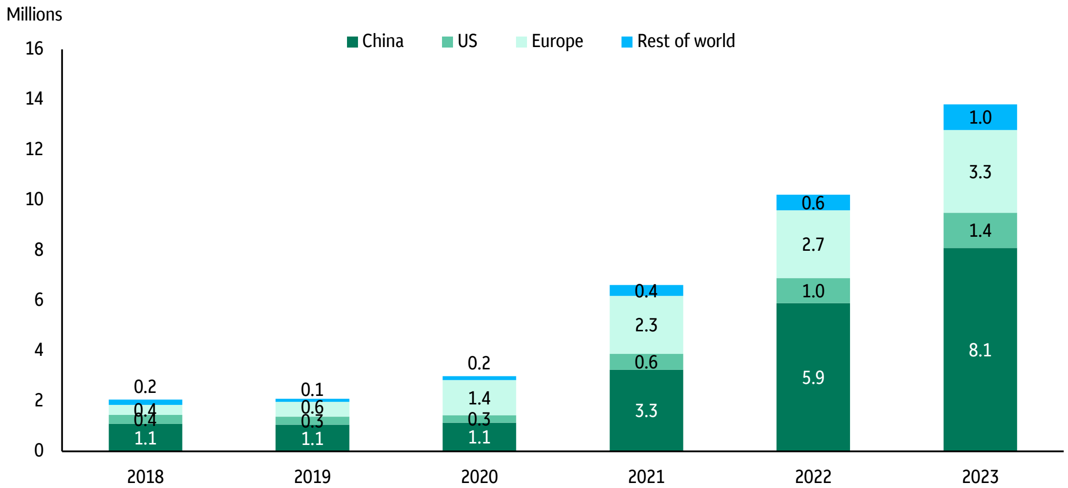
8. For a useful summary see "A brief history of US fuel efficiency standards" by the Union of Concerned Scientists, December 2017.
9. ODYSEE-MURE, "Specific consumer of new cars by country", December 2023.
10. IEA, "Fuel economy in the European Union", December 2021.

EV sales: Rapid growth, but not rapid enough

For PVs, electrification of the fleet is now the accepted path forward[11] and electric motors are a mature, well-proven technology. Batteries have reached at least early majority endorsement levels and keep improving at a steady pace, both in terms of cost and performance. The critical question is whether electrification will proceed quickly enough for the sector to reach net zero by 2050.

Key for PVs will be the speed of EV take-up. Growth rates vary by market and can be heavily influenced by government policy. Globally, the growth in EV sales has been very strong in recent years – sales have gone from 2.1 million in 2018 to 13.8 million last year, a compound annualised growth rate (CAGR) of 46.2%. China has been the largest contributor to this growth, with EV sales in China increasing by 7 million during those five years (from 1.1 million to 8.1 million), accounting for more than half of the total increase in EV sales globally (11.7 million) over the period. Europe has also been a sizeable contributor, with a 2.9 million increase in EV sales over that period, with sales now accounting for more than one-fifth of all sales of new PVs.[12]

Figure 5:
EV sales by region



Source: IEA, "Global EV Data Explorer," April 2024.

11. Hydrogen fuel cells were in theory another option for PVs, but electrification and batteries now appear to have an unassailable lead.
12. European Environmental Agency, "New registrations of electric vehicles in Europe," October 2023.

While growth has been strong, there is still a long way to go to electrify the entire global fleet of around 1,286.3 million PVs.[13] Given the relatively long life of an average car, and the therefore slow turnover of the global car fleet, for the entire fleet to be electric by 2050, EV sales need to hit 100% of sales well before the 2050 deadline.

The average lifespan of a vehicle varies a lot by country – a study covering 31 European countries[14] found that lifespans varied from 8.0 to 35.1 years, with an average of 18.1 years in Western Europe and 28.4 in Eastern Europe. This number for Western Europe is broadly consistent with data from the US Bureau of Transportation Statistics,[15] which shows that the average age of the US fleet was 12.5 years in 2023.[16] In short, an average lifespan of ~20 years for a car would appear to be a reasonable working assumption. In the absence of circulation bans, this would imply that to reach a fully electric fleet by 2050, EV sales would need to reach 100% of car sales by 2030.[17]

Since 2018, EVs' share of all car sales has been rising by around 3 percentage points per year. Extrapolating this forward linearly it would take until 2051 for EV sales to reach 100% of all sales, more than 20 years too late for this segment to reach net zero. Moreover, all else being equal, there is the risk that the rate of increase in sales share slows as penetration rates rise and marginal sales depend on buyers inherently less enthusiastic about EVs. In other words, to reach the net zero target, something needs to change to accelerate the rate of EV take-up.

There are two obvious candidates for an acceleration: market forces and government intervention. The latter could take the form of increased subsidies or outright bans on the purchase, or even circulation, of internal combustion engine (ICE) cars. Subsidies are expensive, but not prohibitively so. For example, 15.5 million LDVs were sold in the US in 2023. A subsidy of $US5,000 per car would cost $US77.5 billion, or around 0.3% of US GDP.[18]

13. This is the BNEF estimate for 2022. The International Organization of Motor Vehicle Manufacturers (OICA) is another useful source and has data for 2020. Extrapolating that forward to 2022 at the same annual growth rate as occurred between 2015 and 2020 gives a number of 1,201.8 million.
14. European Transport Research Review, "Lifespans of passenger cars in Europe: empirical modelling of fleet turnover dynamics," February 2021.
15. US Bureau of Transportation Statistics, "Average Age of Automobiles and Trucks in Operation in the United States," October 2023.
16. The fleet will contain many new cars, so an average age of 12.5 years is likely to imply an average vehicle lifespan of roughly double this, give or take.
17. Even this would not be sufficient to reach 100% electrification as there would be cars that last longer than the 20-year assumed lifespan. But it would get you quite close, particularly in terms of kilometres or miles driven – the cars that are likely to last longer than 20 years will tend to be those that are not driven very much.
18. If the car fleet was to grow slower than GDP going forward, as might be expected in developed markets where penetration rates are high, this percentage would decline over time.

Many countries have indeed set a date for banning the sale of ICEs, and Figure 6 below provides a summary for selected economies and regions. The Nordic countries tend to have the shortest time horizon for bans to go into effect, but a commonly targeted year is 2035. Even this is too late to reach net zero by 2050 and, as recent events in the UK highlight,[19] these dates are subject to political pressure, with that pressure likely to increase as the ban dates approach.

Figure 6:
ICE bans by country and region

Country	Start year	Scope
EU	2035	Cease sale of new petrol and diesel cars and vans.
UK	2035	Cease sales of new non-electric or hybrid cars and vans.
US (nine selected states)[20]	2035	All new vehicles sold in the state to be either electric or plug-in electric hybrids.
Sweden	2030	Cease sale of new petrol and diesel cars.
Norway	2025	Cease sale of all fossil-fuel-based cars.
Canada	2035	All new light-duty vehicle sales must be electric or plug-in hybrid.

Source: Macquarie Asset Management analysis, April 2024.

It would naturally be better if the acceleration came from market forces and EVs became the straight-up preferred choice of consumers. A big component of winning over consumers is cost (although it is by no means the only barrier – more on this below).

Cost comparison: When will EVs be cheaper?

Many forecasters expect EVs to be cheaper on a total cost of ownership (TCO) basis by the mid-2020s, i.e. in the next one to three years. For the time being, the baseline difference in the cost structure of an EV versus an ICE is that EVs have a higher upfront cost but are cheaper to run. Their lower running cost comes down to greater energy efficiency and, by extension, a lower cost of fuel. For example, the US Department of Energy[21] estimates that EVs convert 77% of the electrical energy they receive into power at the wheels, whereas a normal gasoline ICE car converts 12-30%. Other running costs, such as maintenance and insurance, largely offset each other. Maintenance tends to be lower for EVs, while insurance costs are higher because of the higher upfront cost and the fact that repairs tend to cost more.[22]

19. The UK prime minister Rishi Sunak recently announced that the ban would be pushed back from the original 2030 to 2035.
20. The nine states are California, Connecticut, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Washington.
21. US Department of Energy FEG, "All-Electric Vehicles."
22. This is in turn due to the fact that EVs tend to be more technologically sophisticated and integrated and so can require specialist skills (that at present are in relatively short supply) to repair.

