Master plan for CO_2 reduction in the Dutch shipping sector
-
Biofuels for shipping

Report

E4tech (UK) Ltd for

Platform Duurzame Biobrandstoffen

May 2018

Title	Master plan for CO_2-reduction in the Dutch shipping sector – Biofuels for Shipping
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Date	04 May 2018
Version	Final report (v4.0)
Distribution	Steering Board of the Platform Duurzame Biobrandstoffen

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Contents

Abbreviations ... 3
Executive Summary ... 6
1 Introduction ... 10
2 Emissions reduction drivers in shipping ... 11
2.1 International ... 11
2.1.1 GHG emissions ... 12
2.1.2 Future international policy on GHG emissions ... 13
2.1.3 Non-GHG emissions ... 15
2.2 European Union ... 19
2.2.1 GHG emissions reduction policy ... 20
2.2.2 Renewable fuels policy ... 21
2.2.3 Future EU policy on shipping GHG emissions ... 24
2.2.4 Non-GHG emissions regulation ... 24
2.3 The Netherlands ... 26
2.3.1 GHG emissions reduction policy ... 27
2.3.2 Dutch policy on shipping GHG emissions ... 29
2.4 Ports ... 30
2.4.1 Examples of port 'policies' on emissions (GHG and non-GHGs) ... 30
2.5 Summary ... 31
3 Shipping decarbonisation options ... 32
3.1 Ship design, operations and infrastructure ... 35
3.1.1 Ship design and operations ... 35
3.1.2 Dutch ports ... 35
3.2 Energy options ... 37
3.2.1 Incumbent propulsion technologies and fuels ... 37
3.2.2 Diesel hybrid options ... 39
3.2.3 Liquefied Natural Gas (LNG) ... 39
3.2.4 Compressed Natural Gas (CNG) ... 41
3.2.5 Liquefied Petroleum Gas (LPG) ... 41
3.2.6 Methanol ... 42
3.2.7 Biofuels ... 44
3.2.8 Hydrogen ... 44
3.2.9 Electricity ... 45
3.2.10 Nuclear ... 45
4 Biofuels – their potential role in decarbonising shipping ... 47
4.1 Evaluation of biofuel options ... 48
4.1.1 Hydrogenated Vegetable Oil (HVO) ... 49
4.1.2 SVO ... 50
4.1.3 FAME ... 50
4.1.4 Bio-ethanol ... 52

4.1.5 Bio-methanol 54
4.1.6 Bio-Dimethylether (DME) 55
4.1.7 Biomethane 56
4.1.8 FT-Diesel 57
4.1.9 Upgraded Pyrolysis Oil 58
4.2 GHG emission saving and production cost comparison 60
4.3 Non-GHG emissions 62
4.4 Total cost of ownership and payback time 63
4.4.1 Fuel price differentials and other operating costs 64
4.4.2 Investment costs 65
4.4.3 Payback time comparison 65
4.5 Conclusions 66
5 Interventions 70
5.1 Interventions regarding technical and infrastructure barriers 70
5.2 Interventions regarding economic barriers 71
5.3 Interventions regarding organisational & other barriers 72
5.4 Summary of interventions 73

Abbreviations

Abbreviation	Full description
AD	Anaerobic Digestion
CCNR	Commission of Navigation on the Rhine
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
COBALD	Continuous On-Board Analysis and Diagnosis
CSI	Clean Shipping Index
DME	Dimethylether
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
EGR	Exhaust Gas Recirculation
EJ	Exa-joules
ESI	Environmental Shipping Index
EU	European Union
ETS	Emissions Trading Scheme
EUR	Euro (Currency)
FAME	Fatty Acid Methyl Ester
FQD	Fuel Quality Directive
FT-diesel	Fischer-Tropsch Diesel
GHG	Greenhouse Gas
GJ	Giga-joules
HBE	Renewable Fuel Units
HC	Hydrocarbons
HFO	Heavy Fuel Oil

HVO	Hydrotreated Vegetable Oil
IAPH	International Association of Ports and Harbours
ICCT	International Council on Clean Transportation
IMO	International Maritime Organisation
LHV	Lower Heating Value
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LSHFO	Low-sulphur Heavy Fuel Oil
LSMGO	Low-sulphur Marine Gas Oil
MARPOL	International Convention for Prevention of Pollution from Ships
MBM	Market-based Mechanism
MDO	Marine Diesel Oil
MeOH	Methanol
MEPC	Marine Environment Protection Committee
MGO	Marine Gas Oil
MJ	Mega-joules
MRV	Monitoring, reporting and verification
MS	Member State
MSW	Municipal Solid Waste
NL	The Netherlands
NO_x	Nitrogen Oxides
NREAP	National Renewable Energy Action Plan
NRMM	Non-road Mobile Machinery
PJ	Peta-joules
PM	Particulate Matter
RED	Renewable Energy Directive

RED II	Proposed revision of current Renewable Energy Directive
RFNBO	Renewable Fuels of Non-Biological Origin
RPM	Revolutions per minute
SCR	Selective Catalytic Reduction
SECA	Sulphur Emission Control Area
SEEMP	Ship Energy Efficiency Management Plan
SOLAS	Safety of Life at Sea
SO_x	Sulphur Oxides
STS	Ship-to-ship
SVO	Straight Vegetable Oil
TRL	Technology Readiness Level
UCO	Used Cooking Oil
UCOME	Used Cooking Oil Methyl Ester
ULSFO	Ultra-low Sulphur Fuel Oil
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UPO	Upgraded Pyrolysis Oil
USD	US Dollars
VOC	Volatile Organic Compound

Executive Summary

The shipping sector is under pressure to reduce emissions and low-carbon fuels can offer the largest greenhouse gas emissions reductions.

The reduction of greenhouse gas (GHG) emissions to mitigate climate change has become an important global effort, having been given structure, urgency and legitimacy by the Paris Agreement in 2015. Shipping is now one of the last major emitters to take action and implement a GHG reduction strategy.

The Netherlands is a nation with long traditions of shipping both by sea and through inland waterways in Europe, and is also active in decarbonising its economy. It was supportive of targets that match the goals of the Paris Agreement in the IMO GHG strategy negotiations. The current Dutch government is also positioning itself as a leader in decarbonisation in shipping, with a maritime strategy including plans for GHG reductions and the prospect of a green deal for the sector. This strategy includes an ambition to achieve a zero-emissions inland shipping sector by 2050.

Both inland and sea-faring shipping are currently subject to drivers of change due to non-GHG emissions. The International Maritime Organisation (IMO) and European Union (EU) have applied stringent limits on sulphur oxides (SO_x), nitrous oxides (NO_x) and particulate matter (PM) emissions. These constraints are greater for inland shipping through the EU regulations. Therefore, any decarbonisation options need to also comply, and if possible advance, non-GHG emission reductions.

GHG emissions in shipping can be reduced in different ways: by changes in operations like slow-steaming; increases in efficiency through stream-lining or energy recovery systems; or using alternative energy carriers for propulsion and operation of the vessels. This study focussed on the use of alternative energy carriers and fuels, including fossil fuel and low-carbon fuel options.

Whilst there are some advantages to fossil-based alternatives to fuel oil and middle distillates, such as LNG, CNG, LPG and fossil-based methanol, the GHG reduction from these options is limited to approximately 20% GHG savings. The larger GHG emission savings can only be achieved by using low-carbon energy carriers. The most feasible of these options include the use of electricity and hydrogen (whose emission reductions depend only on the source of production as there are no tailpipe emissions); nuclear (which can achieve very high GHG emissions reduction on a lifecycle basis, but has substantial barriers to implementation due to safety and geopolitical factors); and biofuels.

Biofuels can provide large reductions in GHG and non-GHG emissions, offering a range of solutions for decarbonisation in the short and longer term.

The biofuels analysed were hydro-treated vegetable oil (HVO – including from waste oils and fats), FAME, straight vegetable oil (SVO), ethanol (both conventional and advanced production processes), bio-methanol, bio-LNG, Fischer-Tropsch diesel (FT-diesel) and Upgraded Pyrolysis Oil (UPO). These biofuels were qualitatively analysed on their GHG reduction potential, readiness of production, cost and compatibility with the current vessel fleet in each shipping sector. As a reference:

- Deep-sea shipping was assumed to use HFO fuel with scrubbers to comply with SO_x regulations tightening to 0.5% sulphur limit in 2020.
- Short-sea shipping assumed an archetype of MGO to comply with the 0.1% sulphur limit.
- Inland shipping assumed the use of EN590 diesel due to sulphur requirements of less than 0.001%.

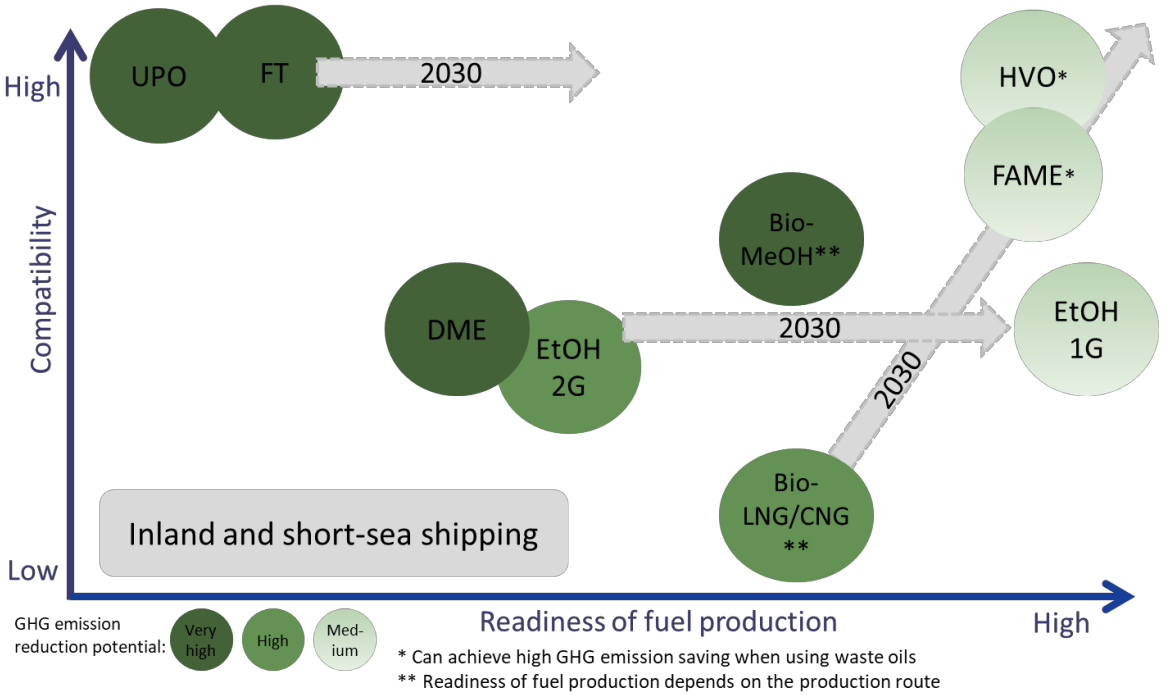

Figure a: Summary of the attractiveness of biofuels in the short-sea and inland shipping sectors

Fuels for use in short-sea and inland shipping sectors are summarised in Figure a. HVO, FAME, FT-Diesel and UPO can be described as 'drop-in' biofuels, as they are liquid fuels that are functionally equivalent to their petroleum counterparts in marine engine combustion and are also compatible with current storage and refuelling infrastructure. SVO from vegetable crops was not a viable option for use in inland and short-sea shipping due to the engine conversion requirements and low overall attractiveness (low GHG reduction potential and issues with sustainability).

HVO is currently available at commercial scale, allows very high GHG reductions when using waste oils and fats, making it the most attractive short-term option to decarbonise the shipping sector. The use of HVO from vegetable crop oils raises sustainability concerns, and their use is being restricted by EU policy. However, the 'drop-in' nature of HVO fuel in road and aviation also leads to strong competition from those sectors, and the limited availability of waste oils and fats may limit their use.

FAME in contrast to HVO is currently produced in larger volumes, but suffers from the same feedstock constraints, has a blending limit of 7% in inland and short-sea vessels if EN590 diesel standards for inland shipping need to be met, and does not reduce NOx emissions. However, higher blend levels of FAME are technically possible, although implications on the engines and non-GHG emissions need to be carefully considered.

FT-Diesel and UPO have a lower commercial readiness, limiting their current availability and in 2030, and implying higher costs. While UPO is at an earlier stage of development, its cost could be relatively attractive, justifying further development of this technology.

Conventional ethanol is widely available today but is incompatible with current marine engines, so is not a good short term option. However, the fuel supply and storage can be adapted in current engines to use ethanol or methanol. This could lead to ethanol compatible vessels being operational by 2030. More substantial GHG savings can be achieved through advanced ethanol production, which should be commercially available by 2030, though again costs will be higher due to the early days of commercialisation of the technology.

Bio-methanol is potentially a very attractive option in terms of costs and GHG emissions reductions, and is commercially produced today from biomethane. However, the production of bio-methanol via gasification of solid biomass is only at early commercial stage, and the production of methanol from renewable electricity is only at a large demonstration stage. Bio-methanol would be more attractive to the inland and short-sea shipping sectors as the 50% lower energy density of methanol (compared to incumbent fuels) limits the vessel's range, which is a major draw-back for deep-sea shipping. DME, which can be produced from or instead of methanol, requires separate storage and bunkering infrastructure, as it is in a gaseous state in ambient conditions and requires a constant 5bar pressure to remain liquid. Even though DME is more compatible with marine diesel engines than methanol, it still requires adaptation of the engine and fuelling system, and is hence deemed less attractive due to more complicated storage and bunkering.

Bio-LNG is commercially available today from biomethane, can achieve high GHG emission reductions, and could be used, either directly or via a mass-balancing system (applied to bio-LNG or biomethane) in existing LNG vessels. When produced from bioSNG, it is at a lower readiness level, due to the ongoing development of bioSNG technologies. There are currently a low number of LNG compatible vessels, and the costs of converting vessels and infrastructure is more expensive than for methanol. If bio-LNG is to be attractive in 2030, a significant increase in the uptake of LNG vessels is needed. Bio-CNG is considered as a potential option in short-sea and inland shipping, but more research is needed on the implications of CNG use on the current vessel fleets.

The outlook only slightly changes for deep-sea shipping. SVO is compatible with the HFO engines used in deep-sea shipping and is included as a viable drop-in option. Additionally, FAME is only allowed in trace amounts based on the ISO 8217 standards applying to HFO in deep-sea shipping.

The price differential between biofuels and HFO used in deep-sea shipping is greater than that of the price differential between biofuels and the fuels used in inland and short-sea shipping. Therefore, biofuels are much less economically viable in the deep-sea sector.

There are technical, economic and operational barriers to the use of biofuels in shipping, however, coordinated interventions from the range of actors shaping the shipping industry can support the uptake of biofuels.

The use of biofuels in shipping is very limited at the moment, but there is the potential for growth via the range of sustainable biofuels described in this study. This will require a set of interventions from different stakeholders, and coordination between them for greatest effect, to address technical, economic and operational barriers. As the short-sea and deep-sea shipping sectors are mainly governed by IMO regulations (and will be influenced by the recent GHG reduction strategy), the Netherlands' efforts may be best focused on inland shipping where it can have greatest impact through Dutch policy and interventions on a national level. However, the Platform for Sustainable Biofuels and other Dutch stakeholders can also play an important role in facilitating change in the short-sea and deep-sea sectors – in particular, by working with ports, who play a key role at the interface between the deep-sea, short-sea and inland shipping sectors. This study is an initial overview of possible interventions, which sets the foundation for the development of more detailed interventions and a roadmap for implementing them on the part of the actors concerned.

Barriers	Actions	Actors
Limited experience with and availability of alternatively fuelled vessels and related refuelling infrastructure	Evaluation of current experience and dissemination of best practice	Government in collaboration with key concerned parties
	Demonstration projects	Government or international / Dutch ports coalition
	Infrastructure grants / finance	Government initiatives to leverage private sector funding
	Port levy to (co-)fund infrastructure	Ports
	Fuels procurement commitments	Shipping industry
	Incentives for transition to alternatively fuelled vessel fleet	Government, ports
Price differential with fossil fuels	Advanced biofuels sub-target for inland shipping. Multiplier for use of advanced biofuels in shipping	Government
	Carbon pricing. Linking tonnage taxes to decarbonisation	Government
	Public procurement of biofuels	Government, public sector
	Reduction in port fees and other incentives at ports	Ports
	Private sector procurement of biofuelled shipping services	Industry (goods)
Lack of certification regulation	IGF codes for ethanol and methanol	IMO, classification bodies
Lack of policy alignment	Initiatives to align policies at European level and between different countries	Government, IMO, EU
	Mass balancing system for biomethane or bio-LNG	Government, EU
Lack of information concerning biofuels use	Information sharing, for example via establishment of a shipping biofuels forum	Relevant industry, associations and government departments

1 Introduction

Greenhouse gas (GHG) emissions are expected to increase significantly from 3% of current total global GHG emissions (from all industries) to 17% by 2050[1]. Whilst the shipping industry is expected to grow, this increase towards 2050 is caused mainly by the decarbonisation of other sectors, increasing the shipping sectors relative share of global emissions. Many industries and sectors have already began reduction measures, whereas the shipping sector has not yet done much to reduce its GHG impact. As a result, the sector's awareness of its social responsibility is emerging and the International Maritime Organisation (IMO) has recently adopted an initial target of reducing international shipping emissions by 50% in 2050, compared to 2008 levels, and is developing measures to significantly reduce GHG and other emissions from international shipping. Non-GHG emission reductions, in particular Sulphur Oxide (SO_x) emission levels, have been tightened for short-sea and inland shipping over the last few years and will become stricter on a global level from 2020 onwards.

The Netherlands, with its significant ports and inland waterway network, are an important economic and logistic hotspot for shipping and supply a large amount of fuel for shipping estimated at roughly 1.5 times that for road transport. Low carbon fuels including biofuels could provide an interesting option to achieve stricter environmental regulations in relation to both air quality and GHG emissions. This study aims to explore what contribution sustainable biofuels could make to the reduction of emissions in the Dutch shipping sector, how the use of biofuels in the shipping sector could be accelerated, and what actions could be taken by different Dutch stakeholders.

To achieve this, this study is split into four main parts:

- Emission reduction drivers
- Decarbonisation options
- Biofuels – the potential role in decarbonising shipping
- Interventions

The first describes the current and evolving policy situation for both GHG and non-GHG emissions on an international, European and Dutch level. The second provides a brief overview of incumbent marine fuels and non-biofuel options for decarbonising the shipping sector. Next the most important biofuel options are described in Chapter 4 and their merits and drawbacks are evaluated. This evaluation is carried out based on the readiness of biofuel production now and in 2030, the compatibility with the vessel fleet and infrastructure both now and in 2030, and the GHG emission reduction potential. This section also compares cost and GHG emission reductions for incumbent and biofuel options, analyses the non-GHG emissions reductions of different biofuels, and evaluates the total cost of ownership and payback time of methanol, Liquefied Natural Gas (LNG) and a scrubber retrofit to comply with SO_x regulation. This allows drawing conclusions on the potential contribution of different sustainable biofuels to GHG emission reductions. The final part of this report, in Chapter 5 explores which interventions could help overcome certain barriers to the uptake of biofuels in shipping in the Netherlands and which actors could deal with these interventions.

[1] Cames, M., Graichen, J., Siemons, A. and Cook, V. (2015) 'Emission Reduction Targets for International Aviation and Shipping' European Parliament, Policy Department A: Economic and Scientific Policy. Available at: http://www.europarl.europa.eu/RegData/etudes/STUD/2015/569964/IPOL_STU(2015)569964_EN.pdf

2 Emissions reduction drivers in shipping

The most important driver for the decarbonisation of shipping, as well as for the reduction of non-GHG emissions in the shipping sector, is legislation. Technical (ship design, engine development), economic (market development), and operational (slow steaming, autonomous shipping) factors can enable or influence emission reductions, but the only real driver is policy and the targets it sets.

Despite the European focus on the decarbonisation of transport, shipping has so far been difficult to reform due to its often international nature, but it is expected policymakers will put in place legislation in the near-term. The reduction of non-GHG emissions in the shipping sector, however, has already been enshrined in air pollutant regulations for some time.

This chapter explores the current regulatory environment that governs emissions of both GHGs and non-GHGs in the shipping sector and looks ahead to future developments. In doing so the **geographical scope** (international, supranational, national), **shipping sector type** (deep-sea shipping, short-sea shipping, inland shipping, ports), and **emission type** (CO_2, NO_x, SO_x, PM) provide the three main categorisations that could be applied when assessing the issue. In this chapter we use geographical scope as the primary categorisation. Within the sections on the international, supranational (i.e. European), and national (i.e. Dutch) regulatory environment, we address shipping sector type and emission type.

In general, deep-sea and short-sea shipping are regulated by international and supranational levels of policy. Inland shipping is mainly governed by national polices and international treaties on the supranational level. The interface between these two 'domains' are sea ports.

2.1 International

At the international policy level, the shipping industry is governed by the United Nations (UN) institution called the International Maritime Organisation (IMO). Within the IMO, the Marine Environment Protection Committee (MEPC) is empowered to deliberate all matters in the IMO that relate to the "prevention and control of pollution from ships". Here, pollution is regarded in the wider sense, including plastic and chemical water pollution and invasive species from ballast water contamination, as well as air pollution and GHG emission (that are the subject of this study). Significantly, the MEPC comprises of all IMO Member States, reflecting the views and agendas of all parts of global shipping[2]. The International Convention for Prevention of Pollution from Ships which was produced by the IMO, commonly known as MARPOL, includes provision in Annex VI which represents the international policy to limit air pollutants from shipping exhaust gases and the regulation on energy efficiency to combat GHG emissions. Annex VI entered into force in 2005 after being first adopted in 1997[3], ratified by 86 of 192 states (as of June 2016) which represents over 95% of the global merchant fleet by gross tonnage[4].

[2] IMO (Accessed March 2018) 'Structure of the IMO'. Available at: http://www.imo.org/en/About/Pages/Structure.aspx
[3] MARPOL Annex VI (Accessed March 2018) 'MARPOL Annex VI NOx Technical Code & SOx explained'. Available at: https://www.marpol-annex-vi.com/marpol-annex-vi/
[4] Hughes, E. (2016) 'MARPOL Annex VI – an update of international regulatory developments for prevention of air pollution and the energy efficiency of ships', International Maritime Organization (IMO), Global Shippers' Forum AGM. Available at: https://globalshippersforum.com/media/1252/edmund-hughes-imo-29-july-2016_final.pdf

International policy and regulation will affect all the **short-sea and deep-sea shipping** sector types, as well as sea port operations. The IMO's jurisdiction covers all of the sea and coastal areas of the world and therefore inland shipping and inland ports will only be affected by the supranational and national frameworks if there is an international agreement outside of the IMO that is directly applied to the inland sector.

There are currently very few policies in place to reduce the emission of GHGs that would allow shipping to make a substantial contribution to emission reduction objectives of international agreements, such as the Paris Agreement[5]. Although, recently targets have been set by the IMO to aim to reduce the GHG emissions by 50% by 2050, compared to 2008 levels. The international nature of sectors like shipping and aviation leads them to a unified, global, top-down approach as the preferred option. The adoption of international policy and legislation is known for its difficulty and slow-progress. However, the IMO has already implemented globally applicable regulations on the emission of SO_x and Nitrogen Oxides (NO_x). This suggests that an IMO GHG strategy may be successful in shipping. Indirectly, the non-GHG emission regulations (SO_x and NO_x) could have an effect on the GHG emissions from shipping, whether positive or negative. For this reason, alongside the growing pressure for shipping to react to the threats of global warming and climate change, the IMO and MEPC have now turned to focus on GHG emissions. The current and possible future regulations that effect GHG emissions, as well as the possible uptake of new fuels and technologies, for example biofuels, are now detailed.

2.1.1 GHG emissions

In the absence of accepted universal GHG targets for international shipping, the IMO and MEPC have implemented a few policies to reduce fuel consumption and, consequently, GHG emissions.

2.1.1.1 Energy Efficiency Design Index (EEDI)

In 2011, the Energy Efficiency Design Index (EEDI) was adopted by the IMO and applied standards to all newly-built vessels that were built from 2013 onwards, covering the sectors of the merchant fleet representing 72% of emissions from newly-built ships[6]. The aim was to reduce GHG emissions through increases in efficiency via continued innovation and technology development, due to the incremental strengthening of the standards (every 5 years). This is aimed to result in a 30% reduction of GHGs emitted per tonne mile (capacity x distance) by 2025, with an intermediate target of 20% in 2020, when compared to the reference of the average efficiency of ships built between 2000 and 2010[6].

The Energy Efficiency Design Index uses an equation to estimate the CO_2 emissions per tonne mile relative to a reference value that is obtained from regression of EEDI values from the reference period. The EEDI is calculated using the initial designs of the ship and then is confirmed in sea trials of new ships and needs to be below that of the reference value. The regulation does not apply to any vessel below 400 gross tonnage (GT) of dead weight tonnage (DWT)[7], or where DWT is not a suitable metric for its transport capacity. For example, Ro-Ro ships, ferries, cruise ships and other speciality vessels[8] .

[5] The Paris Agreement is an international agreement in response to the threat of climate change that limits global temperature increase by 2100 to below 2 degrees Celsius above pre-industrial levels and an increase of 1.5 degrees Celsius should be aimed for.
[6] MARPOL Annex VI (Accessed March 2018) 'EEDI & SEEMP'. Available at: https://www.marpol-annex-vi.com/eedi-seemp/
[7] Deadweight Tonnage (DWT) measures the load-carrying capacity of a vessel. For the EEDI equation, 100% of DWT is used for all vessels, with the exception of containerships where 70% is used.
[8] ICCT (2011) 'The Energy Efficiency Design Index (EEDI) for New Ships'. Available at: https://www.theicct.org/sites/default/files/publications/ICCTpolicyupdate15_EEDI_final.pdf

The responsibility of compliance with Energy Efficiency Design Index falls to the ship's flag state. Member states can only enforce penalties for non-compliance on ships flying their flag but can deny entry to port from vessels from another flag state. This can negatively impact the effectiveness of this policy, as denying port access is a strong geopolitical action that would be unlikely to be taken.

2.1.1.2 Ship Energy Efficiency Management Plan (SEEMP)

Whilst the Energy Efficiency Design Index (EEDI) only applies to newly built ships, the Ship Energy Efficiency Management Plan (SEEMP) is a requirement for all ships[9]. The SEEMP encourages existing vessels to review the new technologies and operational practices that would provide the best efficiency from their ship. It mainly focuses on monitoring a ship or fleet efficiency through tools such as the Energy Efficiency Operational Indicator (EEOI). This allows operators to quantify the effect of any changes made that could benefit the efficiency of a vessel. For example, more frequent propeller or hull cleaning, more efficient journey planning or technical solutions such as waste heat recovery or upgraded ship components[10].

2.1.1.3 Increased monitoring

As part of a larger effort by the IMO to understand what is required to reduce GHG emissions from shipping, the MEPC adopted the requirement that all ships of 5000 gross tonnage or above (85% of CO_2 emissions from international shipping) need to submit consumption data for each of the fuel types used onboard the vessel, as well as transport and cargo work information[11], using a methodology used as part of the Ship Energy Efficiency Management Plan[12]. This monitoring and data collection is aimed to provide the information for decision on future GHG emission reduction measures, which would be implemented by the IMO. This data collection also provides a baseline and the ability to track the progress or success of any adopted emission reduction measures.

