Potential of biofuels for shipping

Final Report

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All opinions, conclusions and recommendations stated in this report are made by Ecofys.

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Summary

Introduction

Biofuels could be one of the options to realize a lower carbon intensity in the propulsion of ships and also possibly reduce the effect of ship emissions on local air quality. Therefore, EMSA, the European Maritime Safety Agency, is evaluating if and how biofuels could be used in the shipping sector as an alternative fuel. To determine the potential of biofuels for ships, a clearer picture is needed on technical and organizational limitations of biofuels in ships, both on board of the ship as in the fuel supply chain to the ship. Economic and sustainability analysis of biofuels should be included in this picture, as well as an overview on current and potential policy measures to stimulate the use of biofuels in shipping. Ecofys has determined the potential of biofuels, based on analysis of collected data through literature review, own expertise and experiences, direct communication with EMSA, research publications, market developments based on press and other media, and consultations with relevant stakeholders in the shipping market.

The world of biofuels

Biofuels are currently globally available, they can be produced from many abundant types of biomass, and they can be optimized to match the existing distribution channels and applications of fuels in all forms of transport. Most commonly used and produced biofuels are biodiesel (from oil containing agricultural crops) and bio-ethanol (from sugar or starch containing agricultural crops).

The market for biofuels for transport was created mostly through national and European policies, setting targets for renewable fuels and energy within the Renewable Energy Directive (RED). For biofuels there is an obligation within the RED, stimulating the market to switch to biofuel (blends). Almost all biofuels are currently consumed within the road transport sector.
The aviation sector has recently finished its orientation within the biofuel market and is now focusing on new production facilities for higher quality fuel from new biomass resources (algae for biofuels) in order to reach their market set ambitions.

Within the current RED the biofuels obligation can be met by implementing biofuels in ship transportation sector for oil companies delivering fossil fuels to both road and marine transport. This will differ per Member State, depending on the Member State translation of the RED in their legislation. Member States are not obliged to directly translated the RED in their national legislation.
The shipping sector is still in early stage of orientation towards biofuels. Several applied R&D projects and tests are known, although the shipping market is also looking at other alternative fuels to replace fossil marine fuels which are increasing in price.

The availability of biofuels worldwide does not seem to be a bottleneck for possible introduction of biofuels in ships. All major ports or bunker stations in Europe also have biofuel production facilities nearby.

Marine fuel market

Marine fuels are produced from crude oil at refineries or in case of LNG based on natural gas extraction. There are different types of marine fuel. A distinction is made in marine fuels between residual (heavy) fuels and the higher quality distillate fuels. For heavy fuels with low viscosity, the required viscosity is achieved by heating the fuel. For distillate fuels, the fuel at ambient temperature can normally have a viscosity within the specified limits. Also, fuel cleaning differs for the different types of marine fuels.

Current practices in bunkering show that ships are usually fuelled for a longer period (up to 70 days of on board storage in multiple tanks), making the fuelling a time consuming process and an expensive transaction for ship owners. Currently up to 50% of the operational costs could be caused by the fuel.

The construction and operation of merchant ships is controlled by a wide range of legislation. Many of these are based on international standards agreed by member states of the International Maritime Organization (IMO). IMO is the United Nations' specialized agency responsible for safety and security of shipping and the prevention of marine pollution by ships. IMO standards are usually agreed under European law before passing into Member State legislation. The primary international regulatory mechanism for controlling ship emissions to air is Annex VI, Regulations for the Prevention of Air Pollution from Ships, of the MARPOL Convention.
Within the MARPOL convention targets are set to gradually reduce the emissions to air caused by ship engines. Also the Energy Efficiency Design Index is installed to stimulate the ship design towards higher energy efficiency and overall lower carbon emissions. The industry has a generic fuel standard (ISO 8217) but all responsibilities for the fuel quality and quantity lie with the ship owners (little to no liability towards the fuel suppliers or bunker parties). Use of biofuels in ships is in all legislation not taken into account, or limited to a very small use (in case of the ISO standard).

Engine manufacturers play an important role in the introduction of biofuels, as they provide the guarantee for the engines to run on fuels with specific properties. MAN B&W Diesel along with Wärtsilä, are engine manufacturers with experience in biofuels for stationary power generation as well as being a significant engine supplier. Marine engines have a typical proven lifespan, ranging from 10 years (for high speed) to over 20 years for the low speed engines. The robust technology even allows them to stay operational up to 50 years, if maintained properly.

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Biofuel case analysis

From a long list of different biofuels currently in the market, six biofuels have been selected for further review and analysis:

1. Biodiesel to replace MDO/ MGO in low to medium speed engines (used in tug boats, small carriers or cargo ships)
2. DME used to replace MDO/ MGO in all types of engines (all sizes of carriers or cargo ships)
3. Straight Vegetable Oil (SVO) used to replace IFO or heavy fuel oil in low speed engines (all sizes of carriers or cargo ships)
4. Bio-LNG or bio-methane in gas engines using LNG
5. Bio-ethanol used in high speed main or auxiliary engines (short distance ships, ethanol tankers, or for electricity production on board of ships like cruise and passenger ships)
6. Pyrolysis bio-oil in low speed engines (all sizes of carriers or cargo ships)

Biofuels in general have a lower energy density than marine fuels, and also a different overall density differing per type of biofuel. This means on average a higher quantity of biofuels is needed to meet the same final energy content as with conventional fossil marine fuels.
Depending on the type of biofuel they can be easily (drop-in fuels) or with huge modifications (new-build, long term) used in the shipping sector. Although not many practical experiences of using biofuels in ships have taken place, technical compatibility of biofuels with marine engines seems high and integration manageable.

From a technical integration point of view, small percentage biodiesel blends (up to 20%) with MDO/MGO seem the most promising fuel for shipping, aside to 100% replacement of HFO by straight vegetable oils, due to best compatibility with current engines and supply chain.
Aside to the limited application of bio-ethanol in diesel engines, the investments needed to the supply chain seem manageable, although less favourable than for biodiesel and SVO.
DME and bio-LNG are still upcoming technologies, with at this point limited biomass feedstock availability. Also, more investments are needed to the fuel supply chain in order to introduce these fuels. For new build ships these fuels seem more promising.
Pyrolysis oil is not seen as a viable option as an alternative fuel for ships at this point.

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The position of biofuel blending (with the bunker parties or on board of the ship) is still in debate. From an organizational point of view, it would be best at this point to blend the biofuels at the bunker level, in order to have one Bunker Delivery Note per fuel supply with all specifications. Ship owners are not in favour of on board blending, as an extra activity on board of the ship that needs their attention. Current practice in sampling (and lack of guidelines on onboard blending) does not allow the ship owner to harvest the environmental benefits of biofuels to the best potential if they would execute on board blending (as a no-sulphur fuel). Blended (low sulphur) bio/ fossil marine fuels bought at the bunker station can easily follow the current sampling practice and little to no alteration (depending on the type of biofuel) are needed to the supply chain. Also, within the Renewable Energy Directive it will be the bunker parties that would have an obligation to deliver biofuels to the market. Furthermore, the technical integration at the bunker station will be easier and would benefit an economy of scale if on bunker level.

The use of biofuels not only is a strong option to realize lower carbon intensity in the propulsion of ships, but also shows potential to reduce the pressure of ship emissions on local air quality. 100% biofuels show no sulphur content. Biofuels, in 100% blends, can even have a Health, Safety, Security and Environment (HSSE) advantage in case of spills to the marine environment due to their biodegradable nature, compared to conventional fossil marine fuels. So, biofuels are good sustainable alternative for fossil marine fuels. The sustainability of the biofuel does need to be accounted for within the sustainability framework of the European Commission as mentioned in the RED.

Operational costs are of major importance to ship owners and are largely dominated by the fuel costs (up to 50%). Biofuels are in most cases more expensive than fossil fuels, due to higher production costs and lower economies of scale. The obligation within the RED forces the fuels market to buy and introduce biofuels anyways. The higher costs (difference between the higher production costs per energy content of biofuels, minus the normal market price of the fossil fuel) are integrated within the overall fuel price in a transport market segment. If Member States allow in their national translation of the RED that biofuels can also be introduced to the shipping sector to meet the obligation, biodiesel in ships could be evenly or even better cost-effective as to be introduced in the road sector, based on the perspective of the obligation owner.

It could also be the case that biofuels are cost-economic beneficial if sulphur restrictions are increasing for marine fuels, especially in case of the cheaper and widely available biofuels like straight vegetable oils and biodiesel, due to their no-sulphur content.

Several niche market options are identified and could lead to faster introduction of biofuels in ships, if additional policy would be implemented, such as for passenger and cruise ships, intra EU ships and offshore supporting vessels within the EU.

Conclusions

There is a market for biofuels to be introduced in ships based on current policy and support schemes, high operational costs and environmental benefits.

It is technically possible to replace marine fossil fuels with biofuels for use in ship engines. The most relevant parameters limiting the potential of biofuels today are: availability, technological development, technical integration, and operational consequences.

However, although market incentives are there, and it is technological possible, still the introduction of biofuels is limited to a few applied test projects and local initiatives. The following conclusions were drafted by Ecofys on market barriers that need to be addressed in order to accelerate the introduction of biofuels in the shipping sector.

The main market barrier that should be addressed is the fact that the market incentives in place (obligation within the Renewable Energy Directive, and the sulphur restrictions within the MARPOL legislation) are affecting different market parties in the marine fuel supply chain. Bunker parties could be affected in the fuel obligation, where ship owners are responsible for meeting the lower sulphur content in their used fuels and for other environmental impacts of their shipping (such as spills, waste etc) and also will have the exposure benefits of green imaging or profiling.

Introducing biofuels to the shipping sector will have both opportunities and threats to the current market players in the fuel supply chain. The major opportunity would be the ability to shift position in the supply or rather value chain (upstream – downstream) if i.e. ship owners would produce biofuels themselves or cooperate with new biofuel entries in the marine market. This could be a threat to the larger players in the conventional market which have position in both fossil fuel supply as well as shipping.

There is no large experience of biofuels use in ship engines. Known R&D projects that investigate the possibilities are all private company initiatives, and applied in operational ships. Public information is limited in availability.
So, there are still some uncertainties around a full scale introduction of biofuels concerning the technical aspects. Current research and stakeholder interviews show contradicting arguments and only small scale test results are available, as a clear indication of first orientations by current market players. Especially the Health, Safety, Security and Environment aspects in the operational situation should be investigated further for introduction of biofuels on a substantial scale (e.g. a fixed percentage for every ship to use biofuels).

The known restraints from the market concerning biofuels (long term storage related to unstable fuel quality and micro biological growth, water content leading to acidity, degraded low-temperature flow properties) are based on unfamiliarity with biofuels in this sector.

Data collection from literature, the current R&D projects, and interviews with stakeholders have not led to recognition of these technical restraints. All restraints seem manageable with mitigation measures such as limited to larger retro fitting adjustments, good housekeeping and set-up of clear fuel specifications for biofuels, depending on the blend percentage. Still, proof of principle on larger scale is missing.

To comply with the expectations on higher environmental performance of biofuels, sustainability of biofuels is of strong importance and affects the production of biofuels and with that the market. In the aviation sector a clear preference is shown towards biofuels from new, more sustainable resources such as algae to prevent potential exposure and liability on using non-sustainable biofuels. As the shipping sector is still in an orientation mode, this aspect and lessons learned from other industries can be taken into account with a head start (e.g. by setting references in fuel standards for marine market to the sustainability criteria mentioned in the Renewable Energy Directive).

Current practice and stakeholder opinion would lead to blending of biofuels at the bunker station. This means the blending initiative will lie with the bunker parties, although current ownership and responsibilities in the fuel supply chain lie fully with the ship owners. The current sampling practice could be amended with better guidelines within MARPOL on compliance with presenting sulphur content in their fuels. This way, the biofuel in its own tank and fuel supply system can be contained and monitored better on board of the ship, and the ownership on fuel quality and its environmental benefits remains with the ship owners.

The consequences of using biofuels for the operational side seem limited if lower blends are used. Biofuels do need special attention if used in higher or 100% blends (mainly due to the higher water content which needs frequent monitoring). This asks for training and integration within the stringent HSSE management on board of ships.
Legislation for shipping is limited to a low level of detail, and not so much EU dominated and highly detailed as for road transport which operates more local/ national. For shipping the International Maritime Organization (IMO) is of major importance and acts on a global scale where a worldwide level playing field is of strong importance. This could be a hurdle for the introduction of biofuels, if the RED for example would be prolonged actively towards the shipping sector.

Production costs of biofuels are still higher than for fossil marine fuels. However, the uncertainty in technological development, scaling and therefore cost reduction could lead to a competitive situation, if marine fuels are to be increasing in price, and if the obligation incentive for biofuels remains within the RED. This remains an unpredictable factor in the future marine fuel market with strong effect on the introduction of biofuels.

Recommendations

EMSA is recommended to stress for more focus in the Renewable Energy Directive (RED) on the obligation at the bunkering parties and not only the general supplying market. This way also obliging bunker parties supplying only to the marine sector with could have a biofuels target. EMSA could focus on a clear proposal for the review of the RED, scheduled for 2014. The coming two years could be used for extended research into the technical uncertainties and the new fuel supply chain (see recommendation 5) should be worked out, with a focus on the European shipping market.

To accelerate the introduction of biofuels in the shipping sector, it is recommended to introduce a separate fuel standard for biofuels to use in ship engines. Experiences in road transport and aviation show that such a dedicated fuel standard accelerates market acceptance and introduction of the fuel. There are several ways to introduce such a fuel standard, in which EMSA could play an encouraging role:

- Through an EC initiative, focusing on the European market such as inland shipping, intra-EU and dedicated offshore maintenance ships. This way the standard could be made binding, and will stimulate fuel quality in general in the shipping market. Alignment with an adjusted RED (with separate ambitions or stronger focus on alternative fuels for shipping) as well as the benefits of accelerate biofuels introduction into ships for air quality should support the EC initiative.
- Through the works of the IMO. The current version of the ISO8217:2010 technical fuel standard for marine fuels does not facilitate the introduction of biofuels. Based on more practical experience (see recommendation 5) the international fuel standard could be altered and could be made legally binding within the MARPOL legislation. This way the international shipping market is targeted to introduce biofuels. With a good biofuel standard IMO would give the market concrete new tools and means to comply with MARPOL legislation on sulphur content.
- Through a market initiative: the market could set up a standard themselves. To have an optimal effect it would be best if both ship owners and bunker associations would align in drafting such a standard. EMSA for example could organize a meeting with ECSA and IBIA to discuss the frameworks of such an initiative.

Much could be learned from the current developments in the aviation industry. EMSA could lobby with IMO to take example of the IATA approach, to set up ambitious targets for biofuel introduction. This way a clear signal to the market is given on how to make the industry more climate neutral and with a better environmental performance in terms of air pollution and spills. IMO this way would motivate ship owners as well as bunker parties to change their supply chains and take position

Some "quick wins'" in addressing market barriers are identified in current MARPOL legislation. A change in Energy Efficiency Design Index for ships is a way to stimulate the introduction; now there is only focus on carbon content without making distinction between fossil carbon and biogenic carbon produced by biofuels. Also, guidelines for the blending of biofuels, either on bunker level or on board of ships, could help the shipping sector to switch to biofuels in order to comply with lower sulphur restrictions. EMSA has a good position to facilitate these changes within the IMO.

More R&D research is required on the technical uncertainties and efficiency potential of biofuels for ships. To prevent scattered market initiatives in R&D trials and to upgrade the test results to a larger perspective, it would be recommended to create a special Framework Programme on the innovation potential and uncertainties of biofuels in ships. This way the knowledge and experience within the is also disseminated properly throughout the market. Article 4C of directive 2005/33 regarding the sulphur content of marine fuels states that European Member States can be exempted from marine fuel sulphur requirements laid out in article 4A and 4B for emission abatement techniques testing purposes. The requirements for testing are that the EC and all involved port states are notified of these tests and that the results are provided to the Commission and made publically available. EMSA could use this possibility for tests together with a cooperation with Department of Research of the EC to fundamentally investigate the effects of larger scale biofuel introduction into ships. Focus areas for research would be the use and limitations of 100% blends of biodiesel and straight vegetable oil for full operation and for longer storage, and the use of bio-ethanol in the auxiliary engines.

Engine manufacturers and classification bodies should anticipate more on the introduction of biofuels in the marine sector and expand their terms & conditions, guarantees and so on to include biofuels. EMSA could motivate these parties to develop energy labels for ships together with them that not only take into account energy efficiency in current and new ships but also look at environmental impact of alternative fuels in mono fuel or dual fuel engines. Lessons from other e-labeling methodologies and implementation schemes (build environment, cars) can be integrated. First initiatives for e-labeling of ships have started, the Dutch government for example has recently asked Ecofys to investigate the e-labeling possibilities for inland shipping.

An overall benchmark of the performance of the different ship types and their emissions with ETS or levy kind of system could lead to incentives for the market. The aviation sector for example will be submitted to European Emission Trading Scheme for carbon emissions as of 2013. EMSA could investigate the effects of this decision by the EC together with IATA or other aviation branch organizations as to define if this measure would also be possible and effective for the shipping sector.

Ship owners and bunker parties in their turn should define their strategic pathway in the coming changes in the bunker fuel market. Long term vision and strategy in this is of strong importance. An important role in this re-positioning and set up of new supply chains is given to the port authorities as clusters of the different fuel industries. EMSA could play a mediating role in this multi stakeholder debate and encourage the market towards a sustainable transition. It is recommended to start with the larger market groups where introduction of biofuels could also have green profiling benefits, such as the cruise and passenger ships and large container carriers.