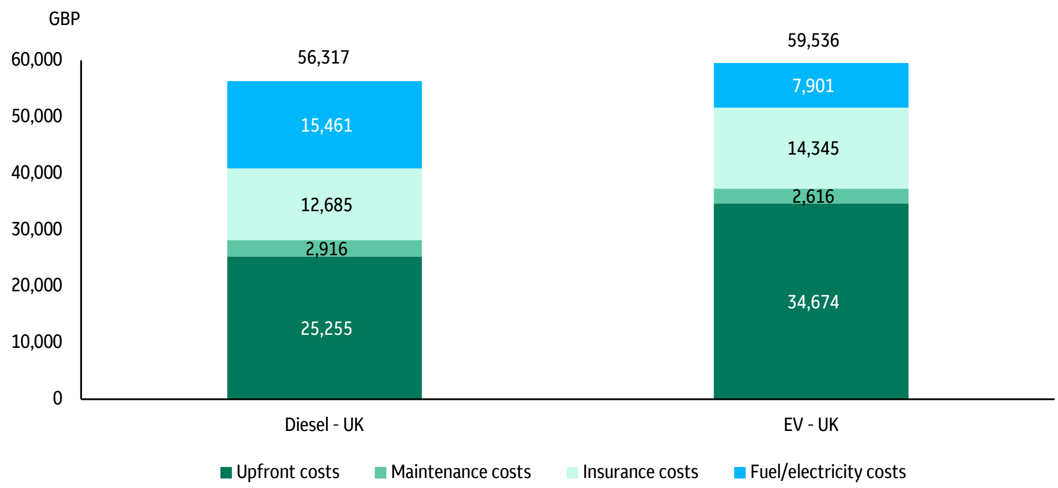
In Figure 7 we compare the net present lifetime[23] cost of a mid-sized UK EV with that of an equivalent UK diesel ICE. Insurance plus maintenance costs are similar in both cases, with the net present value of these costs £1,360 ($US1,741) more for an EV. The big differences are in upfront cost and fuel. In terms of upfront cost, the ICE is £9,419 ($US12,056) cheaper on average, but fuel is roughly twice as expensive.

The main factors affecting EVs' relative cost are therefore:

- Distance driven each year – with a lower fuel cost, the more driving a person does the more attractive the EV will become.[24]
- Discount rate – the higher the discount rate, the less valuable future fuel cost savings become and the less attractive the EV is.

Figure 7 shows the comparison assuming a 5% discount rate and a driving distance of 10,000 kilometres per year. Under those assumptions the EV is £3,219 ($US4,120) more expensive over the lifetime of the vehicle. Shifting to a 10% discount rate widens the cost differential to £5,302 ($US6,787), while doubling the kilometres travelled (to 20,000 per year)[25] makes the EV £4,341 ($US5,556) cheaper than the ICE.

Figure 7:
EV versus ICE – Total cost of ownership



Sources: HSBC UK, "Electric vehicle cost comparison calculator," Macquarie Asset Management calculations, April 2024.

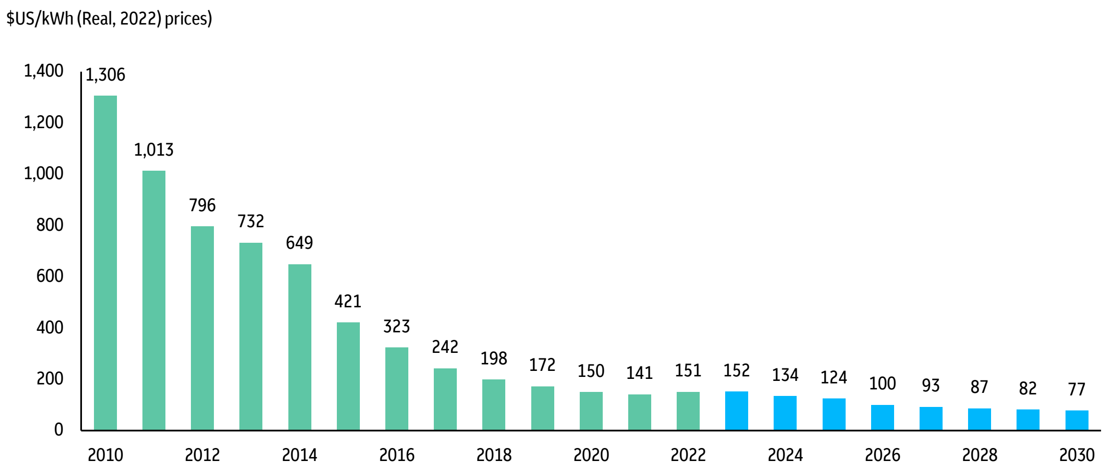
23. We assume a 20-year car life.
24. As a direct or "first round" consideration. Those who drive more, or a lot, often do so for commercial reasons, and for this cohort spending time charging during the day can be a disincentive to use an EV. However, as we discuss later in this paper, we don't think it is powerful enough to materially change the picture.
25. Holding the discount rate at 5%.

This analysis highlights the importance of distances driven, or the intensity of car use, for the economics of EVs. For professional drivers, or for casual drivers that tend to drive longer distances, EVs could be relatively attractive even now on a TCO basis. Working against this, particularly for professional drivers, is the implied cost of the charging downtime. If we assume one hour of charging downtime per workday, at an hourly pay rate of £15 per hour, this amounts to an opportunity cost of £75 per week, or around £3,600 per year (assuming four weeks holiday). But as per the above, at 20,000 kilometres per year the EV is still cheaper in this professional driver scenario (£741 cheaper), and a professional driver working five days a week, 48 weeks a year, is likely to drive well in excess of 20,000 kilometres.

For less intense users, there is the potential for battery prices to fall further and therefore lower the upfront cost of an EV. The battery accounts for about 30% of the overall cost of an EV[26] so price declines do have the potential to move the economics significantly. Taking the initial estimate of EVs being £3,219 ($US4,120) more expensive, closing this gap would require a roughly 10% decline in the upfront cost of an EV, or a 33% decline in the cost of the battery.

Figure 8 below shows the evolution of battery prices in recent years. Prices (in real terms) have fallen 88% since 2010, or around 16.5% per year. Since 2018 the rate of decline has slowed to just 6.6% per year, or 4.6% per year in nominal terms. Based on the BNEF projections shown in Figure 8, they will have fallen 33% in (nominal) price by 2028.[27] Alternatively, if prices simply continue to decline at the rate they have since 2018 (i.e. at 6.6% per year) this threshold will be crossed in 2031.

Figure 8:
Battery prices are expected to continue to decline



Source: BNEF, "EV Outlook 2023", p. 148, accessed April 2024.

26. Statista, "Projected battery costs as a share of large battery electric vehicle costs from 2016 to 2030," April 2017.
27. Assuming 2% inflation.

Many variables go into the cost comparison equation between EVs and ICEs: kilometres driven, battery costs, discount rates, car size, and the cost of electricity and gasoline, to name a few. This makes it hard to generalise about which vehicle type is currently cheaper and to what extent. But there are two main takeaways from our analysis:

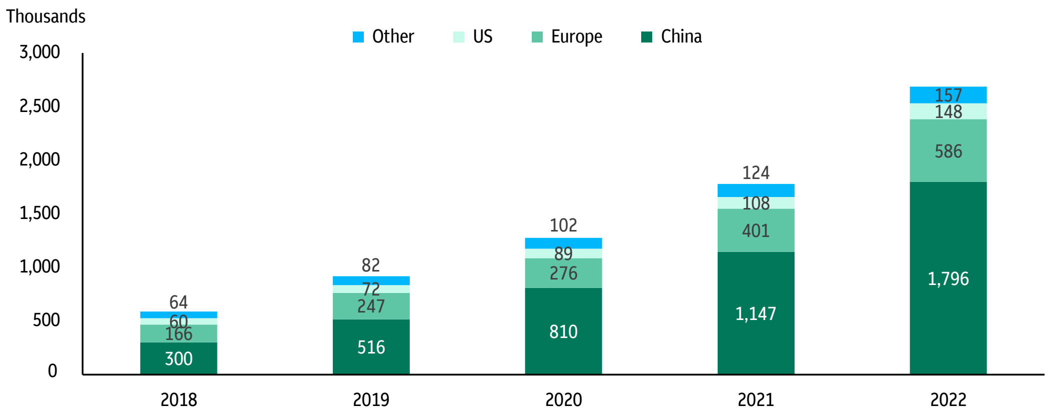
- Estimates that EVs will be cheaper than ICEs in the next couple of years may be too optimistic, but it seems likely that this threshold will be crossed in the late 2020s or early 2030s, even under relatively conservative assumptions for some of the key variables.
- For intense-use drivers, such as people who drive for a living, or casual drivers in geographically large countries where car transport is heavily relied on (such as the US or Australia), an EV may already be cheaper.