2.1.2 Future international policy on GHG emissions

The form of future of GHG emission regulation at the international level is uncertain. However, there is a clear acknowledgement of the issue and the reduction policies for other pollutants have been successful. The reduction of GHG emissions will require larger changes away from the incumbent technologies and fuels. This opens an opportunity for biofuels that can be used as a 'drop-in' fuel or with limited conversion requirements. The possible complexity of decarbonising shipping is acknowledged in the recently adopted monitoring regulations (see above section), the Marine Environment Protection Committee (MEPC) commissioning of a roadmap to implement a "Comprehensive IMO strategy on reduction of GHG emissions from ships" covering the period 2017-2023 and, most importantly the initial GHG strategy adopted by the IMO in April 2018[9].

[9] IMO (Accessed March 2018) 'Low carbon shipping and air pollution control'. Available at: http://www.imo.org/en/MediaCentre/hottopics/ghg/pages/default.aspx
[10] MARPOL Annex VI (Accessed March 2018) 'EEDI & SEEMP'. Available at: https://www.marpol-annex-vi.com/eedi-seemp/
[11] IMO (2016) 'New requirements for international shipping as UN body continues to address greenhouse gas emissions' Briefing 28. Available at: http://www.imo.org/en/MediaCentre/PressBriefings/Pages/28-MEPC-data-collection--.aspx
[12] Hughes, E. (2016) 'Recent developments at IMO to address GHG emissions from ships' COP22 Side Event. Available at: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/UN%20Joint%20side%20event%20presentation.pdf

The MEPC aims to adopt a full IMO strategy for the reduction of GHG emissions in 2023. This strategy is planned to include[13]:

1. Introduction and context including emission scenarios
2. Vision
3. Levels of ambition
4. Guiding principles
5. List of candidate short-, mid- and long-term measures
6. Barriers and supportive measures; capacity building and technical cooperation; R&D
7. Follow-up actions towards the development of the revised strategy
8. Periodic review of the strategy

The focus of the initial strategy is on the vision and level of ambition. After MEPC 72, the vision was stated as "IMO remains committed to reducing GHG emissions from international shipping and, as a matter of urgency, aims to phase them out as soon as possible in this century" and the initial targets adopted included the following[14]:

1. Carbon intensity of the ship to decline through implementation of further phases of the energy efficiency design index (EEDI) for new ships
    - to review with the aim to strengthen the energy efficiency design requirements for ships with the percentage improvement for each phase to be determined for each ship type, as appropriate;
2. Carbon intensity of international shipping to decline
    - to reduce CO_2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008; and
3. GHG emissions from international shipping to peak and decline
    - to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst pursuing efforts towards phasing them out as called for in the Vision as a point on a pathway of CO2 emissions reduction consistent with the Paris Agreement temperature goals.

The targets set were an important sign of the seriousness of the seafaring shipping sectors to decarbonise. There was a strong lobby to make these targets match the levels required to reach the Paris Agreement. These levels are very ambitious at 100% reduction compared to 2008 levels by 2050 for a 1.5C target and 70% reduction for 2C target. These were supported by the EU and pacific island countries.

The guiding principles and specific measures will be researched further. The guiding principles refer to whether the strategy would be based upon the IMO principle of "no more favourable treatment" (NMFT), the United Nations Framework Convention on Climate Change (UNFCCC) "common but differentiated responsibilities and respective capabilities" (CBDR&RC) principle or some combination of both. The NMFT needs to be applied so that ships do not simply change flag state to avoid higher

[13] IMO (2017) 'Summary of the 71st MEPC session 3-7 July 2017'. Available at: http://www.imo.org/en/MediaCentre/MeetingSummaries/MEPC/Pages/MEPC-71.aspx
[14] IMO (2018) 'UN body adopts climate change strategy for shipping' Briefing. Available at: http://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx

targets or more restrictions. CBDR&RC could be included through developed countries contributing more to any development of new technologies needed for large GHG reduction[15].

Possible short-, medium- and long-term measures include[16]:

Short term 2018-2023

- Revision of the ambition of the Energy Efficiency Design Index (EEDI) and make it applicable to the 2023-2030 period
- Introduce operational efficiency standards that will support investment in retrofitting and practices such as slow steaming
- Develop mechanism to apply CO_2 price for shipping fuel
- Increase port-based initiatives such as basing port fees on the environmental performance of the ship.
- Develop a framework that reduces the overall carbon intensity of shipping fuel over time through mandating low-carbon fuels or applying fuel standards.
- Identify the best route to zero-carbon shipping through a stakeholder consultation group.

Medium term (2023-2030)

- Implement the new EEDI with new ambition.
- Strengthen operational efficiency standard
- Implement framework on reducing overall carbon intensity of fuel
- Fully integrate a GHG emission pricing mechanism

Long term (2030 onwards)

- Adjust and incrementally increase policies discussed in the short- and medium-term sections to meet the targets set out in the initial GHG strategy.
- Revise and update strategy where needed

These are only recommendations. The final outcome is unclear and may have significant effect on the deployment of alternative fuels and technologies, such a biofuels.

2.1.3 Non-GHG emissions

The IMO introduced air pollutant regulations for international shipping which particularly effect the emissions of SO_x (and PM) and NO_x. These have been successful in reducing the emissions of these pollutants and are gradually tightening. Currently, these regulations take the form of **global limits** and stronger requirements within **Emission Control Zones (ECAs)**.

[15] European Parliament (2017) 'Key issues at stake at the 71st session of the IMO Marine Environment Protection Committee (MEPC 71). Available at: http://www.europarl.europa.eu/RegData/etudes/BRIE/2017/602062/IPOL_BRI(2017)602062_EN.pdf
[16] OECD (2017) "Further development of the structure and identification of the core elements of the draft initial IMO strategy on reduction of GHG emissions from ships' Available at: https://www.iea.org/media/news/2017/ISWGGHG2214.pdf

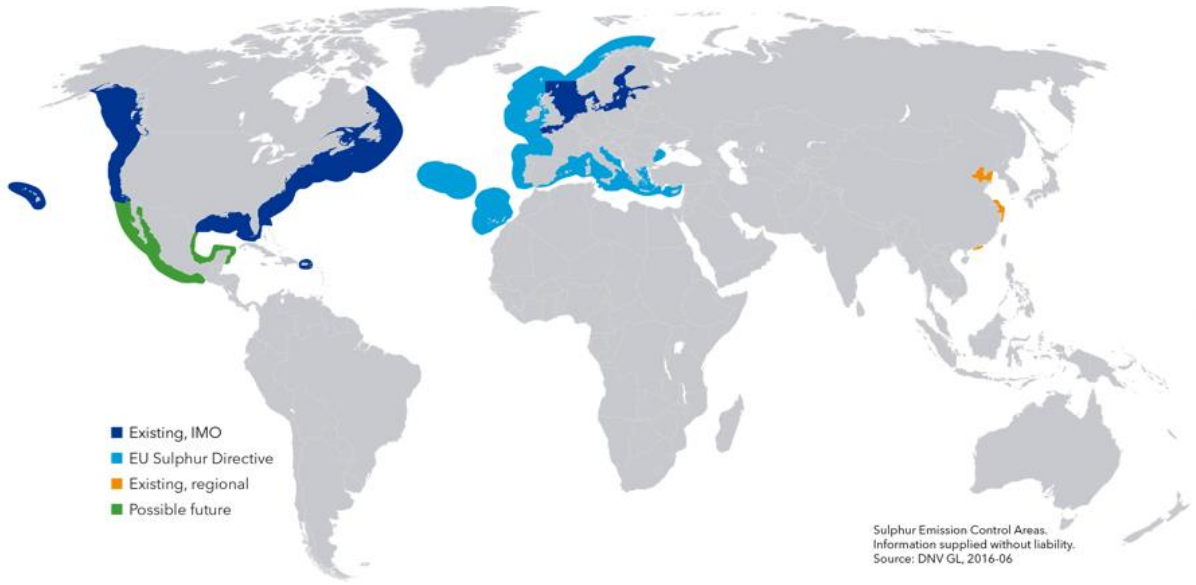

Figure 2-1: Map of non-GHG Emission Control Areas (ECAs)

At this point in time, there are four ECAs under the IMO[17]:

1. The Baltic Sea ECA
2. The North Sea ECA
3. North American ECA
4. United States Caribbean Sea ECA

These areas are represented in Figure 2-1. The SO_x and PM regulation utilises both global limits and ECAs. In the ECAs, the current regulation limit of 0.1% m/m (mass/mass) of sulphur content in the fuel deems regular marine fuel oil, or Heavy Fuel Oil (HFO), unusable without further post-combustion treatment. This has caused the intended fuel switching and technology change that is needed to reach these targets within the ECAs. The ECA SO_x limit was strengthened to its current 0.1% m/m level in 2015 when it dropped from 1% m/m. The global limit is currently set at the level of 3.5% m/m of sulphur content in the fuel. This limit allows the use of most HFOs. Therefore, under this current policy framework, ships that spend most of their time inside the ECAs bunker another more expensive[18] type of fuel such as Marine Diesel Oil (MDO), Marine Gas Oil (MGO) or a low sulphur, or ultra-low sulphur, HFO (LSHFO or ULSFO). These vessels switch to operating on this lower-sulphur fuel when inside the ECAs. The progression of these emission limits for sulphur are summarised in Figure 2-2.

[17] IMO (Accessed March 2018) 'Low carbon shipping and air pollution control'. Available at: http://www.imo.org/en/MediaCentre/hottopics/ghg/pages/default.aspx

[18] Jiang, L., Kronbak, J. and Christensen, L. P. (2014) 'The costs and benefits of sulphur reduction measures: Sulphur scrubbers versus marine gas oil'. *Transportation Research Part D: Transport and Environment*. Volume 28, May 2014, Pages 19-27. doi: https://doi.org/10.1016/j.trd.2013.12.005.

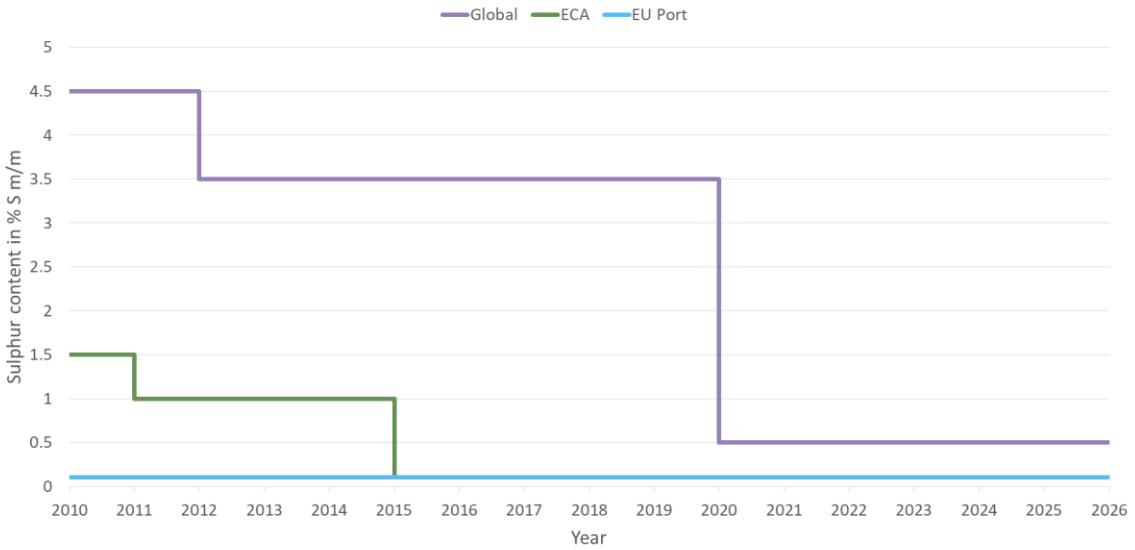

Figure 2-2: Progression of SO_x emission limits. Data Source: IMO[19]

In 2020, the global SO_x limit has been accepted by the Marine Environment Protection Committee (MEPC) to be strengthened to 0.5% m/m. This will prohibit the use of HFO that does not have post-combustion treatment, such as SO_x scrubbers. This could have significant potential fuel and technology changes in the deep-sea and short-sea shipping sectors.

The other controlled air pollutant is NO_x. These emission limits have been applied in a tiered approach, with a similar structure with a lower global limit and a stronger limit for certain ECAs. The level of emission allowed depends on the rated speed of the engine in rpm. Figure 2-3 outlines this.

[19] DNV-GL (2016) 'Managing sulphur limits – updated guidelines'. Available at: https://www.dnvgl.com/maritime/publications/sulphur-limits.html

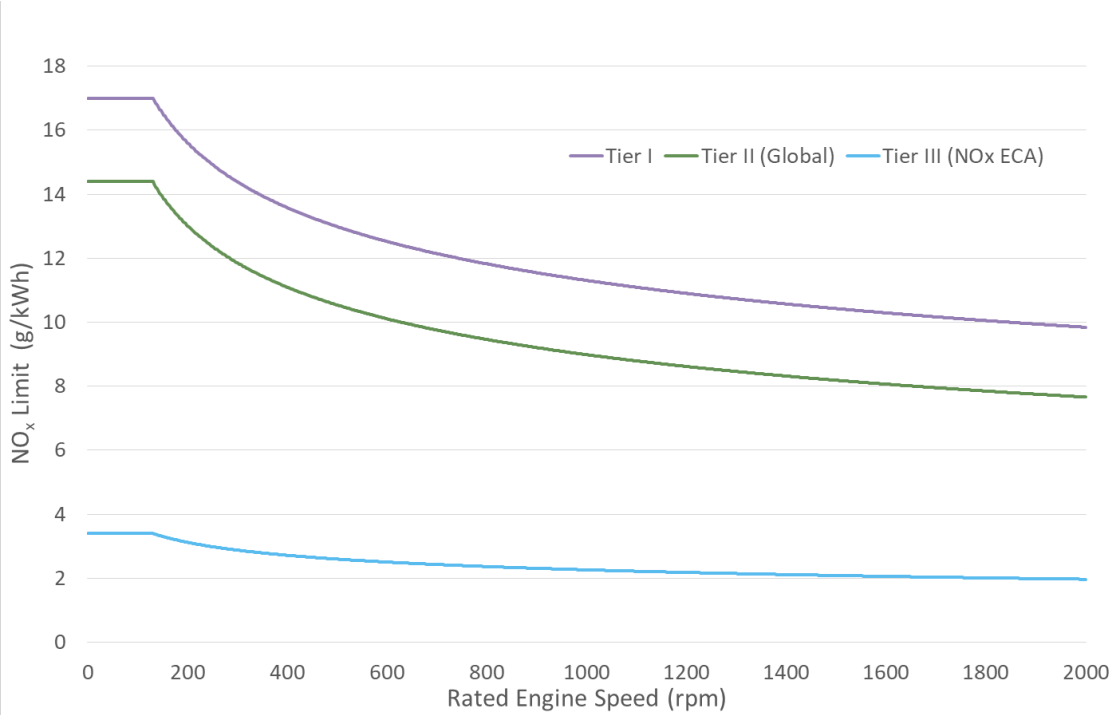

Figure 2-3: NO_x emission limits. Data Source: IMO[20]

From 2011, newly-built vessels have to comply with Tier II emission limits. Whereas, those built before that have only have to adhere to the Tier I limits. However, this would have had limited impact so far as the vessel park in shipping only changes slowly due to the long lifetime of ships. Tier I and II limits are globally applied, whereas Tier III only applies within the NO_x Emission Control Areas (ECA). Currently, only the North American ECA and the United States Caribbean Sea ECA have NO_x Tier III. Tier III regulations are only applicable to those ships constructed on or after the 1st January 2016[20].

In July of 2017, the MEPC voted to accept the amendments to Annex VI of MARPOL that will extend NO_x Tier III emissions controls to the Baltic Sea and North Sea ECAs starting on 1st January 2019[21]. This will standardise the IMO regulated ECAs.

Beyond the developments that have been described there is no clear progression for the SO_x and NO_x regulations. There is no report of development of the Tier III NO_x regulations to be implemented globally or for a Tier IV. Similarly, no further sulphur content reductions are acknowledged at this point in time.

2.1.3.1 The impact on GHG emissions

Currently, in the absence of specific GHG emission limits, the level of GHG emission is controlled by other emission regulation and market drivers, such as technology cost and fuel prices.

For example, the use of scrubbers is currently one of the most common methods for compliance to SO_x limits. Scrubbers are an established technology and one of the cheapest and easiest to install or

[20] IMO (Accessed March 2018) 'Nitrogen Oxides (NO_x) – Regulation 13'. Available at: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx

[21] MEPC (2017) 'Report of the Marine Environment Protection Committee on its 71st session'. Available at: http://www.iadc.org/wp-content/uploads/2017/08/MEPC-71-17-Report-Of-The-Marine-Environment-Protection-CommitteeOn-Its-Seventy-First-Session-Secretariat.pdf

retrofit to gain compliance, especially when compared to other measures such as propulsion technology change like LNG[22]. However, the effect of using scrubbers increases the fuel consumption of a vessel, therefore increasing the GHG emissions, as the fuel remains HFO[23]. All biofuels reduce SO_x emissions drastically because biofuels have a very low-sulphur content, meaning that there is almost no SO_x formation during combustion. Therefore, this is a major advantage for biofuels and could hence be an interesting option to achieve SO_x emission limits.

The use of technologies such as Exhaust Gas Recirculation (EGR) or Selective Catalytic Reduction (SCR)[24] to comply with NO_x emission reduction regulation has a similar effect, increasing fuel consumption and GHG emissions[23].

The use of these technologies not only increases the instantaneous emissions intensity but also results in vessels that may be less likely to adopt a different fuel in the future. The average lifetime of a modern ship is 25-30 years[25], so delay in implementing low-carbon solutions (from an engine technology perspective) may have a significant effect on the industry's ability to meet long-term emission targets. Therefore, it is important to consider all the current and future objectives of air pollution policy to remove barriers to change.

2.2 European Union

On the supranational level, the main organisation producing policy, regulation and other legislation that concerns shipping is the European Union (EU). EU regulations could have a significant effect on the success of biofuel deployment for shipping in both Europe and the Netherlands. Currently, the EU is supportive of MARPOL Annex VI and the IMO regulations on SO_x, with an expansion of the Sulphur Emission Control Areas (SECAs) in Europe with the EU Sulphur Directive. The EU has also introduced the Non-road Mobile Machinery emission regulation (NRMM), which affects mainly the inland shipping and port operation sectors. These range of EU regulations **affect deep-sea, short-sea and inland shipping sectors, as well as ports.** However, not each individual regulation applies to all of these sectors.

Despite a recognition that maritime GHG emissions must be handled to keep within total emission targets and international agreements, such as the Paris Agreement, there is currently no policy or target to reduce maritime GHG emissions at the EU level. The progress on the development of EU maritime GHG policy and how it interacts with international level policy is detailed in this section.

In inland shipping specifically, the EU is not the only supranational organisation. The Central Commission for Navigation on the Rhine (CCNR) also has regulatory powers over inland waterways and the characteristics of the vessels that travel on them. This was formed under the principle of free-shipping and a single jurisdiction of the waterways, governed by the CCNR. These principles are underpinned by the Mannheimer Akte: an international treaty between the European countries that the Rhine and inland waterways run through[26]. At this time, these regulations only include non-GHG

[22] Jiang, L., Kronbak, J. and Christensen, L. P. (2014) 'The costs and benefits of sulphur reduction measures: Sulphur scrubbers versus marine gas oil', *Transportation Research Part D: Transport and Environment*, 28, pp. 19–27. doi: https://doi.org/10.1016/j.trd.2013.12.005.
[23] DNV-GL (2017) "Low Carbon Shipping towards 2050" Maritime White Paper
[24] IVL & CE Delft (2016) 'NO_x controls for shipping in EU Seas'. Available at: https://www.transportenvironment.org/sites/te/files/publications/2016_Consultant_report_shipping_NOx_abatement.pdf
[25] UNCTAD (2011) 'Review of Maritime Transport'. Available at: http://unctad.org/en/Docs/rmt2011ch2_en.pdf
[26] Central Commission for Navigation on the Rhine (http://www.ccr-zkr.org)

emissions but are quickly being replaced by more strict and overarching EU legislation, as discussed in Chapter 2.2.4.

The EU has an action plan to make inland shipping a "quality mode of transport", that has high environmental standards amongst other positive economic, social and governance characteristics. This is called NAIDADES II and sets out a programme for policy action in the period of 2014-2020[27].

2.2.1 GHG emissions reduction policy

In the 2011 White Paper on the Single European Transport Area, the European Commission outlined that EU maritime transport should reduce its emissions by 40% (or 50% if feasible) by 2050 compared to 2005 levels, by utilising alternative technologies and fuels[28]. However, shipping is not currently part of the EU's emission reduction targets. These targets are detailed in Table 2-1 and included milestones are 2020, 2030 and 2050. The 2020 climate & energy package is a set of legislation that includes the 2020 GHG reduction targets, the EU ETS, renewable energy (see below) and energy efficiency directives and funding programmes.

Table 2-1: Summary of EU GHG emission reduction targets

Policy	GHG emission reduction	Renewable energy share	Improvement in energy efficiency
2020 climate & energy package[29]	20%	20%	20%
2030 climate & energy framework[30]	40%	27%*	27%
2050 low-carbon economy[31]	80% (60% by 2040)	-	-

*The value for the share of renewable energy in 2030 is not finalised and still under discussion. The final value depends on the result of the discussion between the European Parliament, Commission and Council. There is a possibility that this value would end up at higher than 27%, which would provide positive policy support for the use of biofuels in all transport sectors.

The EU Emissions Trading Scheme (EU ETS) is a mechanism used to achieve these targets. It uses a cap-and-trade method to reduce emissions from multiple sectors including power generation, industry and commercial aviation[32]. Shipping is being discussed to be included in this sector due to the similarities with aviation.

[27] European Commission (2013) 'Towards quality inland waterway transport NAIADES II' Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013DC0623&from=EN
[28] European Commission (2011) 'Roadmap to a Single European Transport Area–Towards a competitive and resource efficient transport system' Office for Official Publications of the European Union. doi: 10.2832/30955.
[29] European Commission (Accessed March 2018) '2020 climate & energy package'. Available at: https://ec.europa.eu/clima/policies/strategies/2020_en
[30] European Commission (Accessed March 2018) '2030 climate & energy framework'. Available at: https://ec.europa.eu/clima/policies/strategies/2030_en
[31] European Commission (Accessed March 2018) '2050 low-carbon economy'. Available at: https://ec.europa.eu/clima/policies/strategies/2050_en
[32] European Commission (Accessed March 2018) 'EU Emissions Trading System (EU ETS)'. Available at: https://ec.europa.eu/clima/policies/ets_en

In 2013, the European Commission began the process of incorporating shipping emissions into the EU reduction targets[33]. Similarly to the IMO, the EU is currently in the monitoring, reporting and verification phase of its shipping emission reduction strategy and is yet to set any targets or to implement measures to reach those targets. This is part one of a three part approach to the inclusion of the maritime sector in the reduction targets of the EU, which includes[34]:

1. Implementing a system for monitoring, reporting and verification (MRV) of emissions
2. Definition of reduction targets for the maritime transport sector
3. Application of a market based measure (MBM).

The MRV regulation (Regulation 2015/757) obliges all ships above 5000 gross tonnage to report yearly data on CO_2 emissions[35]. This applies to all ships on voyages to, from and between ports in the jurisdiction of EU member states[33]. This is estimated to be 55% of all ships stopping in EU ports and 90% of CO_2 emissions. The GHG gas monitoring is limited to CO_2 to reduce the administrative burden upon ship-owners and operators, as it is the main GHG emitted from shipping[35].

The EU has a strong preference for shipping GHG reduction mechanisms to be led at the international level by IMO[36]. The EU was committed to including shipping emissions in the EU ETS until the IMO reaffirmed their commitment to find a GHG reduction strategy in the near term[37]. The EU would like to maintain the international competitiveness of the EUs shipping sector by the implementation of an even and globally universal policy[28].

2.2.2 Renewable fuels policy

The EU's renewable fuels policy contributes to the overall GHG reduction framework, and is applicable to renewable fuels in shipping, especially biofuels.

Renewable Energy Directive (2009/28/EC)

The Renewable Energy Directive (RED)[38] is the main regulatory framework for renewable energy in the European Union. It defines an objective for the EU to provide 20% of its energy from renewable sources by 2020, including 10% renewable energy in transport. This target is to be achieved by all EU Member States, but each of them defines a specific target, which takes its particular situation (e.g. climate, agriculture, forestry, energy consumption patterns) into account. To fulfill its objectives, each Member State must develop and implement a *National Renewable Energy Action Plan (NREAP).* Most member states, including the Netherlands, have transposed the RED into national legislation in the form of biofuels blending mandates.

The use of renewable fuels in shipping would theoretically count towards this target. However, it depends on whether the MS has implemented policy in the national framework to allow shipping to

[33] EMSA (Accessed March 2018) 'Greenhouse Gas'. Available at: http://www.emsa.europa.eu/main/air-pollution/greenhouse-gases.html
[34] European Union (2013) 'Integrating maritime transport emissions in the EU's greenhouse gas reduction policies EN', p. 9.
[35] European Commission (2015) 'REGULATION (EU) 2015/757 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport, and amending Directive 2009/16/EC', *Official Journal of the European Union*, pp. 1–22. Available at: http://eur-lex.europa.eu/pri/en/oj/dat/2003/l_285/l_28520031101en00330037.pdf
[36] European Commission (Accessed March 2018) 'Reducing emissions from the shipping sector'. Available at: https://ec.europa.eu/clima/policies/transport/shipping_en
[37] Jacques, B. (2017) 'Threat of shipping's inclusion in EU Emissions Trading Scheme recedes'. Available at: http://www.seatrade-maritime.com/news/europe/threat-of-shipping-s-inclusion-in-eu-emissions-trading-scheme-recedes.html
[38] Renewable Energy Directive (2009/28/EC). Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN

contribute to the target. The targets are split into the numerator – the renewable transport fuels that count towards the percentage target – and the denominator – the total transport fuel consumed. Currently, the denominator consists of only road and rail transport fuels. Therefore, implementing policy to include shipping (or other sectors like aviation) into the formula would help to reach these targets. The UK, for example, has not included shipping fuels in the scope of their national framework of the RED, due to there being no international agreement yet on the approach to decarbonising shipping[39]. However, in the Netherlands, it is possible to count the delivery of renewable fuels to shipping bunkers towards the obligation.

The RED also defines the conditions in which renewable energy should be produced, taking into account technical, economic and environmental aspects. Biofuels can only be counted towards the renewable energy target if they comply with sustainability criteria. Biofuels cannot be produced from feedstocks produced at converted natural forests, protected areas, highly biodiverse grasslands, wetlands or high carbon lands (land-use criteria). These criteria do not apply to biofuels made from waste and residues. In addition, biofuels and bioliquids produced in installations starting operations on or before 5 October 2015 must achieve a 50% reduction in greenhouse gas (GHG) emissions over their life cycle, compared to fossil fuels (as of 1 January 2018). For installations starting operations after 5 October 2015 the lifecycle GHG reduction must be 60%. Annex V of the RED details the rules for GHG accounting.

Several options exist to demonstrate compliance of biofuels and bioliquids with the RED sustainability criteria, the most commonly used being through EU-approved voluntary certification schemes[40]. The other possibility is for member states to develop a national verification scheme, but so far, only Austria is using this option. The Netherlands has a verification protocol on double counting of biofuels.