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Abbreviations

CO_2	Carbon dioxide
DME	Di-methyl ether
DWT	Dead Weight Tonnage; DWT is the maximum weight (mass) of a ship when loaded up to its summer load line (Plimsoll line) and is the sum of the weights of the cargo, crew, fuel, passengers, and stores
EC	European Commission
ECA	Emission Control Area; Areas as defined within the MARPOL legislation where lower emissions to air are allowed.
ECSA	Community Shipowners' Associations
EEDI	Energy Efficiency Design Index; Index a set within MARPOL legislation, meant to stimulate innovation and the technical development of all the elements enhancing the energy efficiency of a ship.
EMSA	European Maritime Safety Agency
ETBE	Ethyl tert-butyl ether
FQD	Fuel Quality Directive
GHG	Green House Gases
HFO	Heavy Fuel Oil
HVO	Hydro treated vegetable oil
IBIA	International Bunker Industry Association
IFO	Intermediate fuel oil
IMO	International Maritime Organization; Specialized agency of the United Nations with 169 Member States and five Associate Members. IMO is a technical organization and most of its work is carried out in a number of committees and sub-committee, for example the Marine Environment Protection Committee – MEPC
ktonne	Kilotonne
LHV	Lower Heating Value
LNG	Liquefied Natural Gas
LSHFO	Low sulphur heavy fuel oil;
MARPOL	International Convention for the Prevention of Pollution from Ships (1973) and Protocol of 1978 (IMO)
MDO	Marine diesel oil

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MEPC	Marine Environment Protection Committee (of the IMO)
MGO	Marine gas oil
MTBE	Methyl tert butyl ether
Mtoe	Mega tonnes of oil equivalent
NO_x	Nitrate oxides
PM10	Particulate Matter smaller than 10µm (fine dust)
PPO	Pure Plant Oil
RED	Renewable Energy Directive; This is the main directive setting targets and frameworks for the introduction of renewable energy for electricity, heat and fuels for transport, made by the European Commission.
SFOC	Specific Fuel Oil Consumption
SO_x	Sulphur Oxides
SVO	Straight vegetable oil (equivalent to PPO)
TEU	Twenty-Foot Equivalent Unit; This is a measure used to indicate the capacity of container ships.
ULSD	Ultra low sulphur diesel oil

1 Introduction

1.1 Background

Shipping is amongst the fastest growing modes in the transportation sector. While it is also a relatively low-energy mode of long-distance transportation, it is important that the growth of the sector is sustainable in the long-term, and recently more attention is given to both the negative contribution of ships on air quality as the overall GHG emissions of ships.

To increase the air quality in densely used areas such as ports and inland shipping lanes, the International Maritime Organization (IMO) set up the MARPOL agreement which aims at reducing sulphur, NO_x and particulate emissions of ships.

In the OECD, the marine bunker fuels market was 92.57 Mtoe in 2008, representing about 1.7% of the total primary energy supply in the OECD[1]. Worldwide, shipping is estimated to have emitted 1,046 million tonnes of CO2 in 2007, which corresponds to 3.3% of the global emissions during 2007. International shipping is estimated to have emitted 870 million tonnes, or about 2.7% of the global emissions of CO2 in 2007. Mid-range emissions scenarios show that by 2050, in the absence of abatement policies, carbon dioxide emissions from international shipping may grow by a factor of 2 to 3 (compared to the emissions in 2007) as a result of the growth in shipping[2].

There are three principle options for reducing the greenhouse gas emissions from shipping[3]:

- Less shipping activity, either by reducing the total global transportation (needs) or by shifting to other transportation modes;
- Increasing the energy efficiency of shipping;
- Decreasing the carbon intensity of shipping propulsion.

A possible decrease of total global transportation is unlikely to occur, with growing population and international trade. Marine shipping is already the most efficient form of transportation (aside from pipelines), which means that shifting to other transportation modes will not help. Marine shipping efficiencies have been steadily increasing over the past several decades, but the demand has grown faster than the efficiency improvements. This means that decreasing the carbon intensity of shipping propulsion, may be the best option for really decreasing the greenhouse gas emissions from this sector.

One of the options to realize a lower carbon intensity in the propulsion of ships and possibly reduce the pressure of ship emissions on local air quality, could be the use of biofuels. Therefore, EMSA, the European Maritime Safety Agency, is evaluating if and how alternative fuels could be used in the shipping sector. This is done in close dialogue with the European Commission and their need for a more sustainable transport sector in general.

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[1] IEA 2011, Key World Energy Statistics, OECD, Paris

[2] IMO 2009, Second IMO GHG Study

[3] Pew Center 2009, *Greenhouse gas emissions from aviation and marine transportation: Mitigation potential and policies*, Pew Center on Global Climate Change, Arlington VA USA

To anticipate on current developments of alternative fuels in transport, EMSA wishes to understand the consequences of using biofuels for health, safety, environment and operation.

Conclusion

A clearer picture is needed on technical and organizational limitations for the potential use of biofuels in the shipping industry, both on board of the ship and in the chain of delivery to the ship. Economic and sustainability analysis of biofuels should be included in this picture, as well as an overview on current and potential policy measures to stimulate the use of biofuels in shipping.

1.2 Methodology

In this report the potential of biofuels for possible introduction into ships is investigated. To determine this potential three main questions need to be answered:

- Is there currently a market for biofuels to be used in ships?
- Is it possible to use biofuels in ships?
- What is restraining the market to use biofuels in ships?

To answer these questions as to determine the potential of biofuels for shipping, Ecofys has performed an analysis based on collected data through literature review, own expertise and experiences (mainly in the area of biofuels for road and aviation), direct communication with EMSA, research publications, market developments based on press and other media, consultations with relevant stakeholders through interviews, and a workshop with the main ship owner associations (ECSA). The following stakeholders have been consulted along the project duration (June 2011 – January 2012).

Company / organisation	Sector
Delft University of Technology	Research Institute
Wärtsila	Engine manufacturer
MAN (PON Power)	Engine manufacturer
Shell	Oil and fuel supplier
Lloyd’s Register	Marine certifier
North Sea Group	Oil and fuel supplier
Argos Oil	Oil and fuel supplier
Port of Rotterdam	Port authority
Maersk Line	Shipping company
GEFO (Gesellschaft für Oeltransporte) Hamburg	Bunkerer
International Bunker Industry Association (IBIA)	European association bunkerers
Abengoa (Rotterdam)	Biofuel producer

Company / organisation	Sector
IMO, dept air emissions & fuel quality	Government
ECSA (Community Shipowners' Associations)	Shipowners branch organization

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2 The world of biofuels

2.1 Biofuels as renewable energy carrier

Climate change concerns and the perspective of finite fossil energy sources have resulted in an increasing interest in renewable energy. Where most renewable energy resources produce electricity or heat, biomass is especially suitable to produce storable and transportable energy that can be used in the transportation sector: biofuels.

Biofuels are currently and globally available, they can be produced from many abundant types of biomass, and they can be optimized to match the existing distribution channels and applications of fuels in all forms of transport.

Some project that the world's transport fuel consumption could increase by over 60 percent to some three billion tons oil equivalent (btoe) in 2030[4]. Ecofys demonstrated that through implementing stringent but realistic efficiency measures, the overall fuel use in transport would still peak at some 2.7 btoe in 2020, after which a gradual energy use decrease could be realized resulting in 1.7 btoe from 2040 onwards[5].

Whatever the fuel use in the transportation sector will be, in all cases it will be necessary to source a significant part from renewable sources. Whereas in the future, passenger road transport may (partially) be electrified, other transport sectors, such as road haulage, aviation and shipping likely need biofuels to become sustainable.

2.2 Biofuels production routes

In the scope of the present study, biofuels are liquid or gaseous fuels produced from organic (plant or animal) material, for application in the transport sector. Many different types of biofuels can be produced from a wide variety of raw biomass. All have very different physical and combustion properties (see chapter 4 for full analysis). The conversion technologies along the supply chain are just as diverse and numerous. Figure 1 below gives a quick overview of the most prominent current and future production routes.

There are a few well established routes to produce biofuels:

- Extraction of vegetable oils, mostly followed by trans-esterification;
- Fermentation of sugar or starch to alcohol.

Within these routes, many variations are possible, to address different feedstock, different plant size, with different co-products or to suit differing local situations.

Besides the traditional routes, many new technologies are being developed with promises for improved greenhouse gas performance or fuel quality, higher product yields or cheaper

[4] Fischer G, Hizsnyik E, Prieler S, Shah M and van Velthuizen H, 2009, *Biofuels and food security*, International Institute for Applied Systems Analysis (IIASA), Laxenburg Austria

[5] Ecofys and WWF 2011, *The energy report / 100% renewable energy by 2050*

production. Examples are thermochemical processes via gasification, hydrotreatment or hydro thermal upgrading, and advanced biological processes involving hydrolysis and fermentation.

Sometimes these are called second generation, but this is not a clear and widely accepted definition[6]. A second generation label is not a guarantee for a better sustainability performance. It does not per se lead to better technical or economic performance. And it has no direct or explicit legal implications

Nevertheless, some biofuels produced via advanced technologies and most biofuels produced from residue feedstock have a better chance of meeting the greenhouse gas threshold or may count twice towards the European target for renewable energy in transport (see information on the Renewable Energy Directive in section 2.3.2). The performance actually depends on the feedstock and supply chain and each individual chain should be analysed separately.

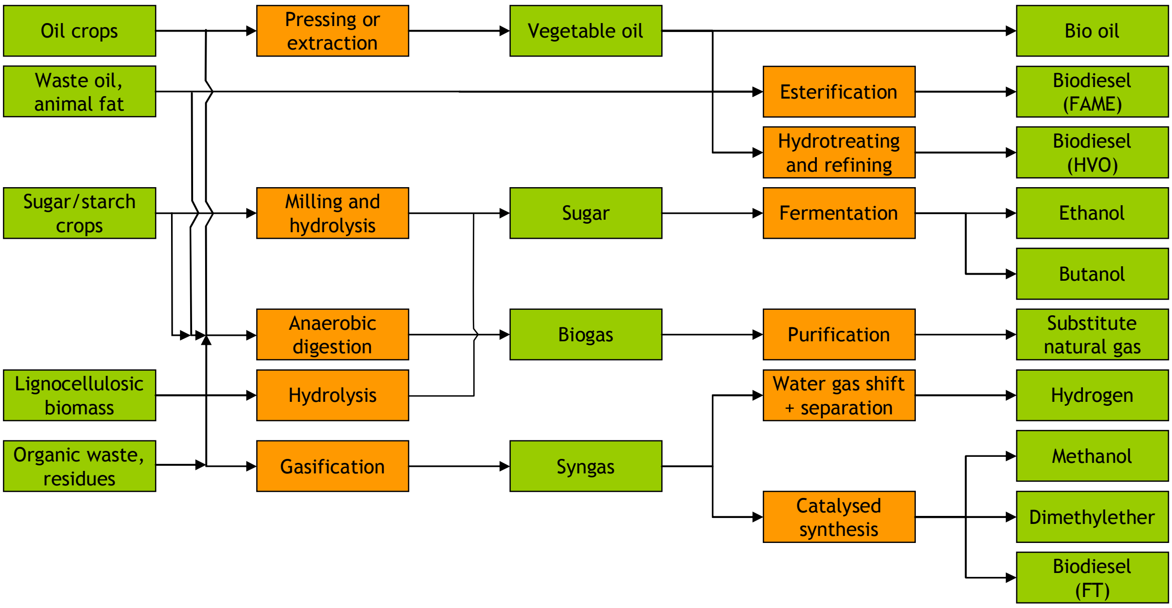

Figure 1 Overview of conversion routes to biofuels (not exhaustive)

Definitions of the presented bioresources in Figure 1 above are as follows:

- Oil crops: these are mainly agricultural crops containing oil in seed or other plant material, that can be extracted through pressing or other forms of extraction. Common examples are palm, rapeseed, and soy. Another biomass source for oil crops could be aquatic biomass such as micro-algae. Many algae species show a tendency for high lipid production. The cultivation and conversion of algae to oil is still in early stage of development.
- Sugar/starch crops: these are common agricultural crops that contain sugar or starch such as sugar cane, sugar beet, wheat, and maize.
- Lignocellulosic biomass: these are woody or herbaceous energy crops, such as wood, bamboo and straw.
- Organic waste residues: a distinction is made between primary, secondary and tertiary residues, depending on the position in the supply/ conversion chain they have.

[6] Some definitions focus on the feedstock, such that biofuels produced from wood, grass, but also from a broad range of residues are contained. Other definitions focus on the technology.

- Primary residues are created on the cultivation area so agricultural residues (including corn stover and sugarcane bagasse) from the agricultural land or woody residues from the forest such as stomps and complementary felling. Secondary residues are created at the first conversion steps (so from agro-food industry or wood processing industry such as sawmill and paper mill discards). Tertiary residues are created at the consumption level, so food residues from households and restaurants, including animal fat, and used items such as paper waste, old woody furniture.

2.2.1 Biodiesel

The term biodiesel normally indicates methyl-esters produced from bio oils (see section 2.2.2). Per tonne of bio oil, about 1 tonne of biodiesel can be produced. Also, about 0.1 tonne of methanol is required for the reaction and about 0.1 tonne of glycerine is produced.

Most used feedstocks currently are rapeseed/oil, palm oil, soybean/oil, used cooking oil and animal fat. The EU is the major producer of biodiesel (see section 2.4) and uses all these feedstocks. Initially, rapeseed accounted for the lion's share of biodiesel feedstock because rapeseed biodiesel best matches some physical parameters of fossil diesel and the biodiesel specifications strongly steered towards the use of rapeseed. Throughout the years, the use of other feedstock has increased, because (1) the biodiesel quality standard has become less strict and somewhat less important since the quality of the resulting blend with diesel is leading[7], (2) other feedstock are sometimes cheaper[8] and (3) biodiesel produced from other feedstock is sometimes more valuable[9].

2.2.2 Straight vegetable oil (SVO) or pure plant oil (PPO)

The vegetable oil that is used for biodiesel production can also be used directly in engines. With minor modifications, most diesel car engines are suitable for the use of SVO. The viscosity of the SVO must be reduced by preheating it. This is often done through a dual fuel system, in which the car is started on regular diesel and after a short while switches to the use of SVO.

With warm ambient temperatures the viscosity is automatically lower. In some tropical countries, SVO is used without any modification to the engine.

Other bio oils, such as animal fat and used cooking oil can also be used in heavy duty engines, provided that it has been cleaned.

2.2.3 Hydro treated vegetable oil (HVO)

New developments seek to produce diesel from vegetable oil that is completely fungible with fossil diesel. These fuels are typified as "drop-in" fuels, meaning that they could be used in any blend with fossil fuel, or even as pure fuel, and that the user should notice no difference.

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[7] It is well possible to produce a diesel blend according to EN590 diesel quality, containing biodiesel that does not match EN14214.

[8] Palm oil and rapeseed oil are fluctuating in prices, palm oil is the cheapest most of the time. See Figure 18

[9] As is explained in Section 29, biodiesel produced from e.g. used cooking oil counts twice against the RED target, which provides an incentive – in some countries – to increase the use of this material.

Several companies develop the production of hydrotreated vegetable oil, in which vegetable oil is treated by hydrogen over a special catalyst. The Finnish company Neste Oil has realised significant production of HVO under the name "NexBTL" (2 x 190 ktonne/year in Finland, 800 ktonne/year in Singapore). The fuels are blended into fossil diesel for road transport.

Several other HVO projects have been announced:

- Galp Energia together with Petrobras in Portugal;
- UOP/Eni in Italy;
- Dynamic Fuels LLC (a venture of Tyson Foods and Syntroleum) in the U.S
- IFP/Axens have developed the Vegan proces.

2.2.4 Fischer-Tropsch (FT) diesel

Fischer-Tropsch (FT) diesel derived from biomass via gasification could be an attractive clean and carbon neutral transportation fuel, directly usable in the present transport sector as a "drop in" fuel like HVO discussed in section 2.2.3 above.

FT diesel could be produced from lignocellulose biomass (woody biomass), in which the full feedstock material could be used for the biofuels production. The feedstock is first gasified to produce synthesis gas (carbon monoxide and hydrogen primarily, $CO + H_2$) which is reacted over a special catalyst to produce carbon chains of varying length.

The Fischer-Tropsch process has been developed almost a century ago. The FT diesel production through coal gasification has been viable in times of limited access to conventional transportation fuels[10]. When produced from biomass, it is assumed that very cheap feedstock could be used with advantages for the overall production costs and that the use of lignocellulose (residues) could be advantageous for the environmental performance.

The commercialisation of biogenic FT diesel seems to be in difficult weather, while the technology is strongly linked to the rather immature technology of biomass gasification. Creating a clean and stable enough bio syngas through gasification on larger scale remains a bottleneck. Also, the required investment for commercial scale biomass gasification-FT plants is very high in relation to other biofuel technologies. On top of this the most prominent European developer on bio FT diesel, Choren, has recently declared insolvency due to financial difficulties.

2.2.5 Pyrolysis bio-oil

Pyrolysis oil is a synthetic crude oil. The pyrolysis process involves heating in absence of oxygen. There are several variations to the pyrolysis process, yielding different combinations of gases, bio-oil (typically 60-70%) and charcoal (typically 10-20%). Some components in the bio-oil may be used as a bio-chemical. Currently much attention goes to the possibility of using the charcoal to improve soils and carbon stock build-up.

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[10] FT synthesis from coal is heavily developed for example in South Africa.

Pyrolysis oil can be stored, pumped and transported like petroleum products and can be combusted directly in boilers, gas turbines and slow to medium speed diesels. It has been stated[11] that pyrolysis oil could substitute heavy fuel oil (HFO), light fuel oil (LFO) or natural gas in a number of applications. This suggests that the use of pyrolysis oil in shipping is possible.

