Department for Transport

The Role of the RTFO in Domestic Maritime

Deep Dive Consultation

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Executive summary

1 Climate change is the most pressing environmental challenge of our time, and there is overwhelming scientific evidence supporting the need to act now. Doing so is a clear priority for the Government, and therefore, in June 2019 we became the first major global economy to pass a law that requires us to achieve 'net zero' greenhouse gas (GHG) emissions by 2050. Transport has a huge role to play in the economy reaching net zero emissions, and the sheer scale of the challenge requires a step change across all transport mode if we are to reach the Government's ambitious decarbonisation targets.

2 In July 2019, the Government launched the Clean Maritime Plan, our strategy to bring UK maritime to net zero emissions by 2050. This includes a comprehensive set of policy interventions to incentivise the uptake of emission reduction options. As part of that, the Clean Maritime Plan set out the commitment to consult on how the Renewable Transport Fuel Obligations Order (RTFO) could be used to encourage the uptake of low carbon fuels in maritime, taking the availability of sustainable resources and the international character of the sector into consideration. The attached consultation document, published as part of the 2021 consultation on amendments to the RTFO, delivers on this commitment.

3 The Clean Maritime Plan highlighted the importance of low carbon fuels in the decarbonisation of the shipping sector and emphasised that fuel prices remain one of the key barriers to their commercial deployment. Fuel prices do not currently reflect the environmental costs (e.g. climate change) that result from the use of fuels, reducing the perceived cost-effectiveness of alternative low carbon fuels and leading to under-investment in related technologies and systems. Support is therefore needed.

4 Government-commissioned research suggests that the RTFO may represent an opportunity to start strengthening the incentives for fuel suppliers to provide greater quantities of renewable fuel to the maritime sector. This consultation document builds on these findings, exploring the potential role of biofuels and of renewable fuels of non-biological origin (RFNBOs) in shipping, and offering possible policy solutions.

5 Biofuels can have a role in reducing maritime emissions: evidence suggests that these fuels produce fewer greenhouse gas (GHG) emissions compared to fossil marine bunker fuels, and are biodegradable, reducing risks around accidental spills. However, there is uncertainty regarding the future availability of biomass. The latest scenarios developed by the Committee on Climate Change (CCC) indicate that

limited biomass resources might be used more effectively in those sectors of the economy where higher marginal GHG savings can be achieved, or those with fewer decarbonisation options compared to shipping. Therefore, this consultation document sets out the Government's current view that the RTFO should not be used to stimulate the uptake of biofuels in shipping.

6 **At the same time, this consultation document includes proposals to support RFNBOs used as a maritime fuel under the RTFO.** Synthetic fuels, including hydrogen, ammonia and methanol, are likely to play a crucial role in the decarbonisation of the maritime sector. Synthetic fuels do not have the same sustainability implications as biofuels and, if produced through certain processes, can be classed as RFNBOs which are already eligible for reward under the RTFO if used in the road, non-road mobile machinery (NRMM) and aviation sectors. Additionally, because of the UK's inherent competitive advantage in these technologies, supporting investment in hydrogen and ammonia supply chains might offer substantial potential economic benefits to our economy, securing a portion of the emerging clean maritime market.

7 Whilst ammonia presents specific challenges regarding air pollutants, storage and handling, it is essential that all new fuels are proven to be safe prior to wide-scale deployment. RTFO support could facilitate the testing of these fuels at commercial level. In turn, this will allow the regulator to investigate safety standards for the use of these fuels at scale, and to monitor their impact on air quality and the wider environment. The Government will review the level of RTFO support provided to RFNBOs including ammonia based on the evidence gathered during the implementation period.

8 The measures outlined in this consultation document will help stimulate the emergent zero emission shipping industry in the UK, offering UK businesses the certainty they need to invest in alternative fuels and the related technology. These policy proposals will enable innovation in clean maritime, positioning the UK shipping industry to take advantage of the opportunities arising from the transition to zero emissions.

Introduction

The scale of the challenge

Shipping is a comparatively carbon-efficient mode of transport[1]. However, it also represents a substantial source of GHG emissions. In 2018, UK domestic shipping accounted for 5.9 MtCO_2e, representing 5% of the UK domestic transport emissions (124 MtCO_2e)[2]. Over this period, the carbon impact of UK domestic shipping was higher than that of the bus and rail sectors combined, as these were responsible for 3% and 1% of the UK domestic transport emissions. In the same year, based on refuelling at UK ports, UK international shipping accounted for 7.8 MtCO_2e[3], roughly one fifth of the emissions generated in the same year from UK international aviation (36 MtCO_2e)[4],[5].

As emissions from other transport sectors begin to decrease because of significant mitigating intervention, the contribution of maritime emissions is expected to increase. Under a business as usual scenario, research commissioned by the Government estimates that the total GHG emissions from UK domestic and international shipping could rise by around 80% between 2016 and 20506. In addition, if no further action is taken, estimates from the IMO suggest that the CO2 emissions from international shipping could grow by between 50% and 250% by 2050[7], and a study for the European Parliament

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[1] EMSA (2019) Greenhouse Gas: http://www.emsa.europa.eu/main/air-pollution/greenhouse-gases.html

[2] https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2018

[3] It is important to note that whether emissions from refuelling at UK ports can be used as an accurate estimate of UK international shipping emissions will depend on what assumptions are being made about how to allocate international shipping emissions to different countries.

[4] https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2018

[5] These figures only refer to tank-to-wheel and tank-to-propeller carbon emissions and do not include upstream emissions produced throughout the production and the transportation of fuels as well as the production of the related powertrain systems.

[6] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

[7] http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf

suggests that international shipping could account for 17% of global CO2 emissions by 2050[8].

Concerning air quality, in 2017 domestic shipping alone accounted for 12% of the UK's total domestic NO_X emissions, 2% of primary $PM_{2.5}$ and 8% of SO_X.[9] Recent analysis carried out by Imperial College estimated that, in 2016, NO_X emissions from UK international shipping and shipping in transit were three and six times higher, respectively, than for UK domestic shipping, and so have a more significant impact on air quality in the UK[10].

Government intervention so far

The Government's action to reduce emissions from UK domestic and international shipping builds on an ambitious policy framework to tackle climate change and air pollution.

In June 2019, the UK became the first major economy to legislate for a net zero domestic greenhouse gas emission target by 2050[11]. The 2050 net zero target was set in legislation through an amendment to the Climate Change Act 2008. This target includes emissions from domestic shipping, making the case for supporting the transition to clean maritime even more urgent[12].

Internationally, the UK continues to be at the forefront of the efforts to reduce carbon emissions. In April 2018, the UK played a leading part in the agreement of the Initial IMO Strategy for the Reduction of GHGs from Ships. The Strategy includes a commitment to reduce GHGs by at least 50% (compared to a 2008 baseline) by 2050, and to phasing out GHG emissions from shipping as soon as possible in this century.

The UK has consistently supported international efforts to limit pollutant emissions from shipping, as air pollution is regulated by the IMO through the International Convention for the Prevention of Pollution from Ships (MARPOL). For instance, the UK backed the establishment of the North Sea Emissions Control Area (ECA) which covers SO_X emissions and, from 1 January 2021, NO_X emissions. ECAs also have been established in coastal waters in Europe and North America. Furthermore, the UK championed the agreement at the IMO for a 0.5% sulphur limit for global shipping outside ECAs, and

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8 http://www.europarl.europa.eu/RegData/etudes/STUD/2015/569964/IPOL_STU(2015)569964_EN.pdf

9 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/850280/env0301.ods

10 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815664/clean-maritime-plan.pdf

11 https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law

12 Whilst international shipping emissions are not formally included in the net-zero target at present, the Government is still required to take these emissions into account when setting carbon budgets under the Climate Change Act.

played a significant role in both the development of the regime, and the supporting guidance for industry before it came into effect on 1 January 2020[13].

At domestic level, the Government published a Clean Air Strategy in January 2019. This strategy set out an ambitious and holistic approach to improving air quality and reducing emissions of air pollutants across all sectors, including maritime, which will halve the impacts of air pollution on human health and the environment.

The way forward

In January 2019, the Government published the Maritime 2050 Strategy which set out its vision for clean shipping in the UK. This vision states that, *'in 2050, zero emission ships are commonplace globally. The UK has taken a proactive role in driving the transition to zero emission shipping in UK waters… as a result the UK will successfully capture a significant share of the economic, environmental and health benefits associated with this transition'*[14].

To deliver this vision, the Government launched the Clean Maritime Plan in July 2019, making the UK one of the first countries to publish a strategy on domestic action to reduce shipping emissions, following the agreement of the Initial IMO Strategy. The Clean Maritime Plan identifies ways to tackle air pollutants and GHG emissions while securing clean growth opportunities for the UK.

The Clean Maritime Plan represents one of the Government's most ambitious strategies to facilitate the transition to zero emission transport. Its implementation is a key component of the Government efforts to meet the target of net zero emissions by 2050 across the economy, and deliver our Industrial Strategy, placing the UK at the forefront of the development and commercialisation of clean maritime technologies[15]. The plan touches on all elements of maritime operations, including cargo and passenger shipping, ports as well as more specialist sectors such as fishing and renewable energy installation.

The Clean Maritime Demonstration Competition, announced as part of the Prime Ministers Ten Point Plan on 1 November 2020, represents the next step in this journey. The CMDC is a £20m competition that will seek to accelerate the demonstration and deployment of low and zero emissions technology in the maritime sector through a group of demonstration projects. The CMDC is planned for launch in Spring 2021.

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[13] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815664/clean-maritime-plan.pdf

[14] Maritime 2050, DfT, 2019 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/773178/maritime-2050.pdf

[15] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815664/clean-maritime-plan.pdf

The Renewable Transport Fuel Obligations Order and the maritime sector

Government-commissioned research supporting the publication of the Clean Maritime Plan identified a wide range of options that can reduce emissions in the shipping sector. These include technologies and operational and behavioural changes that can increase energy efficiency, as well as technologies specific to the capture and treatment of exhaust emissions[16].