The use of particular feedstocks (energy crops, wastes and residues) is promoted over "conventional" feedstocks, which are deemed to pose higher risks of market-mediated effects (e.g. indirect Land-Use Change). This is done through the contributions from biofuels produced from these feedstocks counting twice towards achieving the RED targets – termed 'double counting'. The RED does not define precisely which feedstocks are eligible for double counting, and therefore each Member State has been able to publish its own list, which gave way to inconsistencies across the European Union. Transposition of the RED into national legislation has not been consistent across Member States (e.g. double counting, verification requirements, accounting and reporting rules).

The future developments of the RED are currently under discussion. RED II, for the period 2021-2030, is being debated between the Commission, Parliament and Council and an agreement is expected in late 2018. The result will be implemented post-2020. Based on current suggestions in the RED II, renewable fuels in shipping would receive a multiplier of 1.2 on their contribution.

Fuel Quality Directive (2009/30/EC)

The Fuel Quality Directive (98/70/EC)[41] was initially aimed at defining the characteristics of petrol and diesel fuel used in the European Union. It was revised in 2009 (its reference number then changed to

[39] Department for Transport (2017) 'The Renewable Transport Fuel Obligations Order; Government response to the consultation on amendments'. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/644843/renewable-transport-fuel-obligations-order-government-response-to-consultations-on-amendments.pdf
[40] EU-approved voluntary schemes. Available at: http://ec.europa.eu/energy/node/74
[41] Fuel Quality Directive (2009/30/EC). Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0030&from=EN

2009/30/EC) by adding requirements for fuel suppliers to reduce the greenhouse gas intensity of their fuels by 6% in 2020, compared to the EU transport energy mix in 2010, primarily through the inclusion of biofuels in the fuel mix. To count against the target, biofuels must comply with the same sustainability criteria as those defined in the RED.

The FQD only applies to road transport and gasoil used in non-road-mobile machinery. Therefore, FQD will only apply to the inland shipping sector type and not deep-sea or short-sea. However, in many Member States there is no specific mechanism to ensure compliance with the FQD emission reduction target. Some EU countries have put incentives in place to reward biofuel producers based on GHG savings. This is the case in Germany, where the Federal Emission Control Act (BImSchG) requires fuel suppliers to reduce the greenhouse gas emissions of fuels that they supply. The GHG reduction target is 3.5% for 2015-16, rising to 4% from 2017-19 and 6% in 2020 and beyond. Currently biofuels, renewable fuels of non-biological origin and upstream emissions savings may be used to meet the target, but non-renewable low-carbon fuels cannot.

The FQD also limits to the Sulphur content of diesel fuel used in inland shipping. As of the January 2011 the maximal permissible quantity in inland shipping fuel is 10 ppm or 0.001%. This has large implications on the range of fuels being available for use in inland shipping, with EN590 diesel the only shipping fuel meeting these requirements.

RED/FQD Amendment (2015/1513/EC)

The RED/FQD Amendment 2015/1513/EC (also known as the iLUC Directive)[42], adopted in 2015, attempts to reduce the risk of indirect effects by limiting the consumption of biofuels made from "conventional" feedstocks, i.e. those sugar, starch and oil crops which can be used for food or feed. A 7% "cap" is introduced, which is essentially the maximum contribution of conventional biofuels, which can be counted against the RED renewable energy target. Member States are allowed to use larger volumes of conventional biofuels, but these will not count against the target beyond the defined cap. In addition 5x counting was introduced for electricity from renewable sources consumed by road vehicles.

Member states are also required to set, as of April 2017, a minimum inclusion target for "advanced" feedstocks listed in Annex IXa in the Directive, which should be no less than 0.5% in 2020. The Annex IXa list includes wastes, residues and energy crops, but does not include UCO and tallow, which are in Annex IXb. Whilst Annex IXb feedstocks still double count, they are not considered advanced. However, the advanced targets are indicative, with three criteria defined under which member states may set lower targets, namely:

- limited potential for the sustainable production of biofuels from Annex IA feedstocks, or the limited availability of such biofuels at cost-efficient prices on the market;
- specific technical or climatic characteristics of the national market for transport fuels, such as the composition and condition of the road vehicle fleet; or
- national policies allocating commensurate financial resources to incentivising energy efficiency and the use of electricity from renewable energy sources in transport.

[42] RED/FQD Amendment (2015/1513/EC). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32015L1513

As a result, many Member States are likely to set lower 2020 advanced targets than 0.5%, or no targets at all. However, the Netherlands have transposed these advanced targets into law at above the suggested 0.5%. The percentage of the final consumption of advanced renewable needs to be 0.6% in 2018, 0.8% in 2019 and 1.0% in 2020 on an energy basis[43].

2.2.3 Future EU policy on shipping GHG emissions

The EU is looking to the IMO to take the lead, but is willing to act if adequate progress is not seen, so that it can reach its own legislative targets (which have been discussed in the previous section). The decision on whether to incorporate shipping emissions in the EU ETS has been reported to be deferred until 2023. More information on the IMO roadmap is expected and it is unlikely any further policy will be discussed until its release and implementation.

The outcomes of EU GHG maritime reduction policy remains relatively uncertain. There is a high probability that there will be some mechanism for maritime GHG emission reduction in the short term, whether this is unique to the EU or in compliance with international policy will depend on the results of the full IMO strategy.

RED II will be implemented in a form similar to that of its proposal; whether member states will implement policy to encourage the use of renewable fuels, and specifically biofuels, in shipping may also depend on the results of international policy, as well as contributions of biofuels to aviation applications.

2.2.4 Non-GHG emissions regulation

At the supranational level, the deep-sea and short-sea sector types are only effected by the EU Sulphur Directive. However, inland shipping is subject to many non-GHG emission regulations at this level. The Central Commission for the Navigation of the Rhine[44] (CCRN) set regulations on the emission of non-GHG emissions. These regulations were set out in emission limits called CCR1 and CCR2. CCR1 applied to ships built after 2002 and more strict regulations in the CCR2 for those built after 2007[45]. These CCR regulations interplay with the EU Non-Road Mobile Machinery (NRMM) regulations, with the stronger regulation being the ultimate limit for the specific non-GHG emission. SO_x regulations for inland shipping in the FQD are detailed in Chapter 2.2.2.

Although not a gaseous emission, noise pollution can also be a driver for change in inland shipping. However, the driver is not as strong as for GHG and non-GHG gaseous emissions. The use of electric engines on the inland waterways could significantly reduce the noise to surrounding populated areas.

EU Sulphur Directive ((EU) 2016/802)

The sulphur content of gas oils and heavy fuel oils is regulated in the EU, for both marine and land-based applications[46]. This directive has commonly become known as the 'Sulphur Directive'. It restricts the sulphur content of the fuel to 0.1% (by mass) in the SECAs, as well as a 3.5% sulphur content for

[43] Article 3, point 3 of Draft Ordinance Renewable Energy Transport
[44] CCRN are an international organisation operating at the supranational level and govern the inland waterways.
[45] Tachi, K. (2016) 'EU STAGE V de effecten op de BINNENVAART'. Available at: https://www.verbrandingsmotor.nl/wp-content/uploads/2015/11/2015-10-29-VIV-Stage-V-seminar-Khalid-Tachi.pdf
[46] EMSA (Accessed March 2018) 'Sulphur Directive'. Available at: http://www.emsa.europa.eu/main/air-pollution/sulphur-directive.html

EU waters outside of the SECAs[47]. A SECA is defined as the ECA/SECA detailed in MARPOL Annex VI. See Figure 2-2 in Chapter 2.1.3 for details of the ECA and the wider EU directive zone[48].

The only deviation from the 0.1% sulphur levels is for passenger ships, where outside of the SECA they have to adhere to a 1.5% sulphur content limit because of their proximity to land. Additionally, this directive imposes restrictions of the sulphur content of fuels that can be used by ships berthing in EU ports to 0.1%, as well as prohibiting the sale of marine gas oils with sulphur content above 0.1%[49].

However, Emission Abatement Methods can be used in conjunction with fuels with higher sulphur contents. These include, but are not limited to, using Boil-off gas in LNG carriers, scrubbers and biofuels[49,50].

This applies to all shipping sectors using heavy fuel oil or gas oils, and mainly to deep-sea and short-sea shipping and ports, although it could also be applicable to inland shipping. However, inland shipping has its own specific sulphur content regulations under the FQD, which are much stricter at the level of 10ppm or 0.001% (see Chapter 2.2.2).

Non-Road Mobile Machinery (NRMM) Emissions Regulations ((EU) 2016/1628)

Non-Road Mobile Machinery (NRMM) Emissions Regulations is an EU level regulation implemented to force non-road mobile machinery engines to comply with pollutant emission limits, before they can be sold on the EU market[51]. In the context of shipping, and this project, NRMM is specifically applicable to the inland shipping and port operation sectors. In its current form, NRMM only provides regulation on non-GHG gases like carbon monoxide, hydrocarbons, NO_x and PM. GHG emissions are currently not part of the regulation.

Stage V is the latest in a progression of emission limits under NRMM and will apply to all sales in the EU between 2019 and 2021 depending on the engine size, with approval for new engine types in starting in 2018[52]. The progression of NRMM limits can be seen in Figure 2-4. The Stage V limits will surpass that of the CCR2 regulations from the CCRN. This will see a reduction of 99% from CCR1 for standards for NO_x and 98% reduction for PM.

[47] European Commission (2016) 'DIRECTIVE (EU) 2016/802 sulphur content', 5(1600), p. 58–78.
[48] Tachi, K. (2016) 'EU STAGE V de effecten op de BINNENVAART'. Available at: https://www.verbrandingsmotor.nl/wp-content/uploads/2015/11/2015-10-29-VIV-Stage-V-seminar-Khalid-Tachi.pdf
[49] EMSA (Accessed March 2018) 'Sulphur Directive'. Available at: http://www.emsa.europa.eu/main/air-pollution/sulphur-directive.html
[50] EMSA (Accessed March 2018) 'Emission Abatement Methods'. Available at: http://www.emsa.europa.eu/main/air-pollution/emission-abatement-methods.html
[51] European Commission (2016) 'Regulation (EU) 2016/1628 of the European Parliament and of the Council of 14 September 2016', *Euratom*, 2016(167). doi: http://eur-lex.europa.eu/pri/en/oj/dat/2003/l_285/l_28520031101en00330037.pdf.
[52] ICCT (2016) 'European Stage V non-road emission standards'. Available at: http://www.theicct.org/sites/default/files/publications/EU-Stage-V_policy update_ICCT_nov2016.pdf

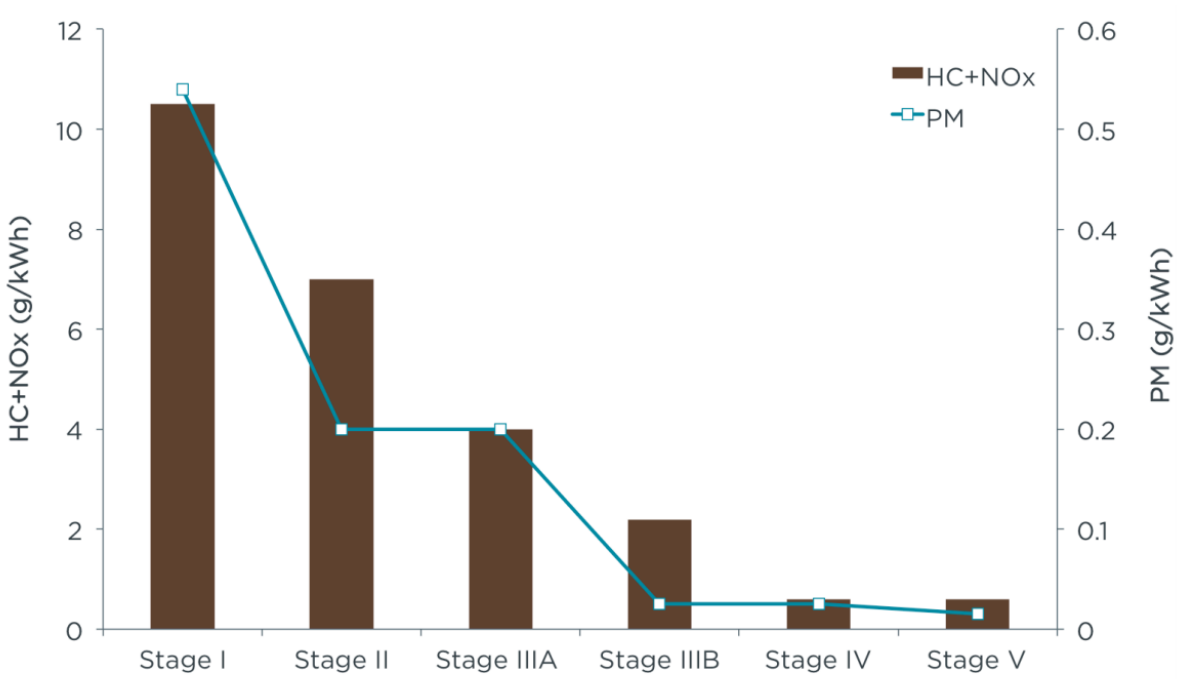

Figure 2-4: NRMM Emission Limits for Hydrocarbons (HC) + Nitrogen Oxides (NO_x)[53]

Although not directly applicable to GHG emissions reduction, the constant tightening of other air pollutants through NRMM forces technology and fuel change, much like the IMO SO_x and NO_x regulations in the deep-sea and short-sea sectors. This is an opportunity as well as a constraint; the implementation of new technology can have a positive or negative benefit upon CO_2 emissions.

Additionally, alternative technologies or fuels have to comply with these regulations, despite the level of CO_2 emission reduction. There is currently no information on further development on the NRMM with respect to the non-GHG emissions or any indication that GHG emissions will be incorporated into this policy.

2.3 The Netherlands

At the national level, Dutch policy and regulation can influence all shipping sector types considered in this study. However, Dutch regulation on the types of shipping that operate internationally (Deep-sea, short-sea and inland) may be detrimental economically if it is stronger than other countries. Therefore, the Dutch national policy recognises that it needs to support and receive support from higher levels of policy, at the EU level (especially for inland shipping and short-sea) and the international level (especially for deep-sea and short-sea)[54].

EU Directives are implemented at the national level. This results in the same coverage of non-GHG emissions as discussed in the above section. Therefore, those non-GHG policies are not discussed again here.

[53] ICCT (2016) 'European Stage V non-road emission standards'. Available at: http://www.theicct.org/sites/default/files/publications/EU-Stage-V_policy update_ICCT_nov2016.pdf
[54] Government of the Netherlands (2016) 'Energy Agenda'. Available at: https://www.government.nl/binaries/government/documents/reports/2017/03/01/energy-agenda-towards-a-low-carbon-energy-supply/Energy+agenda.pdf

2.3.1 GHG emissions reduction policy

The focus of Dutch national policy is on GHG emissions reduction. GHG emissions in the Netherlands are largely regulated by Dutch national energy policy, as non-energy emissions only account for 20% of the national emissions[55] (in 2015).

Dutch national energy policy is the responsibility of the Ministry of Economic Affairs and Climate Policy and the Ministry of Infrastructure and Water Management. The Ministry of Economic Affairs and Climate Policy oversees the overall climate and energy policy. Whereas the Ministry of Infrastructure and Water Management governs the implementation of renewable energy in transport[56,57]. The Dutch national energy policy can be split into its main constituent parts:

- Energy Agreement (Energieakkoord)
- Energy Report
- Energy Agenda (Energieagenda: naar een CO_2-arme energievoorziening)

The 2013, Energy Agreement was signed by the Dutch government and many other organisations and interest groups. It details in a high-level roadmap the targets and strategy of Dutch national energy policy from 2013 to 2023, in line with EU policy[58]. It also includes some longer term objectives for sectors such as transport. Parties signing the agreement agreed to a 60% CO_2 reduction in transport by 2050[59]. This policy includes financial support in the form of subsidy but focusses heavily on the power sector[60]. There is no elaboration on how these targets will be implemented or what modes of transport will be targeted for reduction.

The 2016 Energy Report outlines the post-2020 energy targets. Transport forms one of the four energy functions that is targeted for GHG emissions reduction and biofuels are highlighted as the best alternative to incumbent fuels in heavy-duty and freight transport, by road, water and air[61]. However, it is recognised that there is a limit to the sustainable use of bioenergy, with possible economic effects on the production of food cited as a concern[61]. The Energy Report also highlights the willingness and commitment for the Dutch government to influence stricter CO_2 emission reduction from transport at the EU policy level[61].

The shipping sector is detailed in the 2016 Energy Agenda, which comprises a strategy up to 2050. It highlights international action as the important factor for GHG emissions reduction because of the need to "maintain the Dutch international competitive position in ocean shipping"[55]. This suggests that the Dutch government will not implement ocean shipping policy or regulation at the national level but will support agreements and regulation in this sector on the international and EU levels. Similarly, inland shipping is suggested to be considered at EU level, with additional support to accelerate the

[55] Government of the Netherlands (2016) 'Energy Agenda'. Available at: https://www.government.nl/binaries/government/documents/reports/2017/03/01/energy-agenda-towards-a-low-carbon-energy-supply/Energy+agenda.pdf
[56] Government of the Netherlands (Accessed April 2018) 'Ministry of Economic Affairs and Climate Policy' Available at: https://www.government.nl/ministries/ministry-of-economic-affairs-and-climate-policy
[57] International Energy Agency (2014) 'Energy policies of IEA countries: The Netherlands, 2014 review', *Paris and Washington, D.C.: Organisation for Economic Co-operation and Development*, (October), p. 116. doi: 10.1787/9789264107960-en.
[58] Sia Partners (2015) 'The Dutch Energy Agreement 2013-2023: Where Are We Heading To?' Available at: http://energy.sia-partners.com/dutch-energy-agreement-2013-2023
[59] Sociaal-Economische Raad (2013) 'The Agreement on Energy for Sustainable Growth: a policy in practice', pp. 1–146.
[60] Government of the Netherlands (2013) 'Energy Agreement for Sustainable Growth'. Available at: https://www.government.nl/topics/renewable-energy/documents/publications/2013/09/06/energy-agreement-for-sustainable-growth
[61] Ministry of Economic Affairs (2016) 'Energy Report', *Dutch Government*, p. 10. Available at: https://www.government.nl/documents/reports/2016/04/28/energy-report-transition-tot-sustainable-energy

renovation of the current fleet. However, a national level policy is not suggested. LNG, biofuels and increased efficiency of vessels are all highlighted as possible routes to achieving the 2050 targets set out in the energy agreement. Although, no detail on what each of these decarbonisation options will contribute[62].

Another area of Dutch policy that influences the shipping sectors is the Maritime Strategy (Maritime Strategy and Seaports)[63]. The 2018-2021 version of this strategy was signed off by the coalition government (formed in 2017) in February 2018. The work programme for this strategy includes specific actions for both sea shipping and inland shipping. An ambition for a zero-emission inland shipping sector by 2050 is detailed in the work plan and states that this is aimed to be part of a new 'Green Deal' that will be concluded in 2018 by the government. It also outlines the Dutch involvement with the IMO GHG reduction strategy, with a plan for creating an inventory of measures to help achieve what it hopes are ambitious targets set by this international strategy. It also includes plans for new funding models for the shipping sectors. The maritime strategy work plan describes a strategic policy direction and requires to be enshrined in law separately.

The EU RED was transposed into Dutch national legislation in 2011, which includes an obligation on fuel suppliers to meet renewable fuel targets in transport of 10.4% in 2018, 13.2% in 2019 and 16.4% in 2020[64]. This is higher than stated in the RED, which suggests 10% by 2020. Renewable fuel bunkered in the Netherlands can be counted towards the obligation, regardless if used in inland, shortsea or deep-sea shipping. This provides a policy driver for including biofuels in shipping. However, there is no reason why the biofuels would be directed to ship bunkering rather than road transport, especially as shipping fuel usually has a lower price point compared to both of these sectors and could see the premium on biofuels as too expensive. The RED was implemented via amendments to the Environmental Management Act (Wet Milieubeheer), alongside a Decree on the Renewable Energy for Transport (Besluit hernieuwbare energie vervoer) and the Regulation on Renewable Energy for Transport (Regeling hernieuwbare energie vervoer)[65]. These resulted in the Annual Obligation (HEV) and obligate registered parties to deliver the renewable fuel target[66]. These obligations are managed by the use of renewable fuel units (HBEs). One HBE is equal to one gigajoule (1GJ) of renewable fuel and is created by the Dutch Emissions Authority within the Energy for Transport Registry (REV) when a delivery of renewable fuel is claimed by a party. There is a trading system for HBEs, so obligated parties can either produce their own HBEs or buy them off those that are producing renewable fuels[67]. The double counting for the use of advanced biofuels is included in the HBE system by awarding double the units to these fuels (See Chapter 2.2.2 for description of double counting). HBEs cannot be traded outside of the Netherlands. However, the HBEs currently cover renewable fuel that is delivered

[62] Ministry of Economic Affairs (2016) 'Energy Report', Dutch Government, p. 10. Available at: https://www.government.nl/documents/reports/2016/04/28/energy-report-transition-tot-sustainable-energy
[63] Dutch Government 'Werkprogramma Maritieme Strategie en Zeehavens 2018–2021' Available at: https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2018/02/22/rapport-werkprogramma-maritieme-strategie-en-zeehavens/rapport-werkprogramma-maritieme-strategie-en-zeehavens.pdf
[64] Article 3, point 1 of Draft Ordinance Renewable Energy Transport
[65] CMS (2011) 'Dutch Implementation of the Renewable Energy Directive for Biofuels'. Available at: https://cms.law/en/NLD/Publication/Dutch-implementation-of-the-Renewable-Energy-Directive-for-biofuels
[66] Dutch Emissions Authority (2018) 'Obligations under Renewable Energy for Transport'. Available at: https://www.emissionsauthority.nl/topics/obligations-under-renewable-energy-for-transport
[67] Dutch Emissions Authority (2018) 'Renewable Energy Units (HBEs)'. Available at: https://www.emissionsauthority.nl/topics/renewable-energy-units-hbes

anywhere into the Dutch market, no matter the mode of transport. The current value of renewable fuel units is around 7-9 €/GJ which would be doubled for advanced biofuels[68].

The EU FQD Directive was also implemented in Dutch national legislation through amendments to the Environmental Management Act (Wet Milieubeheer), requiring GHG emissions of all fuels in 2020 in the transport sector to be 6% lower than 2010 and inland shipping fuel to have a maximum Sulphur content of 10 ppm (0.001% by mass)[69].

The Ministry of Infrastructure and Environment has signed the Continuous On-Board Analysis and Diagnosis' (COBALD) Green Deal, which looks to improve the environmental impact of inland shipping. The COBALD system measures the energy consumption and emissions from inland vessels, collecting data for compliance and efficiency improvement. It is similar to the SEEMP in IMO policy and the MRV in EU policy. It should particularly aid older vessels to make efficiency and emissions improvements for emission regulation compliance, instead of having to carry out engine replacement[70].

In summary, the Netherlands has produced policy that looks to influence the national GHG emissions, the emissions from inland shipping and contributions towards renewable energy obligations in transport. There are no direct targets or regulation on deep- and short-sea shipping, due to the international nature of these sector types.

2.3.2 Dutch policy on shipping GHG emissions

The Rutte III Coalition Agreement (Regeerakkoord) has given some insight into policy on GHG emissions in the Netherlands. The Energy Agreement is to be replaced by a new climate and energy agreement with the target a 49% GHG emissions target by 2030, when compared to 1990 levels. The main targets and policy from the coalition agreement and new energy agreement will be transformed into a Climate Act. To reach this new 49% target, further GHG reductions are required and this agreement states biofuels as one of the opportunities[71].

The new coalition agreement means that the Netherlands will produce stricter renewable energy in transport targets than what will be included in RED II, which could be a benefit to shipping decarbonisation. However, this will depend on how incentives may differ across the road, shipping and aviation sectors.

The coalition agreement also highlights that deep-sea, short-sea and inland shipping have a large potential for emission reduction and a 'Green Deal' for ports and shipping will be concluded by the end of 2018[71,72]. The work plan of the maritime strategy suggests that for inland shipping this may have ambitious targets of a zero-emission fleet by 2050. The Dutch government will also support an ambitious IMO GHG reduction strategy.

[68] Maritime Knowledge Center (2018) 'Methanol as an alternative fuel for vessels'.
[69] CMS Law (2011) 'Dutch Implementation of the Renewable Energy Directive, Fuel Quality Directive and Clean Vehicles Directive'. Available at: https://cms.law/nl/NLD/Publication/Dutch-implementation-of-the-Renewable-Energy-Directive-Fuel-Quality-Directive-and-Clean-Vehicles-Directive
[70] Port of Rotterdam (2016) 'Inland vessels to participate in trial measuring their emission levels'. Available at: https://www.portofrotterdam.com/en/news-and-press-releases/inland-vessels-to-participate-in-trial-measuring-their-emission-levels
[71] People's Party for Freedom and Democracy (VVD), Christian Democratic Alliance (CDA), Democrats '66 (D66) and Christian Union (CU) (2017) 'Confidence in the Future: 2017–2021 Coalition Agreement', (October) pp. 41-47. Available at: https://www.kabinetsformatie2017.nl/documenten/verslagen/2017/10/10/coalition-agreement-confidence-in-the-future
[72] Statement by Lucia Luijten (IenW) at the Binnenvaart Rondetafelbijeenkomst on 9 March 2018

The Ministry of Infrastructure and the Environment is currently conducting a series of Rondetafelbijeenkomsten (Round Table Meetings) with the inland shipping sector to understand what emission reduction targets are achievable by when, and how they best could be met. This consultation process will help the government set targets for 2030 and 2050 by the end of the year (and enshrine them in law), but also set a target for 2021, the end of the current government's term.

In general, the political climate in the Netherlands appears supportive and ambitious in relation to GHG emissions reduction policy. There may be policy, regulation and financial support for decarbonisation initiatives for shipping in the near future, especially for inland shipping where the Netherlands can influence policy the most. This presents an opportunity to Dutch shipping (of all sectors) to embrace these changes.

2.4 Ports

Sea ports are the interface between the sea-faring sector types and inland shipping. Therefore, there is also an interface of the geographical levels of policy. However, rules and regulations for specific port operations and emissions are set by local and national bodies, as well as implementation of EU directives (through national law) and regulations. There are only international regulations on non-GHG emissions, ships waste and port security, but no international, supranational or national regulations regarding GHG emissions for ports.

Inland ports are under the jurisdiction of local and national policy. The close to 300 Dutch inland ports are linking up in the Nederlandse Vereniging van Binnenhavens. Together with the Port of Flushing (recently merged into 'North Sea Port') their actions for new sustainability regulations are based on the recent Green Deal 'Werkprogramma Maritieme Strategie en Zeehavens 2018–2021'. Agreements between European countries (EU or multi-laterally) for the inland waterways may also affect these policies, e.g. requirements for LNG bunker facilities in ports.

In the Netherlands, activities in ports (in-port-voyages, cargo-activities and services like repairs and bunkering operations) are considered in the overall Harbour Industrial Complex footprint. These collective emissions cover all industrial processes and ship activities, and are subject to local port bylaws and environmental standards.

2.4.1 Examples of port 'policies' on emissions (GHG and non-GHGs)

Currently both the Port of Rotterdam and Amsterdam are developing policies for reducing shipping emissions in their ports via port bylaws. Clean shipping[73] is promoted by restricting the usage of older engine-types and polluting fuels, and consideration is given to distinguishing between inland and short-sea/deep-sea shipping emissions.