However, pyrolysis oil is not "oil", like a vegetable oil or petroleum oil. It has some properties that lead to additional costs. It is acidic and corrosive which means that more expensive materials must be used in the burner nozzles and the entire fuel system. The bio-oil calorific value (typically ranging between 17 and 23 GJ/ton) is lower than fuel oil (approx. 40 GJ/ton) which leads to increased costs for transportation and storage. Initially, it contains about 25% water. The viscosity of the oil increases during storage, therefore turnover in storage should be shorter than few months.

Production of pyrolysis oil is still in early stages of development. No commercial scale facilities are known worldwide. Several institutes are researching the possibilities for upgrading pyrolysis oil in a regular oil refinery. The final product would then have characteristics very comparable to fossil derived fuels. However, the upgrading of pyrolysis oil may be complex and expensive, and is in this stage of development very immature and uncertain.

2.2.6 Bio-ethanol

Bio-ethanol is currently the most widely used biofuel around the world (see section 2.4). Current commercial bio-ethanol production is based on fermenting sugar or starch. In Europe, wheat and sugar beet are the primary feedstock; maize is more popular in the USA. Bio-ethanol production in tropical countries is largely based on sugar cane. Sweet sorghum and cassava are popular bio-ethanol feedstocks in some countries.

The theoretical maximum ethanol yield from 1 kg sugar is 0.51 kg bio-ethanol and 0.49 kg CO_2:

$$3\ C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$$

For each kg of bio-ethanol about 1 kg of CO_2 is co-produced. Note that this CO_2 is biogenic, i.e. it stems from the biomass. Emission of this CO_2 to the atmosphere does not increase the amount of CO_2 in the atmosphere (because it was captured from the atmosphere by growing the crop). However, there is some interest in capturing this CO_2 for storage or further use. This would further improve the greenhouse gas performance – such a set-up would actually remove CO_2 from the air and lead to a negative carbon emission over the lifecycle of the fuel. The greenhouse gas performance of a range of biofuels is discussed in section 2.5 and 4.3.

[11] Bradley 2006, *European Market Study for BioOil (Pyrolysis Oil)*. Climate Change Solutions, IEA Bioenergy Task 40- Bio-trade

Figure 2 **Map of 2nd generation biofuel initiatives (from cellulosic biomass) [Source: IEA Bioenergy Task 39]**

Ethanol can also be produced from ligno-cellulosic biomass, such as wood and grass. This could have some advantages for the costs (cheaper feedstock) and the yield per hectare, with trickle down effects on environmental aspects such as the overall greenhouse gas balance and biodiversity. As yet the global production of ligno-cellulosic ethanol is still low, but the number of research and development initiatives is enormous (see Figure 2) and the first commercial demonstrations are coming online. The IEA Bioenergy Task 39 lists a total of 87 pilot and demonstration plants based on ligno-cellulosic biomass as of January 2012[12].It is expected that significant volumes of ligno-cellulose ethanol will already be produced in the coming years. The development of ethanol production from ligno-cellulosic biomass includes two crucial steps:

- Hydrolyse cellulose and hemi-cellulose to produce fermentable sugars. This is possible via many different routes: enzymatic, through acids or by treatment with hot water or steam. Every route has advantages and disadvantages;
- Fermentation of C5 sugars. Where most direct plant sugars are C6 (as glucose in the reaction above), a significant part of the polysugars in cellulose and hemi-cellulose are C5 based. Where the traditional C6 fermentation uses yeast, C5 fermentation may be faster through using modified bacteria.

Some researchers focus on the separate optimisation of each step, whereas others try to optimise the combination of the hydrolysis and fermentation in one reactor.

[12] Up to date information can be found at http://biofuels.abc-energy.at/demoplants/

Ethanol has a few technical and logistical drawbacks. It increases vapor pressure, which means that the gasoline in which it is blended, must be adapted on before hand. Furthermore, it attracts water which means that extra measures must be taken in shipping and storage.

2.2.7 Ethyl tert butyl ether (ETBE)

To overcome the bottlenecks of pure ethanol as a biofuel, a part of the ethanol in Europe is applied in the form of ethyl tert butyl ether (ETBE). ETBE is produced from ethanol by reacting with isobutylene, a fossil oil derivate. This means that ETBE is not regarded as a 100% biofuel. The Renewable Energy Directive (see for more information section 0) states that 37% of the energy content of ETBE can be regarded as bio energy.

2.2.8 Methanol

Methanol is a bulk chemical, used for many processes, as well as a fuel. It can be used as oxygen additive in gasoline, either directly or via the derivate MTBE (analogous to ETBE above), at higher fractions in adapted engines such as in flexi-fuel vehicles, and as a neat fuel in fuel cells.

Bio-methanol could be produced from biomass via gasification, analogous to the Fischer-Tropsch process described above in section 2.2.4. The global commercial production of bio-methanol is still limited to one installation in the Netherlands, which uses crude glycerine (from biodiesel production) as a feedstock. Again, the technological development and commercial availability of biomass gasification is the limiting factor.

2.2.9 Di-methyl ether (DME)

Di-methyl ether is currently researched as an alternative fuel to diesel and LPG. It can be applied directly in diesel engines. Especially Volvo Engines in Sweden has been researching the application of bio-DME for many years. The major advantage of DME is the very clean combustion, also it has a appreciable energy density. DME is produced from methanol, or directly from syngas after gasification, and through this connection still in early stages of technological development. No commercial scale production is known worldwide for biofuels consumption.

Recent studies focus on the use of DME as a marine fuel[13]. They claim several technical advantages of DME, but recognise that the current production capacity is little and that infrastructure is insufficient. They propose to tank alcohol and to upgrade on board to DME (OBATE – On Board Alcohol To Ether). In this way, the advantages of the one fuel, in availability and handling, are combined with the advantage of the other fuel in application as a diesel fuel.

With the same technology, it is possible to onboard convert ethanol to DEE (diethyl ether).

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[13] Presentation by P.E. Højlund Nielsen from company Haldor Topsøe: *OBATE: an upgraded alcohol fuel for efficient & clean Diesel engine application*, Marine Days, Göteborg, April 5th 2011

2.2.10 Bio-methane

Methane can be produced from biomass via fermentation, anaerobic digestion or via gasification. Anaerobic digestion is a very common process, however current operational production is de-central and at small scale. Production of bio-methane from ligno-cellulose biomass via gasification could be done at a much larger scale, but this has not been commercialised yet. The biogas produced typically contains between 45% and 75% of methane and has to be cleaned, upgraded and pressurised in order to be used efficiently as a energy carrier. It is possible to distribute biogas via natural gas grids, if upgraded to natural gas quality and specifications.

Under ambient conditions, biogas has a low energy density. To apply biogas for propulsion purposes, it will need to be stored in liquefied or compressed form. The interest in LNG (liquefied natural gas) as shipping fuel opens a possibility to use biogas in the shipping sector. While LNG is a finite fossil fuel and does not contribute much to lower greenhouse gas emissions, bio-methane or bio-LNG would be a better alternative.

Conclusion

There are many biofuel types in different stages of technological development. Historical developments and current trends show the technological potential for biofuels is far from fully exploited and shows a large potential as a sustainable fuel for the future of shipping.

2.3 Policy scene

Governments have played an important role in stimulating the use of bio energy, since most forms of bio energy, as new entry product/ technology, are not yet financially competitive with fossil fuels.

All around the world, countries are formulating biofuels targets, and many have put incentives in place. Figure 3 gives an overview of countries that have installed mandates.
Clearly, the interest in biofuels is concentrated in the largest fuel consuming markets (EU, North America, China) and in profitable feedstock production regions (South America, South East Asia). Beside the countries that installed mandates, many other countries have installed other incentive policies (e.g. excise reductions) or have set biofuel targets for the coming decade. Some other countries, especially in Africa, have installed policies to manage the development of large scale biofuels feedstock projects (e.g. Mozambique, Ghana, Tanzania).

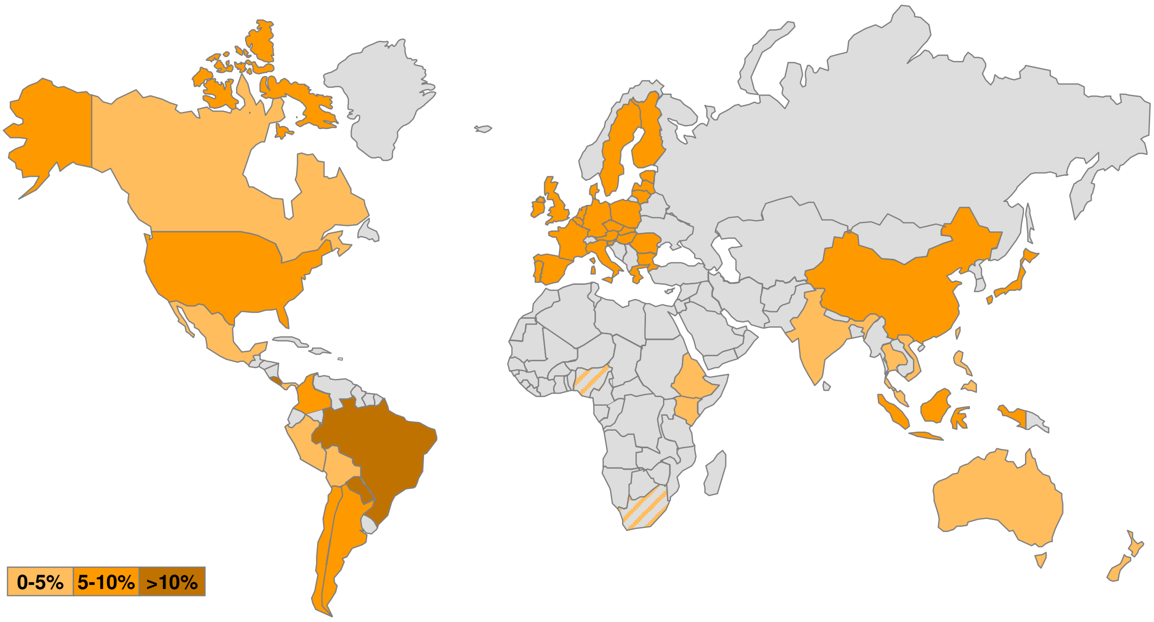

Figure 3 Biofuel mandates around the world [compiled by Ecofys, 2011]

2.3.1 Biofuel policy developments in Europe

During the 1990s the production and use of alternative fuels from biogenic origin for road transport was started in several European countries and expanded significantly in the following decade. At the same time, policy at a European level was initiated, mainly from the security of fuel supply perspective. Larger EU countries like Germany and France also saw benefits of the use of biofuels for transportation to stimulate their local economy and agricultural industry, while the first biofuel conversion routes focused on rapeseed and grain production.

The 1997 White Paper 'Energy for the future: Renewable sources of energy' mentioned a possible 18 Mtoe liquid biofuels target for 2010, and the 2000 Green Paper 'Towards a European strategy for the security of energy supply' was the start for a more comprehensive policy, in which biofuels should contribute to a proposed ambitious target of 20% alternative fuels (biofuels, natural gas, hydrogen) in 2020. This policy was more detailed in the 2003 'Directive on the promotion of the use of biofuels or other renewable fuels for transport' (2003/30/EC, May 8, 2003)

In December 2008, EU leaders reached agreement on the "20/20/20" Energy and Climate Change 'Package' which includes objectives to:

- Reduce greenhouse gas (GHG) emissions by 20% by 2020
- Increase renewable energy use to 20% by 2020
- Improve energy efficiency by 20% by 2020

Renewable energy in the transport sector plays a major role in the EU energy strategy, as it is the sector with the highest greenhouse gas emissions growth. The Package includes two Directives relevant for biofuels: the Renewable Energy Directive (RED) and the Fuel Quality Directive (FQD), which are further discussed in section 2.3.2 and 2.3.3 below.

Actually, these directives do not set a strict requirement to produce or use biofuels, but biofuels are the most logical option to fulfil requirements formulated in those directives.

2.3.2 The Renewable Energy Directive (RED)

The Renewable Energy Directive (RED) (2009/28/EC) was adopted in April 2009 and includes a mandatory 10% renewable energy target for the transport sector in 2020 for all Member States. The 10% target for transport is based on energy content and formulated as follows:

$$10\% = \frac{\textit{All}\text{ Renewable Energy in }\textit{all}\text{ forms of transport}}{\text{Petrol, diesel, }\underbrace{\text{biofuels}}_{\text{In road and rail transport}}\text{, }\underbrace{\text{electricity}}_{\text{In all transport}}}$$

For the calculation of the nominator, biofuels from residues count twice and renewable electricity in road transport counts 2.5 times

Although other renewable transportation options are also allowed, biofuels will play a crucial role in achieving the 10% target. Only biofuels that meet the sustainability and GHG threshold requirements of the RED will count towards this target (see for more details section 2.5). In order to be eligible for government support, biofuels also need to meet these requirements.

The 10% target is measured against fuels used in road transport (and a small portion of electricity in e.g. rail transport). According to the RED, renewable energy used in any form of transport in the EU counts towards realizing the target, including shipping fuels.

All Member States were obliged to transpose the RED to national legislation by December 2010. However, there is no obligation for Member States to provide incentives or obligations for all forms of transport, and to our knowledge there is currently no Member State that has provided explicit incentives or accounting for fuels in the shipping sector. If such legislation were to be introduced by Member States, depending on the incentive system, oil companies that deliver to road and marine transport may have an incentive to market shipping biofuels.

The current Dutch biofuels policy seems to allow obligated parties to fulfil their target partially by supplying biofuels to the shipping sector. Obligated parties are economic operators that sell gasoline, diesel or biofuels to the road transport. So, only companies that operate on both markets would be able to sell biofuels. It must be noted that the legislation does not explicitly mention the marine shipping sector, but also does not rule out the sector.

Conclusion

Within the current RED the biofuels obligation **can be** met by implementing biofuels in ship transportation sector for oil companies delivering fossil fuels to both road and marine transport. This will differ per Member State, depending on the Member State translation of the RED in their legislation. Member States are not obliged to directly translated the RED in their national legislation.

2.3.3 The Fuel Quality Directive (FQD)

Simultaneously with the Renewable Energy Directive, the Fuel Quality Directive (FQD) (2009/30/EC) was adopted that aims to reduce greenhouse gas emissions from transport by at least 6% over the fuel life cycle, between 2010 and 2020. By 2020 this is a binding target and again biofuels will play an important role in achieving it.

Subject to a review by the European Commission, it should comprise a further 2% reduction obtained through the use of environmentally friendly carbon capture and storage technologies, electric vehicles and an additional 2% reduction obtained through the purchase of credits under the Clean Development Mechanism of the Kyoto Protocol[14]. These additional reductions are **not** binding on Member States or fuel suppliers on entry into force of this Directive. The review will also assess their non-binding character.

The FQD contains the same carbon and sustainability requirements for biofuels as the RED (see also section 2.5).

2.3.4 Time schedule

The main concepts and requirements have been set out in the Renewable Energy Directive (RED) and the Fuel Quality Directive (FQD). Nonetheless, a number of definitions and aspects, especially regarding land use, are planned to be reviewed by the European Commission. Table 1 below provides an overview of these planned reviews and their expected date of delivery. This implies that in certain cases additional (sustainability) requirements might be possible or that certain requirements might be adapted.

Table 1 Overview of intended reviews and decisions

Expected date of review	Item to be reviewed	Source
2012	Further detail expected from the European Commission on the definition of highly biodiverse grassland.	RED article 17(3)
2012	Further detail is expected from the European Commission on how to identify degraded land.	RED point 8 of part C, Annex V
2012	Review is planned on operation of the Mass Balance system and the potential of allowing other chain of custody systems.	RED article 18(2)
Early 2012	Impact of Indirect Land Use Change on greenhouse gas emissions	RED article 19(6)
2012	Impact on social sustainability. European Commission will report every two years. First report in 2012.	RED article 17(7)
31 Dec 2012	The Commission to report by 31 December 2012, and every two years thereafter, on the estimated typical and default values with particular attention to emissions from transport and processing.	RED article 19(5)

[14] Paragraph (9) of the Fuel Quality Directive (2009/30/EC)

Expected date of review	Item to be reviewed	Source
31 Dec 2012	The effectiveness of the system in place for the provision of information on sustainability criteria and the feasibility and appropriateness of other mandatory requirements related to air, soil or water protection.	RED article 18(9)
31 Dec 2012	Review on the non-binding character of additional 2 % emission reductions to be achieved from CCS and electric vehicles, and further additional 2 % emission reductions obtained from CDM credits. Review every three years, first report by 31 Dec 2012.	FQD article 19(1)
2014	Review of the Directive	RED article 23(8)

2.4 The biofuels market

2.4.1 Production of biofuels

The production of biofuels around the world is shown in Figure 4 and Figure 5 in this section. There has been an exponential growth of global biofuel production over the last decade, although production has levelled off during the more recent years.
In the EU, biofuel production has largely been focused on biodiesel. The production of biodiesel is related to the agricultural industry in countries like Germany where rapeseed production has been very dominant due to prevailing agricultural policy. Farmers could easily cultivate rapeseed and other oil crops as a seasonal non-food crop without violation of agricultural EU agreements. The EU is by far the largest producer of biodiesel in the world with 5.7 Mtoe in 2008 compared to global production of 11.2 Mtoe (50%), see Figure 4.

In the rest of the world, bio-ethanol plays a much larger role. Total global production was 40.4 Mtoe in 2008, of which only 1.5 Mtoe were produced in the EU (4%), see Figure 5.
Ethanol in the EU was mainly driven by the accesses of grain in countries like France which easily could be fermented to ethanol for fuels. Currently the production of ethanol in Europe is still grain-based, and shifting more and more towards ligno-cellulosic based ethanol.