This research concluded that a shift to low or zero emission fuels in the shipping sector will be essential for emission reductions to be realised at the scale required to achieve the Government's ambitions for zero emission shipping[17].

One of the current barriers to the commercial deployment of emission reduction options, including alternative fuels, is that fuel prices do not fully reflect the environmental costs (e.g. climate change and pollutant impacts) that result from their use. This reduces the perceived cost-effectiveness of alternative fuels, leading to under-investment in related technologies and systems[18].

There is also a challenge that 'marine fuel' is not one market – vessels range in size from small recreational craft through to internationally trading cargo vessels and includes specialist sectors such as fishing and windfarm installation that are covered by the same decarbonisation commitments, but may have specialist technical and operational challenges that favour one decarbonisation solution over another.

Therefore, as part of the Clean Maritime Plan, we committed to consulting on whether and how the RTFO could be used to encourage the uptake of alternative fuels in maritime, taking the availability of sustainable resources, competing uses and the international character of the maritime sector into consideration. This supports the Government's commitment to continue exploring the case for economic instruments to encourage the transition to zero emission shipping.

In its response to the 2017 consultation on amendments to the RTFO, the Government decided not to bring maritime fuels into scope of this policy but committed to keep this decision under review[19]. This consultation is the opportunity to explore what role the RTFO

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16 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816015/maritime-emission-reduction-options.pdf

17 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

18 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815671/identification-market-failures-other-barriers-of-commercial-deployment-of-emission-reduction-options.pdf

19 Fourteen respondents to the 2017 consultation on amendments to the RTFO proposed bringing maritime fuels in scope. Following consideration, the Government decided not to because at that time there was no international agreement yet on how the shipping sector should decarbonise. Also, the Government considered that there may be better alternatives to decarbonise shipping, adding that there is finite resource of biofuel feedstocks and we need to make sure that it is allocated effectively. Further information is available here:

could play in supporting the transition to a clean maritime sector, while enabling a cost-effective decarbonisation of the wider energy system. Inland waterway vessels and recreational crafts that do not normally operate at sea are already in scope of the RTFO[20].

The key policy positions set out in this document are summarised below:

- Chapter 1 – Whilst biofuels can have a role in reducing maritime emissions, it is the Government's current view that the RTFO should not be used to stimulate the uptake of biofuels in maritime transport. This because biomass availability is limited, and these finite resources might be more effectively used in those sectors of the economy where greater marginal GHG savings can be achieved, or in those sectors that have fewer decarbonisation options compared to maritime.

- Chapter 2 – Synthetic fuels do not have the same sustainability implications of biofuels. Research commissioned by the Government[21] suggests that synthetic fuels, including hydrogen, ammonia and methanol, might have a strategic role in decarbonising the maritime fuel mix. If produced using eligible processes, synthetic fuels can be classified as RFNBOs, which are already supported under the RTFO for use in the road, NRMM and aviation sectors. The Government is of the view that the RTFO could be used to encourage the uptake of RFNBOs within the maritime sector as well.

This document sets out the rationale for the above policy positions, provides policy proposals and invites the views of stakeholders.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/644843/renewable-transport-fuel-obligations-order-government-response-to-consultations-on-amendments.pdf

20 https://www.legislation.gov.uk/ukdsi/2018/9780111164242

21 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

1. The role of biofuels in shipping

Summary

Whilst biofuels can have a role in reducing maritime emissions, it is the Government's current view that the RTFO should not be used to stimulate the uptake of biofuels in maritime transport. This because biomass availability is limited, and these finite resources might be more effectively used in those sectors of the economy where greater marginal GHG savings can be achieved, or in those sectors that have fewer decarbonisation options compared to maritime.

Today's shipping fuel mix

The fuel used for shipping has historically been some of the most polluting across all transport modes[22], characterised by low quality and high sulphur content, and at times has been marketed at a price lower than the price of crude oil[23]. This is changing with the introduction since 1997 of international controls on marine fuel.

Fossil fuels used in shipping are produced from crude oil at refineries or based on natural gas extraction (Liquefied Natural Gas, LNG), and can be differentiated between residual heavy fuels and the higher quality distillate fuels[24]. An overview of current marine fuels is summarised below[25]:

- Heavy fuel oil (HFO) is part of the tar-like residue left over from the production of lighter hydrocarbon products. This has accounted for around 75% of the fuel used by all marine vessel types globally: a smaller proportion is used in UK domestic shipping[26]. As a residual fuel, HFO is highly polluting but relatively inexpensive (around 65% of the cost of distillate fuels).

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[22] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815664/clean-maritime-plan.pdf

[23] Bengtsson, Selma, Erik Fridell, and Karin Andersson. "Environmental assessment of two pathways towards the use of biofuels in shipping." *Energy policy* 44 (2012): 451-463.

[24] http://www.emsa.europa.eu/fc-default-view/download/1626/1376/23.html

[25] Kass, Michael D., et al. *Understanding the Opportunities of Biofuels for Marine Shipping*. No. ORNL/TM-2018/1080. Oak Ridge National Lab.(ORNL), Oak Ridge, TN (United States), 2018.

[26] See Table 22 and Table 23 in https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1712140936_ED61406_NAEI_shipping_report_12Dec2017.pdf

- Marine gasoil (MGO) is composed of lighter distillates and comparable to diesel fuel in chemistry and cost. MGO is used predominantly in coastal shipping.
- Marine diesel oil (MDO) is a blend of HFO and MGO. Since MDO is composed predominantly by the latter, the costs are comparable.
- LNG has been suggested by some as a way to meet more stringent fuel quality regulations, and it currently represents around 1% of global marine fuel consumption, largely through its use on LNG carriers. LNG presents significant challenges for retrofit but is being actively considered by some shipowners for newbuild vessels.
- Very low sulphur fuel oil (VLSFO) which is a relatively new product entering the market to comply with more stringent global sulphur standards. Often a blend that can include both residual and distillate elements.

Fuel consumption is a critical factor driving commercial decisions in shipping, as currently up to 50% of the operational costs in the sector are related to fuels[27]. Fuel efficiency measures to reduce fuel consumption and, indirectly, emissions, were adopted by the IMO in July 2011 in the form of the Energy Efficiency Design Index and the Ship Energy Efficiency Management Plan[28].

The global fuel mix has also been influenced by the introduction of regulations to limit sulphur use. In 2008, Member States at the IMO agreed to a 0.5% sulphur limit for global shipping outside ECAs from 2020 (subject to a review on fuel availability). This decision was confirmed in 2016 at the IMO's Marine Environment Protection Committee (MEPC). IMO regulations on reducing SO_X emissions cover all vessel types under the scope of the Convention. In UK law this translates to all vessels operating in the 'marine environment'[29] but does not cover purely inland craft or those operating on some sheltered stretches of deeper water. Only those previously operating on high sulphur fuel oil have needed to implement fuelling or hardware changes, by either switching to low-sulphur fuels or implementing scrubber technologies to mitigate sulphur emissions.

Fossil fuels that can meet increasingly stringent international regulations have been progressively made available in the market. VLSFO, mentioned above, is an alternative fuel with the sulphur reduced, often through blending, in the production process, which is used more since the outset of the IMO regulations on SO_X emissions. Low-sulphur MGO (LSMGO) and Ultra low-sulphur fuel oil (ULSFO) are also available bunker fuels that are used to comply with the IMO regulations[30].

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[27] http://www.emsa.europa.eu/fc-default-view/download/1626/1376/23.html

[28] Bengtsson, Selma, Erik Fridell, and Karin Andersson. "Environmental assessment of two pathways towards the use of biofuels in shipping." *Energy policy* 44 (2012): 451-463.

[29] For full details see MS Notice 1776 - Categorisation of Waters, vessels operating in category A and B, and sheltered category C are excluded from the UK implementation.

[30] https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5c26700dc&appId=PPGMS

The UK maritime fuel market

UK shipping fuel suppliers are a mixture of bunker fuel suppliers focused on the international market, including both international and UK based players, as well as local suppliers who may provide fuel in a small geographic area. For smaller craft, many bunkering facilities are fixed in specific locations, while international shipping fuel supply is often from bunker vessels that operate on a regional or national basis. Small craft in the UK tend to use a lighter fuel that is more comparable to road fuels, while larger craft use marine specific fuels, including the blended products developed for compliance with the IMO requirements.

