Assessment of alternative fuels for seagoing vessels using Heavy Fuel Oil

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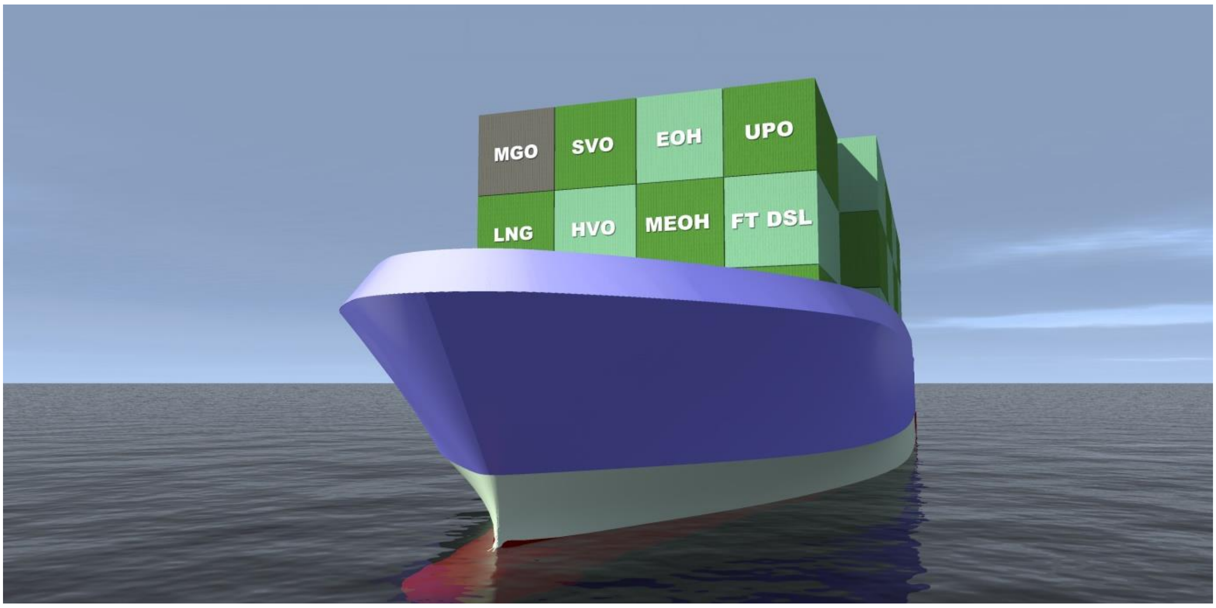
Final Report: Assessment of alternative fuels for seagoing vessels using Heavy Fuel Oil



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1. Introduction

There is a strong international pressure to reduce harmful air emissions in shipping. This is not only true for Emission Control Areas (ECA's) near the coast, but also outside these areas deep sea ships have to comply to a stringent sulphur norm (< 0,5% Sulphur) from the 1st of January 2020 onwards.

At present many scrubber installations are produced and installed on board of seagoing vessels in order to comply with these new emission regulations. Alternatively ship-owners can opt for Ultra Low Sulphur Heavy Fuel Oil (ULSHFO < 0,1% S), Liquid Natural Gas (LNG) or blends of Heavy Fuel Oil (HFO) and Marine Gas Oil (MGO). Many ship-owners have shifted or will shift towards Low Sulphur Marine Gas Oil (LSMGO < 0,1% S) in 2020 in order to comply with the new regulations.

ULSHFO, LSMGO (and LNG) can achieve a substantial reduction of Sulphur Oxides (SO_X). LNG can also achieve a substantial reduction in Nitrogen Oxides (NO_X) and Particulate Matter (PM). However, fossil fuels do not substantially contribute to the reduction of greenhouse gasses (GHG) like CO_2 in the atmosphere. The reduction of GHG is an important issue for (Dutch) main ports. Visiting ships contribute substantially to the CO_2 emissions in the region. This applies to inland vessels, short sea ships and deep sea vessels. The use of non-fossil fuels for Dutch and European waters and ports can substantially reduce CO_2 emissions.

This is not only valid for Tank To Propeller (TTP) emissions, but also from a Well to Propeller (WTP) perspective. Regulatory frameworks, fuel specifications, supply chain transparency, monitoring and control mechanisms are of utmost importance.

In this project an assessment of various alternative fuels for deep sea and short sea shipping is made using LSMGO as a benchmark. The focus is on an investigation of the technical feasibility and the economic impact of the various fuels not only towards 2030, but also towards 2050.

In chapter 2 the state of the art with regard to international rules and regulations (IMO) is described, followed by a multi-criteria analysis of over twenty alternative fuels. From the list of alternative fuels the most promising ones are selected for evaluation in a basic calculation model.

In chapter 3 the business cases for ship-owners are evaluated based on five different seagoing vessels, each with its own operational profile. Capital Expenses (CAPEX) for various fuel systems (tank, engine room and engines) are determined as well as Operational Expenses (OPEX) with regard to (projected) fuel costs. CAPEX and OPEX are inputs for a basic calculation model providing Total Cost of Ownership (TCO) trends from 2020 towards 2050.

Chapter 4 describes important bottlenecks with regard to fuel costs, scalability and availability in more detail. Competition from other modalities (aviation and road transport) for alternative fuels can become a clear threat to the implementation of clean fuels in shipping. Possible implementation routes for clean shipping fuels will be discussed in this chapter as well.

In chapter 5 conclusions and recommendations are given and follow-up projects are suggested in order to assist the shipping industry in a sustainable transition towards clean transport.

By doing so we hope to provide new insights to ship-owners, fuel suppliers, marine suppliers and shipyards, as well as governmental bodies in order to jointly develop solid transition paths for short sea and deep sea shipping; now and for the future.

2. State of the art

2.1. Rules and regulations in shipping

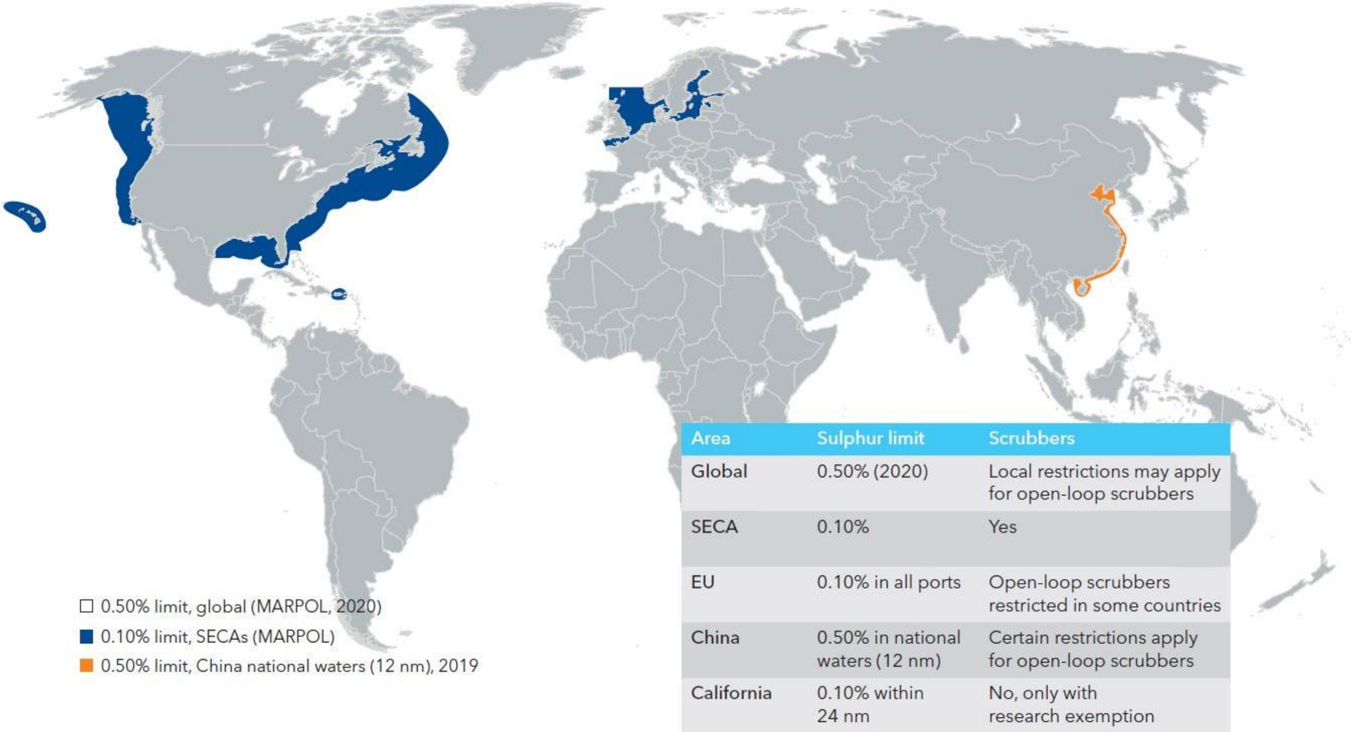
Rules and regulations are important boundary conditions and possibly enablers for the application of alternative fuels in the maritime sector. For the use of alternative fuels for the Netherlands' Shipping industry the regulations set by the United Nations and especially the IMO are most important. However, European rules on climate change policy and various European directives can have a significant impact on the shipping industry as well. A short summary of the most important International and European rules and regulations, in relation to emission reduction targets for the shipping industry is given in the following paragraphs. This excludes safety regulations, which can have a critical impact on the duration of implementation.

2.1.1. IMO pollutants regulations

Under IMO-MARPOL, two types of regulations regarding pollutant emissions were introduced:

- Regulations for maximum sulphur content in the fuel
- Tier legislation to limit NO_X emissions of the engines

The fuel regulations apply to all ships, the NO_X regulations on the other hand, only apply to new ships, build from a certain date. The fuel sulphur limits limit both the SO_X emissions as well as the particulate emissions of engines. We distinguish levels for Emission Control Areas (ECA) as well as global measures. In some Emission Control Areas the use of scrubbers (open loop and/or closed loop) for prevention of SO_X emissions are not even allowed. See also the figure 2.1 and table 2.1 below.



Area	Sulphur limit	Scrubbers
Global	0.50% (2020)	Local restrictions may apply for open-loop scrubbers
SECA	0.10%	Yes
EU	0.10% in all ports	Open-loop scrubbers restricted in some countries
China	0.50% in national waters (12 nm)	Certain restrictions apply for open-loop scrubbers
California	0.10% within 24 nm	No, only with research exemption

Figure 2.1 Emission Control Areas and use of scrubbers. (DNV-GL, 2019)

Table 2.1: Fuel sulphur requirements in order to limit SO_x emissions

Fuel sulphur content	2008	2010	2012	2015	2020
SO_x Emission Control Area (SECA)	1.5%	1.0%		0.1%	
Worldwide	4.5%		3.5%		0.5%

The NO_x limits are presented in figure 2.2 and table 2.2 below. The limits are dependent on the rated (maximum) engine speed. As a consequence, the limits are more stringent for smaller engines than for large engines. Tier II entered into force for new ships build from 2011 onwards. The NO_x limits are 15% to 25% lower than Tier I, which entered into force in 2005. The NO_x limits for Tier III, which only apply to Emission Control Areas, are 80% lower than for Tier I. Tier III entered into force for the USA east and west coasts in 2016. It will enter into force in Europe for the North sea and Baltic Sea in at the 1st of January 2021.

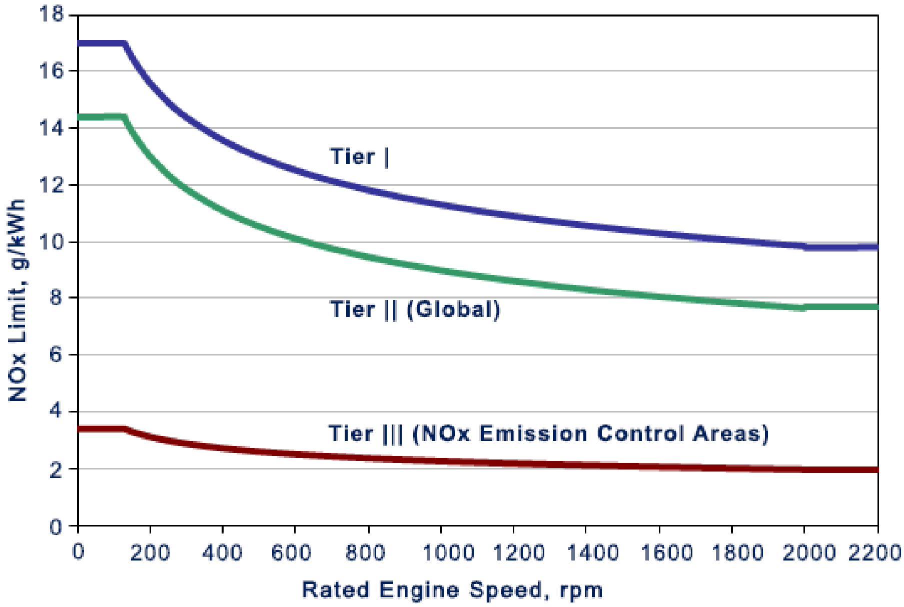


Figure 2.2 NO_x limits Tier I, II and III at different rated engine speeds. (DNV-GL, 2015)

Table 2.2: NO_x emission limits. NO_x limit depends on maximum engine speed. Larger engines have higher limit values.