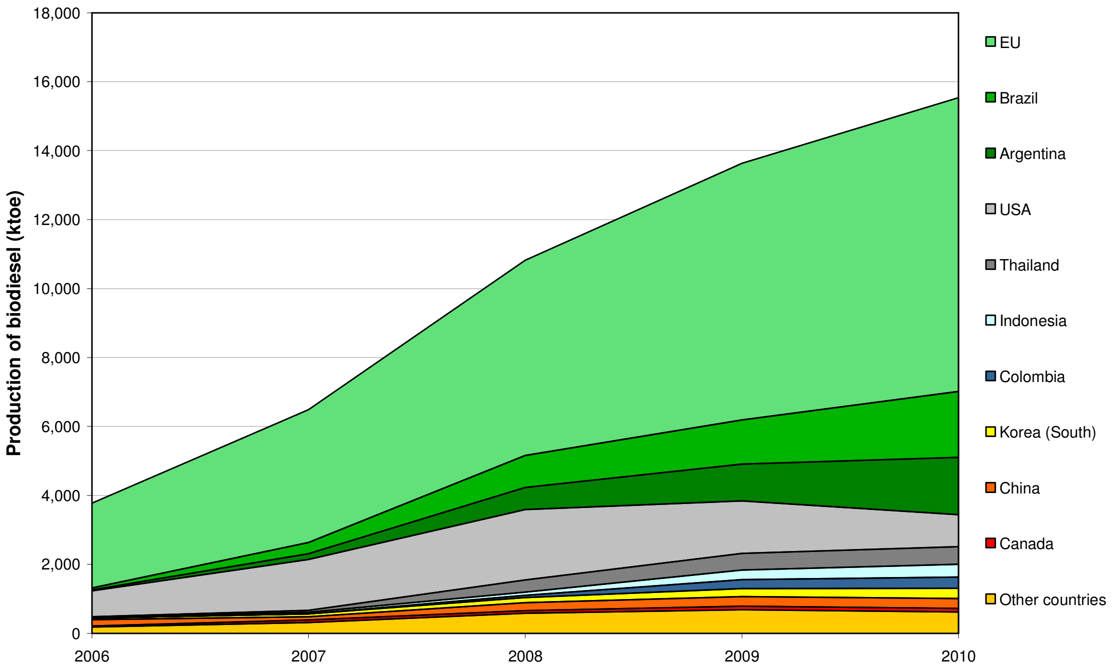

Figure 4 **Production of biodiesel around the world in 2006 – 2010**

The production is shown for the 10 countries with the largest production volume in 2008. The rest of the world is aggregated. [Source: AgraCEAS and US EIA.]

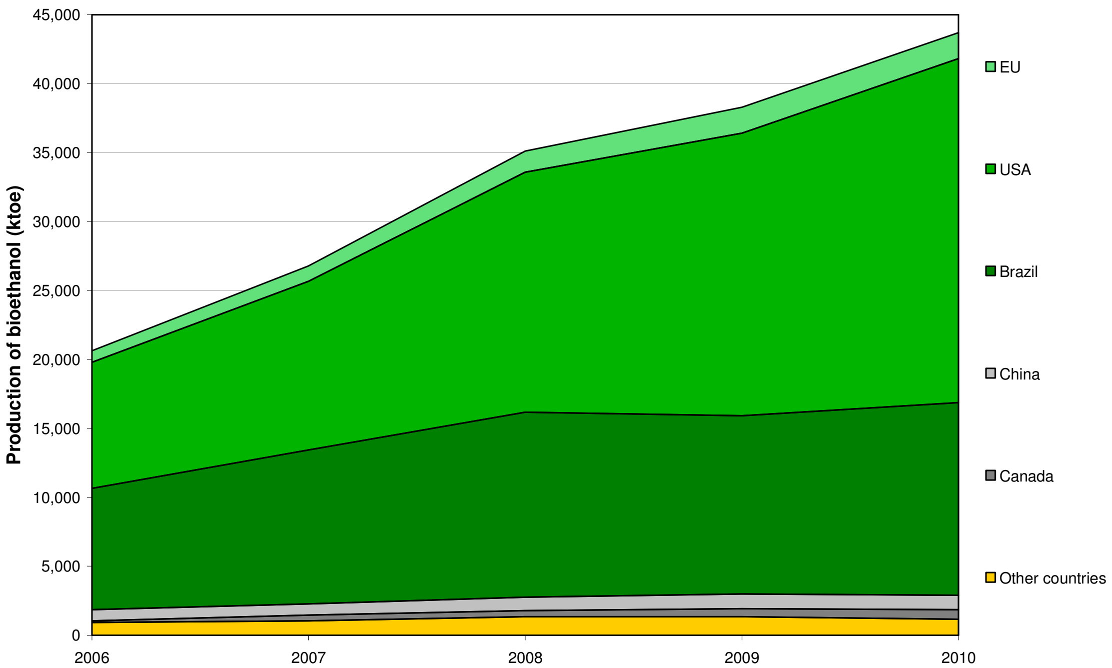

Figure 5 **Production of bio-ethanol around the world in 2006 – 2010**

The production is shown for the five countries with the largest production volume in 2008. The rest of the world is aggregated. [Source: AgraCEAS and US EIA]

For comparison, the global fuel use in domestic and international shipping is about 200 million tonne of oil[15]. This means that the current global biofuel production is about one quarter of the energy used in the global shipping sector.

As mentioned before, Germany and France are the major producers of both biodiesel and bio-ethanol in the EU. Nevertheless, the production of biofuels is located all over Europe, as can be seen in Figure 6. The newest and largest installations are found in international ports and along the major waterways, because of the access to feedstock. Especially along the North West European coasts (between Le Havre and Hamburg), there is significant concentration of biofuels production. Towards the south, there is biofuels (mainly biodiesel) production near every international port. Biofuel production in the Mediterranean is more or less limited to Spain and Italy.

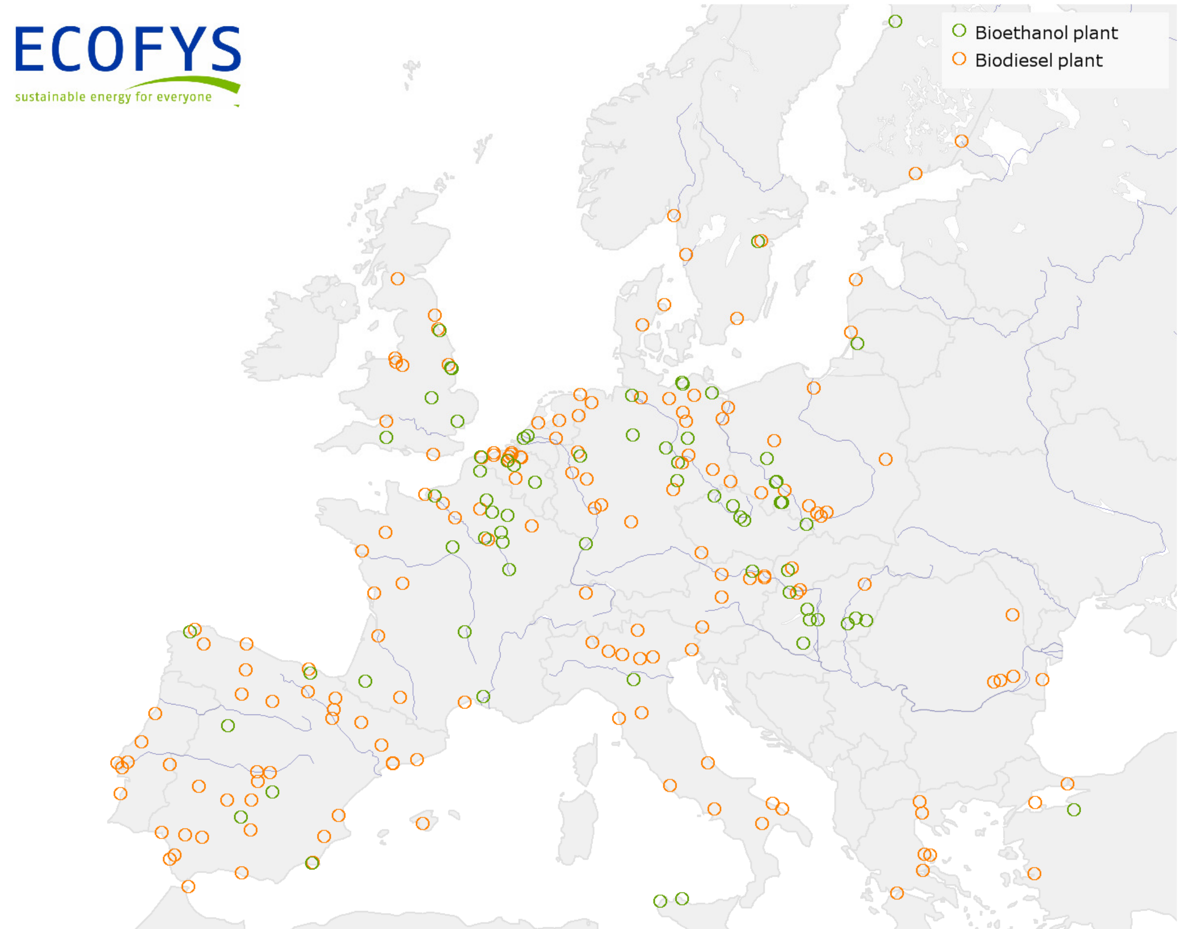

Figure 6 Production locations of biodiesel and bio-ethanol [Compiled by Ecofys]

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[15] Pew Center 2009, *Greenhouse gas emissions from aviation and marine transportation: Mitigation potential and policies*, Pew Center on Global Climate Change, Arlington VA USA

Conclusion

The major European bunkering locations at North West Europe and Gibraltar have in principle good access to biofuels, especially to biodiesel, based on current production facilities. Also for inland shipping the availability of biofuel production facilities near bunker stations and ports is considered not a bottleneck.

2.4.2 Consumption of biofuels in the EU

In Figure 7 the consumption of biofuels in road transport in the EU27 is depicted. In total, 12.2 Mtoe biofuels were consumed in 2009. This covers almost 4% of all fuels consumed in road transport, which is below the 5% interpolated trend target of the Biofuels Directive [2003/30/EC] 2005 and 2010 indicative targets of 2% and 5.75% respectively. The majority of liquid biofuels consumption resides in road transport. Biofuels use in other sectors is still virtually non-existent.

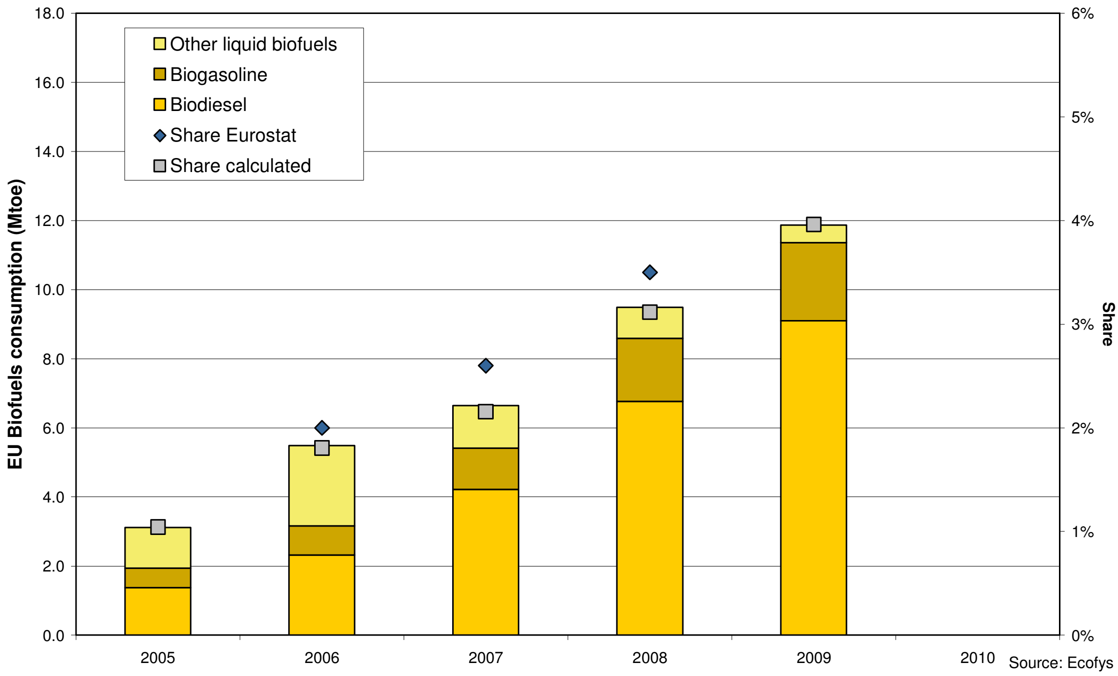

Figure 7 **Consumption of biofuels in road transport in the EU.** The bars represent the absolute volume in Mtoe (left hand scale); the squares represent the calculated share and the diamonds the share as officially reported by Eurostat.

The application of biofuels in the EU in 2020 is more or less determined by the RED and the FQD (see Section 0). The current 4% cannot directly be compared with the 10% RED target. On the one hand, the definition of the denominator in the equation has become broader (to include biofuels in road and rail transport, as well as electricity in all modes of transport) and the total energy use in (road) transport in the EU is projected to grow towards 2020. On the other hand, a significant portion of double counting biofuels is projected, and there may also be a significant fraction of renewable electricity in road transport (counting 2.5 times). As an estimate, we assume that the consumption of biofuels needs to increase with 100 – 150% between now and 2020 to about 24 to 30 Mtoe.

For comparison, a collaboration initiative between the EC and various market players[16] has formulated a modest ambition to consume 2 Mtonne biofuels in the aviation sector. If materialized, this volume of biofuels could in principle count towards the RED target.

2.4.3 Experiences with biofuels in shipping

So currently no significant consumption of biofuels in ships takes place within the EU in order to comply with the RED biofuels obligation (see above in section 2.4.2).
At this point there is also not much practical experience with the use of biofuels in the shipping sector. However, a few large companies have been testing biofuels at small and often local scale, both in freight and passenger vessels. For an overview of known R&D initiatives on biofuels testing in ship engines, see Appendix D.

A number of useful lessons can be drawn from these tests.

First of all, information is not always shared eagerly by the project owners. Most projects are executed by commercial parties such as large ship owners, sometimes in cooperation with classification bodies. Also, test results are not always representative, while these projects are all applied in existing operational ships and engines.
There are examples of testing biodiesel (FAME, fatty acid methyl esters) and an example of testing bio LNG.

The benefits of biodiesel seem to be the following, compared to fossil fuels:

- Blending can be done up to 100% biodiesel (RCCL project);
- Reduced soot emissions are noted (RCCL project);
- No negative impacts on engines are detected, although the amount of test hours were not enough to be conclusive (MAERSK/LR project);
- Higher cetane makes engines easier to start (MAERSK/ LR project)
- No bacterial formations were detected in biofuel storage tanks, during storage of more than 6 months (MAERSK/LR project).

Some issues to be considered:

- Biodiesel availability was a concern for (RCCL, MAERSK/LR);
- Biofuels require elevated attention to housekeeping and need extra training of current ship staff (MAERSK/LR).

In testing (bio) LNG, lower NO_x emissions were observed (Wärtsila) as well as CO_2 emissions reductions of 20% compared to liquid (fossil) fuels. (Wärtsila)

[16] The technical paper "2 million tons per year: A performing biofuels supply chain for EU aviation" was drafted by an editorial team from the European Commission, the paraffinic biofuel producers and the aviation sector. The paper explicitly does not reflect the view of the EC, or the contribution.

Conclusion

There is no large experience of biofuels use in ship engines. Known R&D projects that investigate the possibilities are all private company initiatives, and applied in operational ships.

2.4.4 Other developments in the EU biofuels market

As of 2013 the aviation sector will be part of the European Emission Trading Scheme (ETS), allocating carbon caps to different industries based on best practise benchmarks. Also costs for kerosene are getting higher, forcing the sector to look for alternatives to stay in business.
The aviation sector currently is in an exploration phase for alternative fuels, in which they tap upon the different biofuel types, quality of the biofuels and possible introduction strategies and cost-economic impacts of biofuels for aviation. To meet carbon reduction targets and ambitions, the aviation industry does not have many other alternatives than to switch to carbon neutral fuels (aside to fuel efficiency).
Figure 8 below shows the possible routes to make our energy demand sustainable by facing out fossil fuels for renewables. It clearly points out that biofuels are crucial to replace mainly heavy duty road, sea and air traffic.