All major ports use the Environmental Shipping Index (ESI)[74] as a 'level playing field' incentive for sustainable ship operations and management. This index allows scoring ships based on their environmental performance. Ships' sustainable management and operations are rewarded with

[73] Port of Amsterdam (Accessed March 2018) 'Duurzaamheid'. Available at: https://www.portofamsterdam.com/nl/havenbedrijf/duurzaamheid-toekomstbestendige-metropoolhaven-voor-klanten-en-omgeving#thema
[74] World Ports Sustainability Program (Accessed March 2018) 'Environmental Ship Index (ESI)'. Available at: http://www.environmentalshipindex.org/Public/Home

discounts on various port duties. Another system to encourage and provide incentives for sustainable management and operation of ships is the Green Award certification (for all shipping sectors)[75]. The highest level award is given for complete emission-free shipping.

2.5 Summary

An overview of the current and possible future policies affecting the shipping sector has been outlined in this section and provides a useful insight into the regulatory environment for the shipping industry in the Netherlands. Additionally, it provides important input for the rest of this study.

In conclusion, there is currently very little policy to reduce GHG emissions in the shipping sectors at all geographical levels. The only implemented GHG reduction regulation that currently requires compliance is the IMO's EEDI, applied to new ships in the deep-sea and short-sea sectors. At international and EU level, GHG emissions reduction strategies for the deep-sea and short-sea shipping sectors are starting to be developed; MRV regulations are being implemented at both levels, setting the foundation and baseline for targets to be set. Supranational level policy has had a significant effect on reducing non-GHG emissions in inland shipping. However, whether similar successful policies for GHG emissions for inland shipping at this level will be implemented is currently unknown. At a national level, it appears that policy for inland shipping will be produced within the next political term (up to 2021) and there will be support for an international initiative to reduce GHG emissions in sea shipping, as part of a wider more ambitious GHG reduction target to 2030.

Overall, a supportive environment for alternative shipping fuels should develop in all sectors, as the IMO, the EU and the Dutch government appear to have shipping GHG reduction as a legislative priority going forward. However, the policy and regulation for non-GHG pollutants are currently the major frameworks that affect biofuels in shipping. These policies are outlined in Table 2-2, highlighting the sector(s) they apply to.

Table 2-2: Regulations and policies in Dutch shipping – where they apply. (Red: regulation/policy does not apply; yellow: regulation/policy technically applies but unlikely to take effect; green: regulation/policy applies to this sector.)

Policy	Deep-sea	Short-sea	Inland	Port
IMO SO_x limits				
IMO NO_x limits				
IMO EEDI				
IMO 50% GHG reduction 2050				
EU SO_x Directive				
EU NRMM[76]				
NL HBEs[77]				
EU FQD 10ppm Sulphur limit				

The NRMM and FQD policies that affect ports are highlighted as yellow. It depends on the boundary of the port to where inland waterways start to whether ports are governed by these regulations.

[75] Green Award (Accessed March 2018) 'About the Green Award'. Available at: http://www.greenaward.org/greenaward/
[76] EU Non-Road Mobile Machinery Emission Regulations
[77] Renewable fuel units under renewable obligation in NL

3 Shipping decarbonisation options

Chapter 3 provides an overview of current market conditions in the shipping sector and the foreseen developments. It also explores the different energy options in terms of emission reduction potential, compatibility with the current vessel fleet and cost. Biofuels are specifically explored in further depth in Chapter 4.

A large number of reports and papers have addressed the issue of the decarbonisation of shipping in recent years. Reducing the greenhouse gas (GHG) emissions of shipping can either be achieved by being more energy efficient (i.e. reducing fuel/energy consumption through improved engine efficiency, lower on-board energy consumption, improved aero/hydrodynamics or improved routes) or by using a different energy carrier or fuel with lower life-cycle GHG emissions.

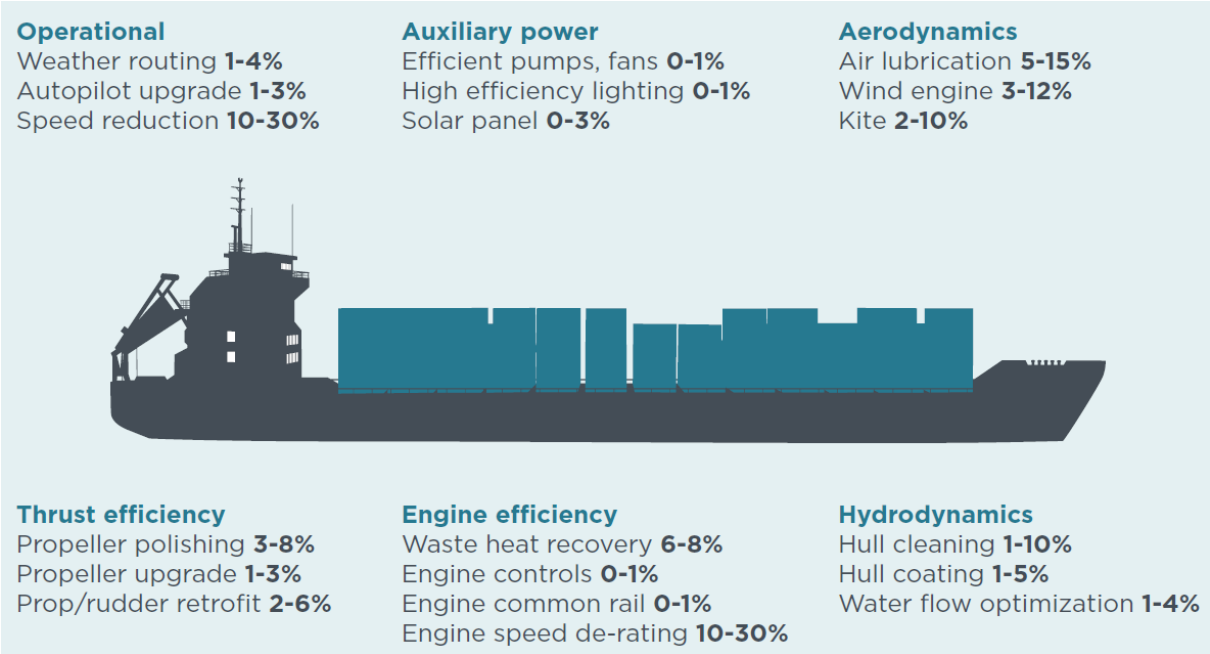

Figure 3-1: Overview of approaches to increase efficiency of shipping vessels

A good breakdown of options for the former was provided in Wang and Lutsey (2013)[78] as shown in Figure 3-1 above. The percentages shown refer to the potential reductions in fuel use reported in ICCT (2011)[79], which directly impact GHG emissions. ICCT (2011) and Wang and Lutsey (2013), conclude that the majority of these efficiency options would potentially lead to negative marginal abatement costs (Figure 3-2).

[78] Wang, H., and Lutsey, N. (2013) '*Long-term potential for increased shipping efficiency through the adoption of industry-leading practices*'. International Council on Clean Transportation, July 2013. Available from: https://www.theicct.org/sites/default/files/publications/ICCT_ShipEfficiency_20130723.pdf

[79] ICCT (2011) '*Reducing greenhouse gas emissions from ships: Cost effectiveness of available options*'. ICCT, White paper number 11, July 2011. Available from: https://www.theicct.org/sites/default/files/publications/ICCT_GHGfromships_jun2011.pdf

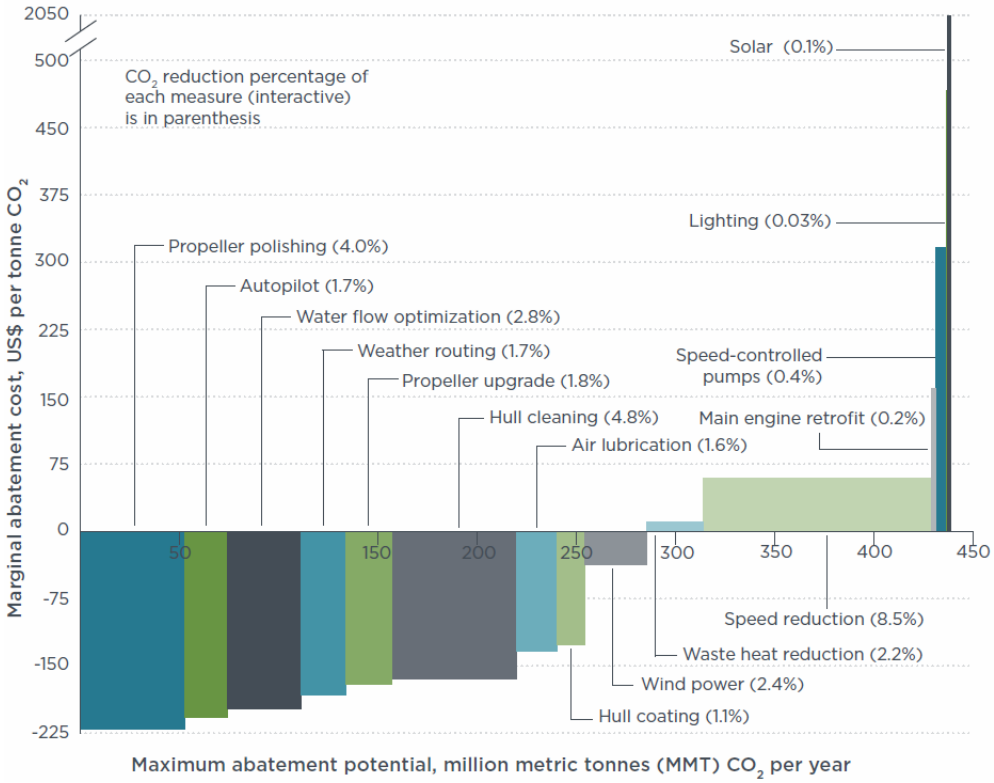

Figure 3-2: Marginal CO_2 abatement costs of CO_2 abatement options from increases in efficiency in shipping in 2020 (the cost to reduce emissions by one tonne of CO_2)

Additional technology improvements such as autonomous shipping could provide further increases in fuel and energy efficiency as soon as 2030[80], although 2050 looks like a more realistic estimate.

A recent review of around 150 studies by Bouman *et al* (2017)[81], aimed at providing a comprehensive overview of the CO_2 emissions reduction potentials and measures in shipping. The review concluded that any significant reduction in emissions will require a combination of measures. It however also pointed to biofuels as having the highest CO_2 emissions reduction potential, compared to other energy efficiency and alternative fuel options (Figure 3-3)[82].

[80] Steenhoff, P. (2016) ‚Hoe ziet de maritieme wereld eruit in 2030?' De blik op de einder, *Maritiem Nederland*. 18 May 2016. Available from: http://www.maritiemnederland.com/achtergrond/de-blik-op-de-einder/item1935
[81] Bouman, E. A., Lindstad, E., Riall, A.I, and Strømmana, A.H. (2017) State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review, *Transportation Research Part D: Transport and Environment*. Elsevier, Volume 52, Part A, May 2017, Pages 408-421, doi: 10.1016/j.trd.2017.03.022.
[82] The review report did not consider full electrification of ships.

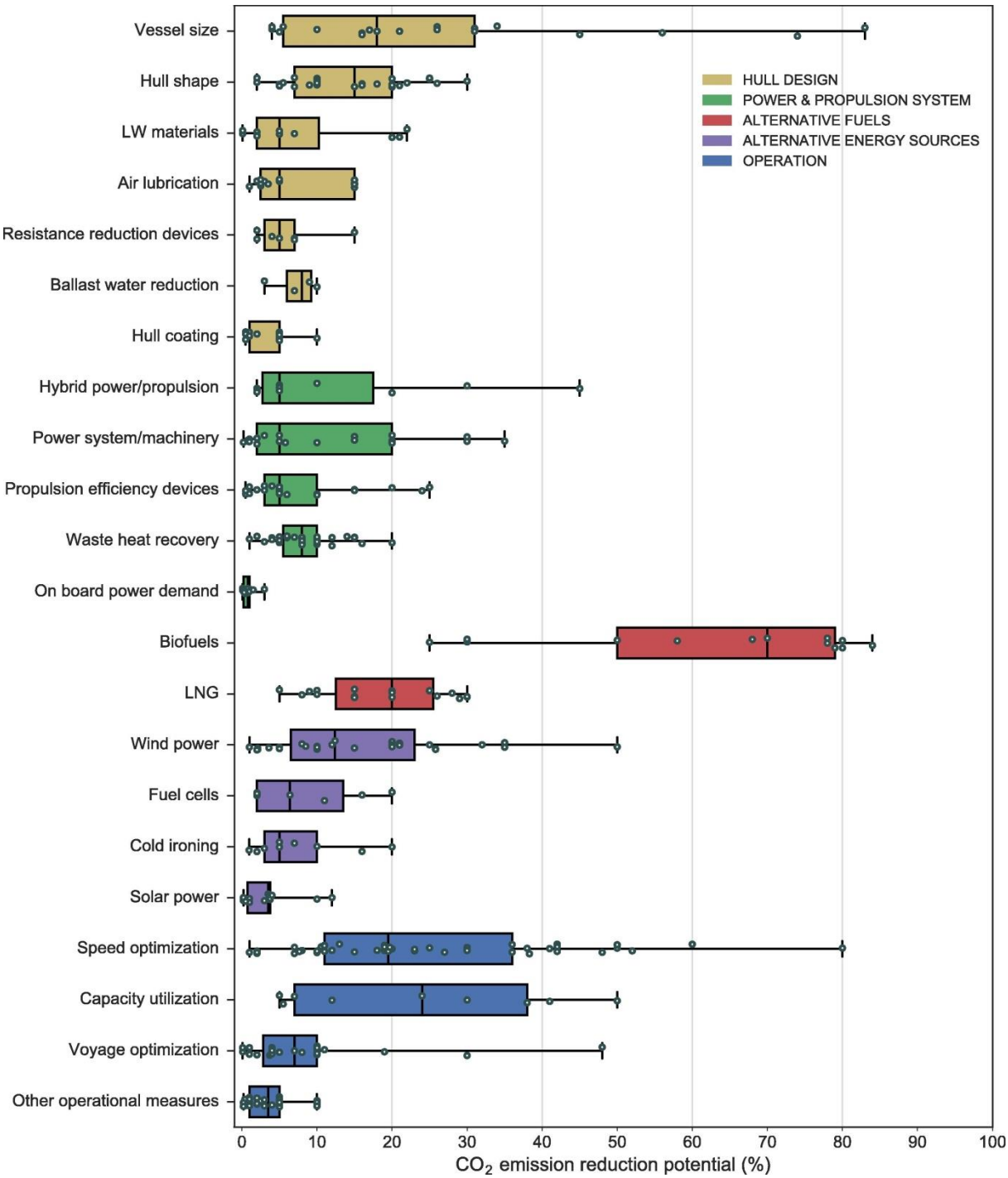

Figure 3-3: Shipping CO_2 emission reduction potential from individual measures[83]

[83] Results are classified in 5 main categories of measures. A solid bar indicates the typical reduction potential area, i.e. from 1st to 3rd quartile of the dataset, and a thin line indicates the whole spread of the dataset.

3.1 Ship design, operations and infrastructure

3.1.1 Ship design and operations

As publications like *Blueprint 2050, the maritime world beyond the horizon*[84] and *Global Marine Technology Trends 2030*[85] illustrate, the maritime sector will have a wide range of technological developments at its disposal to increase efficiency, reduce costs and GHG emissions.

More streamlined hulls (and 'nosejobs'), more efficient propeller design, better hull coatings and even air cushions to reduce friction[86] can be implemented to reduce GHG emissions, as improvements in ship technology, structure and materials emerge. Changes in ship operations could also have major impacts on fuel and energy consumption, and therefore on GHG emissions reductions. For example, slow steaming, the practice of operating ships at significantly less than their maximum speed, or introducing Dynamic Route Planning[87] would reduce fuel consumption drastically. Other innovations related to ship design and operation such as autonomous ships are also projected to make shipping more efficient. YARA Birkeland is expected to be the first autonomous cargoship although Chinese shipyards claim to be first to launch[88].

3.1.2 Dutch ports

Port operations and corresponding strategies respond to international (shipping) markets and policies developments[89]. A common development is their change from formerly being 'landlords' into Private Public Partnership entities. This implicates a more independent position of the port and customers of ports consider Port Authorities to guide and support them to new market opportunities. Given these customer expectations, ports can be early adaptors of innovation and facilitate new pilots and (proofs of-) concepts. Ports are working on many innovations to help deliver decarbonisation options, such as:

- **Port Performance**

Sea and inland ports are crucial interfaces ('spokes and hubs') in logistics. Smooth port operations and accessibility are key and shippers choose their ports on price (handling costs per cargo-unit) and overall port performance.

Ports host services like bunker operations. When introducing new fuels, flexible solutions like Ship to Ship (STS) bunkering and temporary bunker stations (e.g. LNG) could be a useful solution to respond to market demand while infrastructure is being built up[90]. A multi-fuel bunker station is being developed in Dordrecht Inland Seaport by PitPoint Clean fuel[91].

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[84] NISS (2016) '*Blueprint 2050, the maritime world beyond the horizon*'. NISS Support Fund. Available at: http://www.marin.nl/web/Publications/Blueprint-2050.htm
[85] Lloyd's Register, QinetiQ and University of Southampton (2015) '*Global Marine Technology Trends 2030*'. August 2015. Available at: https://www.lr.org/en/insights/global-marine-trends-2030/global-marine-technology-trends-2030/
[86] McLeman, L. (ND) '*Five future trends in the shipping industry*'. Marine-I website. Available at: https://www.marine-i.co.uk/news/article/4/five-future-trends-in-the-shipping-industry
[87] Andersson, P. and Ivehammar, P. (2014) 'Economic impacts. Cost benefit analysis of implementing dynamic route planning at sea'. Norrköping, Sweden: MONALISA Project Bureau.
[88] Kongsberg, 2018. Autonomous ship project, key facts about YARA Birkeland. Available at: https://www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/4B8113B707A50A4FC125811D00407045?OpenDocument
[89] C-W. Koorneef, AddVision, 2018, internal
[90] Port of Rotterdam (2018). 'LNG: import, export and bunkering'. Available at: https://www.portofrotterdam.com/en/cargo-industry/lng-import-export-and-bunkering
[91] Pitpoint clean fuels (Accessed March 2018). Available at: https://www.pitpoint.nl/multifuel-bunkerstation/

The innovation in refuelling and infrastructure in ports governs the pace at which alternative energy options can be implemented. This highlights the importance of continued engagement from ports to drive these changes and guidance from policy to achieve emission reductions in shipping.

- **Smart Ports**

Smart mobility in shipping often starts in ports, which compete to offer the innovations to facilitate operations and reduce costs for their clients. Sensor introduction on ships, jetty's, waterways and bridges provides predictable voyages and port planning. Various smartphone apps for shippers to better plan their voyages and operations have been introduced by both port administration and tech-companies[92]. For example, Riverguide provides the actual occupancy of ship berths and docks. Parkline[93] has an app for barges to see where you can obtain shore connection and one can order port service boats. This is supported by incubator and accelerator programs[94] encouraging start-ups to speed up innovation in shipping sectors.

Port authorities are accountable for ship and terminal performances (e.g. ship port time reduction); the current congestion problems on container terminals on Maasvlakte 2 in Rotterdam suggest that the supply chain from deep-sea to terminal-to inland barges is lacking coordination[95] and data-exchange. The hinterland connectivity via the waterways is not yet used optimally when data is not exchanged and coordinated throughout the supply chain.

These 'smart' and data developments in ports hold huge potential for increases in efficiency and implementation of 'green' policies and practices, and could find applications in relation to alternative fuel refuelling.

- **Green Ports**

There are a number of sustainability initiatives to develop 'Green Ports', which include:

- Volatile Organic Compound (VOC) emission controls and vapour-return requirements on cargo handling are becoming mandatory.
- Shore power connection (cold ironing) is mandatory for inland cargo ships in the city centre-basins.
- Sound-silencers are introduced on funnels to achieve noise reductions.
- And measures related to alternative fuels such as: Port service and patrol boats converted to hybrid and electric[96].
- Hydrotreated Vegetable Oils (HVO), a drop-in biofuel, introduced in port patrol-fleets (see Chapter 4.1.1).

[92] RiverGuide (Accessed March 2018). Available at: http://riverguide.eu
[93] Park-line (Accessed March 2018). Available at: https://water.park-line.nl/Registration/wp/en-GB/select
[94] C-W. Koorneef, AddVision, 2018, World Port Accelerator PORTXL
[95] Logistiek (2017) 'Ruzie in de Rotterdamse haven door falende ketenregie'. Available at: http://www.logistiek.nl/ketensamenwerking/nieuws/2017/10/heibel-de-rotterdamse-haven-door-gebrekkige-ketensamenwerking-101159195
[96] Port of Rotterdam (2018) 'Havenbedrijf Rotterdam neemt hybride vaartuig in de vaart' Available at: https://www.portofrotterdam.com/nl/nieuws-en-persberichten/havenbedrijf-rotterdam-neemt-hybride-vaartuig-in-de-vaart

3.2 Energy options

This section briefly outlines the energy options available to reduce GHG and pollutant emissions from shipping. The use of biofuels is one of these options and is specifically developed in Chapter 4. Energy options consist of the combination of an engine with an energy carrier (fuel, electricity). Due to the nature of this project, energy options will be discussed by energy carrier. Incumbent fuels are first discussed in order to set a baseline. Then alternative energy options are discussed starting with LNG.

The CO_2 emissions of alternative energy options other than biofuels are considered on a well to propeller basis. For biofuels (considered in Chapter 4) the emissions are considered on a well to tank basis and the tank to propeller emissions are assumed to be zero. This allows for comparison between the reduction potentials. However, the values referenced are taken from different studies with different methods for GHG calculations, which may have an effect on the comparison.

3.2.1 Incumbent propulsion technologies and fuels

To set a baseline on which to conduct this analysis, it is important to understand the incumbent propulsion technologies and fuels. In the deep-sea and short-sea shipping sector types, there is one dominant propulsion technology and two main fuel types. The propulsion method is a marine diesel (i.e. internal combustion) engine. The two main fuels used in these sector types are residual[97] fuels such as HFO and distillate[98] fuels such as MGO, as well as variants within these residual and distillate products, such as MDO that is a blend of HFO and MGO. In 2012, HFO and MGO/MDO made up over 97% of fuel consumption in the deep-sea and short-sea sector types (84% HFO and 13% MDO/MGO)[99]. The remainder was comprised of LNG, which was consumed by LNG carrier vessels for propulsion. LNG is one of the first of alternative fuel market entrants and should not yet be considered an incumbent fuel on the same level as the distillate and residual fuels, due to its low market share. Figure 3-4 displays how the main incumbent fuels used in sectors compare in terms of SO_x reduction. LNG is included but in a dashed circle to represent its different market status.

[97] Residual fuels are created from the fraction that does not boil off in the refining process of crude oil and are generally lower quality than distillate fuels.
[98] Distillate fuels are produced from a distillation of crude oil. These fuels are generally of higher quality than residual fuels.
[99] IMO (2014) 'Third IMO Greenhouse Gas Study 2014'. doi: 10.1007/s10584-013-0912-3.

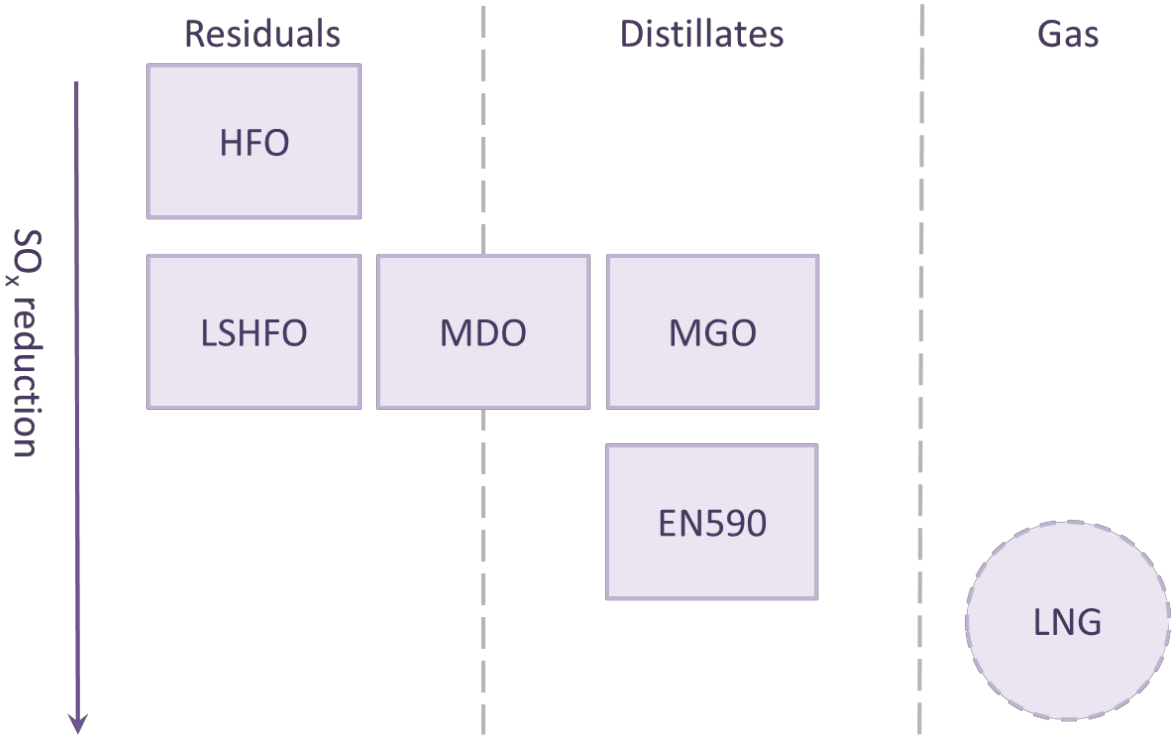


Figure 3-4: Fossil fuels used in shipping[100]

Low-sulphur HFO (LSHFO) is an alternative fuel with the sulphur removed in the production process, which is used more since the onset 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 regulations.

For the analysis in this report, a reference case for each of the three shipping sector types is needed to compare the compatibility of sustainable biofuels. These sectors are each given an archetype fuel (and engine) that reflects the average vessel from the fleet in that sector. The choice of a fuel in each sector is driven mainly by the sulphur regulations in the areas that these sector types operate. To comply with the SO_x regulation on global shipping (<0.5%) in 2020, the reference case for deep-sea shipping was defined HFO with scrubbers. This remains the prevailing option for economic reasons, despite the availability of ultra-low sulphur heavy fuel oil (ULSFO) and the ability to use MDO and MGO (See Chapter 4.4.3)

Short-sea shipping has seen transformation over the last decade, with the introduction of sulphur policy resulting in heavy usage of cleaner distillates (MGO and LSMGO), some use of EN590 diesel fuels (regular road transport diesel) in smaller vessels, ULSFO and use of heavy fuel oils with scrubbers[100]. All short-sea shipping from the Netherlands is assumed to be within the jurisdiction of the EU Sulphur Directive and in most cases the IMO ECA (See Chapter 2.1.3 for details), requiring a maximum sulphur content of 0.1%. Short-sea vessels in general use 4-stroke engines, which suits the use of distillate fuels[100]. Therefore the archetype for short-sea shipping was selected as LSMGO, as this fuel is sold with the guarantee of maximum of 0.1% sulphur[101]. Inland shipping in the Netherlands uses EN590 type diesel to comply with the low sulphur regulation from the EU FQD (less than 10ppm) which has been

[100] IEA Bioenergy (2017) 'Biofuels for the marine shipping sector', (October).
[101] Ship and Bunker (2018) 'Terminology' Available at: https://shipandbunker.com/prices/emea/nwe/nl-rtm-rotterdam#MGO

in place since 2010[102]. The other types of fossil diesels that are used in the other shipping sector types cannot be used in inland shipping.