Biofuel alternatives in maritime

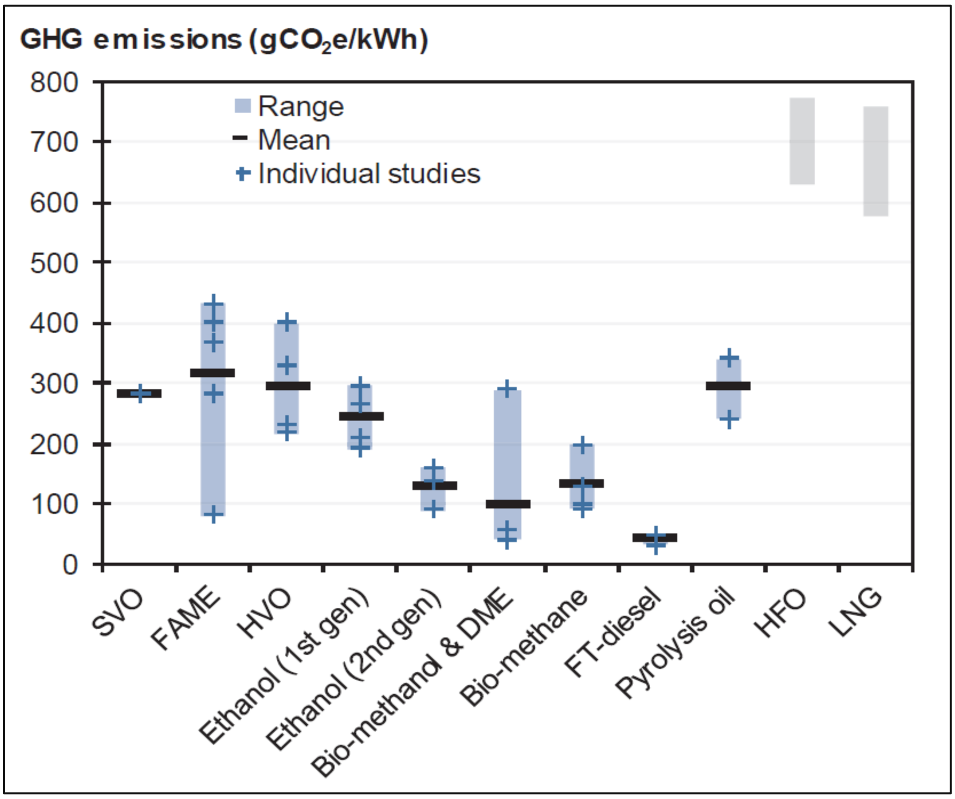
Biofuels are derived from biomass. The latter can be defined as material of recent biological origin, derived from plant or animal matter such as wood, agricultural crops or wastes, and the biological component of municipal wastes. These biomass feedstocks can be processed through direct combustion, anaerobic digestion, gasification and other means to produce direct heat or biogas and liquid biofuels, such as bioethanol and biodiesel.

Biofuels have the potential to achieve GHG emission reductions in shipping[31], and can have a role in meeting stringent IMO sulphur regulations. Additionally, biofuels are biodegradable, which is an advantage over fossil fuels with respect to accidental spills[32].

In general, advanced biofuels have lower GHG emissions than conventional biofuels. This is illustrated in Figure 1 below[33], which shows a broad range of emission estimates both across and within the biofuel categories. To note, the lowest values for Fatty Acid Methyl Esters (FAME) and Hydrotreated Vegetable Oil (HVO) are using waste oils.

[31] Bouman, Evert A., et al. "State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping–a review." Transportation Research Part D: Transport and Environment 52 (2017): 408-421.
[32] Balcombe, Paul, et al. "How to decarbonise international shipping: Options for fuels, technologies and policies." *Energy conversion and management* 182 (2019): 72-88.
[33] https://www.sciencedirect.com/science/article/pii/S0196890418314250

Figure 1. Overview of GHG emissions for selected biofuels and fossil fuels



Source: Balcombe, Paul, et al. "How to decarbonise international shipping: Options for fuels, technologies and policies."

Energy conversion and management 182 (2019): 72-88.

Biofuels, particularly advanced biofuels with a lower level of technology readiness, are generally more expensive than their fossil fuel counterparts in shipping. This even though progress in commercialising the technologies and a focus on low-cost feedstocks, e.g. various organic wastes and residues, has the potential to close the gap with conventional biofuels[34].

Commercial obstacles to the adoption of biofuels by individual ship operators include their higher production and feedstock costs, the current lack of approved marine-grade biofuel specifications, the presence of blending limitations with fossil fuels that are used in shipping, and the current incompatibility of some biofuels with some existing marine powertrain systems.

Overall, biofuels have a lower energy content on a volumetric basis compared to marine fuels. This means that, on average, a higher quantity of biofuels is needed to meet the same final energy content as conventional fossil marine fuels, and therefore greater

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[34] https://platformduurzamebiobrandstoffen.nl/infotheek-item/masterplan-for-co2-reduction-in-dutch-shipping-sector-biofuels-for-shipping/

onboard storage space is required. Finally, whilst some biofuels can represent a drop-in solution, others require extensive engine modifications[35].

Biofuels that could potentially be used in marine applications are listed in Table 1 in pages 16 and 17. Based on published information, this table is intended to provide an illustrative overview of biofuels' suitability to the shipping sector[36]. The level of GHG savings set out in this table for each biofuel is calculated from the fossil baseline of 83.8 gCO_2eq/MJ.

[35] http://www.emsa.europa.eu/fc-default-view/download/1626/1376/23.html

[36] This table is based on information from: https://platformduurzamebiobrandstoffen.nl/wp-content/uploads/2018/12/2018_E4tech_Master-plan-for-CO2-reduction-in-the-Dutch-shipping-sector-Biofuels-for-shipping_Final-Report.pdf; http://task39.sites.olt.ubc.ca/files/2013/05/Marine-biofuel-report-final-Oct-2017.pdf; http://www.emsa.europa.eu/fc-default-view/download/1626/1376/23.html; https://ec.europa.eu/research/participants/documents/downloadPublic/UnExNEdGTGdUbGxNUzdtbXhIQIhmSENjWjdybHJIbm10dzl3anJjL1REU3g4bjc5UjBUczVnPT0=/attachment/VFEyQTQ4M3ptUWYxN3ZpMURrMFhjem1pYVppcjVOOG8=;
http://task39.sites.olt.ubc.ca/files/2013/05/Marine-biofuel-report-final-Oct-2017.pdf

Table 1 Biofuels for use in shipping

Fuel	Specification	Well-to-tank emissions
Hydrotreated vegetable oil (HVO)	Compatible with new and existing marine diesel engines that run on HFO, MDO, or MGO. The fuel matches the characteristics of incumbent fossil fuels used in ships and is compliant with diesel fuel specifications and can hence be used in all existing infrastructure. Its production is commercial, and, because of its drop-in characteristic, there is likely to be strong competition from the road and aviation sectors. This could limit the fuel available to the shipping sector, especially as the price differential with road transport and aviation fuel is lower.	Well-to-tank GHG emission reductions of HVO can be approx. 88% when waste oils and fats are used. HVO has also a very low sulphur content (0.001% by weight).
Straight vegetable oil (SVO)	SVO is compatible with HFO in low speed engines used in deep-sea shipping, but modifications might be required for four stroke diesel engines in short-sea or inland shipping. The viscosity of the fuel requires pre-heating to allow it to flow through the engine. This can be achieved by using a dual-fuel system, utilising the alternative (less viscous) fuel to start and warm the engine and fuel before switching to SVO. The higher boiling point of SVO as well as viscosity might reduce the lifespan of engines, and there are concerns around its compatibility with diesel engines due to acidity.	Typical well-to-tank GHG emissions of rapeseed SVO are approximately 50%. Data on other feedstocks is not provided, but GHG emission savings from other feedstocks will be comparable to HVO or FAME, but slightly higher for SVO due to the more limited processing.
Fatty acid methyl ester (FAME, or Biodiesel)	Commonly known as biodiesel because of its blending (up to 7%) in EN590 which is used in road transport, it is produced from fats and oil at commercial level. FAME can be blended into diesel, generally at low levels. As both the boiling point and viscosity are lower than SVO it is more suitable for use in diesel engines (both in inland and short-sea shipping). FAME might replace MDO/MGO in low to medium speed engines used in tugboats, small carriers or cargo ships. However, due to FAME's ability to dissolve some non-metallic materials, susceptible parts in engines and the fuel supply system might have to be changed prior to its use.	Well-to-tank GHG reductions can be as high as 88% when waste oils and fats are used as feedstock.
Bio-Dimethyl Ether (DME)	DME has a cetane number comparable to diesel fuel which makes it more suitable for diesel engines and could be used to replace MDO/MGO in all sizes of carrier or cargo ships. As it is not available globally in the same way as methanol or ethanol, the infrastructure and distribution network would need to be built up first. As DME is gaseous in ambient conditions, it requires 5 bar pressure to remain in liquid state which makes storage, bunkering and transport more difficult. The lower viscosity and energy density are further disadvantages in the use of DME as a shipping fuel.	Well-to-tank GHG emissions reductions available from DME range from approximately 92-94% depending on the biomass feedstock and internal energy consumption. GHG savings above 100% are possible with CCS.
Bio-sourced Fischer-Tropsch Diesel (FT-Diesel)	Ft-Diesel could be used as a drop-in fuel in all three shipping sectors (inland, short-sea and deep-sea), and would be compatible with existing infrastructure both on the vessel as well as the port side. Whilst FT-diesel can be produced from renewable electricity and CO_2 producing a renewable fuel of non-biological origin (see chapter 3), its production from bio-feedstock is less developed, at pilot/early demonstration stage.	Well-to-tank GHG emission reduction potential for wood FT-Diesel is around 93-95%, going beyond 100% if CCS is used.
Bio-methane	Bio-methane could be used in shipping as bio-LNG and bio-CNG. Bio-LNG is chemically identical to LNG, hence the requirements and challenges for deployment, new infrastructure and storage remain the same. CNG is only at demonstration stage, and the increased storage space needed means that it might only be applicable to short-sea shipping and inland shipping.	The well-to-tank GHG emission savings from bio-LNG are in the range of 71-82%, depending on the electricity source used for liquefaction and methane leakage rates. Bio-CNG savings are

Fuel	Specification	Well-to-tank emissions
		expected to be similar to those of bio-LNG.
Bio-ethanol	Bio-ethanol is commonly used in many countries in road transport. According to some, bio-ethanol could potentially be used in shipping, in high speed main or auxiliary engines, in short distance ships, ethanol tankers, or for electricity production on board of ships like cruise and passenger ships. Ethanol already trialled in some marine applications. Demonstration might be needed to test ethanol in marine engines. To enable its use, engines, fuel injection, supply and storage systems require adaptations or the installation of new dual fuel engines.	The well-to-tank GHG reduction potential for conventional ethanol is estimated at around 71% when using sugarcane, 32-69% for wheat, 56% for corn and 61% for sugar beet. The use of CCS/CCU could produce significantly higher savings.
Bio-methanol	Bio-methanol is also used as a transport fuel, but in limited volumes compared to ethanol. It could be used in inland and short-sea shipping, and its 50% lower energy density compared to the fossil incumbent limits the vessels range. It is produced through fermentation of food-crop sugars and starches. Methanol already deployed on some vessels and IMO currently working on use of methanol as a marine fuel. Bio-methanol from biomethane is commercially available, but in limited volumes.	Well-to-tank GHG emissions for renewable methanol could lead to GHG emissions savings of approximately 90-95%. GHG savings above 100% are theoretically possible with CCS/CCU.
Pyrolysis oil	Pyrolysis oil could be used in low speed engines, in all sizes of carriers or cargo ships. It can be upgraded and distilled to produce diesel, jet fuel and gasoline. Crude pyrolysis oil would need adaptation in the engine and the entire duel system. When upgraded it is compatible with the EN590 standard for inland shipping.	Well-to-tank GHG emissions savings of crude pyrolysis oil and upgraded pyrolysis oil are like those of FT-Diesel.