Other consumer concerns: Charging networks and range

It's not just total or upfront cost that is a barrier for consumers. Surveys show[28] that potential purchasers have several other concerns about EVs. Chief among these are charge point availability, charge time, and the range of EVs.

Encouragingly, there has been significant progress on these issues in recent years. In terms of the charging networks, a large amount of capital has been deployed, leading to rapid growth in the number of public chargers over the past four or five years. As Figure 9 shows, the number of publicly available chargers globally has expanded from 589,012 in 2018 to over 2.5 million in 2022, a CAGR of 46.1%. As with the growth of EVs, China has been a big part of the growth of chargers, but so have Europe and the US, which have seen average annual growth rates of 37% and 25.6%, respectively, in the number of public chargers between 2018 and 2022.

Figure 9:
Public charging connections globally



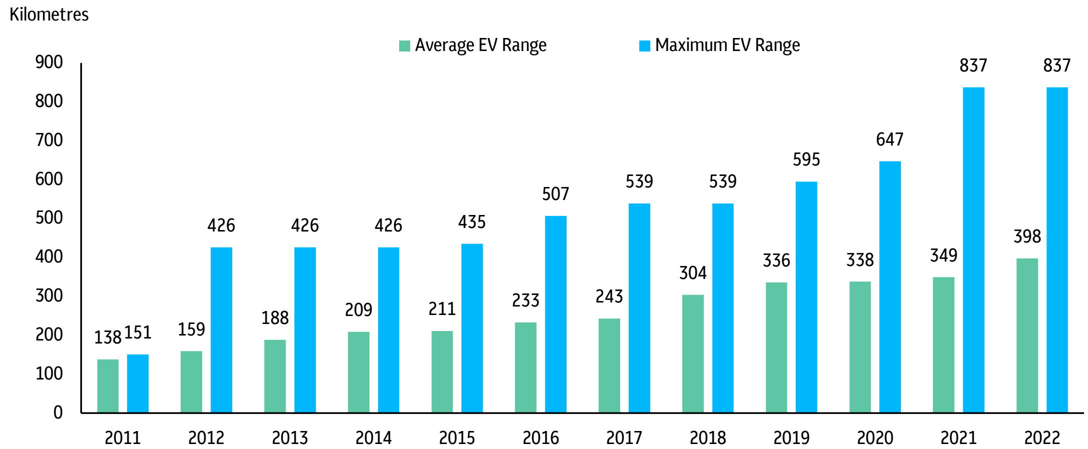
Source: BNEF, "EV Outlook 2023", p. 36, April 2024.

28. Based on surveys conducted by Marsh McLennan "Time to recharge: Accelerating the rollout of EV charging infrastructure," March 2022.

There is still a long way to go, however. While the number of public charging connections needed in a given geography depends on a range of factors, an industry rule of thumb is one charger for every 10 EVs. If we are to electrify the entire US vehicle fleet, which in 2022 stood at 283.4 million vehicles,[29] this would imply a need for around 28.3 million charging connections, or around 191 times the number of connections currently in existence.

EV range has also been lengthening. For example, according to the IEA, the average range for a battery electric vehicle (BEV) has increased from 138 kilometres in 2010 to 398 kilometres in 2022[30] (Figure 10). The 2017 Tesla Model 3 had an advertised range of 220 miles, whereas the 2024 version's range is close to 400 miles.

Figure 10:
EV range over time



Sources: Visual Captialist, "Visualizing the Range of Electric Cars vs. Gas-Powered Cars," September 2022; Sustainability by numbers, "The end of range anxiety: how has the range of electric cars changed over time?" February 2023.

In summary, many of the concerns consumers have about EVs and their viability are being steadily addressed by the market and technological innovation. In our view, it would be reasonable to assume that this will, in time, be reflected in consumer opinion.

29. This is data from the US Department of Transportation (Federal Highway Administration, Office of Highway Policy Information, "State Motor-Vehicle Registrations - 2022," November 2023.) and includes automobiles, trucks, buses, and motorcycles, both privately and publicly owned.
30. IEA, "Evolution of average range of electric vehicles by powertrain, 2010-2021," May 2022; Sustainability by numbers, "The end of range anxiety: how has the range of electric cars changed over time?" February 2023.

Commercial vehicles: Light, medium, and heavy

Compared with PVs, CVs are a smaller market but still significant in number, with a global fleet of 247.5 million in 2022,[31] 19.2% the size of the passenger vehicle fleet of 1,286.3 million vehicles. The electrification of CVs is also lagging that of passenger cars. In 2022, the electrification ratios of various types of CV were as follows:

- 0.6% (or 900,000) of all light commercial vehicles (LCVs)[32]
- 0.1% (or 52,000) of the medium/heavy commercial vehicles (MCVs/HCVs).[33]

The challenge for HCVs is the size and weight of the battery, which brings extra cost and results in a loss of payload – vehicles are generally classified by gross vehicle weight (the total weight of the vehicle including its load), so the heavier the vehicle the less load it can carry. The larger and heavier the battery and therefore the vehicle, the more pronounced the cost and payload challenges. In other words, LCVs are the most suited to electrification, while MCVs and particularly HCVs are likely to face additional hurdles, with penetration of these market segments expected to lag LCVs.

For many of the popular electric LCVs (e-LCVs) the manufacturer has kept the size of the battery small to preserve payload, with a cost in terms of limited range. For example, the Ford E-Transit has upgraded its battery size with its 2024 model to 89 kWh (from 68 kWh previously), giving it a range of around 250 kilometres[34]; the Tesla Model S (a smaller and lighter vehicle) has, by contrast, a heavier battery (usable capacity of 95 kWh) and a range of almost 500 kilometres.[35]

This is likely optimal from an economic point of view as LCVs tend to be driven shorter daily distances than MCVs or HCVs. Globally, in 2023 LCVs averaged 53.8 kilometres per working day, whereas MCVs averaged 80.9 kilometres and HCVs 157.6 kilometres. LCV range requirements are, of course, higher than this, but LCVs are driven quite regularly, with a UK survey showing that around two-thirds are driven at least four days a week.[36] Even if average use is only 2.5 days per week, this implies an average distance driven per day of use of 107.6 kilometres. A range of more than double that (as the Ford E-Transit has) would appear to cover the overwhelming bulk of use cases for this type of vehicle.

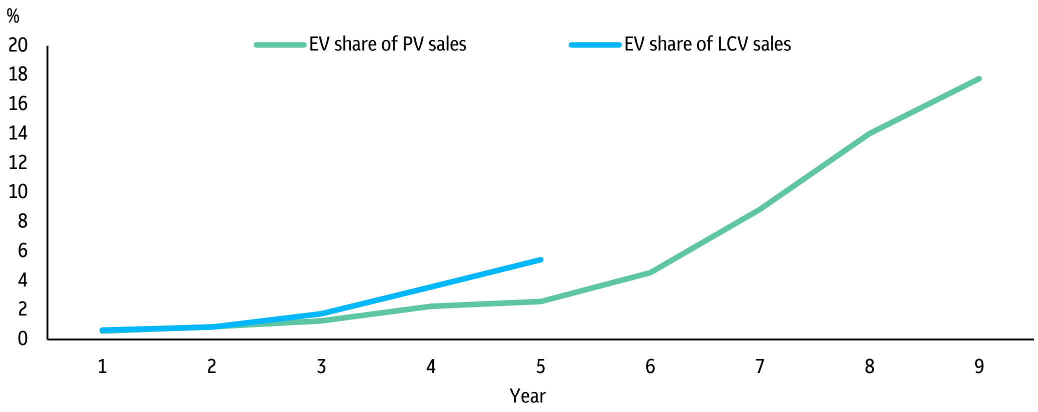
31. Again this is BNEF data. Interestingly OICA has a very different number. Using the same methodology as for PVs gives a 2022 estimate of 416.1 million. We have not been able to reconcile the difference here, although it may have to do with the categorisation of SUVs.
32. LCVs are generally a commercial vehicle with a gross weight of 3.5 metric tonnes or less. These are generally vans and urban delivery trucks.
33. A commercial vehicle with a weight greater than 3.5 tonnes is considered a heavy commercial vehicle. This category is then often divided into two: those trucks with a weight of between 3.5 and 12 tonnes (which we here call MCVs) and those with a weight of greater than 12 tonnes (which we here call HCVs).
34. Car and Driver, “2024 Ford E-Transit.”
35. Electric Vehicle Database, “Tesla Model S Dual Motor.”
36. UK Department of Transport, “Final Van Statistics April 2019 - March 2020,” April 2021.