NO_x emission limits (g/kWh)	Tier I	Tier II	Tier III
Year entry into force	**2005**	**2011**	**USA - 2016 Europe - 2021**
NO_x Emission Control Area (NECA)			2.0 - 3.4
Worldwide	9.8 - 17	7.7 - 14.4	

2.1.2. IMO GHG regulations

Under MARPOL two measures are implemented related to GHG emissions:

- Energy Efficiency Design Index, (EEDI, 2011), which regulated the efficiency of the ship design
- Ship Energy Efficiency and Management Plan (SEEMP, 2011), which merely gives a method to monitor energy efficiency during operation.

Furthermore, in April 2018, the IMO agreed on an overall strategy for the reduction of GHG emissions from shipping. This consists of three main parts:

- to strengthen existing rules for more energy-efficient ship designs
- to reduce GHG emissions in relation to transport work by 40% or more until 2030 and striving to reach 70% by 2050, compared to the 2008 level.
- to reduce shipping's total emissions of greenhouse gases as soon as possible and to release half as much GHG in absolute terms in 2050 as in 2008 (International Maritime Organization, 2018).

Specific measures to reach these goals still need to be worked out.

2.1.3. European general climate policy

The European Union, as one of the Parties to the UN Framework Convention on Climate Change, has set goals for reducing its GHG emissions progressively up to 2050, which are more ambitious. The current policy includes the following GHG emission reduction targets compared to 1990:

- 2020 climate and energy package: 20% reduction
- 2030 climate and energy package: 40% reduction
- 2050 low-carbon roadmap: 80-95% reduction

The EU policy on climate change mitigation is built on two major pillars:

- The EU Emission Trading System (EU ETS, 2009) which has created a market for CO_2 emissions based on “cap and trade”. The system includes major energy consumers (energy producers and industry as well as intra-EU aviation) and comprises of more than 11,000 companies. These companies can receive or buy CO_2 allowances, giving them the right to emit a certain amount. By reducing the total cap (the amount of CO_2 that is allowed to be released by all companies), prices will increase, which will boost CO_2 emission reduction and contribute to the development and deployment of low-carbon technologies.

- The EU Effort Sharing Decision (EU ESD, 2009) covers the non-ETS sectors and sets binding annual targets for GHG emissions for each Member State until 2020, in line with the 2020 climate and energy package. A number of European policies are (being) implemented to help reducing emissions (e.g. CO_2 standards for cars and vans, (EU Ecodesign, 2009)), however the Member States themselves are responsible for developing and implementing additional policies as needed to meet the targets.

IMO is a likely to play a role in the development and implementation of policies internationally, even as policies will also originate within Europe with basis in ports and routes and segments, for instance in Emission Control Areas (ECAs).

EU will likely also be able to engage in programs through technology development and perhaps linkages with broader programs such as emission trading inside and outside maritime shipping segments and the sector itself.

EU regulations affecting the cost of fuels and/or emissions.

2.1.4. EU regulations affecting the cost of fuels and/or emissions

The EU Renewable Energy Directive ((RED Directive, 2009) and (RED II Directive, 2018)) is one of these programmes that can have an impact on the shipping industry, since it offers the opportunity to reduce the prices of renewable fuels in the maritime sector via a rather complicated system of so-called bio-tickets. This RED II Directive and its possible impact on the Netherlands’ Shipping industry will be researched further in this study.

In the international context a system of carbon credits is used in order to attempt to mitigate the growth in concentrations of GHGs. Carbon credits create a market for reducing greenhouse emissions by giving a monetary value to the cost of polluting the air. Emissions become an internal cost of doing business and are visible on the balance sheet alongside raw materials and other liabilities or assets. Although the international carbon credit system can be useful for the Netherlands' shipping industry as well, this subject will not be researched in the scope of this study.

2.1.5. Uncertainties

With the implementation of International and EU regulations there are several uncertainties that still play a significant role. At present there are no concrete implementation goals for the 2030 IMO targets.

Furthermore the EEDI is due for an update, since it does not help (sufficiently) to achieve the aims. Despite these uncertainties the current state of the art can give us an overview of possible fuel options and business cases for the Dutch Shipping sector.

Based on the Climate Agreement of the Dutch Government (Klimaatakkoord, 2019), a GHG taxation plan will be implemented starting in 2021. This start with a cost of 30 euro per ton CO_2eq GHG, and can be increased to 150 euro per ton in 2030. This will significantly impact the business case of alternative fuels. However, shipping and aviation have been exempted for now, and an equal type of approach is discussed which takes into account the complexities of global trade and presence.

2.2. Multi criteria analyses of alternative fuels

In this paragraph an overview is given of various alternative fuels that are available to reduce greenhouse gasses in the shipping sector. These alternative fuels are primarily evaluated based on their current and future technology readiness level (TRL) with regard to fuel production.

The TRL estimates the maturity of technologies. TRL level 3 to 5 indicates the phase of technology development. TRL level 5 to 7 indicates the phase of technology demonstration. TRL level 6 to 8 indicates the phase of system and subsystem development. TRL level 7 to 9 indicates the phase of systems testing for launching and operations. TRL level 10 indicates proven technology.

Other important criteria are:

- Production costs, production routes of the fuels
- Scalability of the fuels and feedstock sustainability
- Fuel compatibility with engine and ship as well as TRL level of the engine
- Competition with other modalities (e.g. road transport)
-

2.2.1. Long list of sustainable fuel options

In table 2.3 an overview is given of the alternative fuel options with the biomass feedstock and/or production route and the TRL level of the fuel production. The latter for 2019 and an estimated value for 2030, based on a workshop with ECN-TNO specialists (Ayla Uslu and Hein de Wilde).

Table 2.3 Current and future TRL levels for various alternative fuels.

End product	Feed stock / Production route	Fuel production	
		TRL 2019	TRL 2030
Conventional			
SVO / PPO	Oil crops	10	10
FAME	Oil crops	10	10
HVO	Oil crops	10	10
Ethanol	Sugar / starch hydrolysis	10	10
Advanced			
HVO	Used oil (used cooking oil)	10	10
Methanol	Black liquor Gasification	6/8	8/9
Ethanol	Lignocellulosic hydrolysis	8/9	9/10
Ethanol/ methanol	Waste based	8/9	10
Butanol	Sugar / starch hydrolysis	7/8	7/8
Butanol	Lignocellulosic hydrolysis	6/8	6/8
LDO (lignin diesel oil)	Lignocellulosic hydrolysis / solvolysis	4/5	6/8
Bio-crude (Upgraded bio-oil)	Lignocelluloses Hydrothermal liquefaction/ catalytic refining	2/4	4/5
Upgraded pyrolysis oil	Lignocelluloses Pyrolysis/ catalysed upgrading	5/6	6/8
Methane / bio-LNG	Lignocelluloses Gasification	6/8	8/9
Methanol	Lignocelluloses Gasification	6/8	8/9
DME	Lignocelluloses Gasification	6/8	8/9
FT-Diesel	Lignocelluloses Gasification	6/8	8/9
Renewable diesel	Wood extractives pulping/ catalytic upgrading	8/9	8/10
Renewable diesel	Algae/oil extraction / catalytic upgrading	4/5	4/5
Methane / bio-LNG	sludge/maize/manure/ residues Fermentation	10	10
Power to X			
Hydrogen	Electrolysis renewable electricity	9	10
Pt methane	H_2 + C + methane synthesis	5/6	6/8
Pt methanol	H_2+C + methanol synthesis	5/6	6/8
Pt diesel	H_2 + C + Fischer Tropsch	5/6	6/8
Pt ammonia	H_2 + N	5/6	6/8
Conventional /fossil			
Hydrogen (grey)	Natural gas steam reforming	10	10

Very important aspects are the sustainability of the feedstock, especially competition with food and ILUC aspects. ILUC stands for Indirect Land Use Change. Basically CO_2 is emitted due to the repression of original vegetation due to the production of crops.

Sustainability is the main factor which determines the permanency and the acceptability of the biofuel and its production route. In general one can say that the permanency for fuels that are made of food crops, unfortunately the majority of the current production, is poor. The permanency is better if the biofuel is made of non-food cellulosic materials such as crop residues, pulp, leaves, saw dust etc. The European RED-II offers insight in the permanency of the biofuel production options. The RED-II sets the boundary conditions for the required growth of the share of sustainable fuel in road transport. This share needs to grow to 14% in 2030 of the total fuel energy for road transport. In figure 2.3 the shares of the various feedstocks for biofuels are depicted. It should be noted that the 14% includes double counting of advanced renewable fuels, which means that the share of renewable fuels in absolute terms will be less (only 10-11%).

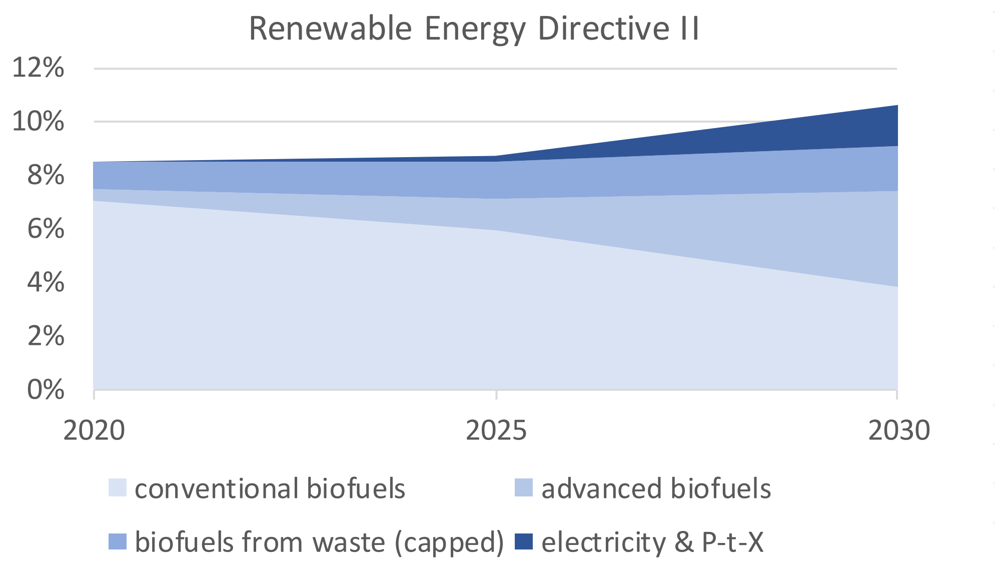


Figure 2.3 (TNO) Projection shares of various types of sustainable fuels to fulfil RED-II requirements

The RED-II sets caps on the use of certain type of biofuels, basically the currently produced biofuels. This is to enforce the phasing in of new more sustainable biofuels and also other renewable fuels such as E-fuels (P-t-X). The caps are as follows:

- Max 7% biofuel from (food) crops
- Max 1.7% biofuel from Used Cooing Oil (UCO)

Shipping and aviation are exempted for the 14% obligation, but they can opt in to contribute to the target. If that is done, the caps apply automatically for maritime.

When maritime follows an independent route, it still would be advisable to follow the RED-II guidelines. Using this as a precondition, the biofuel options are shrunk to those made from cellulosic materials, black liquor, sludge, manure and residues of fermentation.

The processes to make fuels out of this include gasification and synthesis, hydrolysis, residues of fermentation and pyrolysis (with catalytic upgrading). The most suitable fuels are then methanol, ethanol, biogas (bio-LNG) and Fischer Tropsch or renewable diesel.

2.2.2. Fuel compatibility with engine

Table 2.4 provides an overview of the fuel types and engine types. Hydrotreated Vegetable Oil (HVO), Fischer Tropsch (FT) diesel, Fatty Acid Methyl Esters (FAME) and Pure Plant Oil (PPO) - also called Straight Vegetable Oil (SVO) - are (near) drop in fuels for diesel engines. It should be noted that usually some adaptations with respect to the fuel system are necessary. For example, the installation of a special filter. With respect to FAME and PPO, there are more risks in terms of fuel stability and microbial contamination (IEA Bioenergy, 2017). Bio-LNG can be considered as a drop in fuel for an LNG engine. Some drop-in fuels can be used as pure fuels (e.g. HVO) or as a blend with fossil fuels.

For alcohols (methanol and ethanol) similar engine technologies can be used as for LNG; either dual-fuel with diesel as basis for the start of combustion or as single fuel with spark ignition. There are a few other options for alcohols as well:

- To mix an ignition improver (up to 5%) in the alcohol so that it can be used in a diesel cycle, compression ignition engine. This is a special engine since the injection and combustion characteristics are different to diesel fuel.
- To blend the alcohol with diesel fuel, e.g. a low blend limited to some 20% diesel. This can then be used in a more or less standard diesel engine. This concept does have some advantages such as lower emissions potential, but also some adverse effects such as the limited stability of the blend, and increased vapor pressure of the blend.