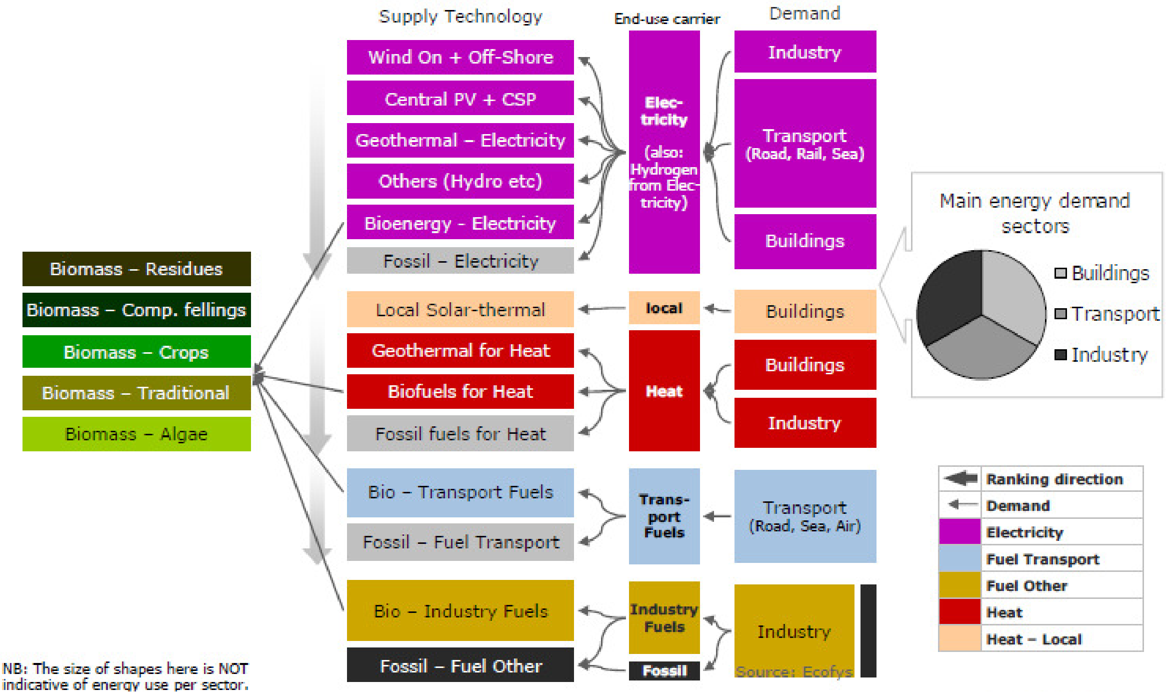

Figure 8 **Possible replacement of our energy demand by renewable sources**
[Source: The Energy Report, Ecofys/WWF, 2011]

At this stage several test flights and R&D trials have started. Aviation companies are seeking collaborations with the more experienced biofuel market players (biofuel producers, oil and gas companies, R&D institutes). One clear trend of recent developments shows that all aviation companies wish to step in on highest technological level possible, so at least "second generation" biofuels from ligno cellulosic bioresources, but even better would be the promise of algae biofuels. They aim for higher quality standards than the current road biofuels in order to comply with current HSSE frameworks.

Conclusion

The aviation sector can be compared with the marine transportation sector, in the aspects that both do not have many alternatives to switch to more carbon neutral operations. Also, both are operating in a global market with high competitive pressure and rising fuel prices.

Difference between the two transportation modes is that aviation uses a high quality, very standardized fuel and shipping is used to low quality residual fuels with little standardization and lack of shared responsibilities along the fuel supply chain (see section 3.2).

2.4.5 Production capacity of biofuels in the EU

The currently installed production capacity is not fully utilized. Table 2 compares installed capacity and actual production to derive an apparent level of capacity utilisation. This data suggests that utilisation of the bio-ethanol capacity amounted to around 55-65% during the years 2005-2009. As installed capacity has grown at the same pace as production and consumption, capacity utilisation has remained relatively stable.

Table 2 Production of biofuels in the EU [Eurostat] compared to the production capacity [EBB 2011, ePURE 2010] (both in Mtoe).

Year	Capacity (Mtoe)	Actual production (Mtoe)	Capacity utilisation
		Biodiesel	
2005	3.76	1.63	43%
2006	5.40	2.46	46%
2007	9.16	3.85	42%
2008	14.24	5.67	40%
2009	18.61	7.44	40%
		Bio-ethanol	
2005	0.92	0.55	60%
2006	1.43	0.84	59%
2007	1.98	1.10	56%
2008	2.75	1.54	56%
2009	2.92	1.87	64%

In general the apparent overcapacity indicates that while sufficient conversion capacity is available for the coming years, instead, use and consumption are lagging behind. Similarly, the biodiesel production capacity has grown faster than the actual production and only 40-46% of production capacity was apparently utilised in the same period.

The overcapacity also indicates that production capacity will not stop the increased import of biofuels to the EU market. Rather the bottleneck may be in the feedstock supply, or the price attractiveness of the European biofuel products. On the other hand, the apparent overcapacity includes a technology lock-in risk, since it may be economically more attractive to use the existing idle capacity, then to invest in new technologies.

Globally, the 2009 marine bunker consumption was 186 Mtoe compared with 51.5 Mtoe of biofuels consumed in road transport that same year[17]. Introducing a 5% biofuel blend across all shipping fuels would mean that an extra 9.3 Mtoe of biofuels would need to be produced, which is less than the EU overcapacity of biodiesel alone[18].

Conclusion

Current availability of biofuels is limited to traditional biodiesel and bio-ethanol from agricultural crops. This could contain a potential threat of lock-in of these types of biofuels and technologies for introduction into ships, while possibly other biofuel types could be more interesting.

2.4.6 International trade

The large and fast increasing demand for biofuels in Europe impacts the international trade, in which shipping plays a major role. In 2008, an attractive combination of incentives in the US for blending biodiesel and in the EU for the application of biodiesel let to a large indirect trade of Argentinean biodiesel via the US to the EU (see Figure 9, top). Both the US and the EU have counteracted these effects and trade normalized from 2009 onwards. Nevertheless, the rapidly unfolding international market leads to strange effects and disputes from time to time.

[17] IEA 2011, Key World Energy Statistics, OECD, Paris

[18] With biodiesel overcapacity in 2009 being calculated to be 11.16 Mtoe. Furthermore, a 5% biofuel blend in all international bunker fuels would represent 18% of the 2009 global biofuel supply.

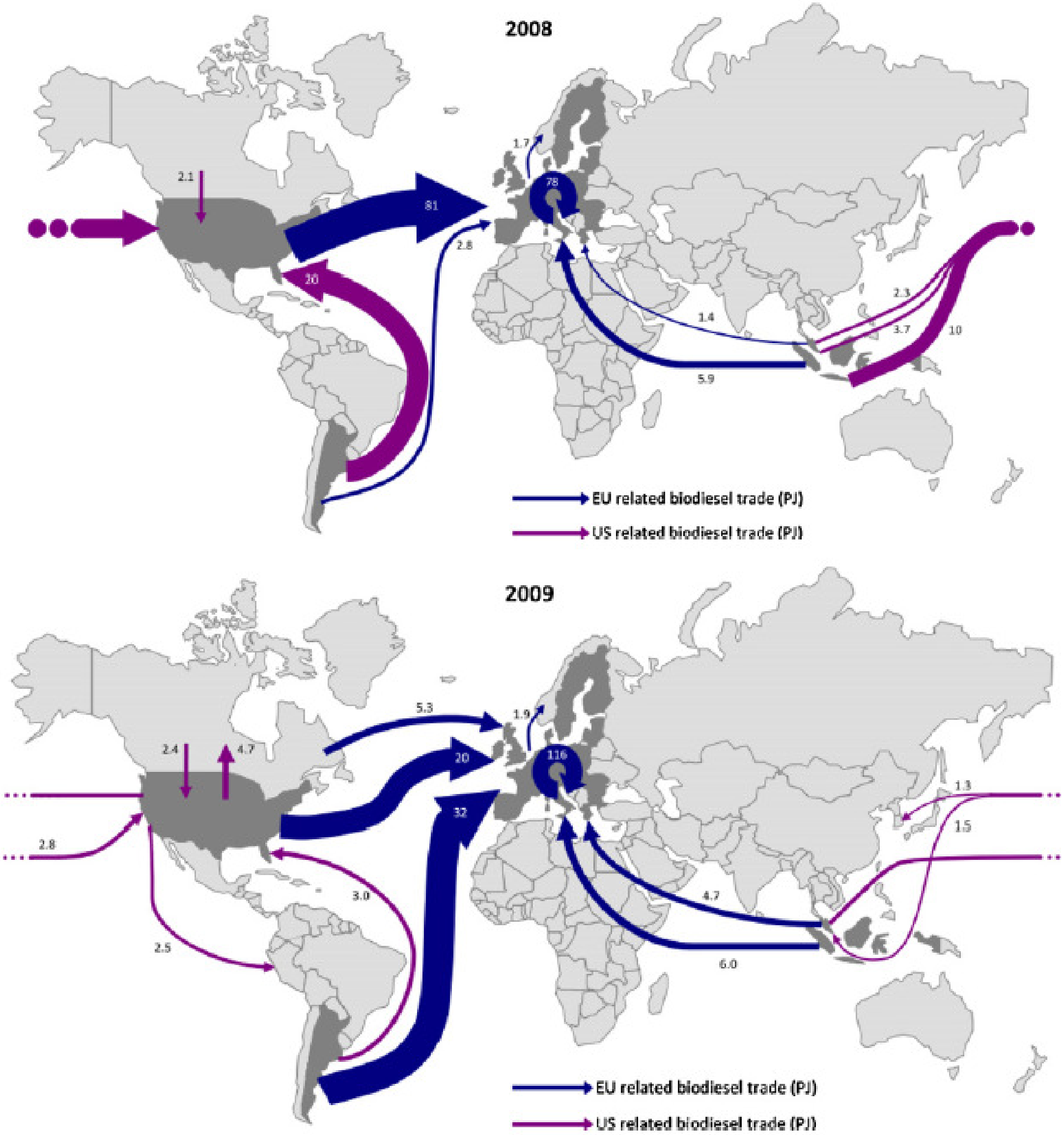

Figure 9 **Global biodiesel trade streams in 2008 (top) and 2009 (bottom) [compiled by Ecofys]**

Conclusion

The availability of biofuels in general (aside to their distribution) is probably not a bottleneck for the introduction of biofuels in the shipping sector. Current underused production facilities in Europe show potential for taking up a possible demand by the shipping sector. The aviation sector is exploring options and could in potential take up a large amount of biofuels, but are aiming on higher quality fuels.

2.5 Sustainability of biofuels

Bio energy will play an important role in developing a decarbonised economy next to other forms of renewable energy and energy efficiency. This is due to the fact that for several sectors with a large and growing energy demand few sustainable alternatives exist.

This includes aviation, shipping, road freight transport and industries requiring high temperature heating (see also section 2.4.3).
Although the bio energy potential seems huge worldwide[19], large scale bio energy production has raised concerns about sustainability. The main concerns relate to greenhouse gas emissions, carbon and biodiversity loss from land use changes, social issues, competition with food and indirect effects.

2.5.1 Direct and indirect effects of biofuels

Bio energy feedstock demand and the associated land requirements can have direct and indirect effects. One of the main direct effects is direct land-use change (LUC). A direct LUC occurs when new areas that were previously uncultivated (e.g. forest areas) are taken into production to produce the additional bio energy feedstock. This can have both positive and negative consequences on biodiversity, carbon stocks and livelihoods.

Direct LUC effects and other direct effects of crop production can generally be measured and attributed to the party that caused them. These properties make direct LUC relatively easy to control. The EU Renewable Energy Directive (RED) and voluntary certification schemes such as the Roundtable on Sustainable Biofuels (RSB) already include criteria for the prevention of unwanted direct LUC for biofuel and bioliquid feedstock production.

The indirect effect that is currently dominating the debate on the sustainability of biofuels is indirect land-use change (ILUC). ILUC can occur when existing plantations or managed lands such as grazing land (see circle B in Figure 10 below) are used to supply the feedstock for additional biofuel production. This displaces the previous productive function of the land (e.g. food production). This displacement can cause an expansion of the land use for biomass production to new areas (e.g. to forest land or to grassland areas, see circles B´and B’’ in Figure 10) if the previous users of the feedstock (e.g. food and feed markets) do not reduce their feedstock demand and any demand-induced yield increases are insufficient to meet the additional demand. It should be noted that such indirect effects are not directly caused by unsustainable practices of biofuel (feedstock) producers but by unsustainable practices by parties producing for other sectors (e.g. food, feed or fibre).

[19] Scenarios indicate a worlwide potential for bio energy up to 1100 EJ annually – compared a current global energy consumption of around 300 EJ.

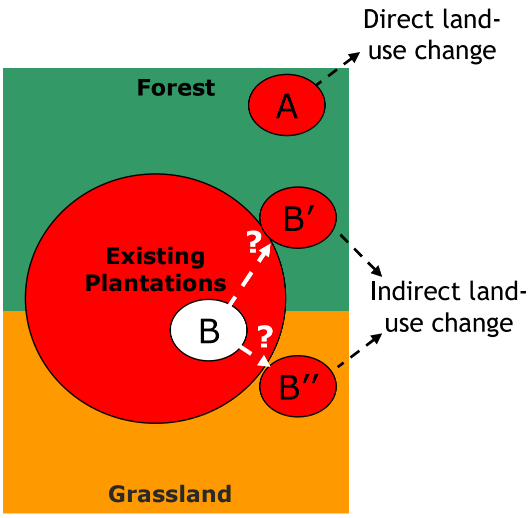

Figure 10 Illustration of the displacement mechanisms that may cause indirect land-use change. [derived from Dehue 2006]

2.5.2 European sustainability requirements

The EU introduced in 2009 a comprehensive and binding sustainability scheme with a number of criteria for biofuels and bioliquids. Under the Renewable Energy Directive (RED, article 17.2 – 17.5) and the Fuel Quality Directive (FQD), parties supplying biofuels to the transport sector have to be able to demonstrate that their products meet mandatory sustainability criteria to be eligible for support from national governments and to count towards renewable energy targets and obligations.

The mandatory sustainability requirements fall within 4 categories, with additional requirements for biofuels produced from feedstocks sourced from within the EU. The four sustainability criteria relate to:

- Greenhouse gas (GHG) emission reductions;
- Biodiversity;
- Carbon Stocks;
- Peatland.

2.5.3 Greenhouse gas reduction (RED article 17.2)

Biofuels must achieve a minimum life cycle GHG emission reduction compared to fossil fuels. This minimum reduction is increased until 2018, and must be:

- 35% from the start (2011);
- 50% from 2017;
- 60% from 2018 for installations of which production has started from 1 January 2017 onwards.

The RED sets out a mandatory methodology to ensure uniform calculation of the GHG emission reduction, as well as predefined default values for some common biofuel types (e.g. rapeseed biodiesel)[20], see Figure 11.

[20] The methodology and default values are given in:

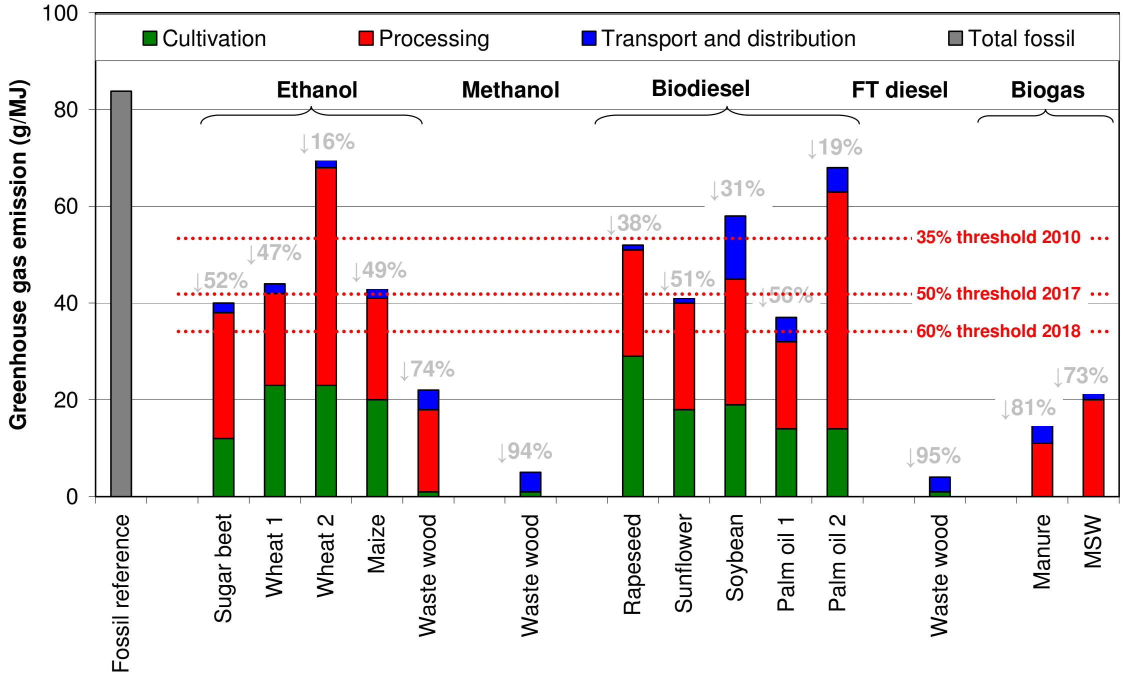

Figure 11 Default GHG emission values as given in the EU RED

- Wheat 1: assuming lignite is used as main source for power
- Wheat 2: assuming natural gas is used as main fuel for power
- Palm oil 1: assuming Palm Oil Mill Effluent (POME) is recovered for biogas production
- Palm oil 2: assuming POME is not recovered.

The RED GHG default values as shown in Figure 11 are split out to emissions resulting from feedstock production, those from conversion to the final biofuel and emissions from (international) transport. In most supply chains, emissions from international transport are small. Emissions in feedstock production (cultivation) are caused by both energy use (machinery) and fertilizer use (especially N_2O emissions from fertilizer production and from fertilizer application).

More detail into the greenhouse gas performance of selected biofuel supply chains please see section 4.3.

In addition to the RED, the European Commission has published a decision[21] with guidelines for the calculation of land carbon stocks, including annotated examples of GHG calculations.

-Annex V of the Renewable Energy Directive, and

-Annex II of the communication from the Commission on the practical implementation of the EU biofuels and bioliquids sustainability scheme and on counting rules for biofuels (2010/C 160/02).

[21] Commission Decision of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC (notified under document C(2010) 3751).

2.5.4 Grandfathering

If any installation in the supply chain was already operational on 23 January 2008, those biofuels from such a supply chain do not have to meet the 35% GHG saving threshold until 1 April 2013. This temporary exemption of compliance is called grandfathering. As a result of this grandfathering, only part of all biofuels placed on the EU market will be required to meet GHG threshold before April 2013 (see Table 2 for the installed production conversion capacity of 2008 and before).