Aside from the commercial and technical limitations to the use of biofuels in shipping that have been highlighted in the previous pages, there are significant uncertainties around the future availability of these fuels. As set out in the following section, current evidence suggests that the potential availability of sustainable biofuels is estimated to be low when considered against the global shipping energy demands, and there are other sectors that might compete with shipping to access this constrained supply.

Biomass supply and demand

It is widely recognised that biomass has an important role to play in helping the UK to meet its low carbon objectives by 2050. However, as with other alternative energy sources, the complex environmental impacts of producing and using biomass including on air quality, biodiversity and water resources must be considered. It is essential that the GHG mitigation potential of biomass is included as part of a system of sustainable land use as there are risks and uncertainties including: the extent that biomass can contribute to carbon reduction; the availability and price of sufficient sustainably sourced biomass (domestic and import); the multifaceted relationship between bioenergy production and other land uses, including food production or construction timber.

As set out in the UK Bioenergy Strategy[37], published in 2012, the Government has a responsibility to ensure that its policies only support biomass and bioenergy in the right

37 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48337/5142-bioenergy-strategy-.pdf

circumstances, recognising that Government policies are only one of the many factors which affect how biomass is deployed in the energy system[38].

The Strategy is based on a statement of 4 principles acting as a framework for future Government policy on biomass and bioenergy. These principles are outlined below. A full explanation of why they are necessary and their application in policy development, including the analysis underpinning them, is publicly available on GOV.UK[39].

- **Principle 1:** Policies that support bioenergy should deliver genuine carbon reductions that help meet UK carbon emissions objectives to 2050 and beyond. This assessment should look – to the best degree possible – at carbon impacts for the whole system, including indirect impacts and any changes to carbon stores.
- **Principle 2:** Support for bioenergy should make a cost-effective contribution to UK carbon emission objectives, in the context of overall energy goals. Bioenergy should be supported when it offers equivalent or lower marginal life-cycle carbon emissions compared to alternative investments which also meet the requirements of the policies.
- **Principle 3:** Support for bioenergy should aim to maximise the overall benefits and minimise costs (quantifiable and non-quantifiable) across the economy. Policy makers should consider the impacts and unintended consequences of policy interventions on the wider energy system and economy, including non-energy industries.
- **Principle 4:** At regular intervals and when policies promote significant additional demand for bioenergy in the UK, beyond that envisaged by current use, policy makers should assess and respond to the impacts of this increased deployment. This assessment should include analysis of whether UK bioenergy demand is likely to significantly hinder the achievement of other objectives, such as maintaining food security, halting bio-diversity loss, achieving wider environmental outcomes or global development and poverty reduction.

These principles underpin the Government approach to supporting biomass and bioenergy deployment across the energy system, recognising uncertainties in the future availability of sustainable biomass against the competing demand from present and future economic sectors with fewer decarbonisation options. Current estimates of the future availability of biomass (international and domestic) are presented in the following sections.

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[38] Difference between ‘biomass’ and ‘bioenergy’: biomass represents the source of bioenergy, while the latter is the term used to refer to energy, heat or electricity that is created by burning biomass.

[39] https://www.gov.uk/government/publications/uk-bioenergy-strategy

Estimates concerning the future availability of sustainable biomass

Global availability

The Committee on Climate Change (CCC)[40], the International Energy Agency (IEA)[41] and the Energy Transition Commission (ETC)[42] have separately produced projections concerning the future global availability of sustainable biomass, estimated to range anywhere between 3.9 thousand to 66.7 thousand TWh per year by 2050[43]. Whilst different scenarios have been elaborated, there is broad consensus that between 13.9 thousand and 27.8 thousand TWh of sustainable biomass could become available per year by the middle of the century[44].

A more optimistic assessment concerning international future availability has been provided by the IEA, which set out that a future supply of up to 83.3 thousand TWh by 2060 may still be considered reasonable, although higher estimates assume a substantial amount of crop-based biofuel, increasing risks to sustainability due to direct and indirect impacts on land use[45].

Crucially, the availability of energy crops might indeed decrease over time, depending on developments in demographics and resource management, which may affect land availability for sustainable biofuel production. For instance, a recent World Wide Fund for Nature (WWF) study estimates that the sub-Saharan production potential from crops might decrease by about 40% between 2010 and 2050[46] due to predicted climate change effects, as well as future demographic changes and improved diets, which means that land will be converted for food production. This study concluded that land-based production of biofuels should be prioritised for aviation. Crucially, aviation is recognised as one of the sectors with fewer decarbonisation options compared to other sectors, such as shipping, by both the CCC and the ETC[47].

UK availability

The CCC suggests that the future UK availability of biomass is limited. According to the CCC report 'Biomass in a Low Carbon Economy', UK biomass production combined with sustainable imports could meet between 5% and 15% of total UK energy demand in 2050, compared to around 7% today[48]. The future emergence of sectors like biomass-based

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40 https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy/
41 https://www.ieabioenergy.com/publications/technology-roadmap-delivering-sustainable-bioenergy/
42 http://www.energy-transitions.org/sites/default/files/ETC_MissionPossible_FullReport.pdf
43 https://www.ssi2040.org/wp-content/uploads/2019/12/SSI-The-Role-of-Sustainable-Biofuels-in-the-Decarbonisation-of-Shipping-Full-report.pdf
44 SSI report
45 https://www.ieabioenergy.com/publications/technology-roadmap-delivering-sustainable-bioenergy/
46 http://awsassets.wwf.org.za/downloads/sustainable_biofuel_potential_ssaf_summaryreport_finalized_v7_2_digital_pages.pdf
47 http://www.energy-transitions.org/sites/default/files/ETC_MissionPossible_FullReport.pdf
48 https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy/

plastic and bio-based chemicals could add further claims on an already limited supply of bioenergy.

Because of limitations in biomass supply, the CCC argues that its deployment across the economy should only be supported in those end-uses where this can produce the greatest overall levels of GHG savings[49].

Today, the greatest GHG savings from biomass are when wood is used in construction, storing carbon and displacing high embodied carbon materials. However, the CCC estimates that this can only deliver GHG savings of up to 3 $MtCO_2$ per year by 2050.

In the long term, the CCC states that biomass should be used to sequester carbon, particularly where this also displaces other emissions. After wood in construction, this hierarchy prioritises bioenergy with carbon capture and storage (BECCS) for power industrial heat or hydrogen applications. To achieve similar GHG savings, biofuels need to be produced in a facility with CCS, and to displace irreducible fossil hydrocarbon use (e.g. aviation fuels) rather than where other low-carbon alternatives are available (e.g. cars, HGVs, ships). The CCC estimates that by 2050, between 20 and 65 $MtCO_2e$ per year could be sequestered through BECCS in the UK, equivalent to up to around 15% of current CO_2 emissions[50].

Should opportunities to sequester biogenic carbon, in construction materials or via BECCS applications, be exhausted the CCC argues that coal should then be displaced, before unabated biomass is deployed in sectors where there are no other viable decarbonisation options, such as aviation Ideally this should form part of a transition to use of BECCS later on. If developed, some biochemical/plastics routes may also be at this level of the hierarchy, displacing high-carbon fossil fuels.

A quantitative assessment of the most effective deployment of biomass across the economy is provided by CCC modelling for their Net Zero ‘Further Ambition’ scenario. This provides a biomass allocation in 2050, based on 235 TWh of primary bioenergy and a total energy demand of 1,867 TWh. CCC modelling allocates 74% of the available primary bioenergy to BECCS, with the remaining biomass allocated to aviation (14%), off-gas-grid residential buildings (6%) and industry (6%)[51].

In their advice to the Secretary of State for Transport concerning the approach to net zero in aviation and shipping, the CCC set out that biofuels are technically feasible in shipping but are not likely to be a priority or cost-effective from a whole-economy perspective. This opinion was given considering the competing uses for this biomass resource, and the potential of zero-carbon shipping options such as hydrogen and ammonia[52].

Whilst the CCC affirms that the use of biofuels in shipping is unlikely to represent the best use of finite sustainable biomass resources in the long-term[53], it recognised that biofuels might have some limited ‘transitional role’ in the shipping sector, because of the technical

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49 https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy
50 https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy
51 CCC (2019) Net Zero ’Further Ambition’ scenario data
52 https://www.theccc.org.uk/publication/letter-international-aviation-and-shipping/
53 https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/

challenges posed by high payloads and long distances to other immediately available low carbon bunkering options[54].

Some have argued that a share of the current supply of sustainable bioenergy might be used in shipping until demand is scaled up in those sectors of the economy where greater marginal GHG savings can be achieved, or in those sectors that have fewer decarbonisation options compared to shipping (i.e. aviation). There is however considerable uncertainty on the duration of this supply window[55]. Also, in the short term the available supply of biofuels could be more effectively deployed in the road sector, where the necessary refuelling infrastructure is in place across the network and biofuels are already deployed at scale.

Conclusions

Whilst biofuels might have a limited near-term role in reducing shipping emissions, given some biofuel options can be deployed in-sector now, available evidence suggests that incentivising their uptake in maritime may result in unintended negative consequences for the overall decarbonisation of the energy system.