A TCO comparison for LCVs is hampered by limited information on key models. However, our analysis of the Renault Trafic (a popular LCV model) suggests that the present value[37] of the lifetime fuel cost saving (which we estimate at £7,964) is not enough to fully offset the extra price, which we assess at £11,510.[38] That said, it would only require a 7.5% fall in the price of the electric model, or a roughly 22.5% decline in the cost of the battery, to equalise this simplified TCO. Based on Figure 8 shown earlier, this could happen around 2027. Another option would be simply to increase the subsidy to around £8,500.

For those who drive more than the global average of 13,500 kilometres per year, the e-LCV would quickly become the preferred option based on the economics. The energy density of batteries is likely to improve further in the coming years (with some suggesting it could triple by the 2040s[39]), which would improve the range and reduce the payload loss of e-LCVs. Factors beyond the TCO may also influence take-up in the years ahead. Regulations, including ICE bans or restricted access to urban areas, as well as corporate emissions reduction commitments, may all work to support sales of electric models.

In any event, e-LCVs are seeing rapid penetration of the market, albeit from a low base. Indeed in 2019 e-LCV sales as a share of total LCV sales was 0.6%, exactly the same as passenger vehicle EVs in 2015. Figure 11 below plots the penetration trajectory of both segments, with Year 1 being 2015 for PVs and 2019 for LCVs. It highlights that electric models are actually penetrating this market segment very rapidly and indeed at a faster pace than electric PVs did in their early stages. Given likely battery density and cost improvements, we would not be surprised if e-LCVs were to track their PV cousins quite closely in terms of take-up.

Figure 11:
E-LCVs are seeing rapid penetration of the market



Sources: Macquarie Asset Management calculations, BNEF data, April 2024.

37. At a 5% discount rate.
38. See the Renault UK website (Renault Business - commercial vehicles and services) where the EV model appears to be priced at £47,400 (after the plug-in vehicle grant) while the diesel version sells for £35,890.
39. Thunder Said Energy, "Lithium ion batteries: energy density?"

HCVs are at the other end of the spectrum. Electric HCV (e-HCV) sales were 0.1% of total HCV sales in 2023, with 85% of all e-HCV sales occurring in China. In the developed world these vehicles are effectively non-existent at present, with many of the high-profile models yet to come to market in any meaningful sense. The Tesla Semi, for example, has been delivered to only one customer, PepsiCo, and only around 100 total vehicles have been delivered.

The challenge for this segment is the size of the battery, given the size of the vehicle and the range required for commercial viability. The Semi has an advertised range and fuel efficiency of 500 miles and 2 kWh per mile,[40] respectively (although comments from CEO Elon Musk and other industry experts suggest it could actually be more like 1.7 kWh per mile). This would imply a battery of 850-1000 kW, which would weigh around four tonnes. A 40-tonne gross weight truck has a curb side weight[41] of around 15 tonnes and a payload of 25 tonnes. A four-tonne reduction in that payload (in the absence of government-allowed weight offsets for e-HCVs) would therefore imply a 16% efficiency and revenue loss.

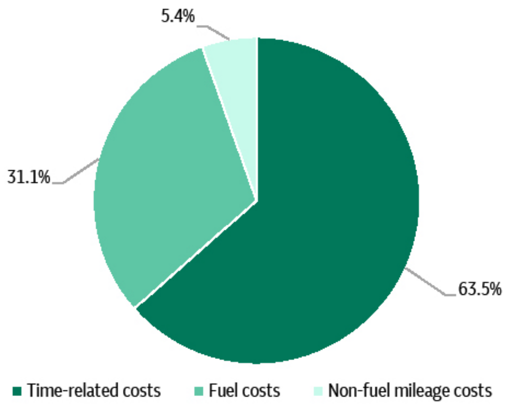
What is intriguing about trucks of this size from an electrification perspective is how much they're driven. From the PV and LCV examples above, we know distance travelled really moves the dial on the economics of the vehicles. In fact, using the assumptions laid out by the UK Road Hauling Association (RHA) in its 2023 cost tables,[42] fuel costs almost £60,000 per year based on a 75,000-mile annual average travel distance. The cost of fuel – whether diesel or electricity – varies between the US, UK, and EU,[43] although the ratio of the cost (with electricity around half the cost of diesel) is quite constant across all three regions.

You can, therefore, roughly halve the fuel cost for an e-HCV.[43] Taking a six-year life of the truck, as modelled by RHA, this adds up to a present value saving of £105,000. So, if a tractor unit sells for around £120,000, the electric version could retail for up to £225,000 and still be appealing. With the Tesla Semi rumoured to be around $US180,000 to $US200,000,[44] it would seem this truck has the potential to be very popular.

But this ignores the payload loss element of the equation. Fuel costs are actually only a fraction of the total costs of running a 40-tonne truck – indeed they are less than one-third (Figure 12). Even if we assume the owner is running on a zero margin, a 16% loss of payload implies an annual revenue reduction of around £30,775. Over the six-year life of the vehicle, this adds up to a present value revenue loss of £156,205, which is well in excess of the fuel saving of £105,000. And this is before we consider the likely higher upfront cost of the electric model. This highlights the potential potency of regulatory based extra weight allowances for e-HCVs.

40. Tesla, "Semi: The future of Trucking is Electric."
41. Weight not including the payload but including standard equipment and fuel.
42. See page 13 for the cost breakdown (UK Road Haulage Association (RHA) Cost Tables 2023).
43. The US is far cheaper, with the UK and EU roughly on a par.
44. This assumes HCVs are paying the retail price for electricity. Fast chargers cost about twice as much, so if the truck did half its charging on a fast charger, the drop in fuel cost would be around 25% only, or £15,000 in this example.

Figure 12:
Fuel costs are less than one-third of total running costs for a 40-tonne truck



Source: UK RHA, 2023 cost tables, p. 13.

While these are all approximate calculations, based on aggregated and publicly available data, and individual circumstances can vary materially from this, it highlights a few key points about 40-tonne HCVs and the competitiveness of electric models.

- **Lower fuel cost.** The fuel cost can be as low as half that of a diesel truck. Fuel costs are higher in Europe (for both the ICE and the EV), due to the higher cost of energy compared to the US, but the ratio is broadly the same. Use of fast chargers can undermine this cost saving, however – if fast chargers were used for half of all charging it would result in a roughly 25% (as opposed to 50%) decrease in the cost of fuel. Working in the other direction, the introduction of a carbon price would push the relative cost of fuel back in favour of EVs (interestingly, the EU's emissions trading system is set to be phased in to road fuels in 2025).
- **Payload loss dominates.** The payload loss, which according to our calculations is around 16%, results in a revenue loss that is greater than the fuel saving, making the electric version less economical on a like-for-like basis. This highlights the desirability of weight offsets for EVs. It also reinforces the potency of potential improvements in battery density. As that improves, and the weight of the battery declines commensurately, so will the payload loss.
- **Repairs and insurance.** If repairs and insurance cost more for e-HCVs (as seems to be the case for passenger EVs), this would further undermine the economics, although it's not a large share of TCO, so it doesn't move the needle all that much. In addition, for both PVs and HCVs this cost differential is likely to narrow over time as the market for these services scales in line with the growth in EVs.
- **Utilisation and miles driven.** For PVs and LCVs, increased utilisation can make a big difference to the economics of BEVs and can quickly tip the TCO in their favour. This lever is far less readily available for e-HCVs, however, given their already high utilisation rate.