2.5.5 Biodiversity (RED article 17.3)

In order to minimise the risks for biodiversity, certain areas are excluded from the production of raw materials for biofuels. The reference date for determining the status of the land is January 2008.

Categories of land that do *not* qualify for biofuels production are:

- Primary forest and other wooded land;
- Nature protection areas;
    - Areas designated by law or by the relevant competent authority for nature protection purposes;
    - Areas recognized by the Commission for the protection of rare, threatened or endangered ecosystems or species[22];
- Natural and non-natural highly biodiverse grasslands.

There are some exceptions to these rules. The European Commission in the coming years will further establish the definitions for various land types. Note that the biodiversity criterion will be relevant only for plantations established in or after January 2008, which represents a minority of the total feedstock used today. However, in every case the status of the land in January 2008 will need to be known and demonstrated.

2.5.6 Carbon stocks (RED article 17.4)

In order to protect carbon stocks, certain areas are excluded from the production of raw materials biofuels. As for the protection of biodiversity, the reference date for measuring this value is January 2008.
Note that *all* GHG effects of any land use change after 2007 must be included in the GHG calculation. Land use change occurs, for example, when forest land is converted to crop land. Changing from one crop to another is not considered a land use change.

[22] The Commission may recognise areas for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations, such as the International Union for the Conservation of Nature (IUCN). This requires recognition of the Commission before such areas are excluded and differs from the previous type of areas that are excluded as soon as they are designated by (national) law or the relevant competent authorities as nature protection areas.

As for the biodiversity criterion, the carbon criterion will be relevant only for plantations established in or after January 2008, which represents a minority of the total feedstock used today. Nevertheless, in every case the status of the land in January 2008 will need to be known.

2.5.7 EU feedstock specific requirements

For feedstocks sourced from within the European Union, additional specific requirements exist.

- Use of default GHG values (based on NUTS-2[23] Regions). For feedstocks sourced from territories that fall within the European Union, economic operators will have to know the NUTS 2 region their feedstock comes from to be able to use default GHG values. It is the responsibility of Member States to submit lists of such regions and their typical GHG emissions from cultivation to the Commission.
- Cross Compliance. Biofuel feedstocks grown in the European Community must be cultivated according to the EC's "Cross Compliance" requirements[24]. This should not mean any additional requirements for Member States or economic operators, as Member States are expected to rely on existing control systems. If a Member State identifies a breach, this will need to be taken into account though.

2.5.8 Non-mandatory sustainability issues

In addition to the mandatory sustainability requirements, the Commission and Member States will need to monitor other sustainability issues. This includes reporting by Member States on soil, air and water protection, as well as labour and land use rights and the availability of foodstuff and food prices. Member States might request information from economic operators for this purpose. Little further information is currently available, although the aspects that Member States are required to report on will be the subject of an EC Decision which is currently being discussed as part of the Comitology process. By the end of 2012, the Commission will assess whether additional mandatory sustainability requirements for soil, air or water protection are needed.

2.5.9 Impacts of Indirect Land Use Change on greenhouse gas emissions

Displacement of agricultural production due to biofuels expansion may cause indirect land use change (ILUC). See section 2.5 for a description of these issues. ILUC can affect human well-being and the environment. This is recognised in the RED. The European Commission will assess the impacts of ILUC by the end of 2011 and will decide whether additional policy measures are warranted. This could lead to additional or more stringent sustainability requirements for biofuels in the EU.

[23] The Nomenclature of Territorial Units for Statistics (NUTS) is a geocode standard for referencing the subdivisions of EU countries for statistical purposes (e.g for use in Eurostat). NUTS-2 usually corresponds to a region or province within a state.

[24] part A and point 9 of Annex II to Council Regulation (EC) No 73/2009 of 19 January 2009

Conclusion

While the European biofuel market is a mandatory market based on the RED, sustainability of biofuels is of strong importance and affects the production of biofuels and with that the market.

Policy and frameworks for mandatory and additional sustainability criteria are still under development, especially in their implementation schemes which will depend per certification scheme and per Member State. The EC is working on harmonizing these certification schemes.

3 The marine fuel market

3.1 Introduction

To provide a clearer picture on the use of biofuels in the shipping sector, its limitations and future opportunities, several aspects of the marine fuels market are described in this chapter. Figure 12 (next page) shows a schematic overview of most common marine fossil fuel distribution and supply chain.

3.1.1 Fuel production

Marine fuels are produced from crude oil at refineries or in case of LNG based on natural gas extraction. There are different types of marine fuel. A distinction is made in marine fuels between residual (heavy) fuels and the higher quality distillate fuels. For heavy fuels with low viscosity, the required viscosity is achieved by heating the fuel. For distillate fuels, the fuel at ambient temperature can normally have a viscosity within the specified limits. Also, fuel cleaning differs for the different types of marine fuels.

3.1.2 Wall Storage and Transport

Through road, inland vessels or piping systems the fuel is transported to the wall bunker station in port areas. Here it is stored until further use. In case of larger ships in need of marine fuel a bunker vessel will load the marine fuel and transport it to the customer. Otherwise, the marine fuel is directly pumped to the ship in the port area.

3.1.3 On Board Storage

Depending on the type of fuel and engine use, the fuel is heated through heat exchangers to achieve right environment for (long term) on board storage.

3.1.4 Fuel Cleaning

Fuel cleaning on board of the vessel exists of two stages: the clarifier and the purifier. Fuel cleaning will depend on the type of marine fuel that is used.
If needed, the cleaned and purified fuel is heated through a heat exchanger to achieve right specifications for the engine.

3.1.5 Engine

The purified and clean fuel is pumped to high pressure in order to be injected into the engine. Depending on the engine type, the pressurized and cleaned fuel is injected into the engine.

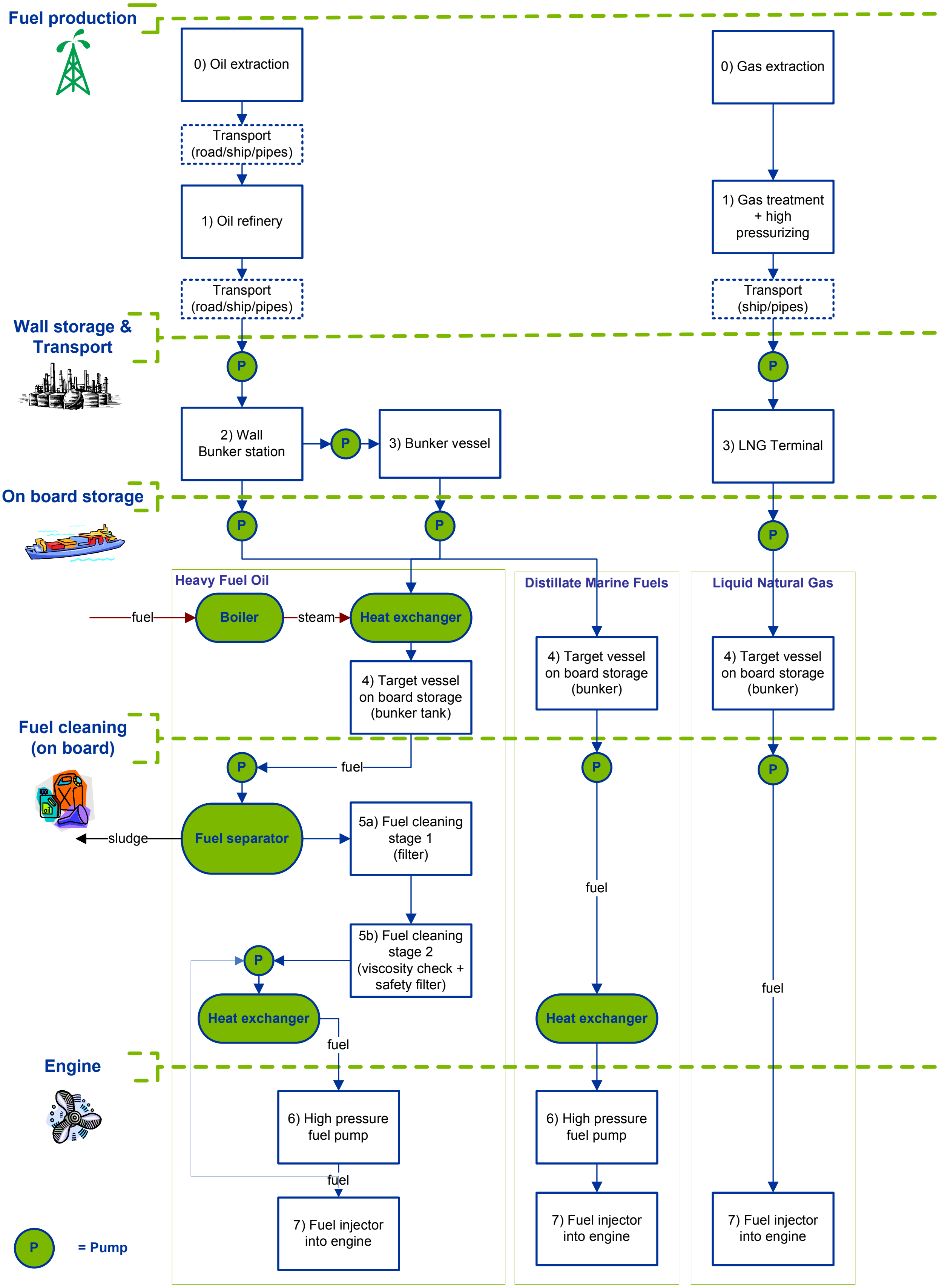

Figure 12 Fuel supply chain for ships

3.2 Bunkering and blending

3.2.1 Current best practices[25]

Bunker fuels are available in every port area. Availability depends on the geographical location (near larger refineries) and crude oil storage. Larger refinery facilities are limited in the world. In Europe for example the larger refinery and crude oil storage only takes place in Rotterdam and Gibraltar ports. Supply or refined fuels to bunker stations in other ports in Europe is quite stable and frequent, enabling ships to tank every where. In poorer areas such as African countries the availability can be much less reliable, forcing ships to await new supplies. Most bunker fuel deliveries goes through the bunker vessel.

Once the operator of the ship (the buyer) has decided on his port, quantity and timing, he will need to have some essential details which will be required by the seller, agent[26] and ship in order to arrange an efficient delivery.
Contracts for fuel delivery are mostly based on spot market: short term requests and deliveries. Special brokers can facilitate a fuel request (often only a couple of days before attending the port area) for a ship owner and come up with a range of suppliers with their prices. Quality depends on the supplier (reputation), and the frequency of refined oil being delivered to the supplier. There will be variations per bulk delivery of refined oil, while bunker fuels are the residual fuels from the refinery process.
Some larger ship owners will have the size, routine and fixed schedules in their ship logistics to set contracts for longer term and with set indexation. Or it could be the case that security of fuel supply, timely delivery and technical services may be slightly more important than price for a ship owner to set a long term contract. The fuel supplier will supply a bunker delivery note to the purchaser containing generic specification of the delivered fuel. However, currently, all responsibilities concerning quality and quantity of bunker fuels lie with the purchaser (so ship owner). It is common practice that the ship owner will take samples themselves to check upon fuel specifications (differing per location of bunker fuel delivery and track record of supplier in fuel quality) and to make sure they comply with marine legislation (see also section 3.5).

Bunkering for large ocean going ships takes typically up to 10 hours (500-700 ton/hour). The larger bunker ships carry around 10 to 14 ktonnes of fuel. This means that very large quantities of whatever fuel the buyer has decided to buy need to be available continuously and at irregular times.

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[25] Based on personal communications and interviews with bunkering parties in the market, classification body and the International Bunkering Industry Association (IBIA) between September and December 2011, workshop ECSA with ship owner assocations on November 22nd 2011, and [Draffin 2010].

[26] The agent, also called 'water clerk', or 'boarding clerk' is the man on the ground of the port who acts on behalf of the ship owner/operator in dealing with all of the companies and individuals who will interact with the vessel in port. A few owners may have their own office in the port but most will rely on a third party, resident in the port, whose business is that of a ships agent. In recent years, many owners have come to rely on the concept of `hub agents', where the owner's contact and direct business relationship is with an agency group. The group in turn instruct local `sub agents' in ports where the hub agent does not have an office or staff of his own. [Griffin, 2010]

Also, fuelling up a large ship will be a large money transaction (up to 2 to 3 million dollars per fuelling). Bunker fuel prices differ per port and are generally lowest when close to refineries. Reference prices for marine fuels can be found through Platts market scans.
Marine fuels in general are free from excise. On international going ships (the majority of the ship activities) no excises are in place. If a ship is active in-land only excises could be charged depending on the country. This will be done by port authorities.

Large container ships typically consume up to 200 tonnes of bunker fuel a day. With their on board fuel storage up to 14ktonnes, the fuels could be stored up to 3 months, spread over various tanks. Most ships are thus able to sail to China and back from Rotterdam without refuelling.

Ships receiving bunkers have multiple storage tanks on board (bunker tanks) as well as treatment tanks (settling tanks and service tanks) and waste oil tanks (sludge tanks and drain tanks). The number and size of these tanks are a measure of how flexible the ship is with regard to loading and storing fuel. Bunker tanks are secondary in importance to cargo space and as a consequence are fitted into the ship wherever the naval architect can put them. This results in tanks of unusual shape and often unusual locations. On average and depending on ship type around 8 fuel tanks are on board.
The storage tanks of ships for heavy fuel oils need heating, so they are fitted with heating coils (steam or thermal oil) although some smaller ships may have electrical heating. The heating will be sufficient to maintain the oil at 10°C above its pour point (about 40°C). The settling and service tanks will also have heating systems and will store the oil at higher temperatures between 60°C and 80°C.

3.2.2 Possible blending of biofuels

Fuel blending could occur at the refinery, at the storage (into a pre-blend), on the bunker ship, and on board the receiving ship. At least some (fossil fuel) blending is currently done on the bunker ship, where additives are added to the standard marine fuels (see section 3.4 for more information on the marine fuels). Bunker tanks get emptied and cleaned before a next bunker fuel is loaded.

Blending of biofuels with marine fuels already takes place on board of several ships (although in small amounts and often not registered, see section 2.4.3 for more details on these applied R&D projects). An advantage of on board blending is that the biofuels could be stored separately, maintaining better fuel properties. This way, blending the biofuel from the separate tank with conventional marine fuels in the main engine could enable temporary sulphur emissions reductions in certain restrained areas (the so-called Emission Control Area or ECA’s, see section 3.5.1), while biofuels do not contain sulphur (see section 4.3.3).
However, blending on board the receiving ship is not seen as an attractive mid term option. The handling of a separate biofuel tank asks additional training and skills of the crew. Also, the ship owner has to have fuel samples from every storage tank, and must submit these samples to the local authorities if it sails in an area with lower sulphur emission restraints on a certain fuel tank. This is due to the historic poor quality of fuels used for shipping. This will make the benefit of the low/non sulphur content of biofuels in blends with marine fuels unable, while no blended tank of which samples have been taken and audited are in place.

Also, the ISO 8217 industrial standard reduces the blending of biofuels to a very small amount (see for more information section 3.5.2). This standard however is only an industry standard and does not obliged the ship owners to not blend biofuels.

While biofuels are not necessary, most likely even, not produced by the same refinery companies in fossil fuels, blending at the refinery level also does not make sense.

It seems more logical to blend marine fuels with biofuels on the bunker storage or bunker ship level. In the Rotterdam area for example a growing interrelationship between the traditional bunker parties and biofuels is seen.
From the perspective of the ship-owner, it would also be preferred to bunker pre-blended fuels, so as to simplify the bunkering process, and reduce the need for dedicated biofuel-tanks on-board, which would lead to extra management costs, and possibly new hardware costs.
Blending at bunker station still enables the benefit of low infrastructural changes, as long as blending can be done as close to the refinery as possible. This way the fuel infrastructure does not change, and the blended biofuels can be used in all ships, without the introduction of an alternative fuel infrastructure or dedicated engines.

Exceptions to this are (biogenic) natural gas, which needs to be stored in dedicated storage tanks on-board, to be blended at injection.

Higher standards and blend percentages for biofuels can result in higher CO_2 savings. However the possibilities are limited due to expected problems with conventional fuel systems. Higher percentage blends can cause problems with the materials used and lubrication of moving parts (see also section 4.2). This requires a dedicated refueling infrastructure and dedicated engines.

For biodiesel, blends of B10, B30 and B100 are common. Because the energy content of 100% biodiesel (B100) is 10% lower than conventional diesel on a liter basis, calculation of the CO_2 savings needs to be done on an energy content basis.

In flexifuel Otto engines (passenger vehicles) higher blends of biofuels are allowed, up to 95% for instance when ethanol is used. The engine efficiency even increases a little when using for instance E85. Therefore the CO_2 savings are a little higher than average on energy content. See section 3.3 for more information on ship engines.

Conclusion

Many parties are involved in the bunkering process, with large amount of bunker parties (in Rotterdam only already 80 bunker fuel suppliers) and many small ship owners (there are only a few large ship owners).

Bunkerers currently do not take sufficient responsibility for the quality of the fuels delivered, which leads to the need for taking samples during bunkering. Testing of the samples will need to be adapted according to the new needs and issues that could be brought by the introduction of biofuels.

At this point blending biofuels would be best at the bunker level.

3.3 Ship types and engines

As a starting point, (large) ocean-going ships can be divided in commercial vessels, recreational or pleasure craft and military vessels. Since this study is limited to commercial vessels, military vessels and recreational or pleasure craft will therefore not be considered.

The term *commercial vessel* is used for all vessels employed in commercial trade or carrying passengers for a commercial rate. A related term is *merchant vessel*, used commonly to indicate all ships transporting cargo or passengers. Merchant ships are, for classification purposes, often divided in the following categories.