Table 3-1: Definition of fuel reference cases for the three shipping sectors

Sector	Fuel	Sulphur requirement	Netherlands fuel consumption (PJ per annum in 2017)[103]
Deep-sea	HFO + scrubbers	<0.5%	403.2 for both
Short-sea	LSMGO	<0.1%	
Inland shipping	Diesel (EN590)	<0.001% (10ppm)	52.8

3.2.2 Diesel hybrid options

As in hybrid cars, an electric engine can be coupled to a diesel engine and power the same drivetrain. This allows a switch to zero-emission electric propulsion if and when required and is for instance being implemented in Dutch inland shipping by *DARI* and *Hybrid Ship Propulsion*[104]. The electric engine can be run off a battery, but a fuel cell would also be able to provide zero-emission power when using a zero-emission fuel such as hydrogen from renewable electricity (See also Chapter 3.2.8). However, the development of battery and fuel cell electric vessels is still at the demonstration phase and usually applied to smaller vessels (like the examples used above), due to the difficulty in reaching the power requirements of a large sea-faring vessel.

Another hybrid option injects hydrogen produced from renewable sources in a diesel engine alongside diesel and can yield considerable CO_2 emission reductions. This has been successfully demonstrated in vans by the British company ULEMCo[105]. It is currently being trailed by Cie. Maritime Belge SA with the Hydroville, a 14-meter passenger shuttle carrying passengers from Kruibeke to Antwerpen[106].

Finally the use of wind sails and solar panels to produce electricity on board could also be considered a hybrid option. SkySails[107] is a concept that uses large kites to propel the vessel with wind, using the higher wind speeds at greater altitude.

3.2.3 Liquefied Natural Gas (LNG)

In general, LNG can be used in spark ignition engines, dual fuel compression ignition engines and converted compression ignition engines. LNG is currently used most widely in dual-fuel engines. The boil-off gas from the LNG storage tanks is pumped to the engine where is combusted with a proportion of conventional fuel (HFO, MDO or MGO) to aid ignition, as LNG has a higher ignition point and will not

[102] Pon CAT (2018)'Verschillende Brandstoffen'. Available at: http://www.pon-cat.com/power/nl/over/sustainability-and-innovation/shipping-emissions/different-fuels
[103] Statline (Accessed March 2018) 'Motor fuels; deliveries by petajoule, weight and volume' Available at: http://statline.cbs.nl/Statweb/publication/?DM=SLEN&PA=83406eng&D1=0-59&D2=0&D3=131,143-145,147-148&LA=EN&VW=T
[104] DARI (2018) 'Ervaringen Hybride Duurzame oplossing' Presentation.
[105] ULEMCo (Accessed March 2018). Available at: http://ulemco.com/
[106] Green Car Congress (2017) '*CMB launching dual-fuel hydrogen-diesel ship*'. 30 November 2017. Available at: http://www.greencarcongress.com/2017/11/20171130-cmb.html
[107] SkySails (Accessed March 2018). Available at: http://www.skysails.info/en/skysails-marine/skysails-propulsion-for-cargo-ships/

self-ignite. LNG carriers commonly use LNG in dual-fuel engines. However, there are now of the order of 100 LNG-powered vessels of others types[108]. The technology readiness of these dual-fuel engines in LNG carriers is high, as they have been commonly used for these vessel types for many years.

It is possible to convert some diesel engines to LNG. Wartsila carries out these conversions and provides the same warranty for a converted engine as with a new engine[109]. A new Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF code) came into force in January 2017, initially focusing on LNG as amendment to the International Convention for the Safety of Life at Sea (SOLAS)[110].

LNG storage can be located on-deck or below-deck. However, there are less safety requirements if the tanks are placed on-deck, according to the regulations surrounding the storage of gas used for marine fuel. For some vessel types this would reduce cargo space and decrease the revenue of the ship. To minimise this loss of revenue, smaller storage capacity could be used. However, this would increase the bunkering frequency. This can be an issue for deep-sea shipping logistically and economically for all shipping types, as the time taken to bunker can impact the total journey distance/time and therefore the profitability. A disadvantage of LNG storage is that capital costs increase with tank size. This problem is compounded by the lower energy density of LNG compared to the incumbent diesel fuels, further increasing the need for larger fuel storage tanks. The increase in space needed for fuel storage creates a barrier that could limit the uptake of LNG in deep-sea shipping as it would reduce the tonnage of the ship, which could result in lower profits or higher shipping prices[111]. Short-sea shipping in Europe holds potential for LNG, due to the shorter voyage distances and the need for compliance with non-GHG regulations, which could compensate for reduced cargo space.

The required changes in refuelling infrastructure and subsequent costs are also barriers for widespread use of LNG as shipping fuel; conventional bunkering infrastructure and techniques cannot be used for this fuel. However, some of the existing refuelling infrastructure used for HFO, MDO or MGO would have to remain if dual-fuel engines were used as the propulsion system. Vessels using LNG propulsion are calculated to reduce CO_2 emissions by up to approximately 20%, when compared to the incumbent diesel fuels[112]. However, when considering GHG emissions other than CO_2 on a lifecycle basis, methane leakage from LNG use in engines can decrease the GHG reduction to as little as 8%[113,114,115]. This effect needs to be considered carefully if LNG is used as an alternative fuel for decarbonisation.

The fuel cost of LNG is also lower than that of the incumbent fuels, approximately 25-50% of the price of MGO[116]. The larger price differential between low sulphur fuels and LNG in short-sea and inland

[108] Moirangthem, K. (2016) '*Alternative Fuels for Marine and Inland Waterways*, *European Commission - Joint Research Centre Technical Reports*'. doi: 10.2790/227559.
[109] Wartsila (2012) 'LNG conversions for marine installations'. Available at: https://www.wartsila.com/twentyfour7/in-detail/lng-conversions-for-marine-installations
[110] IMO (2017) 'Safety for gas-fuelled ships – new mandatory code enters into force'. Available at: http://www.imo.org/en/MediaCentre/PressBriefings/Pages/01-IGF.aspx
[111] DNV-GL (2014) 'LNG as ship fuel: The future - today', (1), pp. 1–60. Available at: https://www.dnvgl.com/Images/LNG_report_2015-01_web_tcm8-13833.pdf
[112] DNV-GL (2017) 'Low Carbon Shipping Towards 2050', pp. 10-12.
[113] Maritime Knowledge Centre, TNO and TU Delft 'Framework CO_2 reduction in shipping' Available at: http://www.koersenvaart.nl/files/Framework%20CO$_2$%20reduction%20in%20shipping.pdf
[114] Bengtsson, S., Andersson, K. and Fridell, E. (2011) 'A comparative life cycle assessment of marine fuels: Liquefied natural gas and three other fossil fuels', *Proceedings of the Institution of Mechanical Engineers Part M: Journal of Engineering for the Maritime Environment*, 225(2), pp. 97–110. doi: 10.1177/1475090211402136.
[115] Verbeek, R., Kadijk, G., van Mensch, P., Wulffers, C., van den Beemt, B., Fraga, F. & Aalbers, A. D. A. (2011) Environmental and Economic aspects of using LNG as a fuel for shipping in The Netherlands., Delft: TNO.
[116] MAN Diesel & Turbo 'Costs and benefits of LNG' Available at: http://mandieselturbo.com/docs/default-source/shopwaredocuments/costs-and-benefits-of-lng3739431d863f4f5695c4c81f03ac752c.pdf?sfvrsn=3

shipping benefits LNG as an alternative fuel, when compared to deep-sea shipping with cheap HFO use. Large-scale adoption of LNG in shipping is often regarded as a possible pathway to reduce non-GHG emissions to very low levels[117] and to begin GHG reductions. The level of the GHG reductions is limited, unless bio-LNG is used and LNG vessels become more widespread. LNG could be well suited for use in inland shipping, due to the strict non-GHG emission regulations and the European Clean Power Directive requiring all inland ports on the Trans-European Transport Networks (TEN-T) to have LNG bunkering facilities by 2025, as well as the price differential driver[118]. There are currently a small number of LNG ships being used in inland shipping[119], for example, the 'Greenstream' barge operated by Shell[120]. However, unless the barriers to LNG are addressed, there may be a lack of market acceptance of LNG going forward. Assuming that the barriers to LNG are addressed, it is forecasted that in 2030 that LNG as a propulsion fuel could have a 10% share of inland shipping, with a further 3% coming from bio-LNG. LNG in deep-sea and short-sea shipping is expected to have a similar share of the market in 2030, with between 10-16% and an extra 3% bio-LNG[121].

3.2.4 Compressed Natural Gas (CNG)

Similar to LNG, compressed Natural Gas (CNG) can be stored on a vessel and can be burned in a gas-burning or dual-fuel engine. Therefore, engine replacement, new storage and other supporting equipment (e.g. refuelling infrastructure) would also be required to retrofit this technology and fuel the current fleet. In addition, the lower energy density of the gas requires extra space for fuel storage compared to LNG. CNG also has much longer refuelling times. This realistically limits the range of a CNG-powered vessel[122]. The cost of CNG as a fuel reflects the natural gas price, which is much lower than current incumbent diesel fuels (especially those needed to comply with SO_x regulations). This is an advantage for the use of CNG. Estimates of the CO_2 reduction potential from CNG range from modest savings of the order of 8-9%, relative to the incumbent diesel fuels[123], to a net increase in emissions[124]. CNG use is currently being demonstrated in a Dutch ferry, between Texel and the mainland (TESO)[125]. More research is necessary to explore the use of CNG or bio-CNG across a wider range of shipping classes, to determine the extent of its applicability.

3.2.5 Liquefied Petroleum Gas (LPG)

A maritime application of LPG could produce a 10-17% reduction in CO_2 emissions on a well-to-propeller basis, when compared to the incumbent diesel fuels[126]. The use of LPG also ensures

[117] Ecofys (2012) 'Potential of biofuels for shipping', pp. 1–114.
[118] Moirangthem, K. (2016) *Alternative Fuels for Marine and Inland Waterways*, *European Commission - Joint Research Centre Technical Reports*. doi: 10.2790/227559.
[119] Kelderman, B (2016) 'Developments in the usage of LNG as fuel in inland waterway vessels' Available at: https://www.danube-navigation.eu/uploads/files/2016-05-04_LNG_as_fuel_in_inland_waterway_vessels_Kelderman_EICB.pdf
[120] Shell (2013) ' Shell launches the first 100% LNG powered barge' Available at: https://www.shell.com/energy-and-innovation/natural-gas/lng-for-transport/news-and-media-releases/shell-launches-the-first-100-lng-powered-barge.html
[121] Lloyds Register (2014) 'Global Marine Fuel Trends 2030', *Mari-Tech: Breaking Waves - A New Marine Era*, p. 60.
[122] McGill, R., Remley, W. and Winther, K. (2013) 'Alternative Fuels for Marine Applications', *IEA advanced motor fuels implementing agreement*, (AMF Annex 41), p. 108. doi: 10.2478/v10161-012-0024-9.
[123] Maritime Knowledge Centre, TNO and TU Delft 'Framework CO_2 reduction in shipping' Available at: http://www.koersenvaart.nl/files/Framework%20CO₂%20reduction%20in%20shipping.pdf
[124] DNV-GL (2014) 'Alternative fuels for shipping' Position Paper 17-2014. Available at: https://issuu.com/dnvgl/docs/dnv_gl_pospaper__1-2014_alternative/26
[125] Teso (Accessed April 2018) 'Texelstroom'. Available at: https://www.teso.nl/en/about-teso/vessels/texelstroom
[126] DNV GL (2016) 'Update on alternative maritime fuels' Available at: https://www.dnvgl.us/Downloads/TW16-Alternative-Fuel_tcm14-80289.pdf

compliance with NO_x and SO_x legislation, as the emissions of these gases is low for this fuel[127]. LPG is available and readily transported, shown by its use in the domestic heating and cooking markets. For this reason, it is often mentioned as an alternative fuel for the shipping sector. However, the price of LPG is too expensive when compared to other alternative marine fuels[128]. As LPG is heavier than air in gaseous form it also presents issues in safety on a vessel, any leaks would remain on the vessel at risk of ignition[129]. When the high fuel cost is combined with the issues of safety, as well as the additional costs of retrofitting a gas or dual fuel engine, then LPG looks relatively unviable as an alternative option for deep and large-scale decarbonisation in the shipping sector.

3.2.6 Methanol

Methanol is a liquid fuel, easier to handle than LNG or CNG. It is currently mainly produced from natural gas[130]. Conventional production from natural gas is estimated to increase GHG emissions from shipping by approximately 5%[131]. However, CO_2 capture and its reinjection into the synthesis loop is being implemented to improve methanol yield and reduce the CO_2 footprint.

Methanol engines are used in ships, though at the early stage of adoption[132]. Several projects have worked on the development of engine conversions to methanol; these include Leanship, Methaship, SPIRETH and PILOT Methanol[133]. The PILOT Methanol project involved the conversion of an existing medium speed four stroke Wärtsila engine on the passenger ferry Stena Germanica. Seven methanol tankers are in use today based on MAN dual-fuel two-stroke methanol (ME-LGI) engines, with four more on order (commissioned by Waterfront Shipping)[133]. These engines also allow the use of gaseous fuels like (Bio-)LNG.

In general, methanol can be used in spark ignition engines, dual fuel compression ignition engines and converted compression ignition engines. Methanol contains oxygen which impacts energy density, ignition, combustion, emissions and other characteristics in comparison to conventional fuels[134]. Methanol has a lower cetane number, which determines the ability to self-ignite, than diesel. It would not be able to be used in traditional marine diesel engines without a pilot fuel or ignition enhancer and adaptations to the engine, injection, fuelling system and storage[139]. Methanol can be stored in non-pressurised tanks. Whether it requires a double barrier design for all parts in contact with methanol due to its low flashpoint is still under discussion[135]. In the case of the Stena Germanica ferry a ballast tank was transformed into a methanol fuel tank[139]. The low viscosity and corrosive nature increase engine wear and require redesigned engine parts or chemical additives[139]. The toxic and corrosive nature of methanol requires specific design considerations and changes to the maintenance and risk

[127] IEA Bioenergy (2017) 'Biofuels for the marine shipping sector', (October).
[128] Moirangthem, K. (2016) 'Alternative Fuels for Marine and Inland Waterways, European Commission - Joint Research Centre Technical Reports'. doi: 10.2790/227559.
[129] McGill, R., Remley, W. and Winther, K. (2013) 'Alternative Fuels for Marine Applications', *IEA advanced motor fuels implementing agreement*, (AMF Annex 41), p. 108. doi: 10.2478/v10161-012-0024-9.
[130] Methanol Institute (2007) 'Use of Methanol as a transportation fuel'. Available at: http://www.methanol.org/wp-content/uploads/2016/06/Methanol-Use-in-Transportation.pdf (Last accessed 14/3/18).
[131] DNV-GL (2017) 'Low Carbon Shipping Towards 2050' Available at: https://www.dnvgl.com/publications/low-carbon-shipping-towards-2050-93579
[132] https://www.methanex.com/about-methanol/methanol-marine-fuel
[133] FCBI Energy (2015) 'Methanol as a marine fuel report'.
[134] Ellis, J. and K. Tanneberger (2015) 'Study on the use of ethyl and methyl alcohol as alternative fuels in shipping'.
[135] IEA Bioenergy (2017) 'Biofuels for the marine shipping sector'

assessment due to potential leakages[136,137,138]. However, according to MAN these challenges have all been overcome in their ME-LGI engine.

Similar to LNG, methanol (see Chapter 4.1.5) has a low flash point in comparison to HFO[136]. This would make methanol currently incompatible with Safety of Life at Sea (SOLAS) regulation and hence requires a risk assessment according to SOLAS Ch. II-2 Reg 17 and a double barrier design for all parts in contact with it[135,139]. The flash point defines "the lowest temperature at which a liquid gives off enough vapour to the surface to form an ignitable mixture in the air", hence the fire hazard of methanol could be higher than that of marine fuels as it evaporates quicker[138]. However, it is more difficult to ignite than diesel fuels and dilutes with water, both characteristics which reduce its fire risk. The risk is higher in a sealed compartment such as an engine room, but with the right measures the risk can be mitigated. Methanol is classified as a Class 3 flammable liquid and solvent similar to gasoline and petroleum distillates[138].

A new International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) entered into force in January 2017 as amendment to SOLAS, it currently only covers LNG[140]. The inclusion of methanol and ethanol and definition of new fuel standards is currently still under discussion in IMO's Sub-Committee on Carriage of Cargoes and Containers. No agreement was reached at the last meeting in September 2017 and the next meeting will likely take place in the second half of 2018[141]. Various safeguards as discussed in Ellis and Tanneberger (2015) will be included in the IGF code.

In addition to the SOLAS regulation, both classification societies, Lloyd's Register and DNV-GL need to have rules in place for low flashpoint fuels. They have drafted tentative rules for methanol[139]. The requirement for double walled fuel tanks for alcohol fuels or possibility for single wall tanks still remains under discussion.

The infrastructure for methanol already exists in the chemical industry with train, truck and ship deliveries in a wide number of locations, and it can be introduced without too much difficulty to the marine sector[136]. Methanol storage terminals exist for example in both Rotterdam and Antwerp and are available in other ports around the world[134]. The actual bunkering facilities are the last missing element[138]. It is estimated that similar barges as for current marine fuels could be used if precautions for the higher fire risk are considered and bunkering from mobile terminals is being developed[137]. Both mobile and land based bunkering of methanol would come with limited additional cost for conversion or new build barges or terminals[138].

The low energy density of methanol (20 MJ/kg) in comparison to diesel or HFO (42.7 and 40.9 MJ/kg) requires around twice the space on board for fuel storage or an increased bunkering frequency for the same storage capacity. A greater weight of the fuel storage system would impact the loading capacity

[136] MAN (2014). 'Using methanol fuel in the MAN B&W ME-LGI series'.
[137] FCBI Energy (2015) 'Methanol as a marine fuel report'.
[138] Ellis, J. and K. Tanneberger (2015) 'Study on the use of ethyl and methyl alcohol as alternative fuels in shipping'.
[139] Maritime Knowledge Center (2018) 'Methanol as an alternative fuel for vessels'.
[140] IMO (2017) 'Safety for gas-fuelled ships – new mandatory code enters into force'. Available at: http://www.imo.org/en/MediaCentre/PressBriefings/Pages/01-IGF.aspx
[141] The International Bunker Industry Association (IBIA) (2017) 'IMO to prioritise provisions for methanol as fuel after lack of progress at CCC meeting'. Available at: https://ibia.net/imo-to-prioritise-provisions-for-methanol-as-fuel-after-lack-of-progress-at-ccc-meeting/

of the ship, and the slightly higher energy efficiency of methanol only balances this out to a limited extend. One of the benefits of methanol is that it is a bio-degradable liquid.

The cost of fossil methanol between January 2017 and March 2018 was 13.6-19.1 €/GJ[142]. This is the most expensive fuel cost out of the fossil fuel options, at approximately double the price of HFO cost and two to three times the fuel cost of LNG. The barriers to entry would be lowest for methanol in the inland shipping sector, as inland shipping requires low non-GHG emission characteristics and already uses the more expensive EN590 diesel.

3.2.7 Biofuels

As this study focusses on biofuels, an overview is not given in this section. Instead Chapter 4 is dedicated to the analysis of biofuel options. However, several of the alternative fuels presented in this section such as methanol, CNG or LNG can have a bio-based equivalent.

3.2.8 Hydrogen

The use of hydrogen in shipping is mainly considered through the use of electric propulsion and fuel cells. However, hydrogen can also be used in a gas turbine to provide propulsion or in a hybrid fuel mix, as discussed in Chapter 3.2.2.

The use of hydrogen in fuel cells does not produce any GHG emissions, from tank-to-propeller. Instead, the GHG emissions from hydrogen depend on its production (well-to-tank). Most hydrogen produced in the world comes from fossil sources, including steam methane reforming and coal gasification. These production pathways generate high GHG emissions, although some of these might be captured at source in the future. Hydrogen may also be produced through an electrolyser powered by electricity. Based on whether the electricity comes from fossil, nuclear or renewable sources, the life-cycle greenhouse gas intensity of the outgoing hydrogen will vary. Therefore, the GHG emissions from hydrogen fuel cells would only be lower than conventional marine fuels if hydrogen is produced from low-carbon electricity (green hydrogen). Currently, green hydrogen is not readily available, especially because of the difficulties to transport and store this fuel. Ammonia is also being investigated as an energy carrier for us in fuel cells and is deemed to have potential as alternative marine fuel. It is currently being tested in a project by Proton Ventures[143].

The marine application of fuel cells requires a new electrical propulsion system, on-board fuel cell systems and new storage capabilities compared to existing marine engines. The storage of hydrogen on board requires a large space due to the low energy density of hydrogen, with an estimated tank size of 10-15 times larger than the required HFO tank[144], which could also reduce its cost competitiveness due to reduced cargo space. A solution for this is to cool the hydrogen to ultra-low temperatures to store it as liquid but this requires more energy and more infrastructure to do, as well as specialised tanks to store, resulting in greater barriers to implementation.

[142] Data taken from Methanex Monthly Average European Contract Price History (Available at: https://www.methanex.com/sites/default/files/methanol-price/MxAvgPrice_Feb%2028%2C%202018.pdf) and assumed a negotiated price of 15% lower than these contract prices of 320-450 €/tonne
[143] Willem de Niet, D (2018) 'Ammoniak als schone brandstof' Available at: http://nh3.world/wp-content/uploads/2017/08/Ammoniak-Schuttevaer
[144] DNV GL (2014) 'Alternative fuels for shipping'.

The storage and usage of hydrogen as a fuel also requires compliance with safety standards, resulting in modifications to ship equipment as well as other barriers. Therefore, it would require a highly modified vessel or a purpose built vessel to make hydrogen as a viable fuel option. This can be implemented more easily into future ship builds but would be a costly to retrofit. Additionally, like for LNG, the decreased energy density and need for increased fuel storage would favour inland and short-sea shipping types, over deep-sea shipping as it requires less on-board fuel storage.

3.2.9 Electricity

Electrification based on low carbon electricity production has been concluded to be a sensible pathway of decarbonisation for many transport sectors, including shipping[145]. With an electrical propulsion system, the options are to generate the electricity on-board or to use electricity produced inland (e.g. from grid). Both options require on-board battery storage.

Due to reduced autonomy, the use of batteries in shipping is possible for short-range journeys or vessels with less power requirement from propulsion. It is also commonly used as a hybrid source of propulsion for vessels with variable loads[145]. The CO_2 reduction potential depends on the GHG intensity of the electricity source that charges the battery. China has launched the first fully electric cargo ship which is powered by a 2400 kWh battery and can transport 2200 tonnes of cargo for 50 miles[146]. This is, however, a very short range for the required amount of storage and cost. Therefore, battery storage should only be considered for short voyage lengths and may only be beneficial to short-sea ferries, port shipping operations and short inland shipping voyages until battery technology improves autonomy and costs are reduced.

Electricity can also be generated on-board through hydrogen fuel cells (discussed in Chapter 3.2.8). Solar and wind technologies can also be used to generate the electricity on-board. However, they are better considered as complementary energy sources to other energy options discussed in this chapter for vessels in commercial shipping. On-board renewable electricity cannot be used as the main energy source for propulsion, due to intermittency and energy requirement of large vessels.

Aside from the propulsion, renewable electricity is a good method of decarbonising the auxiliary power needed by vessels and to power the ships whilst at berth in ports, instead of fossil generators.

3.2.10 Nuclear

Nuclear powered vessels have the potential of reducing GHG emissions significantly and produce no other gas emissions due to the absence of combustion[147]. The use of nuclear reactors as a fuel source for maritime applications is well developed through military uses in submarines[148]. There is currently one merchant nuclear-powered ship operating called the SEVMORPUT, a Russian-built in 1988, which operates across artic waters[149]. Nuclear power offers extended range, limited need for refuelling and extremely high energy density of fuel, making nuclear suitable for large trans-ocean deep-sea shipping.

[145] Moirangthem, K. (2016) '*Alternative Fuels for Marine and Inland Waterways*, *European Commission - Joint Research Centre Technical Reports*'. doi: 10.2790/227559.
[146] China Launches World's First All-Electric Cargo Ship, Will Use It To Haul Coal. Available at: https://cleantechnica.com/2017/12/02/china-launches-worlds-first-electric-cargo-ship-will-use-haul-coal/
[147] DNV-GL (2017) 'Low Carbon Shipping Towards 2050', pp. 1–32.
[148] Royal Academy of Engineering (2013) 'Future Ship Powering Options – Exploring alternative methods of ship propulsion' Available at: https://www.raeng.org.uk/publications/reports/future-ship-powering-options
[149] Ship etails on Sevmorput http://www.marinetraffic.com/en/ais/details/ships/shipid:901605/mmsi:273137100/imo:8729810/vessel:SEVMORPUT

However, the safety to people and the environment, and geopolitical risks related to nuclear powered commercial shipping present many barriers to its uptake as viable main-steam technology in global shipping. It is not envisaged that nuclear will become a viable alternative in the near future[150,151].

[150] DNV-GL (2017) 'Low Carbon Shipping Towards 2050', pp. 1–32.
[151] McGill, R., Remley, W. and Winther, K. (2013) 'Alternative Fuels for Marine Applications', *IEA advanced motor fuels implementing agreement*, (AMF Annex 41), p. 108. doi: 10.2478/v10161-012-0024-9.

4 Biofuels – their potential role in decarbonising shipping

Conventional biofuels account for around 4% of world road transport fuel (3.3 EJ), though the double digit growth in the market prior to 2010 has slowed to 2% p.a. over the last few years[152]. Global biofuel consumption in all sectors represents around one quarter to one third of global bunker consumption (estimated in the range of 10-12EJ), but biofuels are today almost entirely used in road transport, in particular in Europe, the US and Brazil. Biofuels in shipping are only in the testing or early adoption phase, for example via companies like GoodFuels that currently focus on diesel-type fuels such as HVO. The limited use in shipping is a result of the policy focus on road transport to date (due to less overlap with the international arena), and the generally lower cost of shipping fuels and hence larger price gap compared to road transport fuels.

To provide an idea of the quantities involved, deep-sea and short-sea shipping fuel consumption in the Netherlands is of the same order as biodiesel production in the EU, which is in turn about ten times the inland shipping fuel consumption of the Netherlands (see Figure 4-1, note that the vertical axis is on a logarithmic scale). Dutch biodiesel (HVO and FAME) and bioethanol consumption is an order of magnitude smaller than Dutch inland shipping fuel consumption.