All dual fuel and single fuel engines using gasses or alcohols have the potential benefit of significant pollutant emission reductions for NO_X, PM and SO_X (due to the absence of sulphur in the fuel). In case of (bio)LNG, it has been shown that Tier III emissions can be reached without aftertreatment. Also alcohols have shown large emission reductions. Tier III without aftertreatment may be feasible as well, but has not yet been demonstrated.

Table 2.4 Fuel compatibility with engines

	Alternative sustainable fuel	Engine type
Drop in* fuels for diesel engine	HVO, FT diesel, FAME, PPO	(standard) diesel engine
Drop in fuel for gas engine	Biogas / bio-LNG	Dual-fuel or single fuel spark ignition
Alcohol	methanol, ethanol, butanol	Dual-fuel or single fuel (spark ignition or compression ignition with ignition improver)

* some adaptations to the fuel system may be necessary

2.2.2.1.Drop in fuels for diesel engines

These fuels have similar combustion properties as diesel fuel. They have a low auto-ignition temperature which make them very suitable for diesel cycle compressing ignition. This group contains the following types: PPO (Pure Plant Oil, also known as SVO, Straight Vegetable Oil), FAME (conventional biodiesel), HVO (Hydrotreated Vegetable Oil), Upgraded Pyrolysis Oil (UPO) and FT diesel (from lignocelluloses gasification).

2.2.2.2 Drop in fuel for gas engines

Bio-methane or synthetic methane can be blended with LNG, provided it is also liquefied. For the engine and fuel storage on board, this would generally be fully compatible. The quality of the LNG – expressed in methane number – may even be higher for bio-LNG than for fossil LNG. The latter may contain some percentages of higher hydrocarbons such as ethane and butane, which reduces the knock resistance.

2.2.2.3.Alcohols and ethers

Alcohols like methanol, ethanol and butanol have a high auto-ignition temperature, which make them suitable for spark-ignition engines. For ship engines, there is experience with dual fuel options with methanol and ethanol. It is basically a similar engine conversion as for LNG dual-fuel. You can also keep the flexibility to run the engine fully on diesel fuel. A third possible option is adding an ignition improver to the alcohol, such that the auto-ignition temperature is lowered and it can be burned as diesel fuel. It does require a special injection system, which can handle the alcohol fuel properties (including higher volume flows due to lower energy content.

Dimethyl ether (DME), is very similar to methanol with regard to fuel production, however in engine application it is completely different. DME has a low auto-ignition temperature which makes is very suitable for diesel combustion. The injection system is however different from diesel engines (higher volume, lower pressure, lower lubricity). Some demo truck engines on DME have been build, but not (yet) ship engines. Although for the engine DME has some advantage over methanol, the fuel tank would be more expensive and require much more volume, since DME is a liquid gas similar to LPG (10-20 bar pressure at ambient temperature).

2.2.3. Summary sustainable fuel options

In Table 2.5 a summary for the most popular alternative fuel options is given. For the fuel costs, refer to section 3.2. DME and butanol are not included in this comparison. Methanol is considered to be more practical than DME in terms of handling and storage and also somewhat lower in costs. Also Ethanol is considered the better, more economic option for the cellulosic feed stock than butanol.

Table 2.5 summary of sustainable fuel options

	Sustainability	Fuel costs	Engine application	Competition with road transport
HVO, FAME, PPO	-	+	++	-
FT diesel, renewable diesel	+	- -	++	o
Biogas, bio-LNG	+	+	o	o
Bio-Methanol	+	+	o	+
Bio-Ethanol	-/+	o	o	o

For road transport, the RED-II sets the sustainable fuel targets up to 2030. In this target a cap (maximum) is set to the use of biofuels from food crops (primarily HVO, FAME, PPO and ethanol). This max is set to 8.7%. It is advised that maritime also uses this as a maximum or even better focus on the more sustainable biofuels only.

2.3. Possible routes towards clean shipping

There are many studies done with respect to GHG reduction of international shipping. References are for example Eskeland and Lindstad, 2015; Psaraftis, 2016; Miola et al., 2011; Russell et al., 2010; Buhaug et al., 2009; Davidson and Faber, 2012; Lindstad et al., 2015; Carr and Corbett, 2015; Balland et al., 2015; Cullinane and Bergqvist, 2014; Nikolakaki, 2013; Lee et al., 2013, Bouman et al., 2017.

In Bouman et al. 2017 about 150 publications were reviewed and the reduction potential per type of measure is summarized in de figure 2.4. Several studies present Marginal Abatement Costs curves (MACC) which show that the most cost effective measures are operational and technical measures.

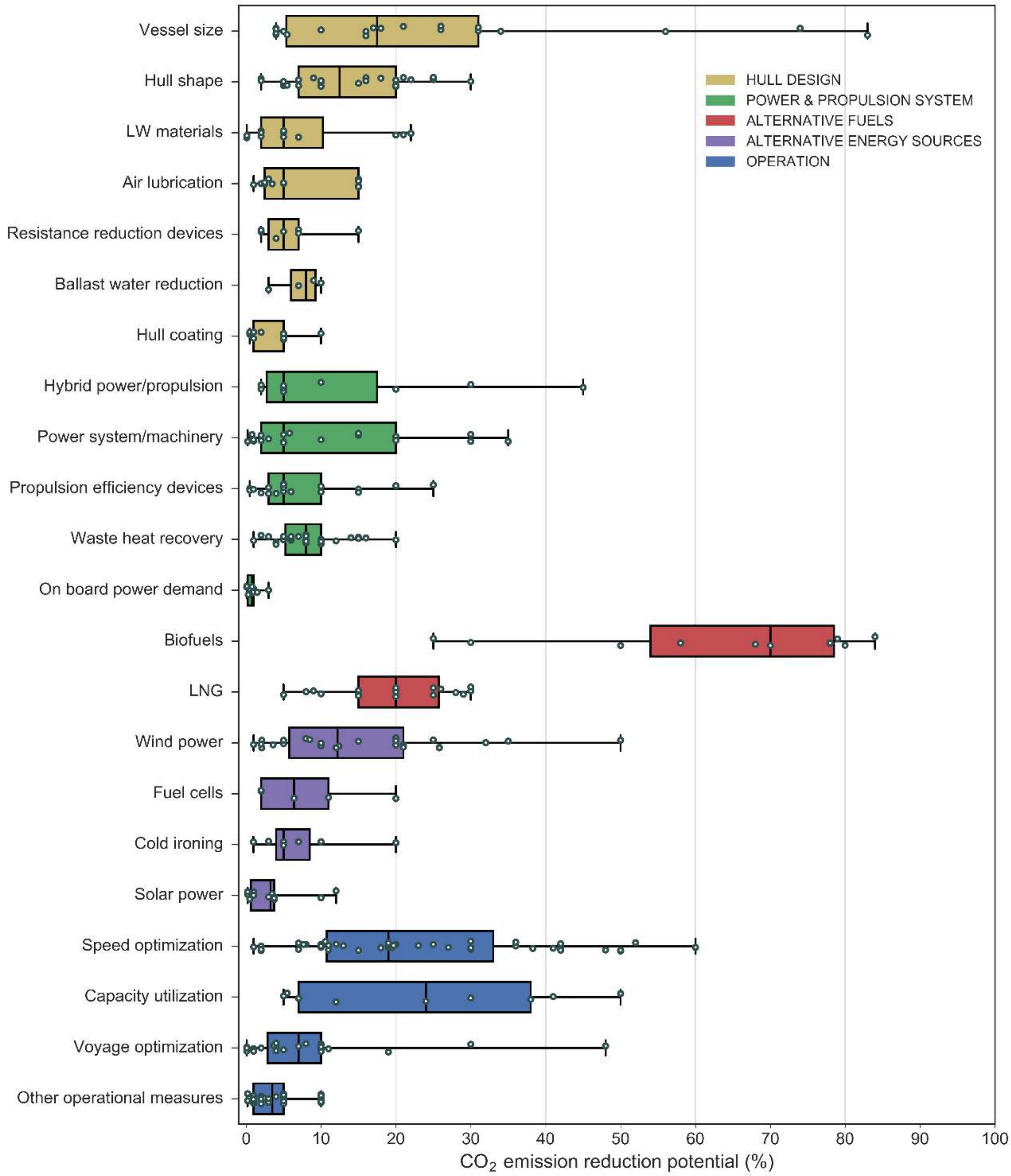


Figure 2.4 CO_2 emission reduction potential from individual measures, classified in five categories of measures

The primary challenge is closing the 'durable shipping business case'. This effectively means that clean shipping must be cheaper than non-clean shipping. To do this there are two main measures:

1. Cost reduction for clean shipping via technical, or operational measures. Such as:
- Technical measures (hull design, power & propulsion system)
- Operational measures to reduce energy consumption

- Alternative fuels and energy sources (LNG, biofuels, synthetic fuels)

2. Increasing the relative cost of non-clean alternatives via taxation of emissions, or subsidizing clean alternatives.

Finally, there is the more complex but essential task of clarifying that the shipped products or maritime activities have been performed in a ‘green’ manner. They should be made visible and recognizable for the greater public, thereby creating added value for the consumer at the end of the chain. A possible solution for this would be GHG tracking of products, with labelling at the final consumer phase.

In Lee et al. 2019 projections are made for the transport demand growth between 2020 and 2050, based on six scenarios of GDP growth. This shows that the container transport demand would grow from about 12,000 ton.miles/yr in 2020 to a minimum of 25,000 ton.miles/yr in 2050. In the highest growth scenario this would even be far above 40,000 ton.miles/yr.

The bulk transport of oil, coal and gas would in total more or less remain constant. It is clear that given this total growth rate, technical and operational energy savings would not be enough to meet the long term GHG targets.

So alternative fuels are needed. However, there are also concerns about the availability and sustainability of biomass. Biomass (and biofuels) might in the long term future preferably be used for industry (chemical products) as well for aviation.

For aviation, it seems the most difficult to switch to other energy carriers with usually a much lower energy density. For maritime shipping, if biofuels would not be an option in the long term, a good alternative would be synthetic fuels. These fuels are based on wind and solar energy.

Synthetic options include (pure) H_2, methanol, methane, ammonia (NH_3) and synthetic diesel. Methanol and NH_3 are put forward as good options for international shipping, because they are relatively economical to produce, although costs projections are higher than those for the current biofuels (HVO, FAME, bio-methanol and -ethanol). Also from a total system perspective, it is not logical to stimulate a fast transition to synfuels, as long as there is not a surplus of wind and solar energy.

From this, we can conclude that a transition to synfuels is not unlikely, but even in a positive scenario, it will take many years before substantial synfuel production can take place. So most likely biofuels is the most important option for GHG reduction for the coming 10-20 years.

A smooth transition from biofuels to synfuels is likely, without massive new investments on ship engines and infrastructure. Both drop in biofuels as well as methanol could be good options in this respect. We can envision the following scenarios with a good transition from bio- to synthetic fuels:

- Drop in biofuels to synfuels: no investments in ship powertrain for the near future, and a slow transition to for example methanol or ammonia powertrains after 2035.
- Bio-methanol to synthetic methanol: gradual investments in methanol powertrain starting in the near future, which makes the converted ships ready for the transition to synthetic methanol.

Of course also a combination of these two scenarios can be sensible. International shipping is a good candidate to absorb both drop in fuels (biodiesel / biogas) as well as methanol depending on the availability and costs of the options.

LNG is regarded as a good candidate to reduce GHG emissions. The LNG price is often lower than the HFO/MGO price and due to the lower carbon to hydrogen ratio, the GHG emission is potentially up to 25% lower.

Unfortunately this potential is not always utilised due to methane emissions (slip) of the engine.

Reports on methane emissions over the past years do not indicate a positive development yet. A possible route is the implementation of MARPOL legislation regarding methane emission of ship engines. This may make LNG engines more expensive and/or lose some engine efficiency.

3. Representative Dutch ships for potential business cases

In this chapter scenarios will be defined for potential business cases with representative ships in the Dutch merchant fleet using different alternative fuel blends. In chapter 3.1 a selection of five representative ship types will be made. In chapter 3.2 an overview of fossil and alternative fuel prices for the maritime sector will be given. In chapter 3.3 the ships system cost will be determined using a basic calculation method. Finally in chapter 3.4 several future scenarios for fuel use are determined.

3.1 Selection process of representative Dutch vessels

The market a ship operates in, as well as the characteristics of the ship, such as main dimensions, design speed, engine power, etc. all may influence the choice of green fuel. As the focus of this research is the Dutch market a quick scan is made of the vessels owned by Dutch ship owners, this is a larger selection than e.g. Dutch flagged vessels, as many owners will not carry the Dutch flag, but still operate here. The goal if this analysis is to select a relatively small number of representative vessels.