- Cargo ships; this category comprises general, ro-ro and refrigerated cargo ships, bulk carriers and vehicle carriers, which collectively represent the great majority of commercial shipping.
- Tankers; this category includes all types of tankers. The vast majority operating in and around EU waters are now double hulled, in line with the international requirement to phase out single hulled tankers.
- Container ships; ship designed for transporting 20 foot containers. The ships grow in size constantly, with a latest version in order in 2010 of 18.000 Twenty-Foot Equivalent Unit (TEU) ship. With such a ship a great variety of engine types is used as for main propulsion but also for auxiliary purposes.
- Passenger ships; this category includes ferries and cruise ships and as with the previous category on this type of ship the variety of engines is also in great abundance present. For cruise ships the energy demand for the passengers on board is larger than for propulsion.
- Fishing ships; this category of ships has their technical installation and thus their engines often from a variety that allows large cargo space and low space for example storage of other bunkers such as lubricants.
- Other type of ships; this residual category covers all of the other types of ship that are engaged in commercial work in and around EU waters, including tugs, offshore support vessels, mobile oil platforms/drill ships, anchor handlers, barges, research vessels, heavy lift ships and dredgers.

3.3.1 Engine types

Distinction is made between Diesel cycle engines and gas-fired engines. Compression-ignition is the dominant technology for marine engines (Diesel cycle) and auxiliary systems (only few ships have turbines). There are three main engine types in this category that can be determined by revolution range or rotational speed, and are used in the mentioned ship types.

Moreover, a distinction is made between 4-stroke and 2-stroke engines. Whereas 2-stroke engines are used less and less for road vehicles, they are considered state-of-the-art for merchant ships with more than 25 MW propulsion power. This is a result of the relatively high efficiencies of these engines, up to nearly 50%, and the possibility to use low-cost residual fuel oil. The efficiency is besides engine type also dependant on the age of the engine, this is presented in Table 3 below.

Table 3 Typical values of specific fuel oil consumption (SFOC) in g/kW•h [GHG study IMO, 2009]

Engine year of build	2-stroke low-speed	4-stroke medium-/highspeed (> 5000 kW)	4-stroke medium-/highspeed (1000–5000 kW)	4-stroke medium-/highspeed (< 1000 kW)
1970–1983	180–200	190–210	200–230	210–250
1984–2000	170–180	180–195	180–200	200–240
2001–2007	165–175	175–185	180–200	190–230

Low speed engines almost exclusively operate on the 2-stroke principle. Contrary to 2-stroke petrol engines, the 2-stroke diesel engine does not mix fuel with oil for its lubrication. Moreover, 2-stroke petrol engines discharge large amounts of the air/fuel/oil-mixture through the exhaust, while their diesel-fuelled counterparts do not. Low speed 2-stroke diesel engines are used as large, high power prime movers and range between ~ 60 to 200 rates per minute. They are commonly fuelled by HFO, IFO, MDO/MGO (see section 3.4 for the terminology and additional information on these marine fuels).

4-stroke engines are commonly seen in applications that demand a compact power plant. The 2-stroke engines are larger in size and of considerable height. This height becomes a problem on many coastal ships, such as ferries. 4-stroke engines have a power range up to roughly 25 MW. Most high en medium speed engines operate on the 4-stroke principle. Medium speed engines range from ~ 200 to 1,000 rates per minute, high speed engines rotate above 1,000 rates per minute. They are fueled by IFO, MDO/MGO, HFO (see section 3.4 for the terminology and additional information on these marine fuels).

Most major manufacturers of medium speed engines make natural gas-fuelled versions of their diesel engines, which in fact operate on the Otto cycle, and require spark ignition.

Marine engines have a typical proven lifespan, ranging from 10 years (for high speed) to over 20 years for the low speed engines. The robust technology even allows them to stay operational up to 50 years, if maintained properly.

Diesel engine manufacturers normally set a range of viscosities over which the engine can be operated. These include a minimum and a maximum viscosity that apply to the fuel at the fuel injection pumps in running condition (see section 3.1 and Figure 12).

Table 4 below shows the different main engine types per revolutions and their presence in the identified ship types, discussed in section 3.3.

Table 4 Engine types per ship type

Ship type	On board engine type by revolutions		
	Low speed	Medium speed	High speed
Cargo ships	X	X	X
Tankers	X	X	X
Container ships	X	X	X
Passenger ships	X	X	X
Fishing ships		X	X
Other type of ships		X	X

A more extensive overview of the different ship types and their engines is presented in Appendix C.

3.3.2 Compatibility of biofuels in marine engines

In an Otto engine the fuel-air mixture will not ignite until a spark is created. The compression ratio is much lower (1:11 versus 1:20) compared to compression ignition (Diesel). In a Diesel engine the air is compressed so much that it heats up and can ignite the fuel. Different fuels with different auto-ignition temperatures require different engine types. When a Diesel engine needs to be converted to Otto this requires major adjustments, large parts of the engine need to be rebuild. Different fuels in the same type of engine need only relatively minor adjustments in terms of fuel lines, filters and injectors.

The following fuels work in Diesel engines:

- Diesel;
- Biodiesel, vegetable oil, DME (Dimethyl ether), GTL (gas-to-liquid), BTL (biomass-to-liquid), FAME (Fatty Acid Methyl Ester) and HVO (Hydrotreated Vegetable Oil).

The following fuels work in Otto engines:

- Gasoline, Ethanol, methanol, natural gas;
- Biogas (both in compressed (CNG) and in liquid form (LNG)) and hydrogen.

Engine manufacturers play an important role in the introduction of biofuels, as they provide the guarantee for the engines to run on fuels with specific properties.
MAN B&W Diesel along with Wärtsilä, are engine manufacturers with experience in biofuels for stationary power generation as well as being a significant engine supplier.

MAN confirms the viability of using biofuels in their engines. According to MANs own Dieselfacts magazine:

> „All MAN Diesel medium-speed engines which are basically designed for Heavy Fuel Oils are ideal for reliable and efficient use of liquid biological fuels.”[27]

In the early 1990's Wärtsilä started to investigate whether biofuels could be compatible with their engines. The first test was done with wood-based pyrolysis oil and showed that acidity was critical to the fuel system.

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[27] ZERO 2007 quoting MAN B&W Diesel 2007

The acidity of the fuel requires the need for acid resistant material and biofuels also require careful temperature control. These technological modifications are not technically advanced operations and biofuels can thus be used in most ship engines.[28]

Throughout the 1990’s, Wärtsilä ran a number of tests and in 1995 rapeseed oil was labelled engine compatible, stating that a minimum of alterations to the engine had to be done. The first commercial vegetable oil fuelled power plant with a Wärtsilä engine was installed in Germany in 2003. Since then, a number of power plants with Wärtsila engines have been installed and operate on biofuels.
Altogether, power plants in operation or under construction with Wärtsila engines have a combined installed capacity of 680 MW_e. Records of these power plants have been good, time between overhauls being about the same as for HFO engines.[29]

3.3.3 Retrofitting

MAN B&W Diesel states that the retrofitting of existing engines for operation on liquid biofuels is possible. For power generating plants the conversion cost is relatively small in comparison with other costs. Based on experience gained from power generating plants, MAN B&W Diesel claims that an engine is consuming its own cost in heavy fuel oil in 3-6 months. This shows that adjustments to the engine or even to order a new engine might not be that big a cost compared to fuel cost.

MAN B&W Diesel gives a rough estimate that an existing ship engine can be converted to run on biofuels for less than 5% of the engine cost. When using biofuels in ships, all ship installations such as; fuel storage, fuel treatment system, piping, centrifuges, etc. need to be evaluated for possible modifications. Due to the corrosiveness of biofuels, the major cost of the conversion according to MAN will be the retrofitting of the storage tank.[23]
MAN reports that the difference in price between heavy fuel oil and liquid biofuels is the main obstacle for further research.

3.3.4 Lubrication oil

Running biofuels in engines could have an impact on lubrication oil. Both because of the emissions from combustion and because of contact of unburned fuel (pyrolysis: acid) with lube oil. For this reason many car manufacturers do not support high FAME blends. Some car manufacturers still allow B30 blends (30% biodiesel).

For the use in cars it is advised to change the lubrication oil more often.

There is only little information on effects of biofuels on the lubrication oil. In the tests with FAME on the KALMAR[30] the influence on lubrication oil performance is unknown. According to Wärtsilä there are no limitations from the engine technical point of view regarding biofuels.

[28] ZERO 2007, O.A. Opdal and J.F. Hojem, Biofuels in ships - *A project report and feasibility study into the use of biofuels in the Norwegian domestic fleet*. ZERO Emission Resource Organisation, Norway, December 2007

[29] ZERO 2007, quoting Wärstilä press release 2007

[30] Bio-fuel Trial on Seagoing Container Vessel, 2011, Maersk

3.3.5 Biofuel storage

Biofuels can be stored in a variety of ways depending on their specifications:

- Liquid form under ambient conditions: this applies for biodiesel, vegetable oil, GTL (gas-to-liquid), BTL (biomass-to-liquid), FAME (Fatty Acid Methyl Ester) and HVO (Hydrotreated Vegetable Oil). Conventional fuels like diesel, gasoline, ethanol & methanol could also be stored like this;
- Liquid form under elevated pressure: this applies for DME (Dimethyl ether);
- Liquid form under cryogenic temperatures and elevated pressure: this applies for liquid natural gas (LNG), bio LNG;
- Gaseous under high pressure: this applies for biogas, hydrogen and natural gas.

Different storage types results in different dimensions and weight for the fuel tank. Biofuels in general have a lower energy density than marine fuels, and also a different overall density differing per type of biofuel, detailed information is available in Table 8. Especially gaseous storage under high pressure is relatively heavy. Cryogenic storage requires an insulation layer and low pressure containers (often cylindrical in shape), adding few weight and some volume. Typically this kind of LNG storage requires about 4 times the space of regular fuel for an equivalent quantity of energy. This will imply that LNG as a fuel will not be suitable for all ship types. For example fishing boats will not be prepared to give up precious and scarce cargo space for LNG tanks if there are less spacious alternatives.

The presence of water in a fuel can lead to microbial growth, which is more of a problem in marine environments (than for example in road transport) as residence times of fuels can be much longer, typically being several months, but possibly years. This technical issue, applying more for biofuels (see section 3.4 and section 4.2 on a fuel comparison) should not be difficult to solve with standard filtering equipment. These filtering equipment is already present on most ships. The tests performed by Lloyds on the MAERSK Kalmar from April to November 2010 (see section 2.4.3 and Appendix D-3) showed that no microbiological growth occurred in the FAME tanks. This could be due to the good quality of the FAME, but is an encouraging result as there were significant concerns about this beforehand.

Material compatibility of paints, seals and synthetic materials should be considered for each installation on board if an acidulous fuel is to be used. In any case engine builders should always be referred to for their engine specific make and type guidance with regards to use of acidulous fuels.[31]
Concerning the issue around acidity of liquid biofuels, Wärtsilä indicates a limit of total acid number (TAN) of 5 mgKOH/g[32]. whereas MAN specifies a TAN limit of 4 mgKOH/g[33].

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[31] Bio-fuel Trial on Seagoing Container Vessel, 2011, Maersk

[32] Juoperi 2007, Juoperi, K. and Ollus, R., Paper NO.: 234: *Alternative fuels experiences for medium-speed diesel engines*, 2007 Wärtsilä Paper presented at CIMAC Congress 2007, Vienna

[33] MAN B&W Diesel, Biofuels in Diesel engines – Presentation, 2006

Conclusion

Although not many practical experiences of using biofuels in ships have taken place, technical compatibility of biofuels with marine engines seems manageable.

3.4 Marine fuels

As mentioned in paragraph 3.1 there are basically two groups of fuels: distillate fuels such as marine gas oil, and heavy fuels or residual fuels such as intermediate fuel oil.

Figure 13 shows the break-down of marine bunker fuel consumption by fuel type. The figure clearly shows the dominance of heavy fuel in international shipping. For 2007, IMO estimates the total HFO consumption to be 174 million tonnes and 54 million tonnes of MDO[34]. A more detailed description of fuel consumption for main engine, auxiliary engine and boiler per ship class is available in Appendix C.

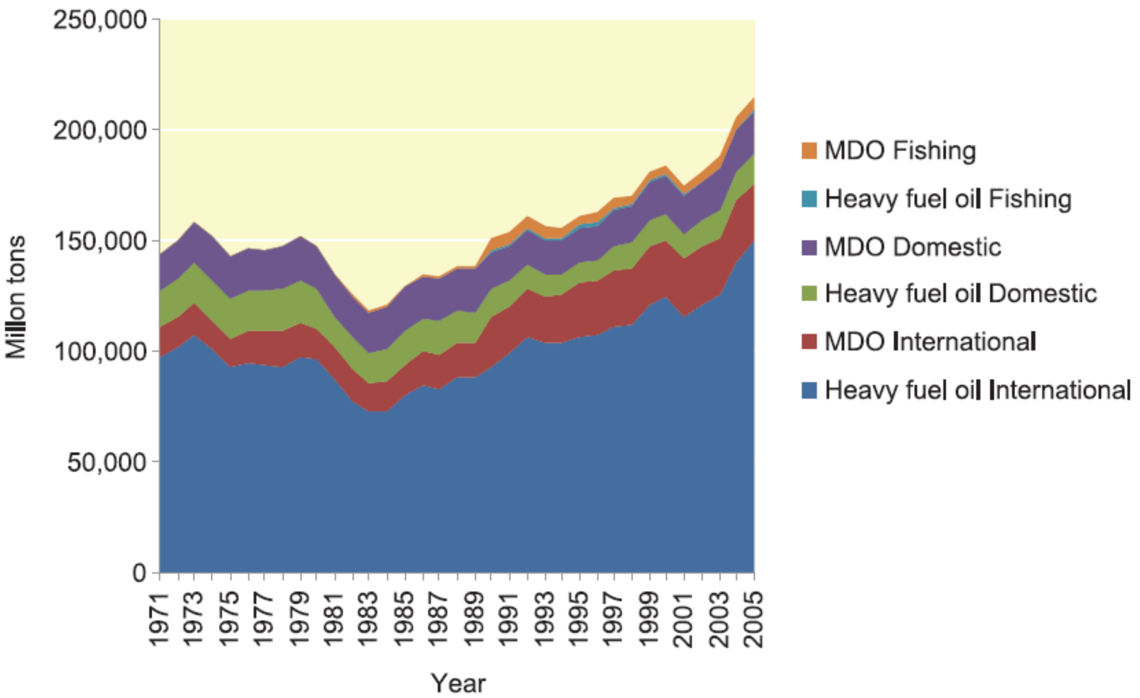

Figure 13 Total marine fuel consumption by ships. [Source IMO, based on IEA data]

The fuels presented below are most frequently quoted in the bunker market, where MDO and MGO are typically used in smaller medium and high speed 4-stroke engines, while IFO fuels are typically used in large low speed 2-stroke engines. As shown in section 3.3 above these fuels are used in a wide range of ship types.

[34] IMO 2009, Second IMO GHG Study 2009

3.4.1 Marine diesel oil (MDO)

Marine diesel oil is a blended heavy gasoil, containing very small amounts of black refinery feed stocks. It has a low viscosity up to 12 Centistokes. It is seen as a marine residual fuel.

3.4.2 Marine gas oil (MGO)

Marine gas oil is a distillate fuel, commonly known as diesel. Gas oil refers to the process of distillation.

3.4.3 Low sulphur heavy fuel oil (LSHFO)

Within the low sulphur fuels we can make a distinction between:

- LS 380; this is low-sulphur intermediate (residual) fuel oil, with a maximum viscosity of 380 Centistokes and less than 1.5% of sulphur content.
- LS 180; this is low-sulphur intermediate (residual) fuel oil, with a maximum viscosity of 180 Centistokes and also less than 1.5% of sulphur content.

For use of LSHFO, the design of a segregated HFO system is quite well known and has been carried out on many ships. It provides for a common HFO bunkering, transfer and purification system, but has separate LSHFO storage, settling and service tanks.
The LSHFO service tank has a separate supply pipe to the changeover valve in the fuel supply system to the engine or boiler.

3.4.4 Ultra low sulphur diesel oil (ULSD)

There is a growing worldwide movement to require the use of ultra low sulphur diesel (ULSD) fuel. The reason for the push to require ULSD is that its use permits the application of new emission control technologies that will permit substantially lower particulate matter and NO_x emissions from diesel engines. Its use will also lead to a reduction in SO_x emissions from engines.

Low sulphur fuels tend to have a viscosity near or at the lower limits of allowed viscosity and the main issue becomes whether they are below the lower limit considering the temperature of the fuel at the injection pumps. Since low sulphur fuels have viscosities close to the permitted minimums, the temperature of the fuel needs to be controlled to prevent clogging of the (pumping) systems.

3.4.5 Intermediate fuel oil (IFO)

Within the intermediate fuel oils, also a distinction can be made based on the average viscosity:

- IFO 380; Intermediate (residual) fuel oil, with a maximum viscosity of 380 Centistokes;
- IFO 180; Intermediate (residual) fuel oil, with a maximum viscosity of 180 Centistokes;

3.4.6 Liquefied natural gas (LNG)

LNG, liquefied natural gas, is becoming more popular as a shipping fuel over the last 2 years, aligned with the increased in LNG logistics worldwide to transport this energy resource by ship in liquid instead of in gaseous form through pipes.

There are many more projects on LNG as an alternative fuel, than on for example biofuels. It is expected that the use of LNG will increase in the years to come[35]. LNG is seen as an alternative fuel for the shipping sector with possibly better effects on local air quality, but it is not a biofuel (unless it is clearly mentioned that bio-LNG is used, produced from bio-methane) and in such not contributing to the decrease of carbon emissions of the shipping sector.