The role of hydrogen: Too slow out of the gate

Hydrogen fuel cell vehicles (FCVs) are another option to decarbonise this sector. Although the price of an FCV is considerably higher than both a diesel engine vehicle and BEV, and the consensus is that it will not reach TCO parity in the near term, hydrogen has a number of advantages. It has the potential to overcome some of the challenges of BEVs, specifically (1) range limitations, (2) weight and the payload penalties that come with large batteries, and (3) long charging time.

For the same range the fuel cell stack required is usually lighter than the battery pack, thereby enabling longer ranges without the substantial payload losses. In addition, an FCV can be refuelled in a matter of minutes, which entails higher operational efficiency, which is crucial for commercial transportation. That said, despite its potential the current uptake of FCVs remains low: among all commercial vehicles sold in 2022, only 2,120 were FCVs.[45]

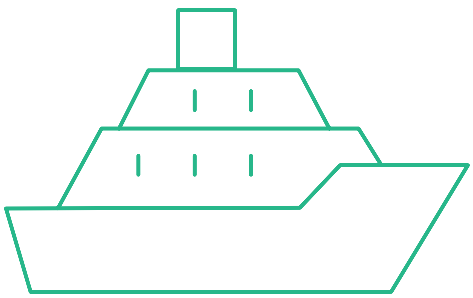
One of the major barriers is lack of hydrogen refuelling infrastructure, which requires substantial investment to build out. The capital expenditure (capex) requirements of a hydrogen refuelling station are much higher than that of an EV charging station. This is partly because hydrogen supply will have to come from a pipeline (either newly fitted hydrogen pipeline or retrofitted gas pipeline) or on-site hydrogen generation. Indeed, at the end of 2023, there were only 921 hydrogen refuelling stations in operation worldwide, the majority of which are in China. By contrast, BEVs have a "ready-made refuelling infrastructure" in the form of an already existing home and business electricity network. Crucially, however, BEVs have what appears to be an unassailable lead on FCVs in terms of consumer acceptance, production scale, and all the cost and network benefits that come from that.

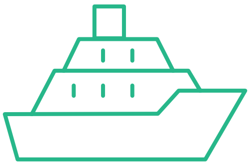
Electricity demand implications

EVs' increasing penetration of car fleets has implications for electricity demand, and the quantum is non-trivial. If the fleet fully electrifies by 2050, we estimate that global annual electricity demand from all vehicles and buses will be 12,779 TWh, comprising 5,873 TWh from cars and 6,906 TWh from commercial vehicles and buses. This is about three times the US's electricity consumption in 2022[46] and about 45.4% of all the electricity consumed today globally (again in 2022).[47] For developed markets, where growth in electricity demand has slowed significantly in recent decades, this could make a meaningful difference to growth rates going forward.

45. BNEF interactive datasets "Commercial vehicles."
46. US Energy Information Administration (EIA), "Electricity explained: Use of electricity," December 2023.
47. IEA, "Electricity 2024: Analysis and forecast to 2026," January 2024.

Shipping: A wide range of options





Shipping is a significant contributor to global greenhouse gas (GHG) emissions, accounting for about 11% of global transport sector CO_2 emissions, or about 2.4% of the world's total emissions.[48] Given that the sector facilitates more than 80% of global trade in goods by volume,[49] and trade plays a key role in driving global growth, finding a way to facilitate these exchanges with minimal carbon impact is crucial to the dual goals of reducing the damaging effects of climate change while maintaining growth in living standards.[50]

CO_2 emissions from international shipping are still generally trending upward, as shown in Figure 13 on the next page.[51] By 2022, emissions had bounced back from their COVID-19-induced drop and had returned to their 2018 peak level. That said, the carbon intensity of international shipping has improved quite significantly over this period thanks to energy efficiency measures. The International Maritime Organization (IMO) estimates that between 2008 and 2018, the carbon intensity of international shipping dropped 21-32%, depending upon the methodology applied.

Our analysis, represented in Figure 14, on the next page shows that between 2008 and 2022 emissions fell 26.7% relative to growth in goods trade volumes, and 21.3% and 43.6% relative to global GDP when measured in market exchange rate and purchasing power parity terms, respectively. While the trade intensity of GDP growth matters, the most relevant comparison here is with trade volumes, and on that basis there has been an average annualised improvement in carbon efficiency of 2.2% per year.

48. IEA, "Global CO_2 emissions from transport by sub-sector in the Net Zero Scenario, 2000-2030," June 2023.
49. United Nations trade and development, "Review of Maritime Transport 2021."
50. While this chapter will primarily discuss reduction of CO_2 emissions, which account for 98% of all shipping GHG emissions, it is worth noting that the emissions from shipping include not only CO_2 but also other GHGs such as methane (CH_4) and nitrous oxide (N_2O), which, although present in smaller quantities, have a higher global warming potential.
51. These are emissions for international shipping only and so are slightly lower than the data in Figure 2. The difference is domestic shipping and fishing. It is also worth noting that the IMO's bottom-up estimates (as opposed to top-down estimates like the IEA's) of international shipping emissions are somewhat higher (937 Mt in 2018) – see its Fourth Greenhouse Gas Study 2020 for more details.

Figure 13:
CO_2 emissions from international shipping

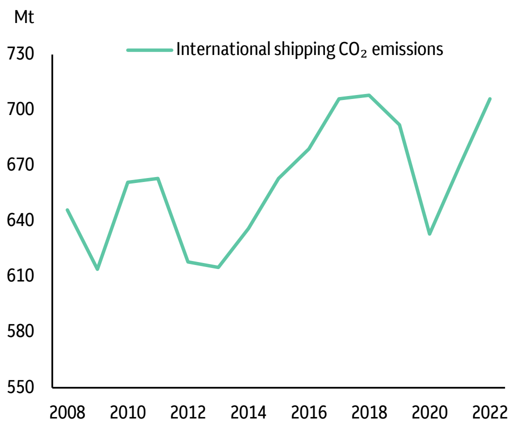
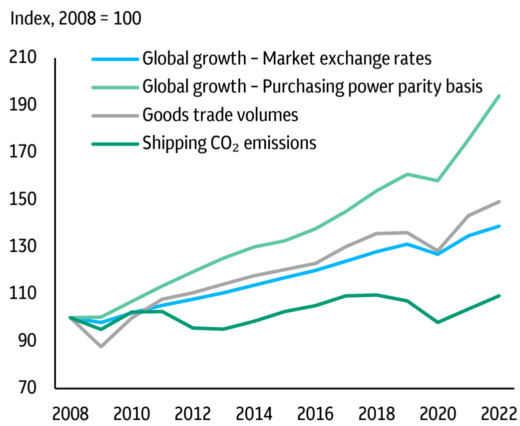


Figure 14:
Carbon efficiency gains in shipping



Sources: IEA, IMF, April 2024.

Looking ahead to 2050, our calculations suggest that if trade grows at the same ratio of global GDP growth as it did over the 2008-2022 period, and the rate of improvement in energy or CO_2 efficiency remains constant, global CO_2 emissions from international shipping will be 770 megatonnes (Mt) in 2050, or around 10% above current levels.

The IMO has set ambitious targets to reduce GHG emissions from shipping in order to align the sector with the Paris Agreement's goal. The revised IMO Strategy on Reduction of GHG Emissions from Ships, adopted in July 2023, includes an enhanced common ambition to reach net zero GHG emissions from international shipping by or around 2050, as well as the following indicative checkpoints for 2030 and 2040:

- To reduce the total annual GHG emissions from international shipping by at least 20%, striving for 30%, by 2030 (compared with 2008 levels)
- To reduce the total annual GHG emissions from international shipping by at least 70%, striving for 80%, by 2040 (compared with 2008 levels)

Options to decarbonise: A variety of possibilities

Currently, most vessels run on fossil fuels and the decarbonisation discourse has focused on finding "greener" shipping fuels. In the context of shipping, the concept of life-cycle emissions is used to assess the cleanness of a fuel. Also known as well-to-wake emissions, life-cycle emissions conceptualises the emission profile of a fuel in two parts, namely (1) well-to-tank (WTT), which covers all upstream emissions associated with extraction, refining, transportation, and bunkering of the fuel prior to combustion, and (2) tank-to-wake (TTW), which covers downstream emissions resulting from burning or using a fuel once it is already in the tank.