Therefore, the Government does not consider that including biofuels for marine transport in scope of the RTFO represents the most effective way to decarbonise shipping in the context of promoting an effective transition to zero emissions by 2050 across the economy. This aligns with the Government strategic approach to supporting the effective deployment of biomass across the energy system and takes into consideration current estimates concerning its future availability.

Q 1 Do you agree with the Governments current position not to support biofuels for use in maritime transport under the RTFO and instead promote the use of bioenergy in other sectors of the economy that have fewer decarbonisation options compared to maritime?

Q 2 Do you consider that there could be biofuel options that would be suitable for use in maritime transport under the RTFO, including sub-sectors like fishing, that address concerns about feedstock availability? When replying please provide any additional evidence you feel is useful in explaining your response.

The present consultation is focused on the issue of whether the RTFO could be used to encourage the uptake of low carbon fuels in maritime. Research commissioned to support the publication of the Clean Maritime Plan assessed the potential role of the RTFO in the shipping sector, reviewing potential options for implementation. This research showed that including the shipping sector in scope of the RTFO might offer some advantages because the policy framework is already in place. It also highlighted potential implications for maritime fuel suppliers and the RTFO Administrator, as well as for UK road and NRMM consumers, who currently pay for the implementation of the RTFO via an increase in fuel

[54] https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy/
[55] https://www.ssi2040.org/news/ssi-report-on-the-role-of-sustainable-biofuels-in-shippings-decarbonisation/

pump prices[56]. Currently, such increase has been offset by improvements in vehicle efficiency in recent years, which have been supported by Government regulation[57].

In the next chapter we will explore the Government proposal to include renewable fuels of non-biological origin used in shipping in scope of the RTFO. As estimated in the accompanying cost-benefit analysis, we do not expect any additional costs to motorists as RTFO target levels will remain unchanged. At the same time, stimulating hydrogen supply in shipping has the potential to increase the scale of clean hydrogen production which, in turn, would lower the cost of this fuel in the road sector, where it is already being used commercially. This is further explored in the next chapter.

56 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816020/potential-role-targets-economic-instruments.pdf

57 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/572976/rtfo-consultation-cost-benefit-analysis.PDF

2. Support for renewable fuels of non-biological origin used in shipping

Summary

Synthetic fuels do not have the same supply constraints that biofuels have. Research commissioned by the Government[58] suggests that synthetic fuels including hydrogen, ammonia and methanol might have a strategic role in decarbonising the maritime fuel mix. If produced using eligible processes, synthetic fuels can be classified as renewable fuels of non-biological origin (RFNBOs), which are already supported under the RTFO for use in the road, NRMM and aviation sectors. The Government is of the view that the RTFO could be used to encourage the uptake of RFNBOs within the maritime sector as well.

Alternatives to biofuels

The range of alternative fuels that might be considered for deployment in shipping is not limited to biofuels. As set out in Government-commissioned research, alternative propulsion options that could be used in the maritime sector include electrification and synthetic fuels, such as hydrogen, ammonia and methanol[59]. If generated via renewable processes, the latter might fall under the category of RFNBOs.

This chapter explores the contribution that RFNBOs could deliver in reducing shipping emissions and sets out our rationale and proposals to support the use of these fuels in shipping as well.

58 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

59 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

This chapter does not cover electrification as this is outside of the scope of the RTFO. However, the Department recognises the role of electrification in reducing emissions from shipping as well as from port operations through shore-side power and the decarbonisation of NRMM. We will consider further the role of electrification and other zero emission technologies as part of a forthcoming call for evidence on incentives to support the transition to zero emission shipping.

Rationale for supporting renewable fuels of non-biological origin in shipping

Research commissioned by the Government suggests that alternative low emission fuels, such as hydrogen, ammonia and methanol, are expected to play a significant role in the decarbonisation of the shipping sector[60]. If produced from eligible processes, these fuels can be classified as RFNBOs. RFNBOs are renewable liquid or gaseous transport fuels for which none of the energy content comes from biological sources[61].

RFNBOs are non-biomass and typically, unlike some biofuels, do not use significant amounts of land. Consequently, they have fewer adverse sustainability impacts, including direct and indirect land-use changes as well as competition with food. RFNBOs also have the potential benefit of providing a way to use remote or constrained renewable electricity resources that would otherwise be too far from the grid or from demand[62].

RFNBOs include renewable hydrogen, which is produced from electrolysis of water using renewable electricity; or renewable methanol generated via catalytic fuel synthesis of renewable hydrogen. Hydrogen also provides the feedstock to produce renewable ammonia, produced via catalytic reaction of renewable hydrogen with nitrogen through the Haber-Bosch process[63].

Government-commissioned research analysed the role that alternative low emission fuels such as hydrogen, ammonia and methanol could play in the decarbonisation of the shipping sector. This research suggests that these fuels are likely to be essential to achieving the Government's ambitions for zero emission shipping, particularly beyond 2030[64].

The available evidence indicates that hydrogen and ammonia production technologies also offer a relatively important commercial opportunity for the UK. Research commissioned by the Government shows that the UK has a strong competitive position in relation to

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60 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816015/maritime-emission-reduction-options.pdf

61 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/855751/rtfo-guidance-part-1-process-guidance-year-2020.pdf

62 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/572971/rtfo-consultation-document-2016.pdf

63 https://www.sciencedirect.com/science/article/pii/0360544296000722

64 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

hydrogen and ammonia production technologies[65]. The research estimated that the global market for elements of alternative fuel technologies[66] in which the UK has a competitive advantage (for example, upfront design) could rise to around £11 billion per year by 2050. If the UK maintains its current export market share, the research estimates that this could result in economic benefits to the UK of up to around £0.5 billion per year by around 2050[67].

However, separate research commissioned by the Government to assess likely commercial options identified several market failures and other barriers that are impending the take-up of these low emission fuels, including that fuel prices do not currently fully reflect the environmental costs (e.g. climate change) that result from their use[68]. Government intervention is therefore needed to overcome these barriers and incentivise the take-up of these fuels.

RFNBOs are already supported under the RTFO for use in the road, NRMM and aviation sectors, and we propose to support the use of these fuels in shipping as well.

Latest developments in the maritime use of hydrogen

Although the fuel technology is still at its early stages, demonstration projects for the use of hydrogen as a fuel for marine use are ongoing. Smaller hydrogen vessels have already been demonstrated, and hydrogen powertrain technologies are now being tested in vessels such as ferries[69]. UK based projects include the HySeas III programme, which aims to deliver the world's first sea-going fuel cell vessel and passenger ferry that will employ carbon-free hydrogen as its energy source. The vessel is planned to operate in and around Orkney and use hydrogen which is currently produced on the islands from renewable energy[70].

Another example is the HyDIME (Hydrogen Diesel Injection in a Marine Environment) project in Orkney, which involves the design and integration of a hydrogen diesel dual fuel injection system on board an existing commercial ferry. The ferry operates between Kirkwall and the island of Shapinsay and will use hydrogen produced from renewable energy by the Orkney-based European Marine Energy Centre (EMEC)[71].

Significant work on hydrogen fuel technology for marine use is also underway internationally. One example is the project established by the Norwegian Government in 2017 to build and operate a hydrogen-electric ferry on the Hjelmeland–Nesvik route on the

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65 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815666/economic-opportunities-low-zero-emission-shipping.pdf

66 This assessment covers hydrogen, ammonia, methanol and Bio-LNG only.

67 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815666/economic-opportunities-low-zero-emission-shipping.pdf

68 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815671/identification-market-failures-other-barriers-of-commercial-deployment-of-emission-reduction-options.pdf

69 E4tech, The Fuel Cell Industry Review 2019

70 https://www.hyseas3.eu/

71 https://hydime.co.uk/; http://www.emec.org.uk/projects/hydrogen-projects/hydime/

southwest coast, which is expected to begin zero-emission operations in 2021[72]. The Norwegian Hyon group is in the process of launching a hybrid fast ferry and a costal freighter powered by hydrogen. A smaller hydrogen fuel cell utility vessel is also planned for Lyon, France, where hydrogen-powered inland waterway vessels are being tested. Progress is being made in the Netherlands, the US, and Japan too[73].

Supply chains for renewable hydrogen are already being developed in the UK, leveraging local competitive advantage. As set out by the CCC, steam methane reformation (SMR) coupled with CCS is likely to represent a key technology to generate low carbon hydrogen at scale[74]. The addition of CCS technology to the SMR production pathway could significantly increase GHG savings but has yet to be demonstrated at a commercial scale in the UK[75].

Electrolysers are expected to continue playing an important role in producing energy in areas without electricity grids, or that are unable to export the electricity produced to an area of demand[76]. This might be particularly relevant to areas where onshore wind can be produced cheaply but upgrades to the electricity transmission system have been required to send electricity to areas of demand, such as south of the border in Scotland[77]. These include the Orkney Islands, where the Surf ‘n’ Turf project is aimed at converting and storing energy as hydrogen which would be also used to provide auxiliary power for ferries while they are berthed at Kirkwall Pier[78].

The next section will review our proposal concerning the treatment and accounting under the RTFO of RFNBOs for use in the shipping sector. The Government welcomes your views on the policy approach presented, including on the technical and commercial feasibility of the proposals.

Proposed treatment for renewable fuels of non-biological origin in shipping

We propose to include RFNBOs for use in shipping in scope of the RTFO, without imposing a supply obligation on marine fuel suppliers. This approach, previously adopted for including aviation fuels under the RTFO, limits compliance costs for marine fuel suppliers without creating a significant impact on motorists.