3.1.1. Ship dimensions

The Clarksons database is used to investigate the characteristics of the Dutch merchant ships. The first element checked is the size of the ships; 3 groups of ships can be seen 0-27,500 DWT (91.6%), 32,500-40,000 DWT (3.3 %) and 55,000-75,000 (3.1%). Given the fact that the other two groups are very small, the focus of this research will be on the first group of vessels between 0 and 27,500 DWT. (see also Figure 3.1)

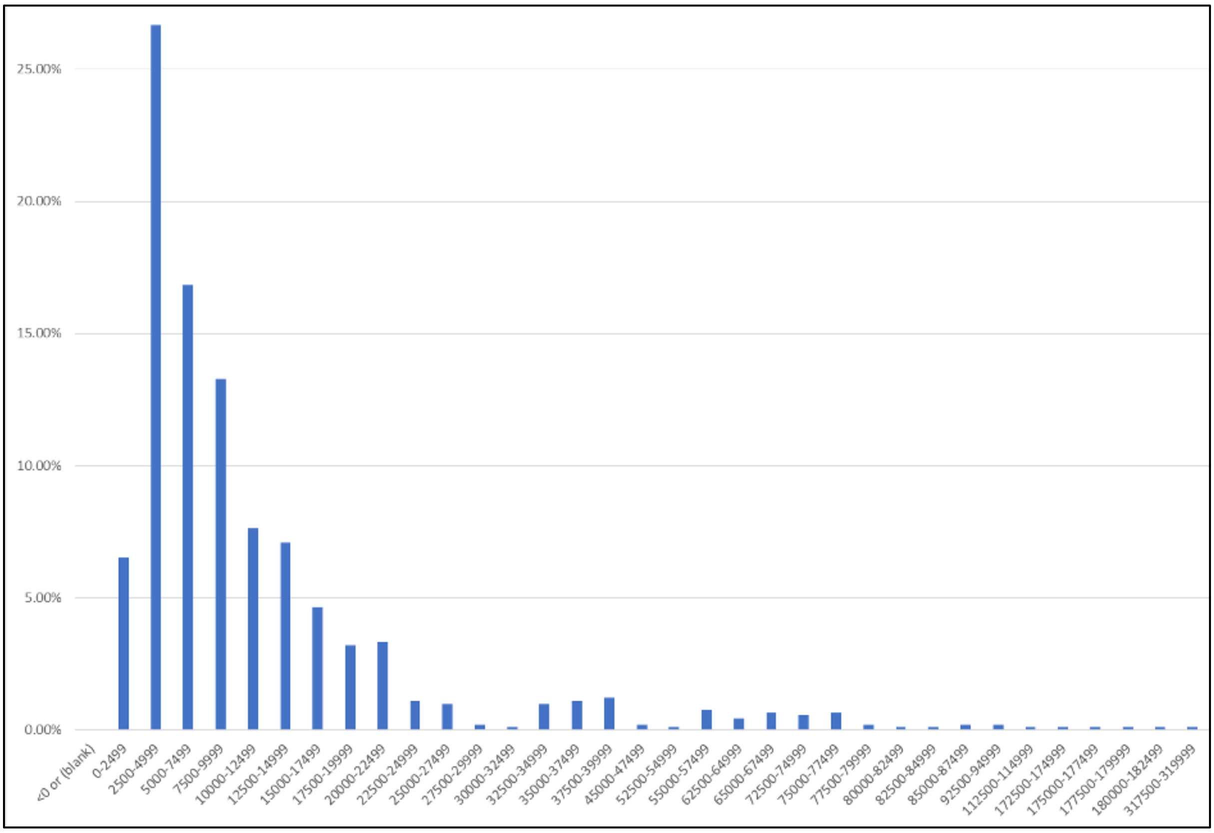


Figure 3.1: Relative distribution of ships in the Dutch fleet (in DWT)

A more detailed investigation of ships up to 28,000 DWT is given in Figure 3.2. of this group shows a clear peak between 3,000-4,000 DWT. Also, the ranges between 8,000-9,000 DWT and 12,000 -

13,000 DWT, 17.000 – 18,000 DWT and 21,000 -22,000 DWT are relatively high compared to the other segments.

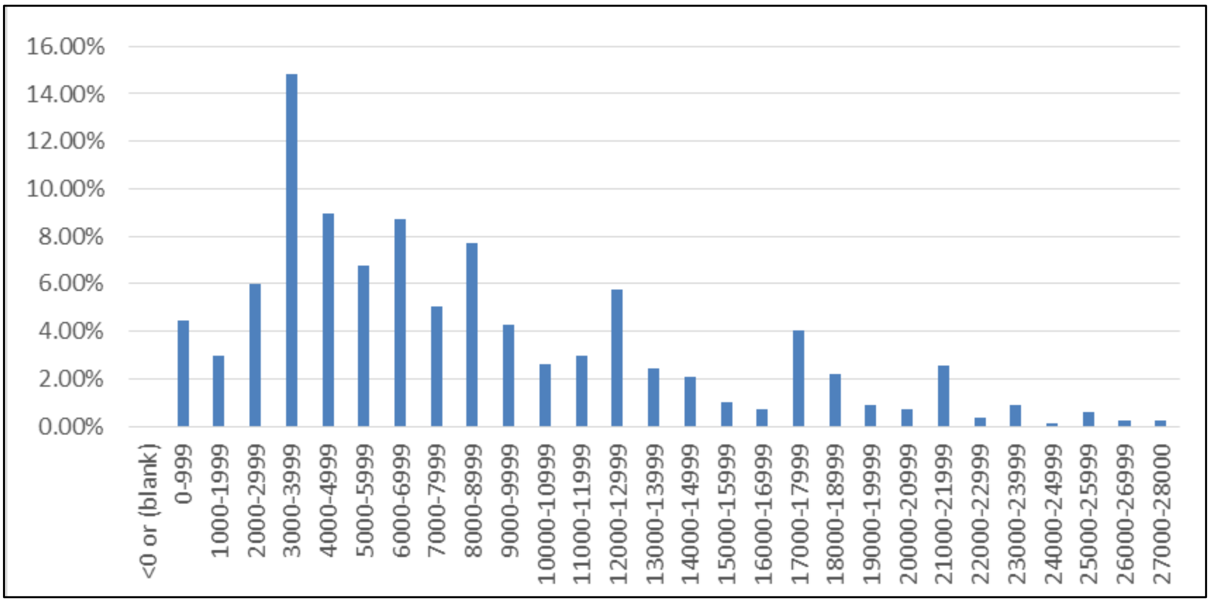


Figure 3.2: Relative distribution of ships up to 28,000 DWT in the Dutch fleet (in DWT)

3.1.2. Ship types

In Figure 3.3 an overview is given of the various types of vessels represented in the Dutch fleet. Looking at the division over type of vessels, Multi-purpose vessels make up 21% of the fleet (including multi-purpose heavy-lift). General cargo vessels (6.7%), Fully cellular container vessels (4.0%), Reefers (2.8%) and Chemical tankers (4.23%) are also well represented in the Dutch fleet.

Non cargo carrying vessels, but with significant presence are Tugs (33%, Anchor Handling Tugs (AHT) and Tugs combined) and Dredgers (10%) also contain significant amounts of vessels. Still the focus will be on the cargo ships, as tugs will have a much more locally focussed operating profile.

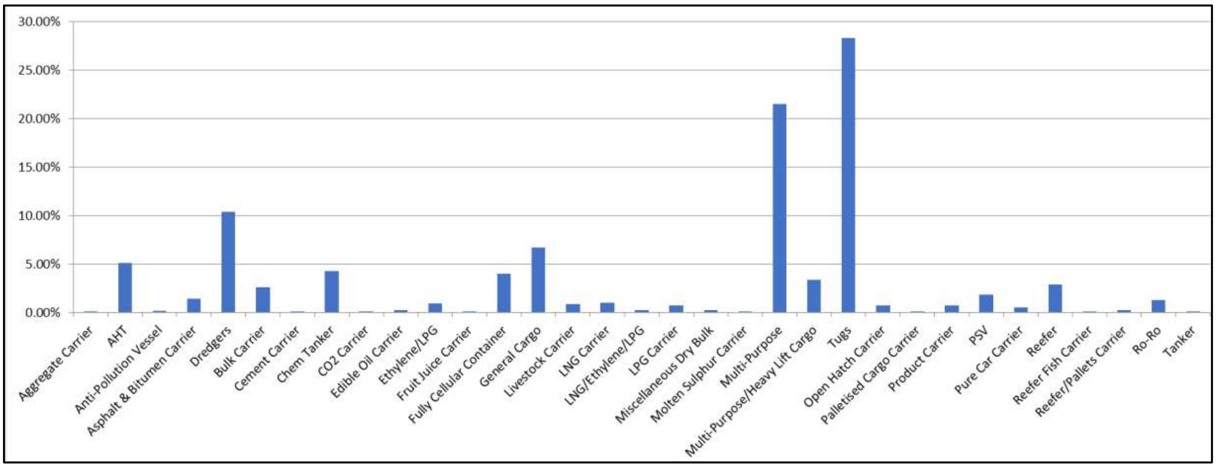


Figure 3.3: Relative distribution of ship types in the Dutch fleet.

3.1.3. Combined ship dimensions and ship types

Each peak of identified DWT ranges in Figure 3.2. will be further investigated, focussing on the five main ship types in Figure 3.3 and are summed up in the DWT tables of Table 3.1 .

Table 3.1. Relative distribution of combined ship dimensions (in DWT) and ship types

3,000-3,999 DWT	**17.21%**
Chemical Parcel Tanker	0.30%
General Cargo	5.79%
Multi-Purpose	10.39%
Multi-Purpose/Heavy Lift Cargo	0.59%
Reefer	0.15%
8,000-8,999 DWT	**8.75%**
Chemical Parcel Tanker	0.13%
Fully Cellular Container	1.63%
General Cargo	0.15%
Multi-Purpose	5.49%
Multi-Purpose/Heavy Lift Cargo	0.59%
Reefer	0.74%
12,000 -12,999 DWT	**6.53%**
Chemical Parcel Tanker	0.15%
General Cargo	0.30%
Multi-Purpose	3.86%
Multi-Purpose/Heavy Lift Cargo	1.34%
Reefer	0.89%
17,000 – 17,999 DWT	**4,30%**
Chemical Parcel Tanker	1.34%
Multi-Purpose	2.37%
Multi-Purpose/Heavy Lift Cargo	0.45%
Reefer	0.15%
21,000 -21,999 DWT	**2,82%**
Fully Cellular Container	0.59%
Multi-Purpose	0.59%
Multi-Purpose/Heavy Lift Cargo	1.63%

As can be seen in the tables above, the multi-purpose is the dominating ship type responsible for the high values in the ranges 3,000-4,000 DWT, 8,000-9,000 DWT and 12,000-13,000 DWT. Therefore it is selected as relevant ship for these ranges. For the 17,000-18,000 DWT range a chemical parcel tanker will be chosen instead of a multi-purpose ship. Finally, although higher than the surrounding values, the peak at 21,000-22,0000 DWT is rather small and will not be taken into consideration further.

3.1.4. Engine power installed per selected ship type

Important for our approach is not only the typical size, but also the typical engine power installed. This is summarised in Table 3.2. Except for the 8,000-9,000 DWT group, there is a clear preferred power range in all groups. Upon further investigation of the 8,000-9,000 DWT range, the preferred power range is clearly 2,500-3,000 kW.

Table 3.2. Relative distribution of engine power installed (in kW) per selected ship type

3,000-3,999 DWT	
Multi-Purpose	**19.72%**
0 - 999 kW	0.56%
1,000 - 1,999 kW	17.18%
2,000 - 2,999 kW	1.69%
3,000 - 3,999 kW	0.28%
8,000-8,999 DWT	
Multi-Purpose	**10.42%**
2,000 - 2,999 kW	4.79%
3,000 - 3,999 kW	4.51%
4,000 - 4,999 kW	0.28%
5,000 - 5,999 kW	0.85%
12,000-12,999 DWT	
Multi-Purpose	**7.32%**
4,000 - 4,999 kW	1.41%
5,000 - 5,999 kW	5.92%
17,000-17,999 DWT	
Multi-Purpose	**4.01%**
7,000 - 7,999 kW	3.76%
9,000 - 9,999 kW	0.25%
Chemical Parcel Tanker	**2.26%**
5,000 – 5,999 kW	2.26%

3.1.5. Representative Dutch owned ships selected for business cases

Based on the previous paragraphs, five following vessels will be selected as representative Dutch owned vessels for further investigation:

1. Multipurpose vessel of 3,500 DWT with an installed power of 1,500 kW. Length x Breadth x Depth is 87.6 m x 12.6 m x 5.29 m and the design speed is 12.0 knots. The main engine is one Caterpillar 3512B-HD-DITA (MDO-Fuel) or a Wartsila 4-stroke 9L20(C) (MDO or IFO380 for C), both are single fuel engines. The auxiliary Engine is mostly one Scania Diesel Gen. Set (MDO). The design consumption is about 6.0 ton/day. Bunker capacity on average is 350 tons of fuel.