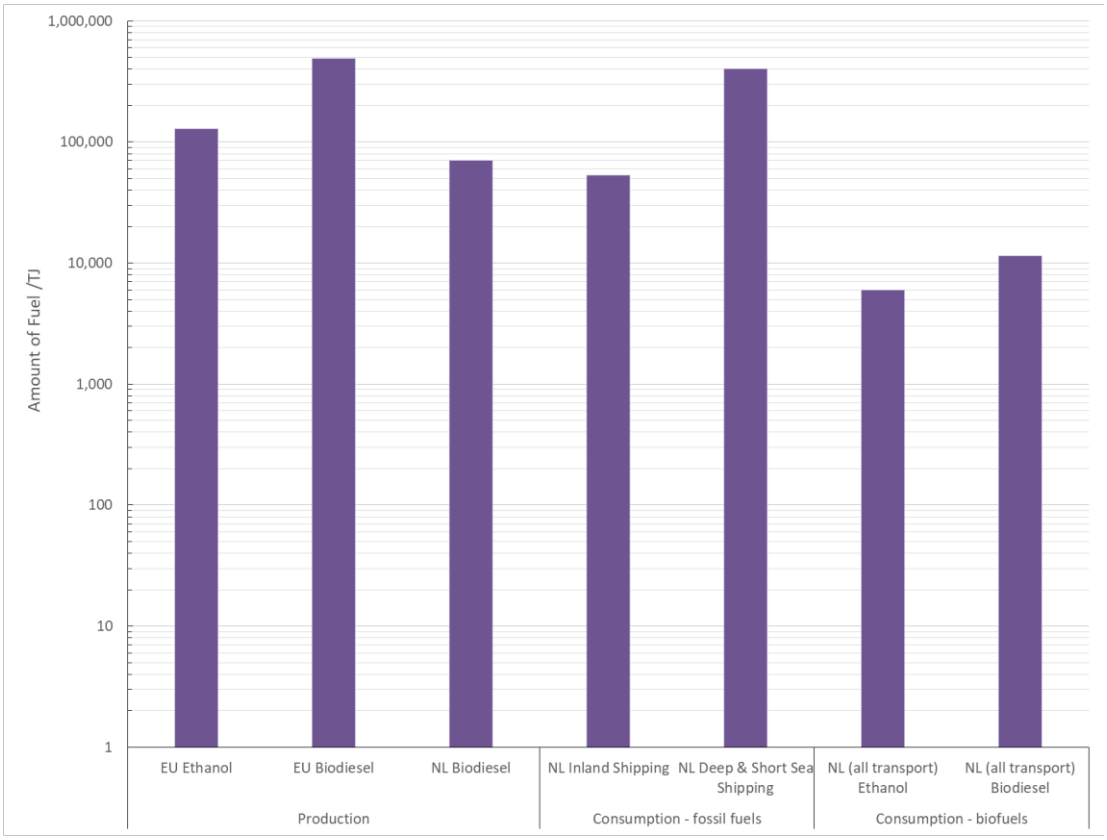


Figure 4-1: Comparison of EU and NL biofuel production with Dutch bunker fuel and biofuel consumption[153,154]

[152] IEA (2017) 'Tracking Progress: Transport biofuels'. Available at: https://www.iea.org/etp/tracking2017/transportbiofuels/ (Last accessed 21/3/18).
[153] StatLine (2018) 'Motor fuels; deliveries by petajoule' Available at: http://statline.cbs.nl/Statweb/publication/?DM=SLEN&PA=83406eng&D1=0-59&D2=0&D3=131,143-145,147-148&LA=EN&VW=T
[154] Global Agricultural Information Network (2017) 'EU-28 Biofuels Annual' Available at: https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_The%20Hague_EU-28_6-19-2017.pdf

4.1 Evaluation of biofuel options

This chapter will discuss and evaluate the main biofuels that can be used for decarbonising the shipping sector, today and in 2030. The biofuels assessed include fuels produced from waste oils and fats (SVO, FAME, UCOME and HVO); alcohols (ethanol and bio-methanol); bio-LNG and synthetic diesels (FT-diesel and upgraded pyrolysis oil). DME is discussed as part of the methanol section.

For each biofuel, the production process, current commercial status and key feedstocks are described before discussing compatibility with existing engines, fuel supply system, storage and infrastructure. Given the required adaptations needed for using ethanol and methanol, the compatibility and regulation and certification requirements are discussed in more detail for both alcohols. GHG emissions savings and production costs are discussed for each biofuel, as well as barriers to their adoption. A comparison of GHG emission savings and production cost for all the biofuels is given in Chapter 4.2.

Biofuels were evaluated based on the technological and commercial readiness of the fuel production and the compatibility with current engines and vessels both today and in 2030, and on their GHG reduction potential, see Table 4-1. As production costs in the period to 2030 are still too uncertain, this was not used as an evaluation criteria. For GHG emission savings, a high level distinction was made to highlight the best performing biofuels. Biofuels with a wide range of GHG emission savings were classified as 'orange'. Non-GHG emissions are an important aspect given the increasingly stringent emissions regulation and are discussed in Chapter 4.3. The low sulphur characteristic makes many biofuels particularly attractive from a non-GHG emissions perspective.

Table 4-1: Biofuel evaluation criteria for decarbonisation in shipping

Indicator	Readiness of fuel production	Compatibility with current engine and vessel (typical to sector type)	GHG reduction potential
	Established and used widely, readily available and fully developed.	No modification to engine or infrastructure - Drop in fuel or high blends	>90% GHG savings
	Commercially available but not in wide use, could be further developed.	Considerable changes to engine, fueling system and/or storage/infrastructure, or low blends	60-90% GHG savings
	Working demonstration plant	New vessel required	<60% GHG savings

For an explanation of the archetypes used for each shipping sector type, see Table 3-1. The GHG savings are calculated from fossil baseline of 83.8 gCO_2eq/MJ that is used in Annex V of the RED[155]. The readiness of fuel production for the various biofuel pathways discussed in this section are included in an overview in Appendix A.

[155] Annex V, Directive 2009/28/EC of the European Parliament and of the Council 'Renewable Energy Directive' Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN

4.1.1 Hydrogenated Vegetable Oil (HVO)

HVO, also called 'Renewable Biodiesel' or 'Hydrogenation derived renewable diesel' (HDRD) is often referred to as a 'drop-in' biofuel in the shipping sector as it is compatible with new and existing marine diesel engines that run on HFO, MDO or MGO[156]. HVO is produced by hydro-treating conventional vegetable oil, or waste oils and fats. The majority of HVO used in the Dutch road transport sector is made from waste oils[157]. HVO production is commercial (TRL 9, see Appendix A), and production is underway in several countries, with several active technology developers. Current worldwide capacity is around 5Mt/year (220PJ) and is expected to increase to 7.5Mt/year (330 PJ) by 2020[158]. Because of the drop-in characteristics of the fuels produced, there is likely to be strong competition from both the road transport 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.

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. It is most similar to the distillate bunker oil DMA (MGO) and already meets ISO 8217 specifications without any blending with conventional petroleum diesel[159]. The blending of HVO can be done at various points in the supply chain, at onshore storage, on the bunkering vessel or even on board the actual vessel[160]. Even though the energy density per unit mass of HVO is similar to diesel and HFO, its lower volumetric density leads to a 7% and 13% lower energy content on a volumetric basis compared to fossil diesel and HFO, respectively[161]. Hence, slightly more storage volume is required compared to fossil diesel and HFO.

The well to tank GHG emissions reduction potential for HVO can be approximately 88% when waste oils or fats are used as feedstock, based on the typical value for biodiesel[162]. Policy in the Netherlands incentivises high GHG performing fuels and has led to larger use of HVO made from waste oils in the Dutch road transport sector, with an average GHG reduction of 74% in 2016[157]. HVO also has a very low sulphur content (0.001% by weight) and complies with current and future SO_x regulation[163]. As drop-in fuel HVO could be used today to decarbonise the Dutch shipping sector. However, the availability of waste oils is limited and demand from the road transport and aviation sectors in and outside the Netherlands will create competition for the available waste oils. When using vegetable oils such as rapeseed oil, typical GHG emission savings decline to around 40-68%[162]. The production cost of HVO using rapeseed oil is in the range of 14-25€/GJ[164].

[156] International Energy Agency (IEA) (2013) 'Alternative Fuels for Marine Applications'.
[157] Dutch Emissions Authority (2016) 'Rapportage Energie voor Vervoer in Nederland 2016'.
[158] Erämetsä, H. (2018) 'Sustainable and renewable mobility: Industry Perspective'. Presented at Future of Fuels Conference, Berlin 22-23 January 2018.
[159] Geraedts, S. (2018) GoodFuels. 'Commercialising marine biofuels'. Presented at Future of Fuels Conference, Berlin 22-23 January 2018.
[160] Geraedts, S. (2018). Personal communication
[161] IEA Bioenergy (2017) 'Biofuels for the marine shipping sector'
[162] Annex V, Directive 2009/28/EC of the European Parliament and of the Council 'Renewable Energy Directive' Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN
[163] International Energy Agency (IEA) (2013) 'Alternative Fuels for Marine Applications'.
[164] European Commission (2017) 'Building Up the Future – Final report'. Sub Group on Advanced Biofuels. Sustainable Transport Forum. Available at: http://artfuelsforum.eu/wp-content/uploads/2017/05/SGAB-Final-Report.pdf

Table 4-2: Evaluation of HVO

Shipping sector	Readiness of fuel production		Compatibility		Current GHG reduction in the Netherlands
Inland	Today	2030	Today	2030	
Short sea			Today	2030	
Deep sea			Today	2030	

4.1.2 SVO

Straight vegetable oils (SVO) are extracted from plants and do not undergo any additional processing steps before being used in an engine[165]. Production is commercial, and the price of rapeseed SVO is in the range 17-24€/GJ[166].

SVO is compatible with HFO in low speed engines used in deep-sea shipping, but modifications are 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. However, the higher viscosity and higher boiling point of SVO have a negative impact on the lifespan of the engine[165]. There are further concerns about its compatibility with diesel engines due to acidity.

Typical well to tank GHG emissions savings using rapeseed SVO are approximately 58%[167]. 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.

Table 4-3: Evaluation of SVO

Shipping sector	Readiness of fuel production		Compatibility		GHG reduction potential
Inland	Today	2030	Today	2030	
Short sea			Today	2030	
Deep sea			Today	2030	

4.1.3 FAME

FAME is produced from fats and oils, in a well-established process that is operating commercially throughout the world today. It is also commonly known as 'Biodiesel' because of its blending (up to 7%) in EN590 diesel which is used abundantly in road transport. FAME is formed by reacting fats and oils with methanol, in a process known as transesterification. Glycerol is produced as a by-product. A

[165] IEA Bioenergy (2017) 'Biofuels for the marine shipping sector'
[166] YCharts (2017) 'Rapeseed Oil Price' Available at: https://ycharts.com/indicators/rapeseed_oil_price
[167] Annex V, Directive 2009/28/EC of the European Parliament and of the Council 'Renewable Energy Directive' Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN

wide variety of fats and oils can be used to produce FAME, including non-wastes such as rapeseed oil, sunflower oil and palm oil, and wastes such as used cooking oil (UCO) and waste animal fats (tallow). The Netherlands has seen a transition from crop-based feedstocks to waste oils and fats in the road transport sector in the last 5 or so years, which strongly increased the GHG emissions reductions achieved from using FAME. FAME is also widely used throughout the world, and the biggest producers are the EU, USA and Brazil[168].

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)[165]. Even though blending in engines used in inland and short-sea shipping is limited at 7% based on EN590 and ISO 8217 (2017 edition)[169] for distillate fuels, blends of up to 20% are described to be widely used[170,171]. In contrast to inland and short-sea shipping, for HFO used in deep-sea shipping, ISO 8217 specifies *a de minimis level* which only allows trace amounts of FAME[172]. However, for example Wärtsilä *"has not set an official limit for the allowed maximum percentage of transesterified or hydrotreated biofuel being mixed with a fossil distillate fuel*" for their engines[176]. Hence, the ship owner can decide to use FAME despite it being off-spec in HFO engines, or use a blend above 7% in diesel or MGO engines. The properties of the fuel mean that its use may result in filter clogging in the engine due to its high cloud point[171]. Due to its ability to dissolve some non-metallic materials, in particular in higher concentrations, susceptible parts in engines and the fuel supply system might have to be changed prior to using FAME[171]. As FAME can degrade after a period of two months, long-term storage needs to be avoided or the fuel needs to be closely monitored to ensure it remains within its specification.

While the lower heating value of FAME is lower than HVO, its volumetric density is higher and similar to fossil diesel[171]. The energy content on a volumetric basis is hence very similar to HVO, 6% and 13% lower compared to fossil diesel and HFO, respectively. Hence, slightly more storage volume is required compared to fossil diesel and HFO.

The well to tank GHG reduction potential for FAME can be as high as 88% when waste oils and fats are used as feedstock[173]. Policy in the Netherlands incentivises high GHG performing fuels and has led to a large use of FAME made from waste oils in the Dutch road transport sector, with an average GHG reduction of 85% in 2016[174]. FAME produced from raw vegetable oils would struggle to meet the 60% GHG emission saving threshold[173]. Compared to HVO drop-in fuel, the 7% blend wall would limit the overall GHG emission reduction of a vessel using FAME to 6% (if using waste animal fats or used cooking oil)[175]. While SO_x emissions are almost zero, FAME could also lead to higher NO_x emissions. Depending on the engine load these can be 2-3 g NO_x/kWh higher compared to light fuel oil[176]. This reduces the

[168] UFOP (2018) 'UFOP Report on Global Market Supply 2017/2018'. Available at: https://www.ufop.de/files/3515/1515/2657/UFOP_Report_on_Global_Market_Supply_2017-2018.pdf
[169] Directive 2009/30/EC of the European Parliament and of the Council 'Fuel Quality Directive' Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0030
[170] International Energy Agency (IEA) (2013) 'Alternative Fuels for Marine Applications'.
[171] IEA Bioenergy (2017) 'Biofuels for the marine shipping sector'
[172] Geraedts, S. (2018). Personal communication
[173] Annex V, Directive 2009/28/EC of the European Parliament and of the Council 'Renewable Energy Directive' Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN
[174] Dutch Emissions Authority (2016) 'Rapportage Energie voor Vervoer in Nederland 2016'.
[175] This assumes a vessel uses 7% FAME produced from used cooking oil with an 88% emission reduction potential.
[176] Juoperi, K. (2016) 'Alternative fuels from a medium-speed engine manufacturer's perspective'. CIMAC Congress 2016 -238.

attractiveness of FAME in inland shipping and short-sea shipping in comparison to HVO. Similar to HVO from waste oils, the limited availability of waste oils constrains the potential for large GHG emission reductions from FAME.

FAME prices are in the range of 20-28€/GJ based on use of waste oils and fats[177,178]. This is approximately twice the price of the incumbent shipping fossil fuels, although FAME is typically slightly cheaper than HVO to produce.

Table 4-4: Evaluation of FAME

Shipping sector	Readiness of fuel production		Compatibility		Current GHG reduction in the Netherlands
Inland			Today	2030	
Short sea	Today	2030	Today	2030	
Deep sea			Today	2030	

4.1.4 Bio-ethanol

Conventional bio-ethanol is commonly used in many countries in road transport, in a blend with gasoline. It is produced through fermentation of food-crop sugars and starches in commercial facilities mainly in Brazil, the US and Europe. Global ethanol production for fuels use was 119 billion litres in 2016[179]. This volume is almost entirely produced via fermentation of food-crop based sugars and starches. The US (52.3 billion litres), Brazil (28.5 billion litres) and the EU (5.4 billion litres) are the largest producers (and consumers)[180]. EU production in 2016 at 128PJ is more than double the annual 53 PJ of Dutch bunker for inland shipping or about 30% of all Dutch bunker sales in 2016/2017[181,182]. In the EU ethanol production represents only a quarter of biodiesel production, however, globally bioethanol production is about double that of biodiesel production[183]. Wheat, corn, sugar beet and sugarcane are the main feedstocks.

Several newer processes produce ethanol from woody biomass and waste streams (advanced ethanol), which are currently at the early commercial stage and expected to reach full commercial availability by 2030.

For the compatibility of ethanol in engines and infrastructure please refer to Chapter 3.2.6 on methanol. However, in contrast to methanol we have found no evidence of existing projects or tests of ethanol in marine shipping engines. As the most widely used biofuel globally, ethanol is available at

[177] These prices are higher than vegetable oil based HVO production cost (Figure 4-3) because of the prices of waste oil and fats are influenced by the double counting policy.
[178] High and low values over past year taken from Greenea (March 2018) Available at: https://www.greenea.com/en/market-analysis/
[179] UFOP (2018) 'UFOP Report on Global Market Supply 2017/2018'. Available at: https://www.ufop.de/files/3515/1515/2657/UFOP_Report_on_Global_Market_Supply_2017-2018.pdf
[180] EUROBSERV'ER (2017). 'Biofuels Barometer'.
[181] USDA Foreign Agricultural Service (2017) 'EU Biofuels Annual 2017'. Available at: https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_The%20Hague_EU-28_6-19-2017.pdf (Last accessed 21/3/18).
[182] Statistics Netherlands (2018) 'Motor fuels, deliveries by petajoule, weight and volume'. Available at: http://statline.cbs.nl/Statweb/publication/?DM=SLEN&PA=83406eng&D1=0-59&D2=0&D3=131%2c143-145%2c147-148&LA=EN&VW=T (Last accessed 21/3/18).
[183] IEA Bioenergy (2017) 'Biofuels for the marine shipping sector'

large chemical storage hubs such as Rotterdam or Antwerp in Europe. Although not as low as methanol, ethanol has a lower energy density (LHV) at 27 MJ/kg and lower volumetric density than marine fossil fuels, which leads to approximately 40% lower energy density by volume. More storage capacity to cover the same shipping distance would hence be required for the use of ethanol. However, bunkering more regularly is also an option for short-sea and inland vessels which would reduce the additional storage capacity required. The additional bunkering time would impact the economics of the vessel.

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 sugarbeet[184]. Using carbon capture (with subsequent sequestration or industrial replacement of fossil CO_2) as done at the Alco ethanol plant in Rotterdam, the GHG emission savings could be significantly higher. The average Dutch GHG emission saving from using conventional ethanol from a range of feedstocks was 60% in 2016[185]. Well to tank emissions strongly depend on the feedstock used, the process fuel used and whether a combined heat and power (CHP) system or a conventional boiler is used. Advanced ethanol, from straw for example, leads to higher GHG emission savings of the order of 87%[184].

The readiness of the fuel production technologies is also reflected in the prices. The price of ethanol through via conventional processes are 19-22 €/GJ[186]. For ethanol produced from lignocellulosic biomass the cost is estimated to be 24-29 €/GJ in 2015[187].

Conventional ethanol is available today for use in marine vessels, however, as described above to enable its use, engines, fuel injection, supply and storage systems require adaptations or the installation of new dual fuel engines. Lignocellulosic ethanol from woody biomass or other waste-based feedstocks would lead to higher GHG emission savings compared to sugar or starch feedstocks in conventional ethanol, see Table 4-5 and Table 4-6. Ethanol could hence represent an attractive option for decarbonisation of the shipping sector. The uptake and decarbonisation potential of ethanol will primarily depend on the adaptation and installation costs of new dual fuel engines, which are evaluated in more detail in Chapter 4.4.

Table 4-5: Evaluation of conventional ethanol

Shipping sector	Readiness of fuel production		Compatibility		Current GHG reduction in the Netherlands
Inland	Today	2030	Today	2030	
Short sea			Today	2030	
Deep sea			Today	2030	

[184] Annex V, Directive 2009/28/EC of the European Parliament and of the Council 'Renewable Energy Directive' Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN
[185] Dutch Emissions Authority (2016) 'Rapportage Energie voor Vervoer in Nederland 2016'.
[186] High and low value taken over past year from Platts. Available at: https://www.platts.com/commodity/agriculture
[187] European Commission (2017) 'Building Up the Future – Final report'. Sub Group on Advanced Biofuels. Sustainable Transport Forum.

Table 4-6: Evaluation of advanced ethanol

Shipping sector	Readiness of fuel production		Compatibility		GHG reduction potential
Inland	Today	2030	Today	2030	(potentially green if with carbon capture)
Short sea			Today	2030	
Deep sea			Today	2030	

4.1.5 Bio-methanol

Bio-methanol is used as transport fuel in the EU, but in limited volumes compared to ethanol[188,189]. Early commercial stage production of renewable methanol is underway using feedstocks such as MSW, waste wood, black liquor, glycerine, as well as renewable electricity.

The Enerkem plant in Canada produces bio-methanol from MSW, and a much larger facility is foreseen to commence production in the port of Rotterdam by 2020[190,191,192]. BioMCN already operates a full scale methanol plant in Delfzijl where bio-methane is converted into bio-methanol. Of the name plate capacity of the BioMCN plant approx. 10% is now used to produce bio-methanol.

An alternate production route involves electrolysis of renewable electricity to hydrogen, which is then converted with carbon dioxide via catalysis into methanol. Methanol derived via this route is known as a RFNBO (renewable fuel of non-biological origin). Large demonstration scale production has started by Carbon Recycling International in Iceland, and Innogy in Germany[190,193].

For the compatibility of bio-methanol please refer to Chapter 3.2.6 on fossil methanol.

Well-to-tank GHG emissions for renewable methanol could lead to GHG emissions savings of approximately 90-95% depending on the production route, and internal energy consumption of the production process[192]. GHG savings above 100% are possible with carbon capture and sequestration or replacement.

Production costs for bio-methanol are only available in the literature, not based on market price data or reported costs from existing plants, and range widely from 16-25 €/GJ depending on the size of the plant, feedstock (wood, waste or CO_2) and the assumptions of the different studies[194,195]. We assumed that bio-methanol production cost could not lead to a lower price than the lower end of 2017 fossil methanol prices in a low oil price world. The cheapest route for bio-methanol production is to replace

[188] Methanol Institute (2007) 'Use of Methanol as a transportation fuel'. Available at: http://www.methanol.org/wp-content/uploads/2016/06/Methanol-Use-in-Transportation.pdf (Last accessed 14/3/18).
[189] E4tech (2016) Internal.
[190] Ellis, J. and K. Tanneberger (2015) 'Study on the use of ethyl and methyl alcohol as alternative fuels in shipping'.
[191] Enerkem (2017) 'Partners agree on initial funding to kick off waste-to-chemistry project in Rotterdam'. Available at: http://enerkem.com/newsroom/?communique_id=122566 (Last accessed 11/4/2018)
[192] E4tech (2017) 'Advanced Renewable Fuels Demonstration Competition – Feasibility Study'.
[193] Innogy (2017) 'innogy launches pioneering methanol project'. Available at: https://news.innogy.com/innogy-launches-pioneering-methanol-project/ (Last accessed 11/4/2018)
[194] European Commission (2017) 'Building Up the Future – Final report'. Sub Group on Advanced Biofuels. Sustainable Transport Forum. Available at: http://artfuelsforum.eu/wp-content/uploads/2017/05/SGAB-Final-Report.pdf
[195] IEA (2013) 'Production of Bio-Methanol'. Available at: https://iea-etsap.org/E-TechDS/PDF/I09IR_Bio-methanol_MB_Jan2013_final_GSOK.pdf (Last accessed 21/3/18)

natural gas with biomethane in a conventional methanol production unit. As biomethane has a higher cost than natural gas, the bio-methanol production cannot be lower than methanol prices.

RFNBO methanol from CO_2 and renewable electricity at assumed electricity costs of 5€cent/kWh would currently lead to production costs of above 100 €/GJ[196]. Costs for RNFBO methanol strongly depend on electricity costs and CO_2 costs, and a wide range of values are currently discussed. Both the studies by Cerulogy and by LBST & Dena arrive at production costs above 100€/GJ, with the LBST & Dena estimates at around 150€/GJ today decreasing to around 80€/GJ by 2050 using electricity costs of 11€Cent/kWh and 8.4€Cent/kWh respectively[197,198].

Bio-methanol from biomethane is commercially available at the moment, but in limited volumes. Bio-methanol produced from woody biomass or other waste-based feedstocks is at the early commercial stage. These volumes are expected to increase in the coming decade and by 2030 could lead to significant GHG emission savings in the shipping sector. In the same way as ethanol, the uptake and decarbonisation potential will primarily depend on the adaptation or installation costs of new dual fuel engines which are evaluated in more detail in Chapter 3.2.6.

Table 4-7: Evaluation of bio-methanol

Shipping sector	Readiness of fuel production		Compatibility		GHG reduction potential
Inland	Today	2030	Today	2030	
Short sea			Today	2030	
Deep sea			Today	2030	

4.1.6 Bio-Dimethylether (DME)

DME is produced through the catalytic dehydration of methanol, or directly from syngas in a similar reaction to methanol catalysis. DME was produced in the Chemrec pilot project in Sweden via bio-based syngas, which has now been mothballed. During the SPIRETH project, DME was produced from methanol via catalytic conversion for use in a converted diesel engine[199]. DME has a cetane number comparable to diesel fuel which makes it more suitable for diesel engines[200]. 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[201]. The lower viscosity and energy density (22.8 MJ/kg) are further disadvantages in the use of DME as a shipping fuel[200]. 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.

[196] Brynolf et al. (2017) 'Electrofuels for the transport sector: A review of production costs' Available at: https://www.sciencedirect.com/science/article/pii/S1364032117309358
[197] Malins, C. (2017) 'What role is there for electrofuel technologies in European transport's low carbon future?' Available at: https://www.transportenvironment.org/sites/te/files/publications/2017_11_Cerulogy_study_What_role_electrofuels_final_0.pdf (Last accessed 21/3/18)
[198] LBST & DENA (2017) 'The potential of electricity-based fuels for low-emission transport in the EU' Available at: https://shop.dena.de/fileadmin/denashop/media/Downloads_Dateien/verkehr/9219_E-FUELS-STUDY_The_potential_of_electricity_based_fuels_for_low_emission_transport_in_the_EU.pdf
[199] Maritime Knowledge Center (2018) 'Methanol as an alternative fuel for vessels'.
[200] FCBI Energy, 2015. Methanol as a marine fuel report.
[201] Marine Methanol (2018) 'Engine technology'. Available at: http://marinemethanol.com/technology/in-practice (Last accessed 21/3/18)

The well to tank GHG emissions reductions available from DME range from approximately 92-94%, depending on the biomass feedstock and internal energy consumption[202]. GHG savings above 100% are possible with carbon capture and sequestration or replacement. GHG savings will be similar to those of methanol, and it is also possible to generate RFNBO DME from renewable electricity and CO_2, although this is not beyond pilot scale yet. Cost data for DME is not available given its early stage of development.

Table 4-8: Evaluation of DME

Shipping sector	Readiness of fuel production		Compatibility		GHG reduction potential
Inland	Today	2030	Today	2030	
Short sea			Today	2030	
Deep sea			Today	2030	

4.1.7 Biomethane

Biomethane can be produced via four different routes, anaerobic digestion (AD), landfill gas, bioSNG, and RFNBO routes, that vary in technology status from early demonstration stage to full commercial scale operation.

Anaerobic digestion (AD) is the decomposition of biological feedstocks by micro-organisms, in the absence of oxygen. The biogas produced comprises mostly methane and CO_2. AD of feedstocks such as manure, sewage sludge, organic waste, and energy crops produces 'raw' biogas. The raw biogas is upgraded by removing some trace gases and CO_2[203]. The upgraded biogas, or biomethane, can then be liquefied to bio-LNG. Landfill gas can also be upgraded and liquefied in the same way as 'raw' biogas from AD. Both AD and landfill gas projects are at commercial scale globally.

In the bioSNG route, biomass or waste feedstock are gasified to produce syngas, which is then cleaned and catalytically reacted to form bioSNG[203]. BioSNG is currently at the large demonstration scale (TRL 7)[203].

The production of methane via methanation of CO_2 using hydrogen from renewable electricity (RFNBO route) is currently only at early demonstration scale (TRL 5-6)[203]. This chapter will focus on the production of biomethane via AD from organic waste and manure, as it is at commercial scale and is the most widely available form of biomethane in Europe.

Biomethane can be used in shipping as bio-LNG and bio-CNG fuels. The use of LNG as a fuel is proven and further discussion on the merits of bio-LNG are included in this section. The use of CNG is only at the demonstration stage in small vessels and the increased storage space needed means that it may only be applicable to short-sea shipping and inland shipping.