Many shipowners have opted to use liquefied natural gas (LNG) as an alternative fuel, claiming that it is more "green" due to its lower CO_2 emissions per energy unit relative to traditional fuels such as heavy fuel oil (HFO) and marine gas oil (MGO). As of 2023, by gross tonnage, ships capable of using LNG account for 40.3% of all ships on the order book, and 78.6% of all ships on the book are capable of using alternative fuels generally.[52] The pipeline of orders is pointing the sector in a clear direction.

However, LNG is far from being a clean shipping fuel: it still emits over 60 grams of CO_2 per megajoule, which is about three-quarters of conventional fuels' CO_2 emissions.[53] Moreover, LNG is a product of methane, whose GHG effect is 87 times stronger than that of CO_2 in the short term and 36 times stronger in the long term. There is a risk of methane leaking into the atmosphere throughout the LNG production process and supply chain, as well as directly from the ship's funnels for some engine types. In short, the overall climate impact of LNG as a marine fuel could actually be worse than that of oil fuels.[54]

In terms of other decarbonising options, biofuel has emerged as an immediate solution due to its technological readiness and compatibility with existing vessel engines. However, as its scalability is limited by the availability of feedstocks, there are alternatives that may overtake biofuel in contributing to the sector's decarbonisation efforts. Specifically, methanol is the most feasible near-term alternative due to its ease of handling and dual fuel compatibility with legacy fuels. Ammonia is a promising option in the medium-to-longer term due to its carbon-free molecular structure. On the other hand, hydrogen is not considered commercially viable because of its low energy density. In addition to alternative fuels, onboard carbon capture and storage (OCCS) and direct air capture (DAC) are mooted as potential solutions, but the required infrastructure for OCCS is not in place yet, while DAC would only become economically viable in the long term.

DAC is a process that removes CO_2 from air through a filter. Today's leading system uses chemical reactions (either liquid solvents or solid sorbents) to capture CO_2 from air and then applies heat to release CO_2 for permanent storage or use. Globally, three companies have a total of 18 DAC plants in Canada, Europe, and the US with capacities that vary between 1 and 4,000 tonnes of CO_2 (tCO_2) per year, capturing a total of just under 8,000 tCO_2/year today. This compares with the 70 $MtCO_2$/year needed in 2030 and 600 $MtCO_2$/year needed in 2050 to meet the net zero target as estimated by IEA.[55] The three companies have received combined investments of $US788 million[56] to date. Since 2020, governments have spent almost $US4 billion in funding specifically for DAC development and deployment.[57]

52. Det Norske Veritas (DNV), "Maritime Forecast to 2050."
53. DNV, "Alternative fuels: the options," October 2018.
54. Transport and Environment, Ships: "Liquefied Natural Gas (LNG)."
55. IEA, "Unlocking the potential of direct air capture: Is scaling up through carbon markets possible?" May 2023.
56. World Resources Institute, "6 Things to Know About Direct Air Capture," May 2022.
57. IEA, "Direct Air Capture, a key technology for net zero", p. 8, April 2022.

The first large-scale DAC plant of up to 1 $MtCO_2$/year capacity is under development in the US and is expected to be operational in late 2024.[58] In November 2022, the company also announced plans to deploy 100 plants by 2035,[59] each with a capture capacity of up to 1 $MtCO_2$/year. More policy support is required to scale up DAC production, and the expected cost reduction is also subject to availability of low-carbon energy sources and CO_2 storage.

Figure 15:
The pros and cons of the multitude of options

	Options	Merits	Key challenges
Alternative fuel	Sustainable biofuels	Mature technology	Limited supply of feedstocks
		Does not require engine modification	Only small reduction in TTW emissions
	Renewable methanol	Relatively easy to handle	Cost and availability of CO_2 from carbon capture (e-methanol)
		Only minor engine modification required	Only small reduction in TTW emissions
	Clean ammonia	Carbon-free molecular structure	Not commercially available yet
		Close to zero TTW emissions	High toxicity
			Required chilled or pressurised fuel tanks
	Liquid hydrogen	Close to zero TTW emissions	Low energy density
			Required specialised fuel tanks
Carbon capture	Onboard carbon capture	No fuel or engine change required	Not commercially available yet
	Direct air capture	No fuel or engine change required	High current production costs

Source: Macquarie Asset Management analysis, April 2024.

58. 1PointFive, "1PointFive and Carbon Engineering Announce Direct Air Capture Deployment Approach to Enable Global Build-Out of Plants," June 2022.
59. IEA, "Carbon Capture, Utilisation and Storage: Direct Air Capture."

Now lets look at each of the decarbonisation options listed in the table on the previous page in more detail.

1. Sustainable biofuels

Biofuels, which are produced from biomass, are one of the few alternative fuel options ready for immediate implementation. Several biofuels, such as fatty acid methyl ester (FAME) and hydrotreated vegetable oil (HVO), can be blended with conventional fossil fuels, and regulations currently permit up to a 20% blend without engine modifications.

The adaptability of these biofuels offers shipowners a way to cut carbon emissions immediately – even if only partially – without making large capital investments. In fact, the International Renewable Energy Agency (IRENA) considers the employment of biofuels one of the four key CO_2 emission reduction measures for the shipping sector, and its proposed pathway to decarbonisation envisions that biofuels will comprise nearly 10% of the total fuel mix in 2050.[60] That said, as of 2022, biofuels accounted for only 0.1% of the mix, which partly reflects a scaling issue due to the scarcity of feedstocks such as used cooking oil and agricultural residues.[61] Another challenge of using biofuels in shipping is competing with demand from other industries, including road vehicles and aviation, which means the price of biofuels will likely remain high. It is also crucial to ensure sustainability in biofuel production such that it does not impact food security, biodiversity, and soil and water depletion.

2. Renewable methanol

Renewable methanol has emerged as the most popular low-carbon alternative marine fuel for the near term. Methanol is a room temperature liquid that stores easily in conventional tanks. Its combustion properties enable its use in conventional ship engines with minor modifications, which allow a vessel to switch between methanol and conventional bunker fuel, thus providing a decarbonisation-ready vessel to the owner without compromising its operations during the transition phase. That said, while methanol can have close to zero CO_2 emissions WTT if produced using clean hydrogen, it barely reduces TTW CO_2 emissions relative to fossil fuels. It is only a low carbon fuel on a net basis after accounting for the carbon it uses during fuel production.

The uptake of methanol-powered ships is growing – by gross tonnage, as of July 2023, 8% of all ships on order are capable of using methanol in dual-fuel engines, a significantly higher level compared with the 0.05% of ships in operation that have this capability.[62]

There are three types of renewable methanol:

- bio-methanol, derived from biomass
- e-methanol, derived from green hydrogen and renewable CO_2
- bio-e-methanol, derived from both biomass and green hydrogen

60. IRENA, "A Pathway to Decarbonise the Shipping Sector by 2050," October 2021.
61. DNV, "Challenging road ahead for retrofitting to dual-fuel engines," May 2023.
62. DNV, "Maritime Forecast to 2050."

Gasifying biomass is currently the cheapest way to produce renewable methanol. The current production costs of bio-methanol are in the range of $US16.4-38.4 per gigajoule (GJ) (assuming less than $US6/GJ feedstock cost) to a range of $US22.9-50.9/GJ (assuming $US6-15/GJ feedstock cost). This range is significantly higher than the cost of fuel oil or LNG, which are in the range of $US2-12/GJ (Figure 16). However, the price range of renewable methanol is expected to drop to a level comparable to fossil fuels and LNG as the technology matures (Figure 17), and CO_2 pricing will further reduce the price gap between them.