2. Multipurpose vessel of 8,250 DWT with an installed power of 3,000 kW. Length x Breadth x Depth is 121 m x 16.1 m x 6.88 m and the design speed is 13.2 knots. The main engine is mostly one MaK 6M32C (IFO180) a single fuel engine. The auxiliary engines are mostly two MAN Diesel Gen. Set (MGO). The design consumption is about 11.5 ton/day. Bunker capacity on average is 550 tons of fuel.
3. Multipurpose vessel of 12,500 DWT with an installed power of 5,500 kW. Length x Breadth x Depth is 139 m x 18.9 m x 8.40 m and the design speed is 14.7 knots. The main engine is one Wartsila 4-stroke 6R46 (IFO180) a single fuel engine. The auxiliary engines are mostly three unspecified Diesel Gen. Set (MGO or MDO). The design consumption is about 22 ton/day. Bunker capacity on average is 1,150 tons of fuel.

4. Multipurpose vessel of 17,250 DWT with an installed power of 7,250 kW. Length x Breadth x Depth is 143 m x 21.5 m x 9.69 m and the design speed is 16.0 knots. The main engine is one Wartsila 4-stroke 6L46F (IFO380) a single fuel engine. The auxiliary engines are mostly three unspecified Diesel Gen. Set (MGO or MDO). The design consumption is about 29 ton/day. Bunker capacity on average is 1,500 tons of fuel.

5. Chemical Parcel Tanker of 17,250 DWT with an installed power of 5,750 kW. Length x Breadth x Depth is 144 m x 22.7 m x 9.04 m and the design speed is 13.5 kn. The main engine is one MAN B. & W. 8S35MC7.2 (IFO380) a single fuel engine. The auxiliary engines are mostly three or four Yanmar Diesel Gen. Set (Unspecified Fuel). The design consumption is about 25 ton/day. Bunker capacity on average is 800 tons of fuel.

A benefit of this selection is that both size increase within a single segment is covered as well as the differentiation to another market segment. For the remainder of the business case all vessels are assumed to use MGO as a fuel currently and only the adaptation of the main engine is considered.

The indicated average bunker capacity will be used and will not be further optimised for the actual trade of the vessel. This leads to the next steps determining the costs of the systems and fuels.

3.2. Determination of fuel prices

The determination of fuel prices is essential in the calculations of Operational Expenses (OPEX). Several studies (e.g. E4 tech, University of Utrecht and Sintef) and alternative fuel experts of ECN have given input with regard to the historical and future (alternative) fuel prices. These values were validated by shipping experts of TNO, TU Delft and MKC.

3.2.1. Determination of alternative fossil fuel prices

Alternative fossil fuels (i.e. grey fuels) for Heavy Fuel Oil (HFO) that are already in use/tested are Marine Gas Oil (MGO), Grey Liquid Natural Gas (LNG) and Grey Methanol (MEOH).

For these alternative fossil fuels the average historical prices and the price spread of the last 5-10 years serves as a basis for the prediction of future prices. There are restrictions to this approach, because the upcoming regulations for harmful emissions will definitely change the fuel mix in shipping and therefore also the fuel prices. However, for the purpose of this study the historical values and the price spread for fossil MGO, grey LNG and grey methanol (MEOH) are used as a basis for the calculations.

Grey methanol is generally produced from natural gas. Grey hydrogen is also produced from natural gas, but at higher costs than grey methanol , especially when transportation of the fuel is taken into account. Furthermore, the Well to Propeller performance of grey hydrogen is worse than natural gas and methanol. Therefore grey hydrogen will not be taken into account in this study, since it is not regarded as a better grey alternative fuel than grey natural gas or grey methanol.

3.2.2. Determination of alternative renewable fuel prices

The determination of alternative renewable fuel prices for shipping is quite a challenge. Some published prices are based on costs estimates for production of the alternative renewable fuel, other prices are market prices for, relatively usually small fuel amounts. Furthermore the source of the biomass as well as the process for producing the alternative fuel are of great influence to the final production costs of the alternative renewable fuels.

The fuel price for shipping (Free on Board (FOB)) does not only consist of the production costs but also distribution costs and a margin for the seller. Levies are not accounted for since bunkering of international marine fuels (e.g. HFO, MGO) is free of duty and VAT. For regular road transport fuels these levies make up the highest portion of the fuel price.

The margin of the producer are unknown and the distribution costs greatly depend on the distance between the fuel production location and the location of the vessels. Market prices for SVO, FAME and First Generation Ethanol are derived from the E4 tech study. The market prices for all other fuels are based on their production cost without taking the distribution cost and profit margin into account.

Another factor that is not taken into account in this study that can be of great importance to the use of renewable fuels in shipping is the use of tickets for the production of alternative fuels as described in the European Renewable Energy Directive (RED II). The price of these tickets and even a possible double counting of these tickets can substantially lower the price of renewable fuels on board ships. Since this is a temporary system until 2030 and due to change in 2023 it is difficult for ship-owners to base their long term investments on these rather unpredictable incentives.

3.2.3. Overview of alternative fossil and renewable fuels for shipping

For the purpose of this study the prices of chapter 3.2.1. and 3.2.2 are taken as the basis for the calculations. An overview of the costs for the various shipping fuels are given in Figure 3.4.

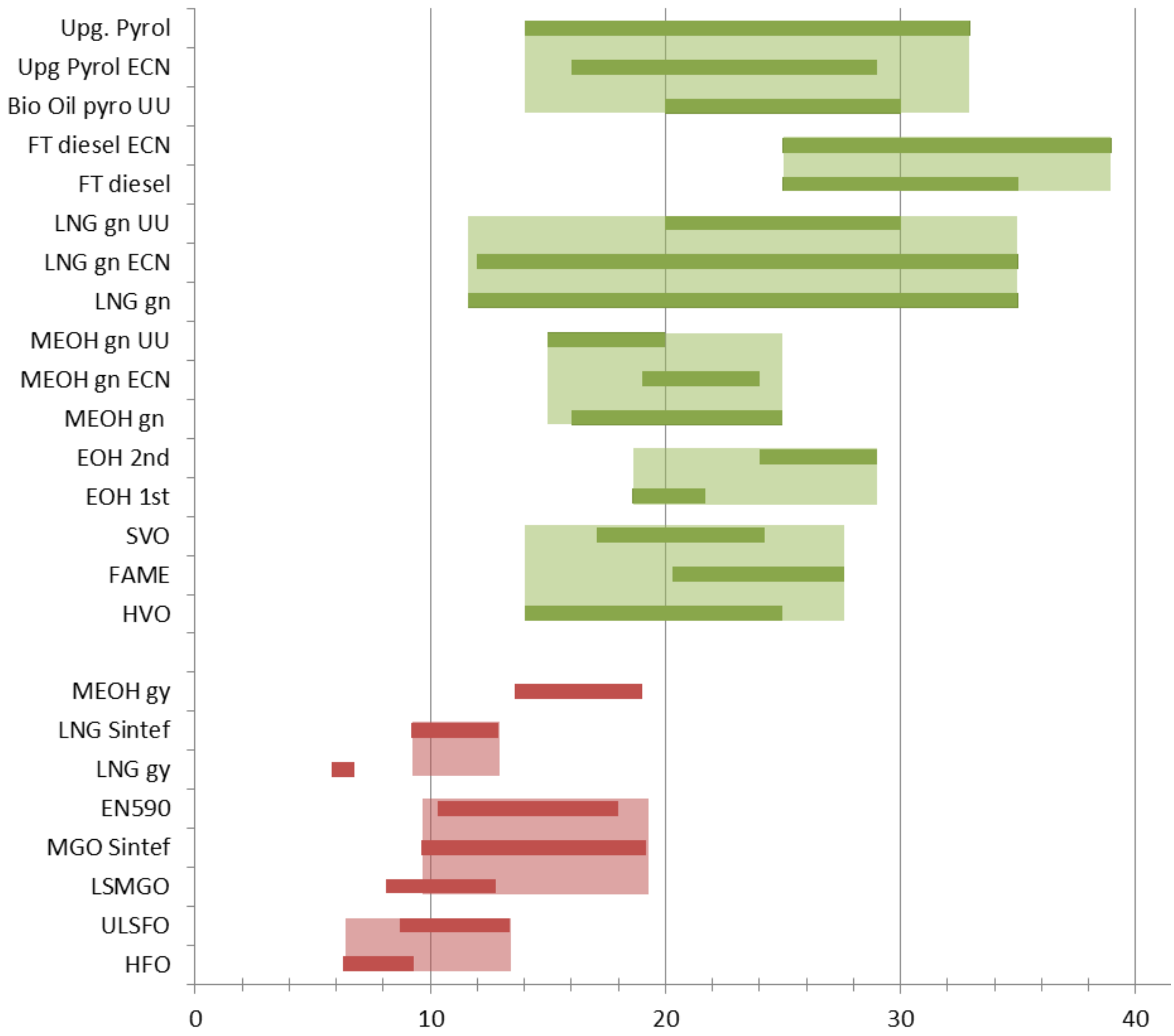


Figure 3.4 Long list of alternative fossil and renewable fuel prices (Euro/GJ)

The long list of alternative fuel prices for shipping is based on prices derived from various sources, i.e. two workshops at TNO-ECN (Uslu and de Wilde, 2019), one workshop at Port of Rotterdam (Mukherjee, 2019) and two publications (Lindstad et al., 2015) (E4tech, 2018).

The fossil fuels are indicated in red, grouping the prices of HFO, MGO and LNG in bigger blocks. The Low Sulphur MGO (LSMGO) price was regarded as rather low and was therefore only partly taken into account in this study. The grey LNG price as derived from E4 tech was regarded as too low compared to the grey LNG prices for shipping over the last years and is therefore disregarded.

The renewable fuels are indicated in green, grouping the prices of green diesel (HVO, FAME and SVO), Ethanol (EOH 1st & 2nd), Green Methanol (MEOH gn), Green Liquid Natural Gas (LNG gn) , Fischer Tropsch Diesel (FT Diesel) and Upgraded Pyrolysis Oil (UPO).

The grouped blocks are used as an input for the fuel prices and their spreads used in the calculations.

From this graph some first conclusions can be drawn in order to limit the number of calculations and to keep a clear overview of alternative renewable marine fuels for the short term (until 2030).

Ethanol is not taken into account any further in this study, especially since the price of 2nd generation ethanol is substantially higher than methanol. 1st generation ethanol is also not the best choice, because it competes with food. The only situation where ethanol could be a better alternative for methanol is in the cases where limited tank space is an important issue.

Upgraded Pyrolysis Oil is not taken into account since it is more expensive than Hydro Vegetable Oil (HVO) and TRL levels are still quite low (5/6) indicating that the fuel is still in quite early development stages.

Fischer Tropsch Diesel is also a rather expensive fuel, but since TRL levels for Fischer Tropsch Diesel are higher (6/8) this fuels will be taken into account for the calculations.

Table 3.3 presents the alternative fossil and renewable fuels prices selected for the calculation of operational and capital cost of five selected ship types relevant for the Dutch shipping sector.

Table 3.3 Prices for selected alternative fossil and renewable fuels in shipping

Fuel	Minimum price (Euro/GJ)	Maximum price (Euro/GJ)
MGO	9,6	19,2
HVO / SVO / Fame	14	27,6
Fischer Tropsch (FT Diesel)	25	39
LNG grey	9,2	12,9
LNG green	11,6	35
MEOH grey	13,6	19
MEOH green	15	25

3.3. Determination of ships system costs

For the remaining relevant fuel options (MGO, LNG, Methanol, HVO and FT Diesel) the costs of the system upgrades need to be determined. Two interesting researches by Brynolf (Brynolf, 2014) and Lindstad (Lindstad et al.,2015) have provided the input for these calculations. The more detailed values of Brynolf were checked both against Lindstad and industry sources available to the team. They proved to be a good match. The benefit of the data from Brynolf is that the investments in the engine are separated from the investments in the storage of the fuel. Furthermore, details were provided for smaller and larger vessels. Given the five selected vessels, the data from the small vessels is used in this research and presented in the table below.

Table 3.4 Estimated ship system costs

Fuel	Engine costs (Euro/kW)	Storage costs (Euro/GJ)
MGO	636	27
Methanol	655	45
LNG	923	100

Only three engine types are required for the five remaining fuels, as it is assumed that MGO, HVO and FT Diesel require no significant adjustments to the current single fuel engines. The storage capacity for each ship is expressed in ton MGO, but can easily be converted to GJ based on the MGO volume in the vessel description. The impact of the larger storage size for alternative fuels on the trading capacity of the vessel is not included in the values above. The direct costs for storage and transport to the engine are taken into account.

3.4. Future scenarios for fuel use

The next step towards the development of the business cases is a discussion of future scenarios for fuel use. In these scenarios for the representative Dutch merchant ships, national and international financial incentives are not taken into account. The most important financial incentive for shipping is probably the incentive to lower the costs of the renewable alternative fuel via RED II.