[202] Annex V, Directive 2009/28/EC of the European Parliament and of the Council 'Renewable Energy Directive' Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN
[203] Enerkem (2017) 'Partners agree on initial funding to kick off waste-to-chemistry project in Rotterdam'. Available at: http://enerkem.com/newsroom/?communique_id=122566 (Last accessed 11/4/2018)

As bio-LNG is chemically identical to fossil LNG, there are no compatibility issues with mixing bio-LNG and LNG. Hence, requirements and challenges for new infrastructure and storage are the same as for LNG as described in Chapter 3.2.3 and the use of bio-LNG in vessels could be accounted for via mass-balancing to avoid transport of bio-LNG. However, given the low numbers of existing LNG vessels in the 'vessel fleet', the overall compatibility of bio-LNG today is low as existing marine fuel vessels would either require significant retrofits or (given the storage requirements for LNG) complete new builds. With a potential increase of LNG to comprise 10% of fuel use in Dutch inland shipping by 2030, the opportunity for bio-LNG could significantly increase[204]. The use of LNG and hence bio-LNG has been described in a new IGF code under SOLAS which entered into force in January 2017[205].

The well to tank GHG emission savings from bio-LNG, produced from organic waste or dry manure AD, is in the range of 71-82%, depending on the electricity source used for liquefaction, and methane leakage rates[206,207]. Bio-CNG savings are expected to be similar to those of bio-LNG. The GHG savings from AD, bioSNG and landfill gas sources can also be above 100% in the case of carbon capture and sequestration, as all these processes rely on separating out CO_2 from the biomethane.

The production cost of bio-LNG via AD is in the range of 12-35 €/GJ[208,209]. The wide range is due to the wide variation in feedstock costs and plant scales.

Table 4-9: Evaluation of bio-LNG (based on biomethane from AD)

Shipping sector	Readiness of fuel production		Compatibility		GHG reduction potential
Inland	Today	2030	Today	2030	(could be green with carbon capture)
Short sea			Today	2030	
Deep sea			Today	2030	

4.1.8 FT-Diesel

Gasification converts lignocellulosic biomass and waste feedstocks to syngas, which is then turned into long-chain hydrocarbon waxes by reactions over metallic catalysts during Fischer-Tropsch (FT) synthesis. These waxes are then upgraded via standard refinery processes to FT liquids including diesel, gasoline and jet[210]. The suitability of the feedstock depends on the design of the gasification reactor and the syngas clean-up steps.

[204] Lloyds Register (2014) 'Global Marine Fuel Trends 2030', *Mari-Tech: Breaking Waves - A New Marine Era*, p. 60.
[205] IMO (2017) 'Safety for gas-fuelled ships – new mandatory code enters into force'. Available at: http://www.imo.org/en/MediaCentre/PressBriefings/Pages/01-IGF.aspx
[206] Annex V, Directive 2009/28/EC of the European Parliament and of the Council 'Renewable Energy Directive' Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN
[207] E4tech (2018) Internal. Calculation of GHG intensity of liquefaction process.
[208] European Commission (2017) 'Building Up the Future – Final report'. Sub Group on Advanced Biofuels. Sustainable Transport Forum. Available at: http://artfuelsforum.eu/wp-content/uploads/2017/05/SGAB-Final-Report.pdf
[209] E4tech (2018) Internal. Calculation of liquefaction cost based on electricity use of liquefaction process of 0.35kWh/kg to 0.7kWh/kg. https://cdn.wartsila.com/docs/default-source/product-files/ogi/lng-solutions/brochure-o-ogi-lng-liquefaction.pdf
[210] E4tech (2017) 'Advanced drop-in biofuels. UK production capacity outlook to 2030.'

FT-Diesel can as well be produced from renewable electricity and CO_2 converted via catalysis into syngas, and then FT-Diesel. FT-Diesel derived via this route is known as a RFNBO (renewable fuel of non-biological origin).

When using fossil feedstocks such as coal, gasification and FT synthesis are fully commercial processes. When using biomass or waste feedstocks, however, the technology is less advanced and currently only at TRL 5-6, hence at pilot and early demonstration scale[210]. A few first-of-a-kind commercial scale plants have recently been financed and are starting construction, and due to start operating from 2020 onwards. It can be estimated that by 2030 several commercial plants could be operating and FT-Diesel would be available in limited amounts. However, given its 'drop-in' characteristics there will be a strong competition from both the road transport and aviation sectors.

Similar to HVO, FT-Diesel would be directly usable as a 'drop in' fuel in all three shipping sectors; inland, short-sea and deep-sea, and would be compatible with all existing infrastructure both on the vessel as well as the port side[211]. At 44 MJ/kg the energy density (LHV) of FT-Diesel is slightly higher than current marine fuels, while the volumetric density is slightly lower[212]. This leads to a 5% and 11% lower energy content on a volumetric basis compared to fossil diesel and HFO and would hence lead to slightly larger fuel tanks for a vessel to travel the same distance.

The well to tank GHG emission reduction potential for wood FT-Diesel is around 93-95%[213]. However, GHG savings above 100% are possible with carbon capture and sequestration or replacement.

Production costs from literature are projected at 25-35 €/GJ[214], but these would still at least be double the current ULSFO and LSMGO prices at 10.4€/GJ and 9.8€/GJ[215].

Table 4-10: Evaluation of FT-Diesel

Shipping sector	Readiness of fuel production		Compatibility		GHG reduction potential
Inland	Today	2030	Today	2030	
Short sea			Today	2030	
Deep sea			Today	2030	

4.1.9 Upgraded Pyrolysis Oil

Pyrolysis is the controlled thermal decomposition of biomass at moderate temperatures, in the absence of oxygen, to produce liquid oil, gas and charcoal. The liquid pyrolysis oil fraction is maximised in a catalytic fast pyrolysis process[216]. The crude pyrolysis oil can be upgraded and then distilled to produce diesel, jet and gasoline streams. This can be done either on-site at the fast pyrolysis plant or off-site in a conventional refinery.

[211] Ecofys (2012) 'Potential of biofuels for shipping'.
[212] IEA Bioenergy (2017) 'Biofuels for the marine shipping sector'
[213] Annex V, Directive 2009/28/EC of the European Parliament and of the Council 'Renewable Energy Directive' Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN
[214] European Commission (2017) 'Building Up the Future – Final report'. Sub Group on Advanced Biofuels. Sustainable Transport Forum. http://artfuelsforum.eu/wp-content/uploads/2017/05/SGAB-Final-Report.pdf
[215] Ship&Bunker (2018) 'Rotterdam Bunker Prices'. Available at: https://shipandbunker.com/prices/emea/nwe/nl-rtm-rotterdam#LSMGO
[216] E4tech (2017) 'Advanced drop-in biofuels. UK production capacity outlook to 2030.'

Conventional fast pyrolysis technologies for making food flavourings and bio-oil for heat and power applications have already been commercialised in a few plants, so fast pyrolysis is currently at early commercial stage (TRL 8). However, upgrading is much less developed at only around TRL 5-6, with some short blending campaigns conducted at demonstration scale in a few oil refineries, but no dedicated upgrading facilities are operational globally[216]. The upgrading step is less advanced than FT-Diesel, which has more active players working towards first-of-a-kind commercial plants. Should technical barriers be overcome, it can be estimated that upgraded pyrolysis oil via co-processing will reach the early commercial stage in the early 2020s, while standalone pyrolysis upgrading plants would reach early commercial stage several years later.

If crude pyrolysis oil were to be examined as a possible shipping fuel, its characteristics would require adaptations in the engine and entire fuel system and its significantly lower calorific value would lead to increased storage and transportation costs[217]. This, combined with its high viscosity, emulsion with water at 20-30% and the fact it does not auto-ignite in a diesel engine make it a much more challenging option to replace fuel oils. Engines could be modified by adding a module with a special fuel/feeding system for crude pyrolysis oil.

However, when upgraded its compatibility is markedly improved, and upgraded pyrolysis oil could get to a 'drop-in' fuel with similar characteristics to FT-Diesel, and could be compliant with EN590. In theory it is possible to produce any intermediary between crude and fully upgraded pyrolysis oil to produce a suitable fuel for particular engines, but this would require detailed testing with an engine manufacturer.

The well to tank GHG emissions savings of crude pyrolysis oil and upgraded pyrolysis oil are similar to those of FT-Diesel (i.e. high) when the upgrading takes place on-site at the fast pyrolysis unit and uses biomass for the internal energy consumption. There is also some potential for CO_2 capture to improve the GHG savings. If the upgrading takes place in a conventional refinery the GHG reduction potential is lower if fossil-produced hydrogen is used in the process.

Production costs are projected at 14-33 €/GJ which are at current oil prices still at least double the cost of current ULSFO and LSMGO Rotterdam bunker prices[218]. Production costs via co-processing in existing refineries are towards the lower end of the range, while stand-alone pyrolysis upgrading plants are towards the upper end of the range.

Table 4-11: Evaluation of upgraded pyrolysis oil

Shipping sector	Readiness of fuel production		Compatibility		GHG reduction potential
Inland	Today	2030	Today	2030	(when upgrading is done on-site)
Short sea			Today	2030	
Deep sea			Today	2030	

[217] Ecofys (2012) 'Potential of biofuels for shipping'.
[218] European Commission (2017) 'Building Up the Future – Final report'. Sub Group on Advanced Biofuels. Sustainable Transport Forum. Available at: http://artfuelsforum.eu/wp-content/uploads/2017/05/SGAB-Final-Report.pdf

4.2 GHG emission saving and production cost comparison

This chapter provides a comparison of GHG emission factors and production costs for the various biofuels and fossil fuels currently used in shipping to gain an appreciation of the potential differences, as well as uncertainties.

GHG emission savings for biofuels are compared to the fossil fuel reference value of 83.8gCO_2eq/MJ in the RED[219]. GHG emission savings above 90% are categorised as 'green', and those below 60% as 'red', with those in between as 'yellow', see Figure 4-2. The comparison is based on the high end of GHG emission savings to ensure that the best performing biofuels would stand out. HVO and FAME have a wide range of GHG emission savings depending on feedstock and process inputs, but can achieve high GHG emission savings when using waste oils. As indicated by the blue bar average, Dutch emission factors for HVO and FAME are at the lower end of the range of emission factors. Even though GHG emission savings from conventional ethanol when produced from sugarcane can be as high as 71% (according to the RED typical values), GHG emission savings from second generation biofuels should be more attractive. Ethanol from woody biomass and bio-LNG from anaerobic digestion lead to emission savings of around 75-90%, bio-methanol, DME and FT-Diesel from woody biomass all lead to typical GHG emission savings above 90%. When produced from renewable electrolysis and catalytic conversion of hydrogen and CO_2, similar GHG emission savings are possible for RFNBO methanol and RFNBO FT-Diesel.

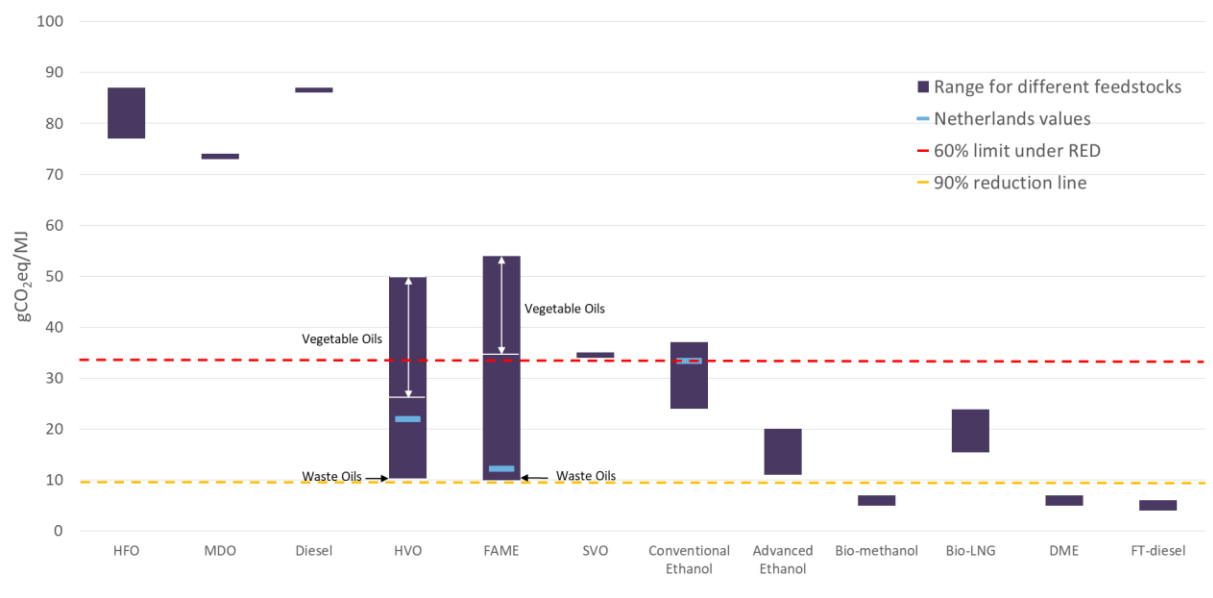


Figure 4-2: GHG emission factors for marine fuels and selected biofuels[220,221,222,223]

[219] Annex V, Directive 2009/28/EC of the European Parliament and of the Council 'Renewable Energy Directive' Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN
[220] The ranges of GHG emission values were taken from: Annex V, Directive 2009/28/EC of the European Parliament and of the Council 'Renewable Energy Directive' Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN
[221] Dutch emissions factors taken from: Dutch Emissions Authority (2016) 'Rapportage Energie voor Vervoer in Nederland 2016'.
[222] Fossil fuel values were taken from: IEA Bioenergy (2017) 'Biofuels for the marine shipping sector'
[223] Note that for bio-ethanol, bio-methanol, bio-LNG, bio-DME and FT-diesel could achieve higher GHG savings when using CO_2 capture technology.

Under the RED, biofuels have to achieve GHG emission savings of 50% for existing plants (from January 2018) and 60% for plants that came into operation since October 2015[224]. Typical GHG emissions only include direct emissions. Indirect emissions do not currently need to be included in the calculation to meet the GHG emission threshold. However, indirect land use change emissions have been discussed over the last years and the "Indirect Land Use Change Directive" provides emission estimations for different feedstock types. A cap of 7% for land-based feedstocks such as vegetable oil, sugar and starch crops has been introduced in the ILUC Directive in 2015 and is being discussed for further reductions to 2030 under the RED II.

Current marine fossil fuels and biofuels are compared on a price basis for traded commodities, but compared on a production cost basis for advanced biofuels that are at an earlier stage of commercialisation (and so do not currently have market data available). The range of production costs reflect a range of feedstocks costs and different levels of technology maturity, with the lower end of the bar reflecting achievable costs in 2030 for low feedstock costs, and the upper end reflecting current production costs and high feedstock costs. These costs should be taken as indicative for the advanced biofuels, as uncertainties around cost projections are high.

Figure 4-3: Prices and production costs of marine fuels and selected biofuels. Prices are in light purple and production cost estimates in dark purple[225,226].

[224] F3Centre (2018) 'EU sustainability criteria for biofuels'. Available at: http://www.f3centre.se/renewable-fuels/fact-sheets/eu-sustainability-criteria-biofuels (Last accessed 9/3/18).
[225] Market prices were taken from the high and low from prices from the previous year ending March 2018 (approximately 45-70 $/bbl crude price during this period). These are Rotterdam prices where available from https://shipandbunker.com/prices/emea/nwe/nl-rtm-rotterdam. More detail on prices can be found in the individual sections 4.1.1 to 4.1.9.
[226] Production costs for HVO, Advanced (LC) ethanol, bio-methanol, biomethane, upgraded pyrolysis oil and FT-diesel are taken from: European Commission (2017) 'Building Up the Future – Final report'. Sub Group on Advanced Biofuels. Sustainable Transport Forum. Bio-LNG costs were calculated by taking biomethane costs from AD and adding costs of natural gas liquefaction, which was estimated to be 0.6-1.2 €/GJ.

Biofuel prices are commercial prices (see detail of Figure 4-3). Figure 4-3 shows that, biofuels, in particular less developed advanced biofuels, are generally more expensive than their fossil fuel counterparts in shipping based on the current oil price of the order of $70/bbl. However, progress in commercialising the technologies and a focus on low cost feedstocks, e.g. various organic wastes and residues, could close the gap with conventional biofuels. Due to the large ranges and uncertainties, it is not possible to categorise prices or production costs for groups of fuels in a similar way as was done for GHG emission savings.

4.3 Non-GHG emissions

This study focuses on the reductions in GHG emissions that can be achieved from the use of biofuels. However, Chapter 2 shows that the non-GHG emission regulations are the current drivers for change in the shipping sector. Therefore, the non-GHG emission performance of biofuels is included in this chapter as an overview.

The sulphur content regulations of marine fuel offer an opportunity for biofuels, as all the biofuels considered here do not contain any (or only very limited amounts of) sulphur and therefore do not emit or only emit very limited amounts of SO_x emissions. Whether biofuel blends comply with sulphur regulations depends on the level of the blend and the fuel the biofuel is blended with. The stricter sulphur limits and the low LNG prices compared to other marine fuels are the main drivers behind the uptake of LNG in shipping. The low-sulphur characteristics of biofuels combined with the introduction of GHG emission regulations may shift the focus to biofuels as a solution to both of these challenges.

NO_x emissions are dependent on the combination of the fuel and the combustion characteristics of the engine. However, some indicative values are provided here, along with the level of PM emissions. All biofuels included in this study result in a reduction in NO_x emissions with the exception of FAME. The combustion of FAME can produce 10-15% more NO_x emissions than the incumbent fossil fuels[227,228,229]. This could require after-treatment processes to reduce the NO_x emissions to comply with specific emission regulations, especially in inland shipping where the Stage V NRMM regulations are the strictest.

HVO performs well, with NO_x and PM reductions (7-14% and 28-46% respectively)[230]. FT-Diesel also achieves similar levels of reductions, with a marginally better NO_x performance than HVO, achieving 10-30% reductions in NO_x and 20-30% reductions in PM[231,229]. The combustion of pyrolysis oil produces less NO_x emissions, however, the PM emissions can be quite high depending on the level of upgrading[228].

[227] Fernando, S., Hall, C. and Jha, S. (2006) 'NO_x Reduction from Biodiesel Fuels', *Energy & Fuels*, 20(1), pp. 376–382. doi: 10.1021/ef050202m.
[228] IEA Bioenergy (2017) 'Biofuels for the marine shipping sector', (October).
[229] Union of Concerned Scientists (1999) '*Emission Control Strategies*'. Available at: https://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean_vehicles/acfosdcrt.pdf (Accessed: 14 March 2018).
[230] Aatola, H. *et al.* (2008) 'Hydrotreated Vegetable Oil (HVO) as a Renewable Diesel Fuel: Trade-off between NO_x, Particulate Emission, and Fuel Consumption of a Heavy Duty Engine'. Available at: http://www.etipbioenergy.eu/images/SAE_Study_Hydrotreated_Vegetable_Oil_HVO_as_a_Renewable_Diesel_Fuel.pdf (Accessed: 14 March 2018).
[231] Szybist, J. P., Kirby, S. R. and Boehman, A. L. (2005) 'NO_x Emissions of Alternative Diesel Fuels: A Comparative Analysis of Biodiesel and FT-Diesel', *Energy Fuels*. American Chemical Society, 19(4), p. pp 1484–1492. doi: 10.1021/EF049702Q.

The most substantial NO_x and PM emissions reductions are achieved by LNG, ethanol, methanol and DME (including their bio-based alternatives)[229,232,233].

In summary, the biofuels considered are generally attractive in terms of non-GHG emissions and could make a significant contribution to reducing non-GHG emissions. However, further testing and research to establish a more solid basis to compare non-GHG emissions is desirable, taking into consideration particular uses (e.g. blend levels).

4.4 Total cost of ownership and payback time

This section provides an overview of the costs and payback times when using methanol and LNG, compared to the currently used marine fossil fuels, as well as the cost of required retrofits for HFO vessels to comply with sulphur regulations. A brief discussion on the competitiveness of HVO is also provided. The overview is based on existing studies which did not consider the additional cost of bio-methanol and bio-LNG compared to fossil methanol and LNG. The cost presented here can only provide an indication of potential investment cost as conversion costs depend on each ship (cargo capacity, space availability for new tanks etc.), and the payback time is influenced by its operational profile such as time spent in emission regulated areas. The studies only consider the current sulphur emission limit of 0.1% in ECA zones (see Chapter 2.1.3), which requires ship owners to use more expensive MGO fuel or installed scrubbers for continued use of HFO. The planned introduction of a 0.5% sulphur limit from 2020 globally has not been modelled yet, as the potential fuel prices of a 0.5% sulphur compliant fuel are still too uncertain. This will however positively impact the payback times of methanol and LNG (and their bio-based equivalents) given their significant reductions in sulphur emissions.

The total cost of ownership and hence the payback time is influenced by three key elements:

- The fuel price differential between methanol, or LNG, and diesel in inland shipping, MGO for use in short-sea shipping and HFO for use in deep-sea shipping. The ship owner could as well decide to use HFO with a scrubber in short-sea shipping inside ECAs.
- The investment cost for engine and vessel conversion to use methanol or LNG, for new build vessels and the cost for retrofitting scrubbers to existing vessels using HFO. This needs to include the cost for new or adapted storage and bunkering infrastructure outside the vessel. Both conversion and new build cost will change from a first of a kind to an 'nth' conversion or new build, which can be assumed to be similar to current HFO vessels[234]. As stated above these costs are very ship-specific and can only be considered as indicative.
- The operational profile of the ship which impacts the time spent inside emission control zones. Operational costs inside these zones are higher; however, the current cost differential will become smaller once the new global sulphur limit is implemented in 2020. This overview will only include the most beneficial case for alternative fuel use, that of 100% operation within ECAs, which could be considered as the short-sea and inland shipping sectors.

[232] Ecofys (2012) 'Potential of biofuels for shipping'.
[233] Su, J., Zhu, H. and Bohac, S. V. (2013) 'Particulate matter emission comparison from conventional and premixed low temperature combustion with diesel, biodiesel and biodiesel–ethanol fuels', *Fuel*. Elsevier, 113, pp. 221–227. doi: 10.1016/J.FUEL.2013.05.068.
[234] Maritime Knowledge Center (2018) 'Methanol as an alternative fuel for vessels'.

4.4.1 Fuel price differentials and other operating costs

The economic viability of using methanol, ethanol or LNG in shipping depends on the price differential between these fuels and MGO and HFO, as additional capital investment in conversion or new build vessels would need to be recuperated through the price differential over time. Methanol had a consistent price advantage to MGO from early 2011 to early 2013 see Figure 4-4, which has been eroded since the crude oil price decline in 2014[235]. As natural gas is the primary feedstock in fossil methanol, natural gas prices as well as methanol production capacity will impact the methanol price. Despite new methanol production facilities being added over the last few years, the price differential between methanol and MGO has remained low, see Figure 4-4. Existing studies use low, medium and high oil price scenarios to calculate the viability of methanol, ethanol or LNG use. Ellis and Tanneberger, 2015, have used MGO prices of 718 $/t (60 $/MWh) for the low oil price, 1066 $/t (89 $/MWh) for an average scenario and 1600 $/t (134 $/MWh) as a very optimistic, or high oil price scenario, while keeping methanol prices around 400$/t (72 $/MWh)[235]. Methanol prices in 2017 have even been above 400 $/t. The DNV-GL study on methanol used a high MGO price of 865$/t (based on a mid-2014 Rotterdam price) and a low MGO price of 450$/t (based on mid-2015 Rotterdam price)[236], hence prices closer or below the low price scenario of Ellis and Tanneberger, 2015. The lower MGO price is in the middle of the price range presented in Figure 4-3.

Ellis and Tanneberger, 2015, have considered equipment operation and maintenance costs as well, giving LNG estimated operating costs at 5-6 $/MWh and methanol at 3-4.5 $/MWh, while MGO was considered as the baseline.

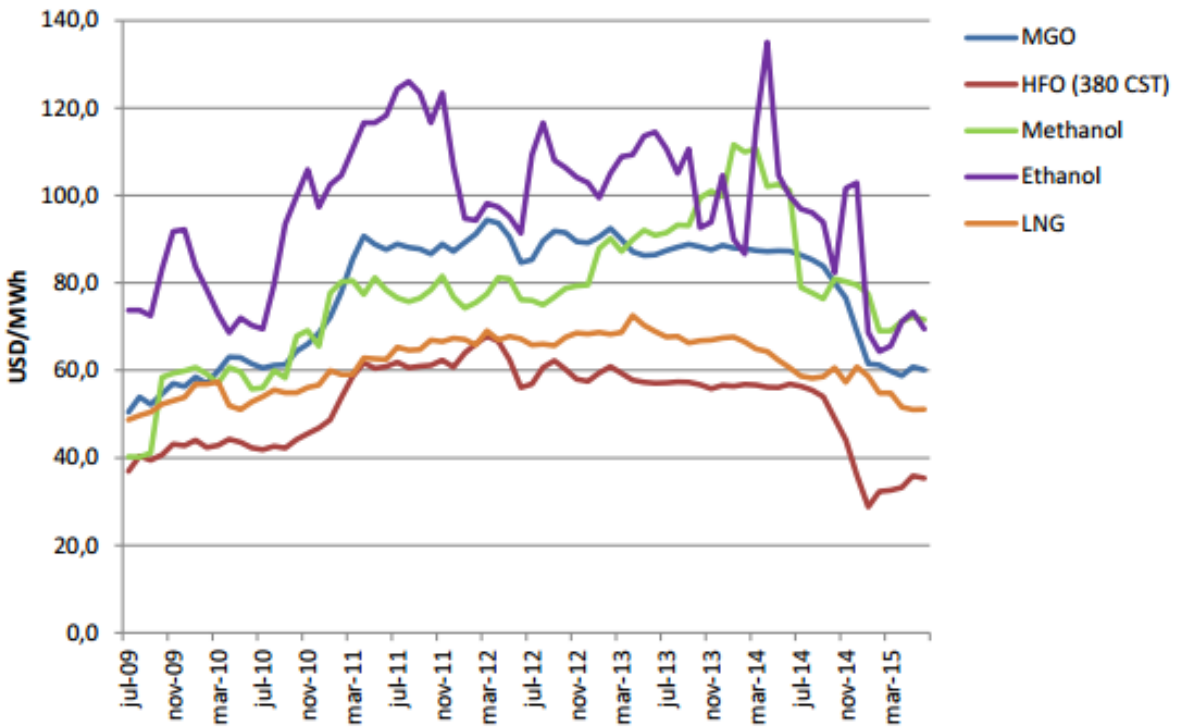


Figure 4-4 Historical MGO, HFO, methanol, ethanol and LNG prices (approximated) on an energy basis[235]

[235] Ellis, J. and K. Tanneberger (2015) 'Study on the use of ethyl and methyl alcohol as alternative fuels in shipping'.
[236] DNG-GL (2016) 'Methanol as a marine fuel: Environmental benefits, technology readiness, and economic feasibility'.

4.4.2 Investment costs

Conversion of existing vessel and engine

The conversion cost of a 24MW Stena Germanic ferry to methanol amounted to €13m while the total project cost was €22m including the methanol storage tank onshore and the adaption of the bunkering barge[237]. Specific conversion costs were 542€/kW or 917€/kW when including the full infrastructure cost. However, as a first of a kind conversion, the project included costs such as new work on technical adaptations or safety assessments, which can be reduced for future projects. Future conversion costs are estimated at 350€/kW (392$/kW) to 390 €/kW[238,239]. Conversion costs for LNG are estimated at 650-1000€/kW, around two to three times the cost of a methanol conversion[240,237]. A scrubber conversion to existing HFO fuel engines is estimated at 250 €/kW by DNV-GL and 437 €/kW by Ellis and Tanneberger, 2015[240,239].