Figure 16:
Renewable methanol cost range estimates – 2021

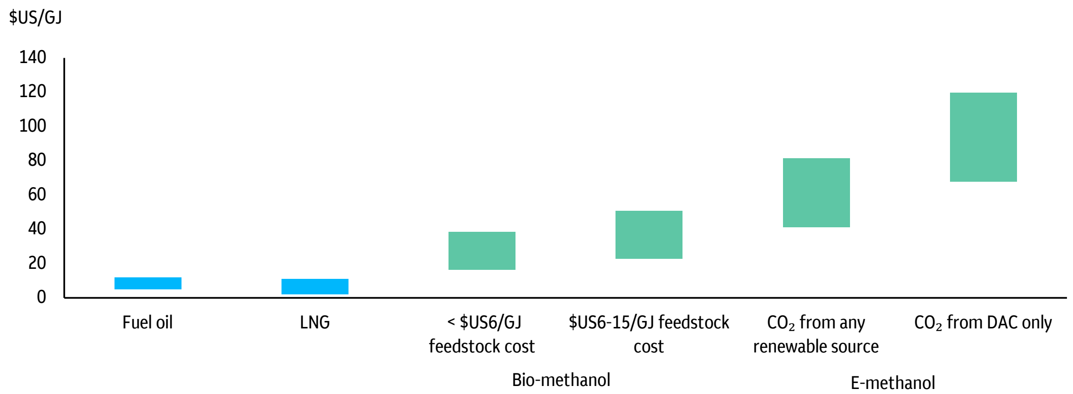
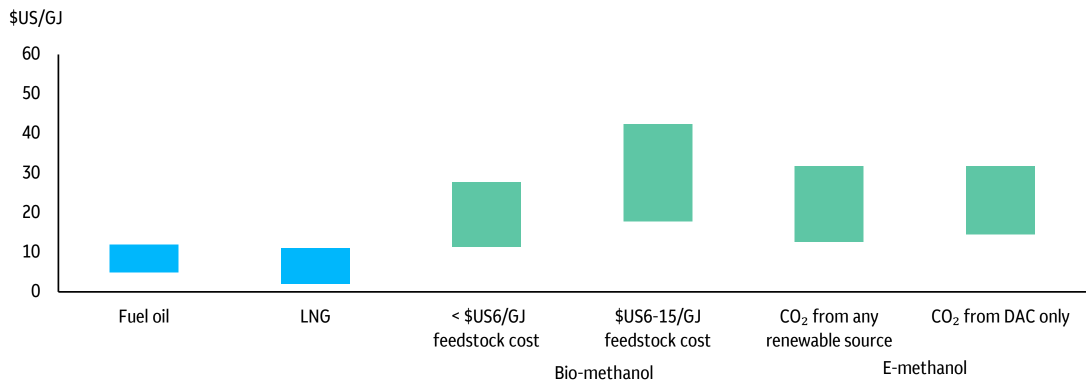


Figure 17:
Renewable methanol cost range projections – 2050



Sources: IRENA, IEA, April 2024.

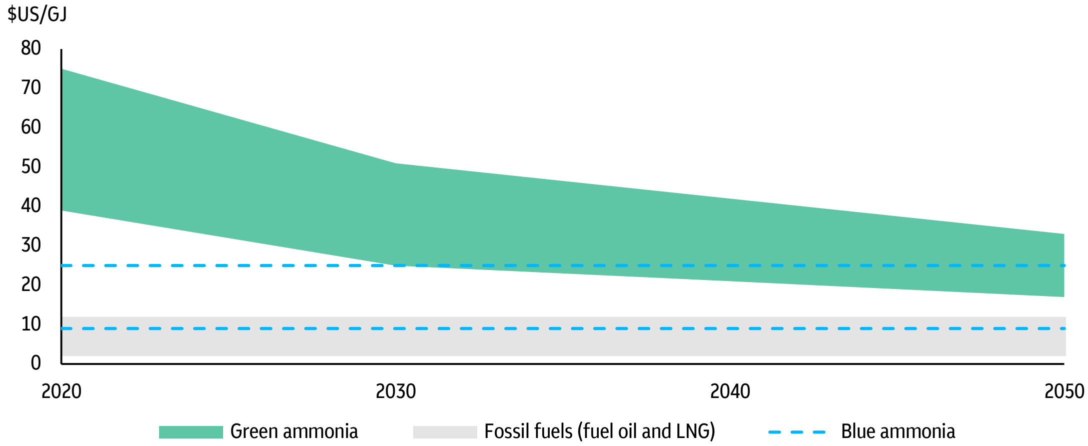
Proposed ideas to lower production costs include co-production of heat, electricity, or other chemicals as well as simplification of the feedstock logistics, among others.[63] Adding clean hydrogen as an additional feedstock can potentially double the methanol output per tonne of biomass, but its cost-efficiency depends on the price of clean hydrogen. Methanol derived from biomass faces the same sourcing challenge as biofuels. For e-methanol, the availability and cost of CO2 that is not derived from fossil fuels is a key constraint. Therefore, while methanol is expected to play a part in shipping decarbonisation, it likely has to be complemented by other alternatives.

3. Clean ammonia

Clean ammonia is derived from clean hydrogen, but unlike e-methanol it contains no carbon, and is therefore free from the sustainable carbon or biomass supply constraints of methanol and biofuel. For this reason, even though ammonia-powered ships are still under development, ammonia is expected to become the primary zero-carbon fuel for shipping in the medium and long term. IRENA estimates that ammonia could represent as much as 43% of the shipping fuel mix by 2050.[64]

In terms of cost, the current cost range of blue ammonia – fossil-fuel-based ammonia with carbon capture – is $US9-25/GJ, while that of green ammonia – ammonia derived from hydrogen produced using renewable electricity via electrolysis – is estimated to be $US39-75/GJ (Figure 18). Although the current price of green ammonia is significantly higher than that of blue ammonia, the price gap is expected to narrow over time and by 2050 could have a cost range of $US17-33/GJ.[65]

Figure 18:
Ammonia production cost range projections ($US/GJ), 2020-2050



Source: IRENA, April 2024.

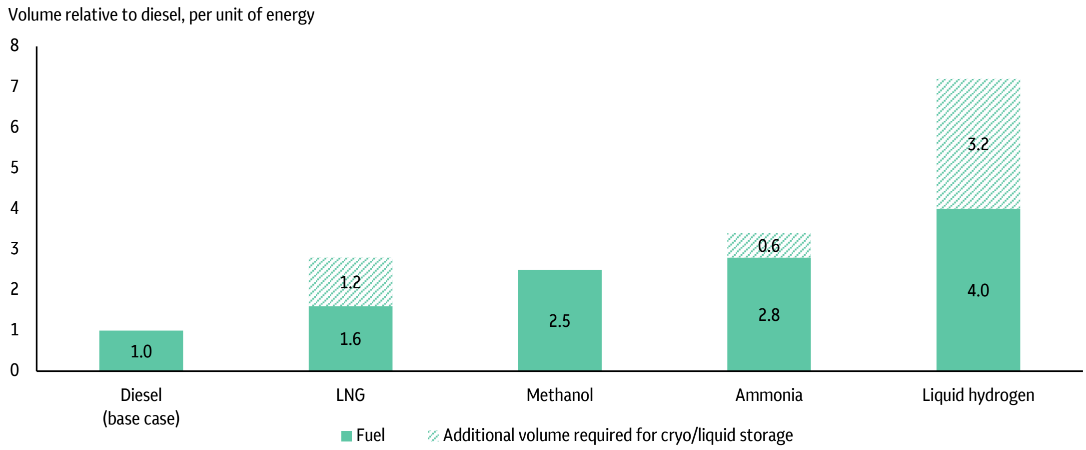
63. IRENA AND METHANOL INSTITUTE (2021), Innovation Outlook : Renewable Methanol, International Renewable Energy Agency, Abu Dhabi.
64. IRENA, "A Pathway to Decarbonise the Shipping Sector by 2050," October 2021.
65. IRENA and AEA (2022), Innovation Outlook: Renewable Ammonia, International Renewable Energy Agency, Abu Dhabi, Ammonia Energy Association, Brooklyn.

In addition to the technological readiness, there are still other hurdles that need to be overcome before widespread uptake of green ammonia as a marine fuel is likely to occur. Ammonia needs to be stored in refrigerated tanks and, as ammonia is toxic, it likely also requires a double-walled fuel piping system for safety reasons. Adoption of ammonia will also necessitate large-scale investments in clean ammonia production as well as port and refuelling infrastructure. Demand for green ammonia for international shipping alone could amount to 183 million tonnes by 2050, which is an amount comparable to today's global ammonia production.[66] A recent study by the University of Oxford estimates that $US2 trillion of investments in green ammonia infrastructure will be needed for global uptake of it as a marine fuel.[67] In addition, the implementation of safety standards and training will also be critical as ammonia is corrosive and toxic if inhaled in high concentrations.