Based on the future scenarios and time paths the following situations have been modelled. The current situation with 0% green fuel, the situation in 2030 with a mix of 40% green fuel and 60% regular fuel, the situation of 2050 with a mix of 70% green fuel and 30% regular fuel and finally a situation in which 100% green fuel is used. This last option may represent a very distant future, but it might be that regulations will allow spreading your green fuel usage, in that case one vessel on 100% green fuel could compensate 2-3 other vessels who continue sailing on regular fuel.

The increase (or decrease) in yearly costs consisting of the system costs (interest, maintenance, depreciation) and fuel consumption will be compared with the base case of a vessel sailing on MGO for each situation. To convert the system investment costs to yearly system costs a fixed percentage of 12% is used (8% depreciation and interest, 4% maintenance costs), based on research by Lindstad (Lindstad, 2015). To calculate the fuel used the consumption per day is converted to GJ and multiplied by the active time of the vessel. A high active time and therewith high fuel consumption will be beneficial for solutions with lower fuel costs, but higher investment costs. To investigate a situation with low utilisation 4000 hours per year was chosen, while 8000 hours per year was chosen to indicate full utilisation.

This approach has led to a wealth of scenarios to study; 5 vessel types x 4 fuel types x 4 mix ratios x 3 prices (high, low, average) x 2 utilisations = 480 data points. These will be discussed below per example vessel.

3.4.1. Multipurpose vessel of 3,500 DWT

In the table below the key properties of this vessel are summarized. Using this input the average costs differences and the cost differences using the low or high fuel prices for both fuels were calculated. In the graph below these differences are displayed. The costs differences are yearly. For convenience, each fuel has a colour (blue for HVO, red for FT diesel, Green for green methanol and Purple for green LNG), while the 4000 hours option has the dark colour, the 8000 hours situation has the lighter colour. The black bars indicate the variation in the difference (high-low), while the coloured bar indicates the average difference. Finally, each set of bars represents a certain mix of green and regular fuel (of the same type). In the first case no HVO or FT diesel is mixed with MGO, hence these bars are all zero.

Ship speed	12 Knots	
Engine Power	1,500 kW	
Consumption	6.0 ton/day	256 GJ/Day
Bunker Capacity	350 ton	15,000 GJ

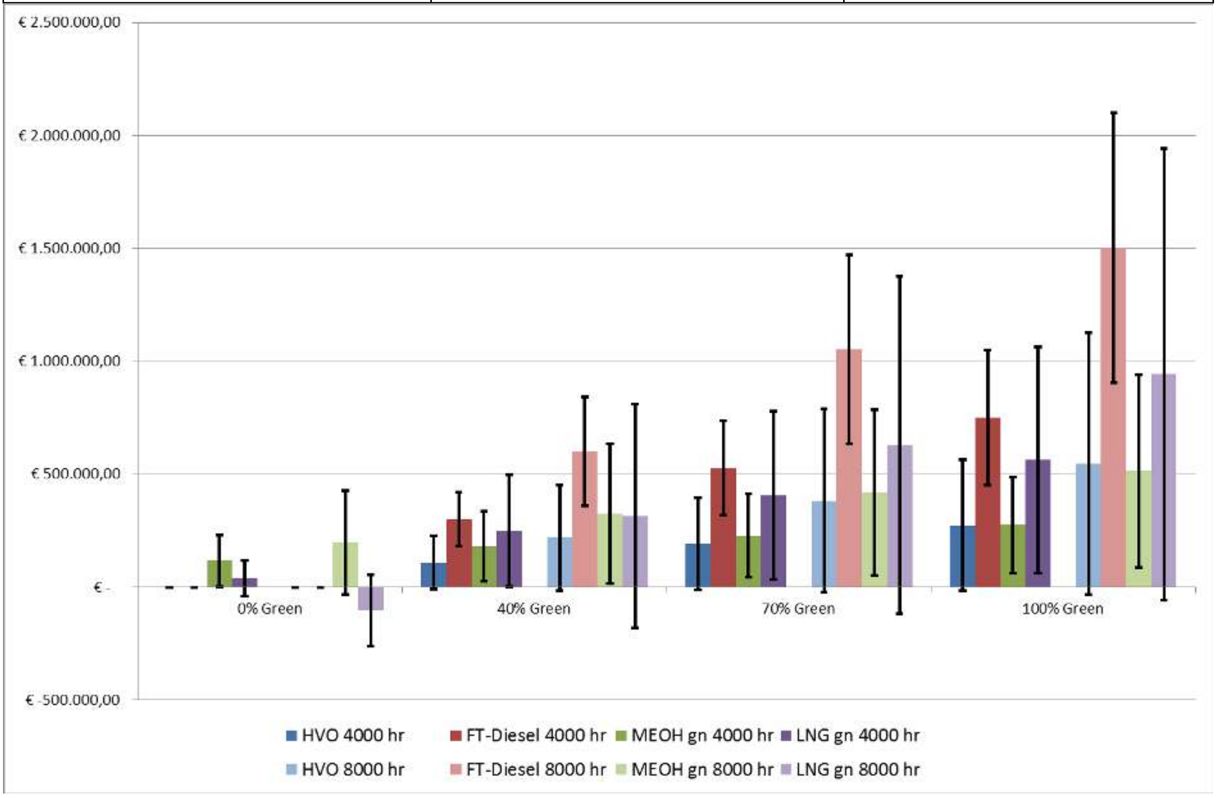


Figure 3.5 Increase in annual system and fuel costs for a multipurpose vessel of 3,500 DWT

Three important observations can be made from the graph above. The first one is that FT diesel is too expensive to be a viable fuel in all situations. As this is the case for all situations, it will be discarded in the discussion of the other representative vessels. The second observation is that HVO is the cheapest solution in almost all cases. Unfortunately, HVO has a very limited feedstock and will primarily be viable for early adoption. Finally, and most importantly, LNG and methanol are both identified as the second-best solution, depending on the situation. The situation of 40% green fuel and 8000 running hours per year is special as it forms a tipping point, more running hours or less green fuel and LNG is better, less running hours or more green fuel and methanol is the cheaper option.

It should also be noted that due to the large uncertainty in green LNG prices the uncertainty in the LNG costs are increasing with each increase in the green fuel ratio. It is therefore not unlikely that in the 100% green fuel situation LNG may still outperform methanol, even in the low utilization situation. The lowest LNG point is below the lowest methanol point.

3.4.2. Multipurpose vessel of 8,250 DWT

The second reference vessel is slightly larger and has a higher design speed. Its range based on the bunker capacity is about equal to the smaller option. Although FT diesel has been removed from the results graphs the colours for the fuels are identical to the graph above (blue for HVO, Green for green methanol and purple for green LNG).

Speed	13.2 Knots	
Engine Power	3,000 kW	
Consumption	11.5 ton/day	491 GJ/Day
Bunker Capacity	550 ton	23,500 GJ

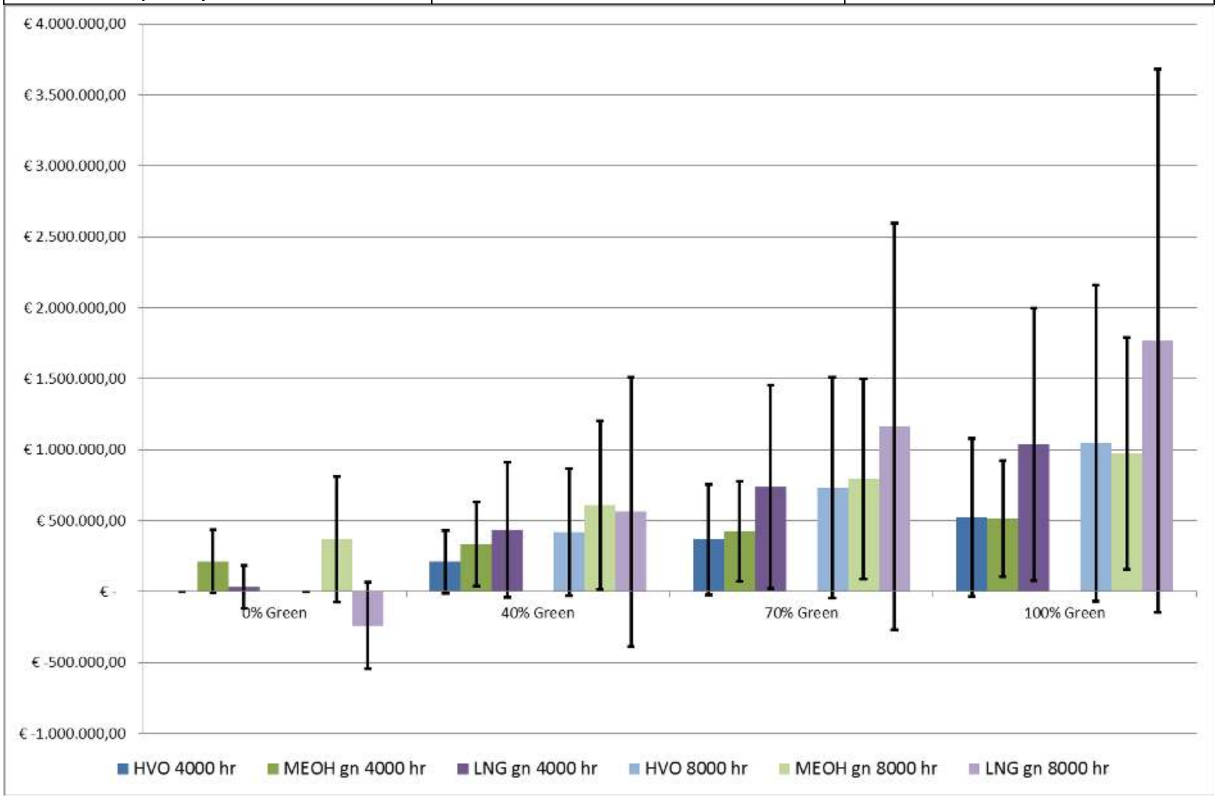


Figure 3.6 Increase in annual system and fuel costs for a multipurpose vessel of 8,250 DWT

The same observations about green LNG and green methanol can be made in this case as well. Fossil LNG is a viable alternative compared to MGO, if the consumption is relatively high. However green LNG is much more expensive than green methanol and introduces a preference for methanol if the green part of the fuel is increasing. Hence in the future methanol may be preferable still.

3.4.3. Multipurpose vessel of 12,500 DWT

The increase in vessel size and speed has led to a doubling of the consumption compared to the 8,250 DWT version. The bunker capacity is again close to 50 days. In the graph below the fuels have the same colours as the graphs above (blue for HVO, Green for green methanol and purple for green LNG). Light colours are for the 8000 running hours case and dark colours for the 4000 running hours.

Speed	14.7 Knots	
Engine Power	5,500 kW	
Consumption	22 ton/day	940 GJ/Day
Bunker Capacity	1,150 ton	49,500 GJ

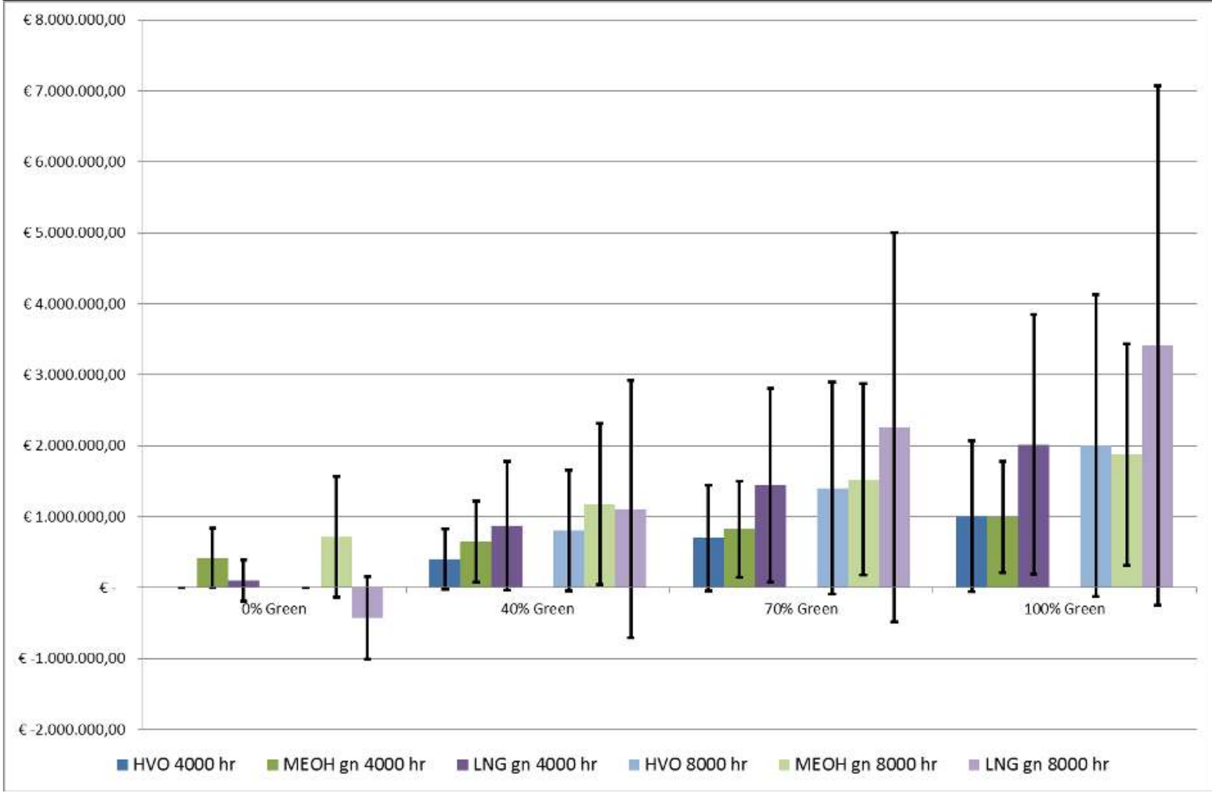


Figure 3.7 Increase in annual system and fuel costs for a multipurpose vessel of 12,500 DWT

With the increase in consumption and engine size, the benefits for methanol, but also for HVO are diminishing. Fuel consumption is the dominant part in the cost difference shown above and with more consumption the impact of system costs is reduced, making green LNG relatively more attractive. This can be seen by the range bar extending further below the methanol alternative in all cases.