New build vessel and engine

The costs for new build methanol vessels are estimated at 270€/kW for a 10MW MAN engine when including engine costs, engine work, fuel supply system, fuel tanks and piping[239]. These costs are expected to come down over time and it is assumed that costs will be similar to new build HFO vessels, but no particular figure has been provided in the literature. FCIB and DNV-GL argue that new build cost is lower, as the tank is incorporated into the design at the start, hence avoiding an additional cost to place the fuel tank for a vessel conversion. In contrast, Ellis and Tanneberger, argue that new build costs are higher, reported at 700 €/kW, as the new build includes costs for generators, electrical equipment as well as associated equipment while the conversion of an existing vessel does not[240]. LNG new build costs are higher than methanol, likely in the range of 2-3 times higher, similar to the conversion case. Conversion and new build for ethanol is estimated to be the same as for methanol.

4.4.3 Payback time comparison

The payback time is calculated as the time for fuel savings to compensate for the initial investment costs. At a low MGO price of 450 $/t DNV-GL have calculated a payback time of 6.8 years for a methanol new build ship if fossil methanol price would be at 75% of the MGO price. This would decrease to 3.2 years in the high MGO price scenario of 865 $/t or increase to 6.9 years in the high MGO price scenario when retrofitting an existing vessel. In all cases the payback times for a scrubber retrofit are lower than a conversion to methanol, or a methanol new build. Methanol can, hence, only be attractive at high oil prices, when the methanol price represents 75% or less of the MGO price and should ideally be considered for methanol new build ships. The first two conditions, plus the higher bio-methanol production costs, make it very difficult for bio-methanol to be an economically viable option without any policy support.

Ellis and Tanneberger, 2015, have calculated pay back times of 3.1 years for a methanol conversion and 3.8 years for an LNG conversion when using their 'average' MGO price scenario at 1066 $/t (23% above the high price scenario of DNV-GL) and a methanol price of around 400 $/t[240]. A scrubber retrofit to an existing HFO vessel would be most attractive at 2.2 years payback time. At their lower oil price

[237] FCBI Energy (2015) 'Methanol as a marine fuel report'.
[238] Using a exchange rate of 1.12 from USD to EUR
[239] DNG-GL (2016) 'Methanol as a marine fuel: Environmental benefits, technology readiness, and economic feasibility'.
[240] Ellis, J. and K. Tanneberger (2015) 'Study on the use of ethyl and methyl alcohol as alternative fuels in shipping'.

scenario, a methanol conversion would not break even and ethanol does not receive positive payback times even in the average oil price scenario.

A scrubber retrofit to existing vessels using HFO and operating in ECAs is the most economically viable option based on the existing literature. The economic viability of bio-methanol depends on high oil prices, a large price differential to MGO and HFO, a reduction of bio-methanol production cost as well as reduction in cost of methanol ship conversions and new build methanol vessels. Even though infrastructure cost for onshore storage and adaptation or new build of bunkering vessels is mentioned in the literature, it does not seem to have been incorporated in the cost calculations. This would in particular impact LNG whose initial capital investment costs are already 2-3 times higher than for methanol. The on average higher ethanol prices, make ethanol a less attractive option than methanol. Ethanol prices from lignocellulosic biomass, compared to sugar and starch feedstocks, would make the economic case for ethanol less attractive.

However, the possibility to count biofuels used in shipping towards the renewable energy target in the Netherlands, in order to receive 'renewable fuel units' with a value of 7-9€/GJ (see Chapter 2.3.1) could make the economic case more attractive. Advanced biofuels can currently be doubled counted, hence for bio-methanol one could receive at the moment around 16 €/GJ or 340 €/t in policy support[241]. However, double counting is likely to disappear post 2020. Assuming an MGO price of 11 €/GJ (460 €/t or 43 $/MWh) based on the average price in 2017, bio-methanol production costs of 19 €/GJ (510 €/t) could lead to the same price when accounting for the 8 €/GJ value of renewable fuel units (without considering double counting). It would require further research to investigate bio-methanol production cost in detail and evaluate whether the existing policy support could make the use of bio-methanol viable in shipping.

'Drop-in' fuels, such as HVO, do not require investment costs as they are compatible with the existing engine technology and refuelling infrastructure. Therefore, there is no capital payback and the TCO depends only on the price differential between the 'drop-in' biofuel and the fossil incumbent. The production cost of HVO is 14-25 €/GJ. The value for 'renewable fuel units' can be subtracted to give a fuel cost of approximately 5-18 €/GJ. The lower end of this range is competitive with all incumbent fossil fuels (See Figure 4-3).

4.5 Conclusions

The qualitative analysis of the biofuel options considered the fuel readiness now and in 2030, compatibility of the fuel with the current and 2030 vessel fleet and infrastructure, as well as the GHG emission reduction potential. This chapter also discussed non-GHG emissions and the total cost of ownership and payback times of methanol, ethanol, LNG and scrubber retrofits to existing engines using HFO to comply with SO_x limits in ECAs.

Some biofuels can be described as 'drop-in' biofuels, as they are liquid fuels that are functionally equivalent to their petroleum counterparts in marine engine combustion. Importantly, they also have full functionality in the existing petroleum infrastructure.

HVO is the only 'drop-in' biofuel that is currently available at commercial scale, allows high GHG emissions reduction when using waste oils, and hence is the most attractive short-term option to

[241] Maritime Knowledge Center (2018) 'Methanol as an alternative fuel for vessels'.

decarbonise the shipping sector, as shown in Figure 4-5. Its drawback lies in the limited availability of waste oils and fats, as HVO from vegetable oil crops can raise sustainability concerns and their use is limited under EU policy. The 'drop-in' nature of the fuel in road and aviation also leads to strong competition from those sectors. FAME is an attractive biofuel option in terms of readiness and compatibility for decarbonising the shipping sector in the short term.

FAME in contrast to HVO is more readily available, but suffers from the same feedstock constraints, has a blending limit of 7% in inland and short-sea vessels, and does not reduce NO_x emissions. Due to engine conversion requirements and its low overall attractiveness, SVO has been dismissed as a viable option for inland and short-sea shipping.

Conventional ethanol is widely available today, but its incompatibility with current marine engines represents a significant barrier for short-term decarbonisation of the Dutch shipping sector. However, in existing marine engines, fuel supply and storage can be adapted to use ethanol (or methanol). To achieve more widespread use by 2030, it would require demonstration projects to test ethanol in marine engines and the inclusion in the IGF code for the SOLAS regulation (see Chapter 4.1.4), as well as adoption of new rules by the certification bodies. This could instigate early ramp up of ethanol compatible vessels by 2030. The use of advanced ethanol, which should be commercially available by 2030, would achieve high GHG emissions savings. The key barrier for more widespread use of ethanol is cost. Ethanol, in particular advanced ethanol, is significantly more expensive than MGO as an option to comply with the 0.1% SO_x limit in ECAs and under current assumptions, can never recuperate the initial investment cost for the vessel conversion or the higher cost for a new build ethanol compatible vessel. The payback time for retrofitting a scrubber to a vessel using HFO in ECAs has been modelled as lower than ethanol and methanol in all cases (See Chapter 4.4.3).

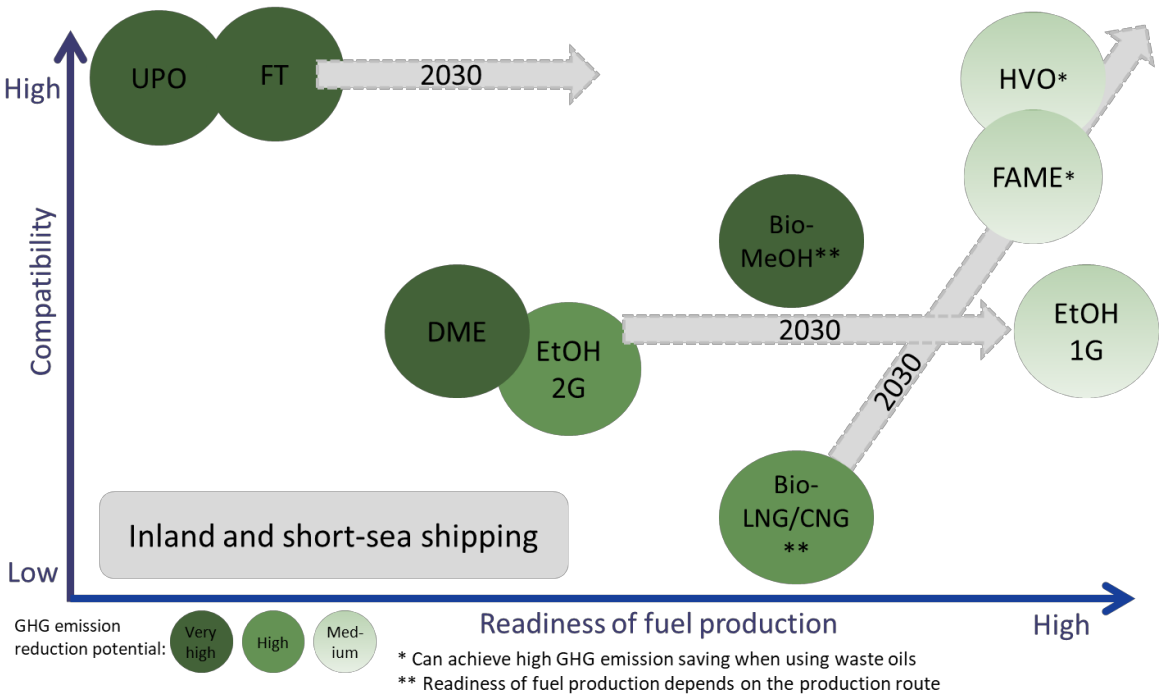


Figure 4-5: Overview of sustainable biofuel options in inland and short-sea shipping

However, bio-methanol, in a scenario with higher fuel prices than today (currently ~$70/bbl) and if a production cost of 15-25€/GJ could be achieved, has a better potential than ethanol in 2030 and GHG emission reductions could be higher. Bio-methanol could be readily available today, when produced from biomethane; however, the production of bio-methanol via gasification of solid biomass is only at early commercial stage. The more widespread use of bio-methanol would require a ramp-up of the current production facilities, further testing, adoption of the discussed IGF code and, as discussed in Chapter 4.4.3, policy support. Bio-methanol would be more attractive to the inland and short-sea shipping sectors as its 50% lower energy density (compared to the fossil incumbents) limits the vessels range required in deep-sea shipping.

DME, which can be produced from methanol, requires separate storage and bunkering infrastructure. Its gaseous state in ambient conditions requires a constant 5bar pressure. Even though more compatible with marine diesel engines than methanol it still requires adaptation of the engine and fuel system and is hence deemed less attractive due to more complicated storage and bunkering.

Bio-LNG is an interesting option as it is commercially available today from AD of organic waste or manure, achieves high GHG emission reductions (particularly with carbon capture) and could be used, either directly or via a mass-balancing system, in existing LNG vessels. When produced via bioSNG it is at a lower readiness level. Its compatibility has been judged as low, however, as the number of existing LNG vessels is marginal at the moment and the costs for converting existing vessels and infrastructure to LNG are significantly higher than for methanol due to the onerous storage, bunkering and infrastructure requirements. To make bio-LNG an attractive option by 2030 would require a significant increase in available LNG vessels and a high oil price environment. Bio-CNG is considered as a potential option in short-sea and inland shipping, but more research is needed on the implications of CNG use on the current vessel fleets.

The two other 'drop-in' biofuels, FT-Diesel and UPO, are attractive due to their full compatibility with current diesel engines and marine fuel infrastructure, but their lower commercial readiness will limit their availability in 2030. The readiness of FT-Diesels is not far away from bio-methanol via gasification, however, the use of FT-Diesel in shipping will receive strong competition from road and aviation due to its quality. UPO has a potentially attractive cost when compared to the other biofuel options, and especially FT-Diesel, although this is relatively uncertain given the early stage of development. The further development of production pathways for UPO may be beneficial for the shipping sectors in the long term.

Deep-sea shipping varies only in three aspects to the conclusions for inland and short-sea shipping:

- The price differential between biofuels and HFO used in deep-sea shipping is significantly larger than between biofuels and MGO or diesel, hence for biofuels to achieve economic viability will be even harder. The introduction of the global SO_x limit of 0.5% in 2020 would likely reduce this price differential, but it will remain larger than in inland and short-sea shipping.
- SVO is compatible with engines used in deep-sea shipping
- FAME is only allowed as de minimis based on ISO 8217.

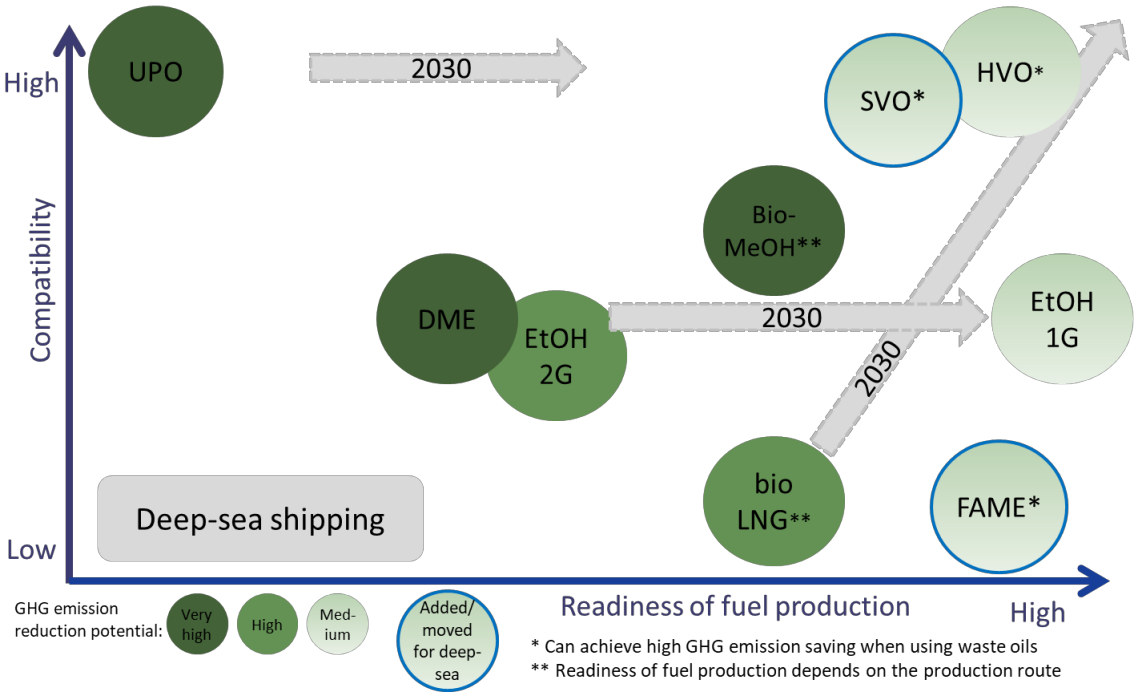


Figure 4-6: Overview of sustainable biofuel options in deep-sea shipping

5 Interventions

The use of biofuels in shipping is very limited at the moment, but there is the potential for growth via the range of sustainable biofuels described in chapter 4.5, which could significantly contribute to the decarbonisation of the sector, including in the Netherlands. This would require a set of interventions from different stakeholders. As the short-sea and deep-sea shipping sectors are mainly governed by IMO regulations (and will be influenced by their forthcoming full GHG reduction strategy, including measures for decarbonisation), the Platform for Sustainable Biofuels' efforts may be best focused on inland shipping where it can have greatest impact through Dutch policy and interventions on a national level. However, the Platform can also facilitate change in the short-sea and deep-sea sectors - in particular, by working with ports, who play a key role as the interface between the deep-sea, short-sea and inland shipping sectors. This chapter links key technical, economic and organisational barriers for the uptake of sustainable biofuels in the Netherlands to a range of interventions to overcome these barriers, and the associated actors. This is an initial overview of possible interventions, which sets the foundation for the development of more detailed ones and a roadmap for implementing them on the part of the actors concerned.

5.1 Interventions regarding technical and infrastructure barriers

Technical barriers that hinder the uptake of non-drop-in biofuels in shipping relate to the incompatibility of the current vessel fleet bunkering and fuel storage infrastructure and, for certain biofuels, further development and testing activities.

- Existing marine engines, the fuel system, and storage as well as bunkering infrastructure can be adapted to use ethanol or methanol, and dual-fuel engines are available off the shelf, but there is limited operational experience to date with these fuels. Methanol has been tested in a few retrofitted engines, and several new build methanol dual-fuel engines are in operation since 2016 on Methanex vessels, but ethanol has not been tested in marine vessels so far. For these fuels to become more widespread, there is a need to evaluate the success of current experience, disseminate best practice, and demonstrate further deployment. Possible interventions include:
  - An **evaluation of current experience**, with an emphasis on technical and economic viability, and **dissemination of best practices**. Such activity could be undertaken by **government in collaboration with key stakeholders**. The long term impacts on ship and fuel infrastructure should be assessed, and evaluation data be made available.
  - Additional **demonstration projects**, in particular for methanol and possibly ethanol retrofits, which could be **jointly funded by the public and private sector**. The demonstration activities should include data collection and evaluation programmes, as mentioned above. An **international or Dutch ports coalition** for biofuels could co-finance demonstration projects and accelerate scale-up possibilities for suppliers and end-users to achieve their own decarbonisation and sustainability targets. This could be initiated and coordinated by the International Association of Ports and Harbours (IAPH).

- Existing onshore storage and bunkering infrastructure needs to be adapted or expanded for methanol, ethanol and LNG. Possible interventions could include:
  - **Infrastructure grants / finance** by the Dutch government to co-fund new infrastructure, mitigate risks in new infrastructure development, and leverage private sector funding.
  - **Ports** could levy a **new duty** on ships to (co-)fund infrastructure.
  - **Shipping industry commitments** to adopt related fuels e.g. joint procurement commitments.

- Engines in marine vessels have a long life-time of around 20 to 30 years which leads to a very slow change across the vessel fleet. Hence, the introduction of new dual-fuel engines today will only have a marginal impact across the vessel fleet by 2030. Possible interventions to change the replacement rate could include:
  - Government and major ports could provide **incentives to alternatively fuelled vessels** e.g. preferential access for alternatively fuelled vessels that are part of green fuel procurement programmes, hence improving their economic viability through more rapid port handling, etc.

5.2 Interventions regarding economic barriers

The large price differential between marine fossil fuels and biofuels is the main barrier to the use of biofuels to decarbonise the shipping sector and has to date hampered initiatives in the industry. Additional conversion costs for ships and supply infrastructure are further important economic barriers.

- The cost of biofuels, in particular of advanced biofuels, is significantly higher in comparison to fossil marine fuels and their use is not economically viable unless incentivised. Although advanced biofuels costs could reduce in the future, bridging the gap with fossil fuels will depend on the oil price. It would be difficult for biofuels to compete with fossil fuels at the current oil price. Competition with road transport and aviation represent further economic barriers. A strong advanced biofuel target in the EU's RED II is essential to incentivise the introduction of advanced biofuels overall; but not sufficient to incentivise biofuels in shipping. The possibility to count biofuels supplied in shipping towards the renewable fuel obligation in the Netherlands is an important, existing incentive for the use of biofuels in shipping. Possible interventions to address the cost differential in shipping are:
  - Introduction of an **advanced biofuels sub-target for inland shipping** either in the EU or in the Netherlands. A strong target would create an incentive for biofuel producers, fuel suppliers, ship owners and ports. This could be formulated as a compulsory GHG emission reduction target for Dutch inland shipping too, and hence open it to a wider array of technologies and fuel types to ensure compliance.
  - An **increased multiplier for use of advanced biofuels** in shipping. A multiplier is particularly of interest if it helps accelerate the commercialisation of advanced biofuels routes. A multiplier of 1.2x for use in aviation or shipping is currently suggested in the RED II.

- **Carbon pricing** in the inland shipping sector, either via **carbon tax** or inclusion in the **European Emission Trading** (ETS) Scheme, could be options to make biofuels use in shipping more economically viable by including external costs and reducing the price differential. Given the volatile carbon price in the ETS at the moment, a carbon price floor, as introduced in the UK, would be essential to ensure it has an impact. This would have to be introduced either at EU or Dutch level.
- The Netherlands could make decarbonisation one of the conditions for **tonnage taxes** and make it more attractive for ships to use biofuels[242]. Tonnage taxes are already used by different countries to provide a favourable tax regime for the shipping sector. It is linked to requirements on seafarer training for instance, but could be extended to conditions on decarbonisation measures[242].
- The government, regional provinces or cities could include requirements for biofuels in their **public procurement** of inland shipping services, be it for ferries, police or custom ships. This could secure demand for biofuels in shipping and provide an early route to market. This could include wider cooperation amongst governmental fleet owners (e.g. 'Rijksrederij').
- Ports have provided **reductions in port fees** for ships with better environmental performance mainly related to local air pollutants. As air pollutants are now regulated strictly in ECAs and by the NRMM in inland shipping, ports could now include requirements on the use of sustainable biofuels and GHG reductions. This could be based on a voluntary initiative like the Clean Shipping Index (CSI) or the Green Award[242]. Besides reducing port fees, ports could give **priority to ships using biofuels** which would make port operations more efficient for those ships and hence provide an economic incentive.
- Companies such as Heineken with a strong drive on carbon footprint reduction along the supply chain could lead an **industry initiative on private sector procurement of biofuelled shipping services.** This would have the similar benefit to public procurement, providing a secure demand and a market signal to biofuel producers.

- Besides the higher costs for biofuels, the additional costs for converting existing vessels or building new vessels, plus the needed infrastructure, to enable the use of ethanol, methanol or bio-LNG represent a further considerable barrier to their uptake. Similarly to the technical and infrastructure barriers interventions discussed above, government grants, loan guarantees, and incentives / levies at ports can help address economic barriers to raising the capital required to convert and introduce new vessels and infrastructure.

5.3 Interventions regarding organisational & other barriers

In addition to technical and economic barriers, organisational barriers such as the lack of certification regulation, limited information about biofuels, and policy alignment between countries currently limit the uptake of biofuels in shipping. Similar to technical and economic barriers, these barriers depend strongly on the type of biofuel and do not apply to all biofuels equally.

- Low flashpoint fuels, such as ethanol and methanol, are currently not compliant with SOLAS regulations and require a specific risk assessment before being used on existing or new build

[242] OECD, 2018. Decarbonising Maritime Transport.

vessels. This includes the requirements for double-walled storage leading to higher cost for a retrofit or new build.

- **There is need for a new IGF code for both ethanol and methanol** by the IMO and publication of similar rules by the classification bodies. Both are currently under discussion and in the draft stage. This would make the safety and certification requirements for both ethanol and methanol clearer and their use in converted or new build vessels more straight forward.

- Misalignment in policies for marine biofuels between EU countries, and consistent application of rules such as mass balancing for biomethane (or bio-LNG), also represent barriers.
  - As the RED is implemented through a Directive, Member states have flexibility how the RED is implemented in national law which could lead to the divergence of biofuel policies for shipping. **Initiatives to align policies** should take place at European level and between different countries, e.g. possibly between neighbouring countries on inland shipping
  - The application of a **mass balancing system for bio-LNG or biomethane** allowing ship owners to bunker fossil LNG but claim for the use of bio-LNG or biomethane via a mass-balancing system.

- The current lack of clear information about compatibility, infrastructure requirements, costs, and certification requirements represents a barrier to the uptake of biofuels (and RFNBOs). The following interventions could help to improve this:
  - Ports, ship owners, engine providers, fuel providers and other stakeholders could increase **information sharing**. This could include sharing information on best practice, conversion and new build costs, as well as information about technical difficulties and how these could be overcome. One possible way of enhancing information sharing is the establishment of a **shipping biofuels forum**.

5.4 Summary of interventions

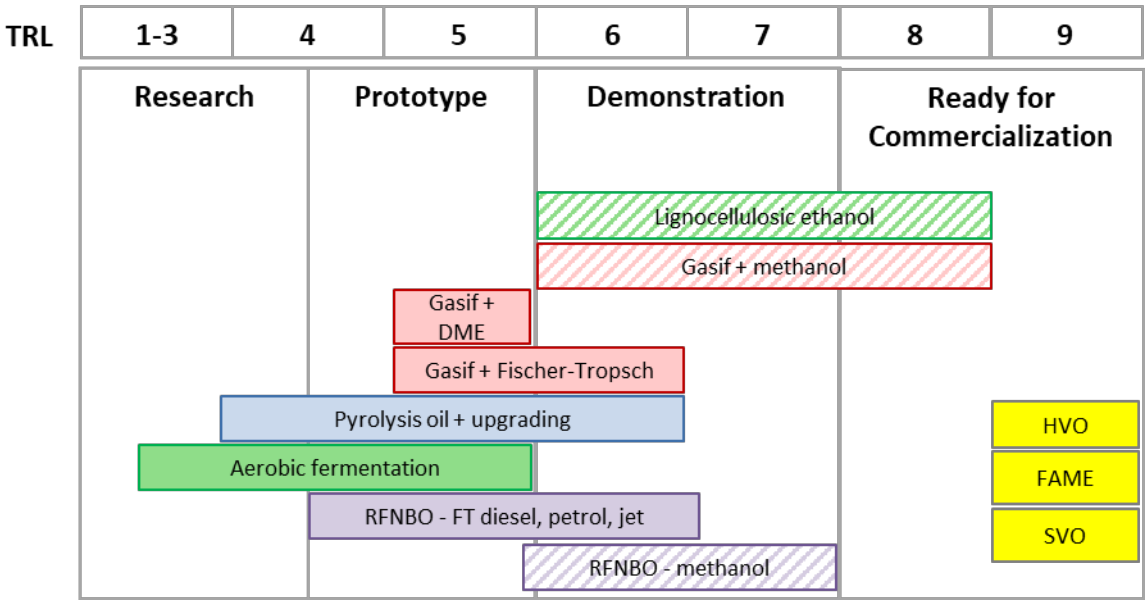
The following Table 5-1 summarises the possible interventions to overcome the technical, infrastructure, economic and organisational barriers discussed above.

Table 5-1: Summary of interventions

Barriers	Actions	Actors
Limited experience with and availability of alternatively fuelled vessels and related refuelling infrastructure	Evaluation of current experience and dissemination of best practice	Government in collaboration with key concerned parties
	Demonstration projects	Government or international / Dutch ports coalition
	Infrastructure grants / finance	Government initiatives to leverage private sector funding
	Port levy to (co-)fund infrastructure	Ports
	Fuels procurement commitments	Shipping industry
	Incentives for transition to alternatively fuelled vessel fleet	Government, ports

Price differential with fossil fuels	Advanced biofuels sub-target for inland shipping. Multiplier for use of advanced biofuels in shipping	Government
	Carbon pricing. Linking tonnage taxes to decarbonisation	Government
	Public procurement of biofuels	Government, public sector
	Reduction in port fees and other incentives at ports	Ports
	Private sector procurement of biofuelled shipping services	Industry (goods)
Lack of certification regulation	IGF codes for ethanol and methanol	IMO, classification bodies
Lack of policy alignment	Initiatives to align policies at European level and between different countries	Government, IMO, EU
	Mass balancing system for biomethane or bio-LNG	Government, EU
Lack of information concerning biofuels use	Information sharing, for example via establishment of a shipping biofuels forum	Relevant industry, associations and government departments

Appendix A - TRL of biofuel processes



Colours represent the principle conversion process, hydrolysis (green), pyrolysis (blue), hydrothermal liquefaction (grey), gasification (red), oil-based (yellow), and non-biogenic routes (purple). Shaded boxes refer to oxygenated fuels. Boxes with block colours represent non-oxygenated fuels