4. Liquid hydrogen

In addition to hydrogen derivatives, liquid hydrogen is another potential solution for decarbonising shipping. It is produced by cooling hydrogen gas to a liquid state to make it more energy dense. However, its energy density is still low relative to other fuels, meaning that it would take up much valuable space within a cargo ship and thus reduce payload (Figure 19). In addition, using liquid hydrogen will also require new fuel infrastructure and the development of specialised fuel tanks to handle its cryogenic storage requirements. All in all, direct use of hydrogen as marine fuel is unlikely beyond niche applications.

Figure 19:
Fuel and storage volume relative to diesel for alternative shipping fuels



Source: BNEF, April 2024.

66. IRENA AND METHANOL INSTITUTE (2021), Innovation Outlook : Renewable Methanol.
67. Oxford Martin School, "Optimal fuel supply of green ammonia to decarbonise global shipping," January 2024.

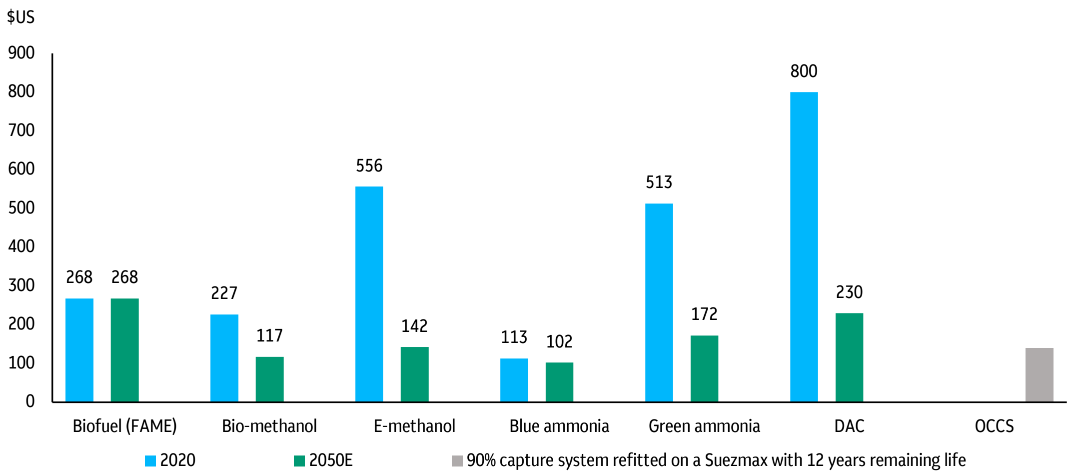
5. Onboard carbon capture and storage and direct air capture

OCSS involves capturing CO_2 emissions directly from ship engines and storing it until it can be offloaded at port facilities for storage or utilisation. This approach can potentially reduce the carbon footprint of existing ships significantly without requiring a switch to alternative fuels, although it is a significant change to add the OCCS equipment.

A feasibility study conducted by the Oil and Gas Climate Initiative (OGCI) and Swedish tanker owner Stena Bulk in 2021 shows that OCCS could be an economically viable option for large-size vessels. According to their estimation, the capex of refitting a system capable of capturing 90% of all CO_2 emitted at sea by a Suezmax tanker running on heavy fuel oil is about $US30 million, and the operating expenditure (opex) is estimated to be about $US2 million a year, which is about a 25% increase in the ship's current annual opex.[68]

Based on this study's result, the cost per tonne of CO_2 equivalent reduction on a Suezmax with 12 remaining years of life is about $US140, which is comparable to the price of blue ammonia today (Figure 20). The cost per tonne could be even lower if the ship has more remaining years. OCCS requires port facilities to offload and store CO_2, as well as a logistics chain equipped with pipelines to get the CO_2 to factories (to be used as feedstock for synthetic fuels) or permanent storage sites. Investment in this infrastructure, which is currently inadequate, will be a prerequisite for implementation. Currently, only a few ports are capable of handling CO_2. A recent report by the Global Centre for Maritime Decarbonisation estimates that capex of $US33-244 million is required for installing infrastructure to accommodate OCCS depending on the CO_2 offloading method used.[69]

Figure 20:
Alternative shipping fuels and the cost of one tonne of net CO_2e reduction



Sources: International Council on Clean Transportation (ICCT), Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, April 2024.

68. Oil and Gas Climate Initiative, "Is carbon capture on ships feasible?" November 2021.
69. Global Centre for Maritime Decarbonisation, "Concept study to offload onboard captured CO_2" April 2024.

Similar to aviation (to be discussed in our second report), DAC is also a potential solution to offset shipping emissions. Figure 20 shows the cost of reducing one tonne of CO_2 equivalent emissions relative to low sulphur fuel oil (LSFO) for different alternative fuels and carbon capture methods. Biofuel, bio-methanol, and blue ammonia are currently the cheaper options to reduce GHG emissions on a per tonne basis. By 2050, we expect the cost gap between these options to narrow, with DAC becoming an economically viable option.

In addition, there are a few caveats to our analysis that suggest that DAC is a more attractive option than these figures suggest. First of all, our figures are not adjusted for the payload reduction associated with using methanol and ammonia. The mass and volume of methanol is roughly double that of fuel oil, while ammonia is about 180% and 300% of fuel oil's mass and volume, respectively.[70] Ammonia also requires extra space and mass on board for a chilled (or pressurised) storage tank.

H2SHIPS estimates that for an 8,000-12,000 20-foot equivalent unit (TEU) containership, the economic cost associated with lost payload capacity and fuel tanks (relative to a ship with an ICE using marine gasoil) has a range of about $US17-51/nautical mile (nm) if methanol is used and $US24-60/nm if ammonia is used.[71] The Shanghai-Rotterdam route – one of the world's major sea routes – is about 10,600 nm, making the total onboard energy storage cost of using methanol and ammonia would be about $US180,000-540,000 and $US254,000-593,000, respectively. Therefore, for an 11,000 TEU ship that charges $US3,000 per 40-foot equivalent unit (FEU), the cost of using methanol and ammonia is about 1-3% and 2-4% of revenue, respectively. Finally, the 2050 estimate for DAC is based on technology available today. It is therefore possible for DAC to become even cheaper than our estimation as carbon capture technology advances.

In summary, there is an increasing level of decarbonisation commitment within the shipping industry, evident by the IMO's ambitious targets and the increasing number of ships on order that are capable of using alternative fuels. The adoption of alternative fuels and carbon capture to reduce CO_2 and GHG emissions more broadly may increase shipping costs. But shipping accounts for less than 3% of the costs of goods,[72] so the overall cost impact on the end consumer is likely small.[73]

The relatively large number of distinct decarbonisation options and, together with their different infrastructure requirements and the lack of certainty on which option will prevail in the long term, means that it is a challenge to plan for and invest in the necessary infrastructure. We think that in the medium to long term, ammonia and carbon capture (both DAC and OCCS) will likely be the winners, considering their cost trajectory and scalability. The uncertainty associated with using ammonia as a fuel is also likely to diminish significantly in the next few years once IMO finalises the standards and current trials of ammonia-powered ships conclude.

70. MDPI, Energy-Saving and Carbon-Neutral Technologies for Maritime Transport, "A Comparison of Alternative Fuels for Shipping in Terms of Lifecycle Energy and Cost," December 2021.
71. Interreg North-West Europe, H2SHIPS, "System-Based Solutions for H2-Fuelled Water Transport in North-West Europe: Comparative report on alternative fuels for ship propulsion," July 2020.
72. European Central Bank, Economic Bulletin Issue 3, 2021, "What is driving the recent surge in shipping costs?"
73. The Drewry World Container Index composite index, which tracks the freight costs of a 40-foot container via eight major routes, was $US2,719 as of 18 April 2024.

For more information, or to speak to the authors of this issue, Yufei Zhang, Audrey Lee, and Daniel McCormack, please contact your Macquarie Asset Management Relationship Manager.

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Gross domestic product (GDP) is a measure of all goods and services produced by a nation in a year. It is a measure of economic activity.

Inflation is the rate at which the general level of prices for goods and services is rising, and, subsequently, purchasing power is falling. Central banks attempt to stop severe inflation, along with severe deflation, in an attempt to keep the excessive growth of prices to a minimum.

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