3.4.4. Multipurpose vessel of 17,250 DWT

Even though the size step is about similar to the previous one (50% more DWT), the increase in engine power is much smaller than before. Only 50% compared to 100% before, resulting also in a lower increase in consumption. Still the bunker capacity is similar, about 50 days. In the graph below the fuels have the same colours as the graphs above (blue for HVO, Green for green methanol and purple for green LNG).

Speed	16.0 Knots	
Engine Power	7,250 kW	
Consumption	29 ton/day	1,238 GJ/Day
Bunker Capacity	1,500 ton	64,500 GJ

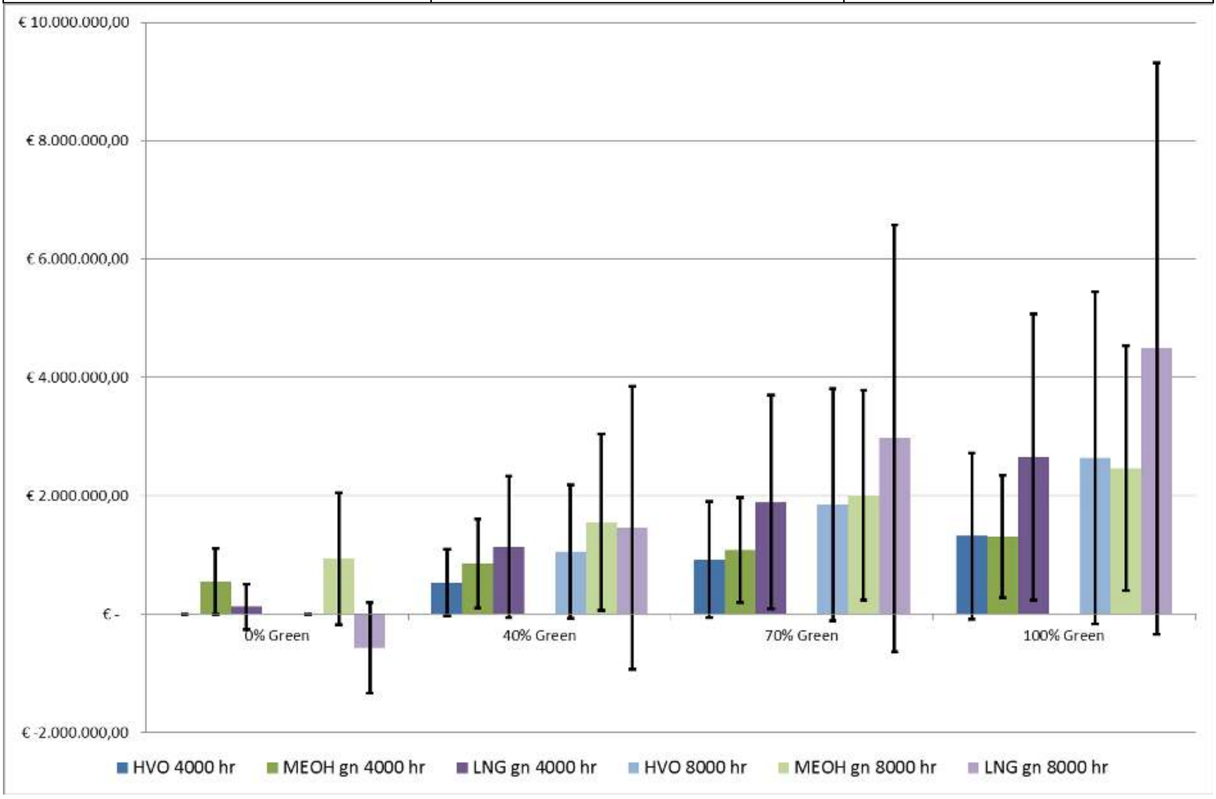


Figure 3.8 Increase in annual system and fuel costs for a multipurpose vessel of 17,250 DWT

From the graph above it is clear that there is no significant break from the trends observed with all previous vessels, neither is the increase in suitability of green LNG, when considering the variation bars.

3.4.5. Chemical Parcel Tanker of 17,250 DWT

From the summary table below, it can be observed that the chemical tanker is sailing at a slower speed, reducing the engine size and consumption significantly. Also, the range is reduced to 32 days instead of 50. This will have an impact on the differences. In the graph below the fuels have the same colours as the graphs above (blue for HVO, Green for green methanol and purple for green LNG).

Speed	13.5 Knots	
Engine Power	5,750 kW	
Consumption	25 ton/day	1,067 GJ/Day
Bunker Capacity	800 ton	34,500 GJ

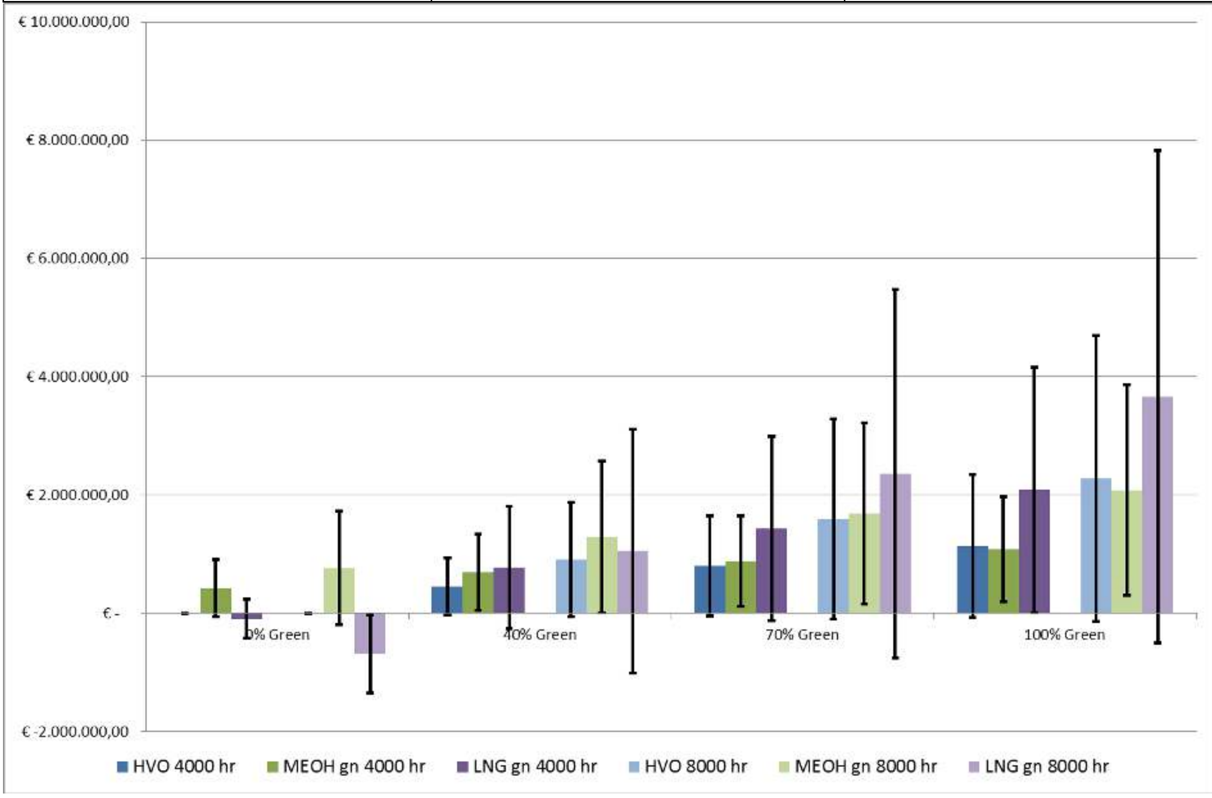


Figure 3.9 Increase in annual system and fuel costs for a chemical parcel tanker of 17,250 DWT

Although the same general trends are present once more, the preference for LNG is maintained longer than with the Multipurpose vessel of the same size. The smaller engine and smaller bunker storage, are contributing to this. It has reduced the initial investment by about 30% Therefore green LNG is still preferred compared to green methanol in the case of 40% green fuel and 8000 running hours.

3.4.6 Intermediate results

On the basis of this study, there is one (fossil) alternative fuel that can presently qualify as a true competitor to HFO and MGO. LNG is the only fuel that (potentially) has a lower cost price than MGO and HFO, especially when the sulphur percentages in HFO are going to drop as from the 1st of January 2020.

Overall it should be noted that HVO is the cheapest alternative fuel option available today. However, it has a very limited feedstock, requiring more readily available alternatives to be considered as well.

Depending on the mix between green and fossil-based fuels as well as the consumption or engine size, the range of the vessel and the size of the vessel. LNG and methanol may both be viable alternatives when considering the total costs of ownership.

In general, the larger the green fraction in the fuel is, the less likely bio LNG is as a fuel. On the other hand, the higher the consumption, the more likely bio LNG is to be relevant.

It should be noted that the above graphs are based on linear costs of engines and storage, it is highly likely that especially for smaller vessels (installed engine power < 1,000 kW) these costs are higher than assumed in the above calculations, due to complexity and minimal system costs.

In that case bio methanol is a much more likely candidate fuel, as its investments are relatively small and the extra costs of the fuel are bearable.

Finally, in this study ship size and ship type hardly have any impact on the results for the various MGO and HVO blends, LNG and bio LNG blends as well as Methanol and Bio-Methanol blends.

LNG and Bio LNG

Although fossil LNG can compete with other fossil fuels, the cost of bio LNG poses a serious challenge for LNG in the future. The current spread of bio LNG prices is the largest of all alternative bio fuels. This implies that a transition to LNG seems to be a good choice for the short term, but as rules and regulations start requiring the blending of LNG with bio LNG, this will lead to a great price uncertainties and connected risks. The larger the percentage of bio LNG is blended with LNG, the larger the uncertainties will become.

The LNG-bio LNG blend might still be cheaper than MGO, but changes are high that it will be far more expensive than MGO. It appears even the most expensive blend available when high ratios of bio LNG are required (70-100%).

At lower blending ratio's (0-40%) and high utilisation rates of the engines (8000 running hours per year) LNG or the LNG- bio LNG blend is the best option from a business case perspective.

MGO and HVO

HVO is the best alternative fuel with blending rates up to 40%. This is especially true when bearing in mind that HVO is a drop in fuel for MGO which does not require any serious modification to the engines.

HVO blending rates ranging from 70% to 100% still offer a good alternative and is comparable to Methanol - Bio methanol blends of 705 to 100%. Low or high utilisation of the engines hardly has an impact on the price differences for MGO- HVO blends and Methanol - Bio Methanol blends.

When the spread of the fuel prices is taken into account at higher blending rates, MGO – HVO blends pose a bigger risk than Methanol – Bio Methanol blends.

Methanol and Bio Methanol

Methanol at lower blending rates (up to 40% Bio Methanol) and high utilisation of the engines (8000 hours) is a relative costly option in shipping since the average fuel price of methanol is higher than the average fuel prices MGO and HFO.

For low utilisation of the engines (4000 hours) and higher blend rates (70% - 100% Bio Methanol) Methanol offers a serious alternative for HVO, especially when the lower price spread is taken into account and the expected limited availability of HVO in the future.

4. Potential bottlenecks towards clean fuels implementation

4.1. Fuel costs estimations

A description on renewable and fossil fuel prices was given in chapter 3. Biofuels prices have a broad range. Price insights are based on current knowledge, while investments and interests for various fuels may significantly alter these insights over time. Therefore it is recommended to regularly update these values. Especially the movement of the bandwidth of Bio LNG will be of a significant influence on the outcome of these calculations. LNG might be the only solution to make the business case without support from regulations or subsidies, on the other hand it is also the most likely one to fail, due to too high costs.