Theoretically, as set out by Government-commissioned research, introducing maritime in scope of the RTFO without obligating maritime fuel suppliers might result in an additional increase in fuel pump prices for motorists[79]. This because the implementation of the RTFO

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72 https://www.sciencedirect.com/science/article/pii/S1464285919300549
73 E4tech, The Fuel Cell Industry Review 2019
74 https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/
75 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/739460/road-to-zero.pdf
76 https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/
77 https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/
78 https://www.gov.scot/policies/oil-and-gas/hydrogen-and-hydrogen-fuel-cells/
79 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816020/potential-role-targets-economic-instruments.pdf

is paid for by UK road and NRMM in the form of an increase in fuel pump prices. The latter has been offset by improvements in vehicle efficiency in recent years, which have been supported by Government regulation[80].

However, as estimated in the accompanying cost-benefit analysis, we do not expect any additional costs to motorists as RTFO target levels will remain unchanged. At the same time, the cost-benefit analysis considers that stimulating hydrogen supply in shipping has the potential to increase the scale of clean hydrogen production which, in turn, would lower the cost of this fuel in the road sector, where it is already being used commercially.

We propose that RFNBOs for marine transport will be eligible for rewards in line with the approach currently set out under the RTFO. Those fuels made from eligible feedstock will be eligible for double rewards and, in the case of renewable hydrogen, will count towards the RTFO development fuels sub-target.

As described, the market for RFNBOs used in the shipping sector is in its infancy, currently limited to a few demonstration projects for hydrogen vessels. Therefore, we do not intent to obligate marine fuel suppliers to supply a percentage of RFNBOs, however those suppliers supplying RFNBOs into the marine market would be able to claim Renewable Transport Fuel Certificates (RTFCs) for eligible fuels.

As with other aspects of the obligation, the Government will continue to keep this area under review to ensure the mechanism is meeting wider policy objectives. We will assess the evidence concerning the level of uptake and the number of RTFCs issued which will emerge during the implementation of this measure. We will then consider whether to raise the level of the development target or support the supply of RFNBOs for shipping under an alternative support scheme for marine fuels.

Specific considerations on ammonia

DfT-commissioned research estimates that alternative fuels including ammonia will be essential to achieving the Government's ambitions for zero emission shipping[81]. If produced with eligible processes, ammonia can qualify as a RFNBO. We propose with certain caveats that renewable ammonia used as a maritime fuel is included in scope of the RTFO, alongside other RFNBOs.

Ammonia presents potential air quality challenges and was recognised in the Clean Air Strategy as one of the five most damaging air pollutants[82]. If used in an unabated ICE ammonia will produce NO_X emissions[83]. However, selective catalytic reduction equipment can be used to reduce these emissions. Any new vessels with engines over 130kW

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80 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/572976/rtfo-consultation-cost-benefit-analysis.PDF

81 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

82 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770715/clean-air-strategy-2019.pdf

83 https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/

utilising ammonia will still be required to comply with the IMO air quality requirements including NO_X Tier II globally and NO_X Tier III requirements in an ECA[84].

Ammonia in an ICE application, in common with other combustion fuels, carries some risk of 'slip' in certain engine configurations, where partial combustion of fuel occurs, and some unburnt fuel exits the engine system in the exhaust stream. This has potential air quality implications if uncontrolled.

Deployment of ammonia as a fuel for fuel cell applications does not carry the same air quality risks as combustion of ammonia in an ICE application.

Ammonia is a toxic chemical that requires safe storage and handling[85], although it can be argued that this fuel has a risk profile that can be managed with existing standards and procedures[86]. Over decades of industrial experience with ammonia, rules and regulation have been formulated for several applications, including for marine transportation[87].

A study produced in 2019 by TU Delft and C-JOB provides a technical assessment of ammonia as a marine fuel. This study suggests that ammonia's risk profile is comparable to that of other fuels. For example, it is less flammable than CNG and LNG and is no more toxic to aquatic life than ULSFO, a currently used fossil marine fuel[88].

It will be essential to demonstrate the safety of hydrogen and any alternative carriers like ammonia before their use can be scaled up[89]. Moreover, further evidence is needed regarding the impact on air quality of using ammonia as a fuel in shipping, including combustion emissions, potential 'slip' of un-combusted ammonia and emissions from handling and storage. RTFO support to RFNBOs used in shipping, including ammonia, will facilitate the testing of these fuels at a commercial level. In turn, this will allow the regulator to investigate safety standards for the use of these fuels at scale, and to monitor their impact on air quality and the wider environment. The Government will review the level of RTFO support provided to RFNBOs including ammonia based on the evidence gathered during the implementation period.

Research to better understand, quantify and manage air quality risks from ammonia is currently underway in the UK. Maritime Research and Innovation UK (MarRI-UK) recently awarded funding under the DfT-sponsored Clean Maritime Call to investigate advanced, zero emissions, ammonia fuelled maritime engines. The Clean Maritime Call, which was open to expressions of interest between July and October 2019, was launched as part of the implementation of the Clean Maritime Plan to support innovation in the field of shipping emission reductions[90].

Ammonia in fuel cell applications is increasingly being considered by international shipping companies as an option for hybrid and full electric vessel designs and has been used experimentally in some small craft already. The Department is of the view that supporting

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[84] https://europe.edf.org/file/399/download?token=agUEbKeQ
[85] https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/
[86] https://europe.edf.org/file/399/download?token=agUEbKeQ
[87] https://repository.tudelft.nl/islandora/object/uuid%3Abe8cbe0a-28ec-4bd9-8ad0-648de04649b8
[88] https://repository.tudelft.nl/islandora/object/uuid%3Abe8cbe0a-28ec-4bd9-8ad0-648de04649b8
[89] https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/
[90] https://www.marri-uk.org/funding-opportunities/clean-maritime-call

renewable ammonia for use in Fuel Cells is a sensible step to accelerate the deployment of such systems.

For use in ICE however there remain the air quality concerns highlighted above, and the Department would seek stakeholders' views on support for renewable ammonia in ICE applications, and views on any air quality measures that should be required. Our general principle is that support for a fuel under this mechanism cannot result in a worsening of UK air quality, and ideally should improve it.

Q 3 Do you agree that RFNBO's for use in maritime transport, such as renewable hydrogen and ammonia, should be eligible for reward under the RTFO?

Q 4 Do you agree that renewable ammonia should be eligible for reward under the RTFO when used in marine fuel cell applications?

Q 5 Do you agree that renewable ammonia should be eligible for reward under the RTFO when used in marine combustion applications if air quality concerns can be adequately addressed? If yes, do you have any views on what standards should apply to the use of ammonia in ICE applications in order to attract reward under the RTFO, for example NOx IMO Tier III[91]? Please include in your response any evidence on air quality implications arising from the use of ammonia in ICE applications.

Support for renewable hydrogen and other RFNBOs including ammonia

Hydrogen is expected to play a strategic role in the decarbonisation of the shipping sector, both as a fuel and as a feedstock for the production of other synthetic fuels. Renewable hydrogen is a type of RFNBO which is supported under the RTFO development target for use in the road, NRMM and aviation sectors. It is important that this fuel is also supported when supplied for use in marine applications.

Research commissioned by the Government suggests that ammonia might also have a strategic role in the decarbonisation of the future shipping fuel mix[92]. Therefore, we propose that ammonia used as a marine fuel is supported under the RTFO main target, when this is produced as a RFNBO using renewable hydrogen.

We propose to amend the RTFO to support these fuels by:

- Aligning the treatment of renewable hydrogen and other RFNBOs for use in the shipping sector to that of RFNBOs supplied for use the road, NRMM and aviation sectors. This involves setting the number of RTFCs for which 1kg of renewable hydrogen and other RFNBOs are eligible, to reflect their energy content.

[91] http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx

[92] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816015/maritime-emission-reduction-options.pdf

- Ensuring that renewable hydrogen and other RFNBOs supplied for marine usage are eligible and can be properly accounted for. This involves identifying the most suitable assessment time[93] for rewarding early adopters using these fuels.
- Rewarding renewable hydrogen for use in shipping in the RTFO development fuels sub-target, and reward other RFNBOS for use in shipping under the main RTFO target, including renewable ammonia and renewable methanol.
- Rewarding RFNBOs for use in marine applications, consistent with their energy content.

Setting the level of reward for RFNBOs in shipping

For gaseous renewable transport fuel, RTFCs are awarded on a kg-basis. The number of RTFCs awarded per kg of each gaseous fuel reflects the energy density of the gas compared to the average energy density of liquid renewable transport fuels supplied.

Based on the approach for renewable hydrogen set in the Government response to the latest RTFO amendments, published in 2017[94], we propose to introduce an RTFC multiplier of 4.58 for hydrogen to reflect that 1kg of hydrogen contains as much energy as an average litre of liquid biofuel. In line with the treatment of other renewable fuels, the fuel would receive double RTFCs where the resultant fuel is a RFNBO.

Based on the same approach, focusing on the energy content, calculated similarly to the method used to introduce gaseous[95] fuels, and based on the lower heating value for ammonia (18.6)[96] divided by the average value for a liquid biofuel (28.34), we propose to introduce an RTFO multiplier of 0.66 for ammonia, to reflect that 1kg of ammonia contains this multiple of energy relative to an average litre of liquid biofuel[97]. Again, in line with the treatment of other renewable fuels, the fuel would receive double RTFCs where the resultant fuel is a RFNBO.

In order to evenly incentivise fuels in maritime use we propose to also apply an energy multiplier to renewable methanol. The methanol energy multiplier based on the same methodology as ammonia is 0.7.

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[93] Approach for duty point and non-duty point fuels is outlined in https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/855751/rtfo-guidance-part-1-process-guidance-year-2020.pdf

[94] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/644843/renewable-transport-fuel-obligations-order-government-response-to-consultations-on-amendments.pdf

[95] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/346424/consultation-document.pdf

[96] https://www.sciencedirect.com/science/article/pii/S1540748918306345

[97] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/346424/consultation-document.pdf

Q 6 Do you agree with the proposed treatment under the RTFO for RFNBOs used in shipping, including the proposed level of reward for renewable hydrogen, ammonia and methanol? Please provide an explanation as to why you agree or disagree.