4.2. Scalability, availability and sustainability

Biofuels can roughly be split in two groups: those based on food crops and the non-food based biofuels. The latter groups does include the non-edible part of the food crops and all kind of waste streams from cellulosic materials such as black liquor, sludge, pulp, manure, residues of fermentation, leaves, sawdust, etc.. Food crops are also often associated with Indirect Land Use Change (ILUC) aspects, where CO_2 is emitted due to the repression of original vegetation for the production of the crops. This compromises the CO_2 reduction.

Apart for the competition with food, biofuels for maritime will also compete with biofuel needs for road transport and aviation and the need for biomass for industry. GHG studies across the sectors (total energy system) priorities biomass for aviation fuel and for the (chemical) industry, because for those sectors it will be the most difficult to switch to use other options. For example the Energy Transition Commission, 2018 support this and recommends NH_3 as the future fuel for shipping (NH_3 can be made as E-fuel (P2X) from H_2 and N_2 from air).

So the competition for biomass will be enormous in the future. We see also that RED-II limits the amount of biofuel from food crops for 2030 to 8.7% in total: 7% for crop based biofuel plus 1.7% for Used Cooking Oil (UCO) based biofuel. The remainder for the 14% sustainable fuel target needs to come from battery-electric, advanced biofuels (based on waste and residues such as cellulosic materials and manure) and P2X fuels.

Taking into these developments, it is recommended that maritime also maximizes the use of food crop based biofuels. The 8.7% max for the RED-II could be used as a maximum, but also a lower maximum should be considered or possibly even refrain from the use of food crop based biofuels at all.

Limiting food crop based biofuels would lead to prioritizing the non-food based biofuels. These are especially biogas (bio-LNG), methanol, FT diesel and renewable diesel and ethanol from cellulosic materials. Among these options, biogas and methanol are probably the most economical ones. Ethanol can probably best be reserved for road transport since it is an ideal blend fuel for petrol..

4.3. Competition for fuels

In table 4.5 an overview is given of the energy consumption for the Netherlands. Maritime shipping and aviation include all the bunkering for the international transport. For the Netherlands, maritime shipping has the largest energy consumption due to the fact that the Port of Rotterdam is one of the largest bunkering ports of the world. For other European countries, and for most countries worldwide, maritime shipping is much smaller than road transport.

Table 4.5: Energy consumption of different modalities for the Netherlands (Peta-Joule).

PJ	Maritime shipping NL (EU)	Road transport	Aviation
2017	495 (2000)	462	169
2030	594 (2260)	400	177

For road transport diesel fuel the share of biofuel in 2017 was 4.0%. For 2030, the target for road transport is formulated in the RED-II Directive. This is 14%, but this also includes electricity. The physical blend on energy basis may be limited to 11-12% It is clear that blending of biofuels into the marine bunkers to a similar amount as road transport would put a large demand on the biofuels availability and production, especially if a similar split is used between food-crop-based and non-food-crop based. On top of that also aviation probably start to draw on these fuels (e.g. HVO-kerosene).

Two deployment scenarios for biofuels are possible:

Under RED-II: the target for road transport can also be fulfilled by using the biofuels in the maritime sector. This even receives a multiplying factor of 1.2. So the contribution is 20% larger than the actual amount used. This may be an economical scenario for the fuel suppliers, to fulfil their blending obligations. Of course if maritime uses the blend obligation for road transport, one can argue that the maritime sector is not reducing GHG emission on its own: e.g. there is no net additional GHG emission reduction. For the Netherlands, the bunker fuel quantity is so large, that up to 100% of the road transport obligation could theoretically be fulfilled by the maritime sector.

Maritime on its own (contributing to IMO goals): In this case, the maritime sector develops its own instruments. In this case there would be competition with road transport and aviation to get sufficiently biofuel with the right quality, both in composition as well as in GHG reduction.

4.4. Possible implementation routes for clean fuels in shipping

Under the current policies, significant growth of sustainable fuels in maritime shipping is very uncertain. Firm policies for GHG reduction are not yet implemented, and when they would be implemented, shipping companies would as much as possible focus on technical and operational measures to reduce energy consumption and hence GHG emissions. This is because costs per GHG unit reduction, is higher for sustainable fuels than for the technical and operational measures.

So dedicated instruments for sustainable fuels are important. European instruments for road transport can be used as an example for instruments for European or world-wide shipping.

For road transport we distinguish the following regulations:

- CO_2 or energy efficiency regulations for cars and trucks
- Fuel quality regulations controlling the quality and quantity of sustainable fuels: e.g. biofuels via the Fuel Quality Directive (FQD, 2009) and RED II.
- Regulations for Deployment of Alternative Fuels Infrastructure, e.g. Directive (DAFI, 2014)

In this way two main stakeholders, car producers and oil companies contribute to the GHG reduction.

For maritime shipping, it might be advisable to regulate four areas to reduce GHG emissions:

- CO_2 or energy efficiency of the ship: e.g. Energy Efficiency Design Index (EEDI, 2011)
- Energy efficiency of operations (SEEMP)
- Fuel quality regulations (e.g. production chain and fuel specifications for biofuels)
- Regulation for deployment of infrastructure

If the first three options are combined in one target, most probably the focus will be fully on the first two options. Biofuels will only take up significantly with dedicated targets and instruments. The instruments introduced for EU road transport can serve as an example. These are the Fuel Quality Directive and the Renewable Energy Directive. The FQD primarily regulates the CO_2 reduction of the biofuel, while the RED regulates the share of biofuels as percentage of the total fuel over time. The fuel suppliers have the obligation to supply this minimum share of biofuel within their fuel mix. They can do this in the most economical way, by choosing between different options such as low ethanol blends with petrol, low biodiesel blends and with high blends or pure biofuels. The total amount of renewable fuels needs to be reported to the Netherlands Emission Authority (NEA) via a system of renewable energy tickets (HBE).

For international shipping a similar system would be advisable. The question then would be: who would be responsible for achieving these targets? Would that be the ship operators or the bunker fuel suppliers? Either way could work depending on international agreement (at least within Europe) such that a level playing field it maintained.

Suppose similar to road transport, a system with renewable energy tickets (HBE) is introduced. In that case, the ship operator can fulfil the biofuel-share requirement in several ways:

- A low blend, distributed over all his ships
- A high blend or pure biofuel in a part of his ships
- Just purchasing renewable energy tickets, without actually using the biofuel in his own ships

A flexible system like this would offer several advantages, since the biofuel can be used in the most economical way and it is also neutral towards the type of biofuel. In certain applications there are additional benefits such as positive impact on air quality. A higher share of biofuels can for example be used for work ships (e.g. dredgers) operating close to shore, or ferries, which frequently enter ports. Biofuels often lead to lower emissions, due to the much lower sulphur content (also much lower than ECA fuel, max 1000 ppm S).

This leads to lower SO2 and particulate emissions. In addition with (bio)LNG and methanol NO_X will likely be reduced, although this advantage might be lost when new engines need to comply with Tier III (2021). Then also diesel engines have to comply to low NO_X emissions.

In summary the following can be concluded:

- For the introduction of sustainable fuels, e.g. biofuel, dedicated instruments will be necessary. Otherwise the focus will be fully on technical and operational measures to increase energy efficiency.
- A flexible system with 'Renewable Energy Tickets' would be a good way to offer a level playing field for both drop in and non-drop in biofuels and at the same time make sure that the biofuels are used in the most economical way.
- If assumed that there will be a long term transition to synthetic fuels, then both drop in biofuels (biodiesel, HVO, bio-LNG) as well as methanol would fit well as transition fuels. If it would be concluded in the future, that NH_3 would be the main synthetic maritime fuel, then methanol and bio-LNG might be less optimal, since there would be an additional transition to NH_3 engines or fuel cells.

5. Conclusions and recommendations

5.1. Conclusions

5.1.1. Biofuel sustainability and costs

- The biofuels can be split in two groups: 1) based on food crops and 2) based on non-food cellulosic materials. The majority of the currently used biofuels are food crop based. For road transport the food based biofuels are capped to a maximum of 8.7%[1] of the total fuel in 2030.
- Maritime shipping would preferably aim for the use of the more sustainable non-food based biofuel, e.g. to avoid food based biofuel shortage or not meeting the national GHG emission reduction targets[2].
- Bio-methanol and bio-LNG are the preferred options for the non-food based biofuel, because they can be produced at a similar costs as the food based biodiesels (HVO, FAME, PPO).
- Bio-methanol and bio-LNG are also very suitable for a transition to E-fuels.
- Bio-methanol is less suitable as a blending fuel. It can be blended with fossil methanol, but the costs of fossil methanol are relatively high.

5.1.2. Instruments to reduce GHG emissions

- It is still uncertain what kind of instruments to reduce GHG emissions for maritime will be developed and who will execute those instruments, e.g. national government, EU or IMO. IMO is working on a short, medium and long term approach.
- There are many approaches for instruments. E.g. there could be one all-inclusive instrument which targets one (maritime) stakeholder or there could be several instruments targeting different stakeholders e.g. the shipping company and the fuel suppliers. For road transport we see the latter; both vehicle producers and fuel suppliers are encountered with GHG reduction targets. Also for maritime shipping this seems a recommendable approach. The shipping companies can then focus on the reduction of energy consumption, while the fuel suppliers focus on the GHG reduction of the fuel.
- Maritime can use the European RED-II system for the introduction of sustainable fuels, either only contributing to the road obligation (piggy bagging) or with a separate mandate (independent obligation). The latter is preferred, although the first option can be used to make a quick start. The RED-II comes with a system with 'renewable energy tickets', HBE's (Bio tickets). This is to administer the obligations of the different fuel suppliers. HBE's can be purchased or sold to fulfil the target.
- Instruments like the RED-II with HBE system for road transport, carbon tax and an Emissions Trading Scheme can create a level playing field for the different biofuel options and can stimulate the production of more sustainable biofuel options.
- In the Netherlands the bunker fuel quantity is similar to the fuel quantity for road transport. In most countries the bunker fuel quantity is much lower. It is important to take this into account when developing instrument options.

5.1.3. TCO calculations with biofuels and blends

- Five representative Dutch owned vessels were selected. These are four multipurpose vessels and one chemical parcel tanker. The vessel are in the DWT range from 3500 to 17,250 DWT. Total engine power ranges from 2000 to 8000 kW, and fuel oil consumption ranges from 6 ton to 29 ton per day.

[1] 7% cap for food crop based biofuel and 1.7% cap for biofuel base on Used Cooking Oil according to RED-II
[2] Maritime can contribute to the RED targets, but this does not contribute to the national GHG reduction targets

- Biofuel prices ranged from about 12 to 39 EUR/GJ. The averages prices for bio-LNG, bio-methanol, FAME and HVO are similar, although for bio-LNG the price range is broader. The price of FT-diesel is on average 50% higher.
- TCO calculations were done with the biofuel price range and also additional engine and fuel storage costs compared to MGO fuel. This was done for both 4000 and 8000 operational hours and relatively high blends of 0%, 40%, 70% and 100% biofuel. This leads to the following conclusions:
    - At the 40% blend, HVO is usually the most economical due to the low cost fossil part (MGO). Bio-methanol and bio-LNG 40% blends have similar average addition costs per year: 0,25 to 1,5 million EUR per year depending on the vessel size.
    - At 70% biofuel blend, HVO and methanol are closer in terms of additional costs. Bio-LNG becomes more expensive due to the reduced share of the very economical fossil LNG. Average additional costs range from 0,25 to 3 million per year.
    - With 100% biofuel, the average additional costs for HVO and bio-methanol are about equal. The average additional costs for bio-LNG are about 50% higher, basically due to the high investment costs of fuel tank and engine.
    - With the lowest price projection, bio and fossil LNG can have a lower cost price than MGO. Consequently all bio-LNG blends potentially have a lower TCO than 100% MGO (up to 1 million EUR lower).

5.2. Recommendations / Possible follow-up projects

It is recommended that the Dutch maritime stakeholders carry out an independent in-depth study towards GHG reduction instruments. In particular to evaluate IMO and EU GHG reduction plans for maritime shipping and the proposed instrument options. This should contain the following items:

- Different general GHG reduction instruments such as a climate levy (carbon tax), Emissions Trading Scheme (cap and trade system), sustainable fuel (blending) obligation and possibly offsetting (purchasing CO_2 credits from other sectors (e.g. (Kachi et al., 2019))).
- Describe historic development of instruments for road transport (will act as an example for maritime)
- Analyse instruments for maritime to introduce sustainable fuels on national, European and worldwide (IMO) level. As part of this: RED-II system with separate mandate for maritime and a transparent bio ticket system in shipping (e.g. HBE or carbon credits)
- Analyse and quantify biofuel market by type of feedstock and production routes. Summarize developments of advanced biofuels (using waste streams and residues). Sketch impact of maritime and aviation demand on total production of biofuel.
- Create clear storyline for all stakeholders
- Develop roadmap with all necessary legislative and standardisation procedures (such as formal fuel specifications).
- Research to lower the spread in production costs for green alternative LNG.
- Developing long term scenario's for shipping with regard to the transition to various alternative green fuels (i.e. HVO, LNG, MEOH, H_2 and batteries)
- Segmentation of the maritime sectors between those within the EU regulatory framework, and outside

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