Accounting for renewable fuels of non-biological origin in shipping

Under the current RTFO, the duty point, i.e. when the duty of excise becomes payable, is used as the control point for most fuels. This control point is used to determine which fuels should be counted, when they should be counted, and to determine ownership at the time of counting. Owners of eligible fuels at the control point can apply for RTFCs.

There are no specific tax codes for hydrogen, methanol and ammonia used as shipping fuels. These fuels are taxed at the point of usage as ‘fuel substitutes’ only under certain circumstances, i.e. the liquid or gaseous state of the fuel, the type of engine in which this is used, and the type of journey.

The supply chain for renewable hydrogen of non-biological origin and for the fuels produced using this hydrogen as feedstock is currently short, with the main model consisting of generation equipment and storage situated in the premises of the refuelling facility. It is possible that in future, other models might emerge. However, because of the lengthy processes involved in legislative changes, it is important that the most appropriate assessment time – one which will be applicable for the foreseeable future – is decided as soon as possible.

We are therefore, proposing to use the point at which RFNBOs are dispensed to a ship for use as a navigation fuel as the assessment point. This will mean that the supplier of RFNBOs is eligible to claim RTFCs, if they can provide evidence that the fuel has been supplied for the appropriate use. In those cases where the fuel is dispensed as part of a financial transaction between the fuel supplier and the final user, sales invoices will represent the appropriate evidence. However, where the organisation or the consortium of organisations producing the RFNBO, operating the refuelling infrastructure and the vessel are the same (e.g. as part of a demonstration project), additional documentation would be needed to support an application for RTFCs.

Q 7 Do you agree that the point at which RFNBOs are dispensed to a ship for use as a navigation fuel is an appropriate ‘assessment time’ for these fuels? Please provide an explanation as to why you agree or disagree.

It might not be possible on all occasions, for the RTFO Administrator to access HMRC records to validate the amounts of RFNBOs for use in shipping which have been reported. Direct examination by the Administrator, of evidence held by industry applicants might be feasible. However, if the Administrator receives a significant number of applications, they may seek independent assurance (verification) of the amounts of fuel supplied by independent verifiers, in line with the current RTFO regulation.

It is therefore, our intention that the Administrator is given powers to do this where it is necessary. It is envisaged that, as currently set out for the road sector, this independent assurance would be as similar as possible to the verification of sustainability information already required under the RTFO, and therefore that it would be carried out using the assurance standard ISAE 3000.

To provide the Administrator with the required level of assurance over the volumes supplied, and one that is comparable to the cross checking of all volumes against HMRC data, we believe that it is necessary to require the more detailed 'reasonable' assurance level provided for under ISAE 3000 for fuel volumes, rather than the 'limited' level which is used for renewable fuel sustainability information.

Where suppliers are required to provide independent assurance for fuel volumes, this will be in addition to the independent assurance for sustainability information. The Administrator will work with fuel suppliers to develop guidance on how this can be achieved with the minimum of administrative burden and cost.

Q 8 Do you agree that the proposed powers for the Administrator are sufficient to ensure the independent verification of the amounts of RFNBOs used in shipping? Please provide an explanation as to why.

Q 9 Do you agree that the requirement for a reasonable level of assurance, rather than the lower limited level of assurance, is appropriate? Please provide an explanation as to why.

Conclusions

Synthetic fuels do not have the same supply constraints that biofuels have. Research commissioned by the Government[98] suggests that these fuels including hydrogen, ammonia and methanol might have a strategic role in decarbonising the maritime fuel mix. Whilst available evidence indicates that hydrogen and ammonia production technologies offer a relatively important commercial opportunity for the UK[99], the take-up of these fuels is currently impended by several market failures[100].

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98 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

99 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815666/economic-opportunities-low-zero-emission-shipping.pdf

100 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815671/identification-market-failures-other-barriers-of-commercial-deployment-of-emission-reduction-options.pdf

If produced using eligible processes, synthetic fuels can be classified as renewable fuels of non-biological origin (RFNBOs). RFNBOs are renewable liquid or gaseous transport fuels for which none of the energy content comes from biological sources[101]. RFNBOs are already supported under the RTFO for use in the road, NRMM and aviation sectors. This chapter explored the contribution that RFNBOs could deliver in reducing shipping emissions and set out our rationale and proposals to support the use of these fuels in shipping as well.

101 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/855751/rtfo-guidance-part-1-process-guidance-year-2020.pdf

Annex 1: Full list of consultation questions

For each of the following questions, please set out the reasons for your answers, including the impacts of any alternative that you may propose and any anticipated implications. Please also provide any supporting evidence you may have.

Chapter 1: The role of biofuels in shipping

Q 1 Do you agree with the Governments current position not to support biofuels for use in maritime transport under the RTFO and instead promote the use of bioenergy in other sectors of the economy that have fewer decarbonisation options compared to maritime?

Q 2 Do you consider that there could be biofuel options that would be suitable for use in maritime transport under the RTFO, including sub-sectors like fishing, that address concerns about feedstock availability? When replying please provide any additional evidence you feel is useful in explaining your response.

Chapter 2: Support for renewable fuels of non-biological origin used in shipping

Q 3 Do you agree that RFNBO's for use in maritime transport such as renewable hydrogen and ammonia should be eligible for reward under the RTFO?

Q 4 Do you agree that renewable ammonia should be eligible for reward under the RTFO when used in marine fuel cell applications?

Q 5 Do you agree that renewable ammonia should be eligible for reward under the RTFO when used in marine combustion applications, if air quality concerns can be adequately addressed? If yes, do you have any views on what standards should apply to the use of ammonia in ICE applications that might be eligible for this support, for example IMO (International Maritime Organization) NOx Tier III[22]? Please include in your response any evidence on air quality implications arising from the use of ammonia in ICE applications.

Q 6 Do you agree with the proposed treatment under the RTFO for RFNBOs used in shipping, including the proposed level of reward for renewable hydrogen, ammonia and methanol? Please provide an explanation as to why you agree or disagree.

Q 7 Do you agree that the point at which RFNBOs are dispensed to a ship for use as a navigation fuel is an appropriate ‘assessment time’ for these fuels? Please provide an explanation as to why you agree or disagree.

Q 8 Do you agree that the proposed powers for the Administrator are sufficient to ensure the independent verification of the amounts of RFNBOs used in shipping? Please provide an explanation as to why.

Q 9 Do you agree that the requirement for a reasonable level of assurance, rather than the lower limited level of assurance, is appropriate? Please provide an explanation as to why.

Annex 2: Glossary of terms

Administrator	The Secretary of State is the Administrator of the scheme. This function of the Secretary of State is exercised through the RTFO Unit in the Department for Transport.
Air pollutants	Toxic emissions including fine particulate matter, ammonia, nitrogen oxides, sulphur dioxide, non-methane volatile organic compounds.
Air quality	A term used to describe the degree to which air is suitable or clean enough for humans, animals, or plants to remain healthy.
Alternative fuels	Fuels that are derived partly or wholly from a source other than petroleum and that are less damaging to the environment than conventional fossil fuels.
BECCS	Bioenergy with Carbon Capture and Storage is the process of extracting bioenergy from biomass and capturing and storing the carbon, thereby removing it from the atmosphere.
Bioenergy	A term that covers all energy produced from biomass. Most common uses are transport, heat and electricity.
Biofuel	A liquid or gaseous fuel used in transport that is produced wholly from biomass.
Bunker fuel	Bunker fuel is the generic term given to any fuel used to power a ship's engines. 'Bunkering' is the supplying of fuel for use by ships, including the logistics of loading fuel onboard and distributing it among available bunker tanks.
Carbon Budget	Introduced as part of the Climate Change Act 2008 to help the UK reduce greenhouse gas emissions to net zero by 2050. Covering a period of five years, a Carbon Budget places a restriction on the total amount of greenhouse gases the UK can emit. Five-yearly carbon budgets currently run until 2032. The UK is currently in the third carbon budget period (2018-2022).
Carbon Capture and Storage (CCS)	A range of technologies that can capture carbon dioxide emissions produced from the use of fossil fuels in electricity generation and industrial processes, thereby preventing the carbon dioxide from entering the atmosphere.
Carbon Capture and Utilisation (CCU)	The process of capturing carbon dioxide to be recycled for further usage. This process differs from CCS (above) as CCU does not aim to, nor result in, permanent geological storage of carbon dioxide.
Carbon sequestration	The process involved in the capturing and long term storing of atmospheric carbon dioxide.
Catalytic reaction	A chemical reaction which includes the addition of a catalyst to increase the rate at which this reaction proceeds (e.g. in the Haber Bosch process), and where the catalyst is not consumed in the reaction.
CCC (Committee on Climate Change)	An independent, statutory public body formed under the Climate Change Act (2008) to advise the UK and devolved governments on emissions targets and to report to Parliament on progress made in reducing

	greenhouse gas emissions and preparing for and adapting to the impacts of climate change.
Clean Air Strategy	The strategy of the UK Government setting out plans for dealing with all sources of air pollution, making our air healthier to breathe, protecting nature and boosting the economy.
Clean Maritime Plan	The Government's route map for the transition to a future of zero emission shipping.
Climate Change Act (2008)	The basis for the UK's approach to tackling and responding to climate change, requiring that emissions of carbon dioxide and other greenhouse gases are reduced and that climate change risks are prepared for.
CNG (Compressed Natural Gas)	Compressed natural gas is a fuel made of methane which is stored at relatively high pressure and which can be used in place of fossil fuels.
CO_2	Carbon dioxide.
Crude Oil	Unrefined petroleum composed of hydrocarbon deposits and other organic materials that can be refined to produce products such as gasoline and diesel and other petrochemicals.
DAC (Direct Air Capture)	A process of capturing carbon dioxide directly from the atmosphere.
Drop-in fuel	A drop-in alternative fuel is a substitute for conventional petroleum-derived hydrocarbons which does not require adaptation of the engine, fuel system or the fuel distribution network to be used.
ECA (Emissions Control Area)	Sea areas in which stricter controls have been agreed internationally (at the IMO) to further reduce emissions to air from ships, these are defined in Annex VI of the 1997 MARPOL Protocol and can cover SOx and NOx, examples include the North Sea ECA and North American ECA.
EEDI (Energy Efficiency Design Index)	A technical measure adopted by the IMO which requires a minimum energy efficiency level per capacity mile/equivalent for different ship type and size segments. This level will be tightened incrementally every five years for new vessels entering the international shipping market.
Electrolysis	A technique that uses a direct electric current to drive an otherwise non-spontaneous chemical reaction. Electricity is used to split water into hydrogen and oxygen. This reaction takes place in a unit called an electrolyser.
EMEC (European Marine Energy Centre)	A test and research centre focusing on wave and tidal power generation established in 2003 and based in the Orkney Islands. It provides developers of both wave and tidal energy converters (technologies that generate electricity by harnessing the power of waves and tidal streams) with purpose-built, accredited open-sea testing facilities.
Energy crop	Crops grown for the purpose of generating heat and electricity from biomass/biogas via anaerobic digestion. These typically include wheat and sugar beet for bioethanol, and oilseeds for biodiesel. Dedicated energy crops are non-food crops including ligno-cellulosic material and non-food cellulosic material except saw logs and veneer logs.
Feedstock	Raw, unprocessed material used to produce goods, energy or intermediate materials for future finished products.
Fuel cell	A fuel cell is a device that converts energy stored in molecular bonds (i.e. hydrogen fuel) through a chemical process into electricity.
gCO_2eq/MJ	Grams of CO_2 equivalents per megajoule. This represents the emission intensity of a given pollutant relative to the intensity of a specific activity or an industrial production process.
GHG (Greenhouse Gases)	A gas which in the atmosphere absorbs and emits radiation causing the 'greenhouse effect' whereby heat is trapped in the atmosphere making the earth warmer and leading to climate change. Greenhouse gases include carbon dioxide (CO_2), nitrous oxide (N_2O), methane, water vapour, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride.
Haber Bosch process	The Haber Bosch process combines nitrogen from the air with hydrogen derived mainly from natural gas (methane) into ammonia. It is the main industrial procedure to produce ammonia.
Indirect land-use change	Land-use change where the cause is at least a step removed from the effects – the knock-on effects on expansion of agricultural land use resulting from the cultivation of biofuel feedstocks.

Industrial Strategy	The UK's strategy to boost productivity through four Grand Challenges in artificial intelligence and big data; clean growth; the future of mobility; and meeting the needs of an ageing society. It aims at creating jobs and increasing the earning power of people throughout the UK with investment in skills, industries and infrastructure.
Initial IMO Strategy for the Reduction of GHGs from Ships	Agreed in 2018, the Initial Strategy sets out the IMO's targets for reducing greenhouse gas emissions from international shipping. The Initial Strategy commits Member States to reducing GHGs by at least 50% by 2050, while continuing efforts to phase them out as soon as possible this century.
Internal Combustion Engine	A device in which the reactants of combustion (oxidizer and fuel) and the products of combustion serve as the working fluids of the engine. Such an engine gains its energy from heat released during the combustion of the nonreacted working fluids, the oxidizer-fuel mixture. This process occurs within the engine and is part of the thermodynamic cycle of the device. Useful work generated by an ICE results from the hot gaseous products of combustion acting on moving surfaces of the engine, such as the face of a piston, a turbine blade, or a nozzle.
International Maritime Organization (IMO)	A specialised agency of the United Nations setting standards for the safety, security and environmental performance of international shipping. Its main role is to create a regulatory framework for the international shipping industry that is fair and effective, universally adopted and universally implemented.
Lifecycle carbon emissions	The overall greenhouse gas impacts of a fuel, including each stage of its production and use.
Liquid Natural Gas (LNG)	Liquid natural gas is a natural gas that has been chilled to a liquid state for shipping and storage. The volume of natural gas in its liquid state is about 600 times smaller than its volume in its gaseous state.
Low Carbon Fuels	Fuels that result in less carbon pollution compared to petroleum-based fuels. If produced according to specific sustainability criteria and from eligible feedstock these can quality for support under the RTFO.
Maritime 2050 Strategy	This strategy sets out the government's vision and ambitions for the future of the British maritime sector. It focuses on seven different themes, including the environment. The Clean Maritime Plan is the environment route map of the Maritime 2050 Strategy.
MARPOL	Adopted in 1973, the International Convention for the Prevention of Pollution from Ships is the main international convention covering prevention of pollution of the environment by ships from operational or accidental causes. It covers both air pollution and energy efficiency issues, alongside marine pollution matters.
MEPC (Marine Environment Protection Committee)	The Marine Environment Protection Committee addresses environmental issues under IMO's remit. This includes the control and prevention of ship-source pollution covered by the MARPOL treaty, including air pollutants and greenhouse gas emissions.
$MtCO_2e$	Mega tonnes of carbon dioxide equivalent. This is a consistent measure of assessing the contribution of greenhouse gases to global warming.
Net Zero	Net zero means any emissions would be balanced by schemes to offset an equivalent amount of GHGs from the atmosphere, e.g. by planting trees or using technology such as CCS.
NO_x	Nitrogen oxide.
NO_x Tiers	These relate to IMO Regulation 13 and apply different levels of control applied to ships depending on the vessel's construction date and intended area of operation. Within each tier, the actual NO_x limit value is determined by the engine's rated speed.
NRMM (Non-Road Mobile Machinery)	A term used to collectively refer to non-road mobile machinery (including inland waterway vessels when not at sea), agricultural and forestry tractors, inland waterway vessels and recreational crafts that do not normally operate at sea.
Obligated supplier	A transport fuel supplier upon whom a renewable transport fuel obligation is imposed. Non-obligated suppliers include fuel suppliers of fuel below the minimum threshold of 450,000 litres per annum. Currently, non-obligated suppliers in the road, aviation and NRMM sectors might open a Renewable

	Transport Fuel account with the Administrator and apply for tradeable Renewable Transport Fuel Certificates.
$PM_{2.5}$	An air pollutant consisting of fine particles with a diameter of 2.5 μm (micrometres).
Renewable Energy Directive (Annex V)	Annex V of the Renewable Energy Directive (RED) sets out detailed rules for calculating the greenhouse gas impact of biofuels, bioliquids and their fossil fuel comparators. The RED 2009/28/EC requires EU Member States to meet a target of 10% renewable energy in transport by 2020. The revised RED 2018/2001 raised the target to 14% by 2030.
Renewable fuel	A fuel used from a source that is either inexhaustible or can be indefinitely replenished at the rate at which it is used. Such as a biofuel or other fuels produced from a renewable energy source i.e. renewable fuels or non-biological origin.
Reward under the RTFO	Renewable fuels that pass sustainability criteria under the RTFO are eligible for a tradeable Renewable Transport Fuel Certificate (RTFC, the 'reward'). Renewable fuels derived from certain waste or residue feedstocks are awarded double the RTFCs per litre or kilogram supplied. The Administrator will award double RTFCs where it believes it is appropriate to do so in light of the 'effects', set out in the Energy Act (2004) Section 126(4), produced by that fuel.
RFNBO (Renewable fuel of non-biological origin)	A renewable transport fuel that does not have any biological content – rather, the renewable energy content comes from renewable energy sources other than biomass. For example, renewable methanol produced from waste CO_2 and hydrogen where the process is powered by geothermal electricity.
RTFC (Renewable Transport Fuel Certificate)	Renewable Transport Fuel Certificate. One RTFC is awarded for every litre of liquid biofuel reported. Biofuels from wastes receive double the number of RTFCs. They can be traded between suppliers. Their value is determined by the market.
RTFO (Renewable Transport Fuel Obligations)	Renewable Transport Fuel Obligations. Introduced in 2008, it is the UK's main mechanism for supporting the supply of renewable fuels in transport. It places an obligation on fuels suppliers of more than 450,000 litres per year of fuel intended for road transport and NRMM use to ensure that a certain percentage of the fuel supplied is renewable and operates as a certificate trading scheme. Aviation has been included in scope of the RTFO following the 2017 amendments.
SEEMP (Ship Energy Efficiency Management Plan)	A measure that establishes a mechanism to improve the energy efficiency of a ship's operations in a cost-effective manner. It also provides an approach for shipping companies to manage ship and fleet efficiency performance over time.
SMR (Steam Methane reformation)	A method for producing hydrogen by reacting methane with water in the form of high-pressure steam. SMR is currently the most widely used gas reforming technology and has been used commercially for many decades.
SO_x	Sulphur Oxide.
Sulphur limit	For ships operating outside designated ECAs, the IMO has set a limit for sulphur in fuel oil used on board ships of 0.5%m/m (mass by mass) from 1 January 2020 unless the vessel is capable of technical equivalence to this standard.
Surf 'n' Turf	A renewable energy project in Orkney, led by Community Energy Scotland. It generates hydrogen from tidal and wind energy which is then used to overcome grid limitations and supply energy to local demands, including shore power for the interisland ferries.
Synthetic fuels	A liquid or gaseous fuel obtained from syngas which was derived from gasification of solid feedstocks such as coal or biomass or by reforming of natural gas.
TWh	A terawatt-hour is a unit of energy equal to outputting one trillion watts for one hour. It is equal to 3.6×10^{15} Joules. This value is large enough to express annual electricity generation for entire countries. It is often used when describing major energy production or consumption.
Verification	The process of providing assurance of renewable fuels sustainability data or other fuel related data (e.g. place of purchase, volume produced)

	supplied on behalf of reporting parties. Verifiers must be independent of the reporting party whose data they are verifying.
Well to tank emissions	An average of all the GHG emissions released into the atmosphere from the production, processing and delivery of a fuel or energy vector.