LNG can be used in dedicated monofuel engines (Otto cycle) with lower efficiency as diesel engines. When LNG is mixed with the inlet air in a diesel engine (dual fuel process) the high efficiency is maintained while a large part of the diesel consumption can be reduced. These dual fuel engines are often also referred to as gas engines.

3.4.7 Waste management and disposal

Current use of fossil fuels in shipping leads to costs when dealing with waste. Figure 12 shows that waste is produced as sludge at the stage of the fuel separator. This is commonly called purifier sludge. Aside to this main waste flow other waste is generated at the ship, of which the most important ones (listed by IMO 2008):

- Hydraulic oil pump & tank coaming drain
- Waste oil pump & tank coaming drain
- Lubrication oil pump & tank coaming drain
- Bilge equipment coaming drain
- Main engine piston underside
- Compressed air drain
- Oil mist drain
- Work shop drain

Wastes arising from a spillage or tank cleaning should be disposed of in accordance with prevailing regulations, preferably to a recognised collector or contractor. The competence of the collector or contractor to deal satisfactorily with this type of product should be established beforehand.

Palabiyik[36] estimated from different sources that about 2% of the daily heavy fuel oil (HFO) consumption can be estimated to remain as sludge and about 0.5% of the daily marine diesel oil (MDO) consumption. Correlating to this volume the costs of waste disposal for a ship owner are also estimated at around 2-3% of their annual fuel costs.

3.4.8 Biofuels to replace marine fuels

When biofuels are used the CO_2 emissions at the exhaust are nearly equivalent (on an energy content basis) to running an engine on conventional fuels, although ofcourse the CO_2 emission of the biofuel is considered to be carbon neutral while this is short-cycled CO_2 instead of long-cycled fossil CO_2. Combustion in a marine diesel engine is very efficient, much higher than in an Otto engine. Therefore to see the CO_2 benefit in using biofuels, analysis needs to be performed

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[35] An extensive overview of many experiments and projects on the use of LNG in the shipping sector is given on http://blogs.dnv.com/lng/2011/02/a-review-of-the-world-fleet-of-lng-fuelled-ships/

[36] Palabiyik 2003, *Waste Management Planning for Ship Generated Waste*, Journal of Naval Science and Engineering, Volume 1, Number 2, July, 151-159

on a Well-to-Wheel basis. Marine alternative fuels can be implemented in two main types of use mono-fuel and dual-fuel. Each type has advantages and disadvantages that are described below.

- Mono fuel: When the engine type needs to be changed from Diesel to Otto (major adjustments, parts of the engine need to be rebuild), for instance when a shift is made from diesel to CNG, LNG, Ethanol or Hydrogen, the CO_2 savings are lower than could be expected based on energy content. Marine diesel engines are about 30% more efficient than Otto engines, due to their higher compress ratio. When switching from diesel to CNG (Otto) this results in a combined emission reduction of 10-15% CO_2.
- Dual fuel; When gas and diesel are combusted simultaneously in a Diesel engine the CO_2 savings are as high as can be expected based on energy content. This technology involves two fuel systems on the ship. The ship can run on a variable combination of the available fuels. For instance a variation of 100% diesel up to 97% LNG and 3% diesel is possible, resulting in high CO_2 savings and high variable cost savings.

Temperature control is crucial for running on liquid biofuels[37]. The fuel temperature must always be kept at least 10 – 15 °C above the fuel's cloud point and hot spots need to be cooled (risk of blocking due to polymerization). For ships running on residual fuel, heating devices in storage tanks are already in place.

The waste production in the event of biofuel use is lower, because of reduced sludge amount. This results in cost savings compared to the use of MDO and even more when compared to HFO.

Conclusion

The marine fuel market is a well developed commodity market, based on residual products from our oil and gas refineries. The main difference with biofuels is the long-cycled fossil CO_2 in fossil fuels, versus the short-cycled carbon neutral CO_2 from biofuels.

3.5 Legislation

The construction and operation of merchant ships is controlled by a wide range of legislation. Many of these are based on international standards agreed by member states of the International Maritime Organization (IMO). IMO is the United Nations' specialized agency responsible for safety and security of shipping and the prevention of marine pollution by ships. IMO standards are usually agreed under European law before passing into Member State legislation.

3.5.1 MARPOL

The primary international regulatory mechanism for controlling ship emissions to air is Annex VI, Regulations for the Prevention of Air Pollution from Ships of the MARPOL Convention which is an international convention for the prevention of pollution from ships.

[37] Wartsila 2007, *Alternative fuels for medium speed diesel engines*

Measures have been taken under MARPOL to regulate the sulphur content and other in fuels. IMO has subsequently replaced the SECA designation with ECA (Emission Control Area), since it implies control of more emission components than only those associated with sulphur compounds.
In the revised Regulation 14, effective 1 July 2010, other harmful emissions including particulate emissions and NO_x emissions can be limited in ECAs. Appendix III of the Revised MARPOL Annex VI lists the Criteria and Procedures for Designation of Emission Control Areas.

For a ship operating in an ECA sulphur limits apply. At present, fuel with a maximum of 1.5 percent sulphur must be used in an ECA. Some coastal areas, countries and regions, such as the state of California and the EU, as described in Section III of this Advisory, are placing even stricter controls on ship emissions in coastal areas and in port. They are implementing new regulations outside the IMO since these localities feel there is a health and environmental urgency to controlling ship-sourced emissions. In some ports, there is also a goal to stop all emissions from ships at the dock by requiring the use of shore power while the ship is alongside.
Regulation 14 requires suppliers of any fuel to be used in an ECA to document its sulphur content in accordance with Regulation 18. Such fuel shall be segregated from higher sulphur content fuel. Ships shall carry on board a written procedure showing how the fuel oil changeover is to be accomplished, allowing sufficient time for the fuel system to be flushed of all non-compliant fuel. The date, time and place of the changeover when entering and leaving the ECA plus the volume of low sulphur fuel in each tank at such time shall be logged.
Normally a bunker delivery note of the fuel supplier, together with accredited samples of the fuel are sufficient, if stored on board for at least 12 months time. These documents can than be shown to the authorities in designated ECA's to show compliance with the fuels speficication as stated in Regulation 14 and 18.
Through revision Annex VI MEPC.182(59) guidelines are given on other means of compliance with fuel quality demands in ECA's, such as guidelines on how to prevent already produced sulphur on board of the ship of emission to air. This can be done through installation of exhaust gas cleaning systems, which can be in complianc with the guidelines based on certification.
For the possibility to prevent sulphur emissions by means of on board blending of different fuels no current guidelines are given in the MARPOL legislation.

3.5.2 Fuel standards

There are internationally recognized standards that define the characteristics of fuel oils and what they can contain so that they will be suitable for use on board ships. The following standards can be quoted:

- ISO 8217 is the most widely used standard, with a revised edition issued in 2010 (MEPC 61/4/1 document), stating general specification for both distillate fuels and residual fuels;
- Europe-based International Council on Combustion Engines (CIMAC);
- British standard BS6843-1:1996;
- US standard ASTM D-975.

The ISO 8217 is most commonly used. The latest version of 2010 has added more specifications of the fuels and also takes into account other legislation such as the sulphur restrictions from the MARPOL Annex VI and the flashpoint demands of the SOLAS convention. See Appendix B of this report for the specifications of the marine fuel standards.

The ISO8217:2010 also includes now an annex on bio-derived products (Annex A of ISO 8217-2010, MEPC 61/4/1) which could be introduced for ship propulsion. Four main concerns are stated there on the technical implications for specifically FAME as a biofuel for ships:

- a tendency to oxidation and long-term storage issues;
- affinity to water and risk of microbial growth;
- degraded low-temperature flow properties;
- FAME material deposition on exposed surfaces, including filter elements.

Ship owners wanting to use FAME are warned in this Annex to make sure their equipment and systems is suitable for contact with FAME. Specifically an oily-water separator is mentioned as possible treatment equipment. The Annex mentions furthermore that FAME can already be included in some heavy fuel oils, while larger refineries currently already blend in biofuels at refinery level to comply to the Renewable Energy Directive. Due to lack of practical experience of FAME in this sector, the Annex steers upon the restricted use of FAME to a *de minimis* level:

- In the case of distillate fuels (DMX, DMA, DMZ and DMB when clear and bright), it is recommended that "de minimis" be taken as not exceeding approximately 0.1 volume % when determined in accordance with EN 14078.
- In the case of DMB when it is not clear and bright and all categories of residual fuels, "de minimis" cannot be expressed in numerical terms since no test method with formal precision statement is currently available. Thus, it should be treated as contamination from the supply chain system.

This is also confirmed in Clause 5 of the ISO standard where clearly any additives or chemical waste components are not allowed to be mixed with the marine fuel. In clause 5.4 it states:

> *The fuel shall be free from bio-derived materials other than 'de minimis' levels of FAME (FAME shall be in accordance with the requirements of EN 14214 or ASTM D6751). In the context of this International Standard, "de minimis" means an amount that does not render the fuel unacceptable for use in marine applications. The blending of FAME shall not be allowed.*

3.5.3 Fuel Safety

Marine fuels are pollutants in both liquid and gaseous forms. The risks inherent in marine fuels are identified in Material Safety Data Sheets (MSDS), which, as a requirement of SOLAS legislation, must be made available to all personnel dealing with them and provided to each ship at the time of delivery. The key sections to an MSDS are as follows:

- Product name: Including synonyms and government identification codes
- Summary of hazards: Usually written in understandable but precise terms
- Hazardous ingredients: Individual components that have their own particular hazards
- Physical data: Colour, density, smell, boiling point, etc.
- Fire and explosion hazard data: This describes the flash point, auto ignition temperature and flammability in air. The procedures for fire fighting are covered as are the particular fire and explosion hazards

- Reactivity data: How product will react when in contact with other materials
- Health hazard information: Specific health risks covering all methods of exposure to the product
- Emergency first aid: Detailed advice on first aid measures and guidance for doctors on treatment
- Precautionary measures: How to avoid the health and fire/explosion hazards
- Spill and leak procedures: How to deal with spillages of the product and how to clean it up.

Furthermore, the International Bunker Industry Association (IBIA) has published a guide to MSDS terminology, and an IBIA Safety card that gives a summary of the risks, similarly to the MSDS.

In addition to the requirements on fuel, all bunker operations should follow the safety guidance appropriate for shipboard operations, the guidance issued by flag states, the advice from bodies involved with shipboard safety (such as Intercargo, Intertanko, OCIMF, SIGTTO, classification societies and P&I clubs). Where road tanker deliveries are involved, the operations must comply with the safety requirements of the local licensing authority. For deliveries by pipeline at oil refineries or tank terminals, the refinery or terminal operators will have their own requirements for safe operation that must be followed by the receiving vessel[38].

3.5.4 Energy Efficiency Design Index (EEDI)

The Energy Efficiency Design Index (EEDI) was added to MARPOL Annex VI in july 2011 and enter into force on 1 January 2013.
The index is meant to stimulate innovation and the technical development of all the elements influencing the energy efficiency of a ship, thus making it possible to build more energy-efficient ships in the future. The method for calculating the index is given in the 'interim guidelines on the method of calculation of the energy efficiency design index for new ships'[39]. The current formula is complex, and shown in Figure 14.

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)}\, C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}*\right) + \left(\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w}$$

Figure 14 Interim formula for calculating the Energy Efficiency Design Index

At its core the index can be simplified into the following formula:

$$EEDI = \frac{CO_2\ emission}{transport\ work}$$

[38] Draffin N., *An introduction to bunker operations*, 2010

[39] IMO - Ref. T5/1.01, 17 aug 2009]

Where CO_2 emissions are measured in g *based on carbon content.* This means the formula does not take into account the life-cycle emissions of the fuel. Also, no distinction is made between the short-cycled carbon content of biofuels, which are considered carbon neutral, and the long-cycled fossil carbon. Since the carbon content for biofuels per energy unit is higher than for most fossil fuels, this formula implies that biofuels will be disadvantaged with respect to fossil fuels, in terms of CO_2 emissions.

While developing the index, the issue of how to deal with biofuels in was eventually dropped from the discussion, as it was deemed too complex to included calculations for the benefits of introducing biofuels. Since efficiency is measured on carbon content of the fuels, the only fuel that may benefit is LNG because of its lower stochiometric carbon content (low CO_2 out per MJ), and therefore low tailpipe emissions.

Conclusion

Legislation for shipping is limited, and not so much EU dominated as for road transport which operates more local/ national. For shipping the International Maritime Organization (IMO) is of major importance, setting guidelines through the MARPOL convention on restriction or air pollution from ships. This will stimulate the shipping sector to reduce mainly sulphur emissions by using fuels with a low sulphur content.

Several guidelines or legislation are not yet in favour of biofuels, or will stimulate the introduction of biofuels such as the non differentiation between biogenic carbon and fossil carbon content in the EEDI, or the lack of guidelines for blending on board to comply with lower sulphur content in fuels.

4 Biofuel case analysis

4.1 Selection of cases

Table 5 below shows the possible biofuels that can be introduced for ship propulsion per engine type. The long-list consists of the eight biofuels that have briefly been discussed in Chapter 2. It is in principle technically possible to use these fuels in diesel or gas engines on board of ships. Some biofuels have been left out in this long-list e.g. MTBE, ETBE, bio synthetic gasoline (all not considered an option for marine engines due to their specifications aimed for blending with high quality gasoline). A few other biofuels are in such an early stage of development that insufficient information is available for further evaluation (such as HTU diesel and furanics diesel), and therefore excluded from this long-list.

The long-list of suitable biofuels for ship engines as presented in Table 5 below are assessed on selection for further analysis based on the following criteria:

- Availability of the biofuel: is it currently or could in short term be produced in large amounts and made available in European ports;
- Production costs of the biofuels: while reduction of fuel costs are a key driver for ship owners, most expensive biofuels to produce should be left out unless there is a clear niche market potential;
- Technology maturity: The stage of technology development will affect the current and future production costs and availability of the biofuels, and is taken into account as a potential risk factor if immature for a stable quality of the produced biofuel;
- First estimate into technical compatibility with marine engines: see Table 5 below.

Based on a first qualitative assessment of the technical compatibility of biofuels in marine engines, a colour scheme in Table 5 is presented. The green ( ) shaded fields indicate that the fuel-engine combination is technically possible. Red shaded ( ) areas indicated combinations that are estimated to be impossible. The yellow shade ( ) indicates an uncertainty or pre-conditional scope in order to technically integrate this biofuel in this type of engine.
Typically, it is possible to use alcohols (ethanol, methanol) in diesel engines with some adaptations, but only in the high speed engines. Pyrolysis oil can be rather viscous (depends on production technology and shelf time) and could be more suitable for lower speed engines.

Table 5 Estimation of technical compatibility of various biofuel-engine combinations

Fuels	High speed (auxiliary engine)	Medium speed (aux/ main)	Low speed (main engine)
Straight vegetable oil (SVO)			
Biodiesel			
Hydrotreated vegetable oil (HVO)			
Bio-methane			
Bio-ethanol			
Bio-methanol			
Di-methyl ether (DME)			
Pyrolysis bio-oil			

Within this long-list, six biofuels have been selected for further review and analysis based on the criteria described above:

7. Biodiesel to replace MDO/ MGO in low to medium speed engines (used in tug boats, small carriers or cargo ships)
8. DME used to replace MDO/ MGO in all types of engines (all sizes of carriers or cargo ships)
9. Straight Vegetable Oil (SVO) used to replace IFO or heavy fuel oil in low speed engines (all sizes of carriers or cargo ships)
10. Bio-LNG or bio-methane in gas engines using LNG
11. Bio-ethanol used in high speed main or auxiliary engines (short distance ships, ethanol tankers, or for electricity production on board of ships like cruise and passenger ships)
12. Pyrolysis bio-oil in low speed engines (all sizes of carriers or cargo ships)

We have strived for diversity in the selected cases, with a slight focus on biofuels in low speed and medium speed engines due to the larger fuel consumption in these engines. We also looked at the current state of play in biofuels, to align availability and global trade patterns in biofuel types with the shipping sector (e.g. ethanol and biodiesel are as shown in chapter 2 widely traded worldwide for use of transportation fuels). We also looked at market expectations and first tests with biofuels in ships, such as the first biofuels projects in ships mentioned in paragraph 2.4.3. Others for example already stated that vegetable oil and biodiesel can replace HFO and MDO[40].

Bio-methane connects to the increased interest in the shipping sector for LNG as alternative fuel. The same argument is given for the selection of DME as a possible alternative fuel, while much interest is given already by the shipping sector to this fuel. Ethanol has been added as a more exotic option, being a higher quality distillate fuel, because ethanol is the most widely used biofuel in the world for the next decade with much interest in USA and South America. Also, it can be produced from many different feedstocks all around the world. Use of ethanol in the diesel sector is not obvious, but possible.

The other biofuels from the table have not been further assessed for different reasons. HVO has a very high quality; it can be produced up to jet-specification. It is therefore assumed to be too valuable for wide application in the shipping sector. If HVO would be applied in the shipping sector, there would be no technical hurdles on the bunkering or ship side, since it would be used as a drop-in fuel. Application of bio-methanol is not assessed, because the analysis would basically follow the lines of thought of ethanol application. Methanol could play a role in on board DME production.

Below the selected fuels are analysed on technical implications, sustainability impact and cost-economic effects if they were to be introduced into ship engines, blended or in pure form.

[40] Pew Center 2009, *Greenhouse gas emissions from aviation and marine transportation: Mitigation potential and policies*

4.2 Technical analysis on marine versus biofuels

In Table 6 below the most important characteristics of the six selected biofuels are compared with the characteristics of marine fuels, as quoted in the ISO 8217 technical standard for marine fuels (see Appendix B for the full version of the fuel specifications within ISO 8217).

Table 6 General specification of most common marine fuels and selected biofuels [source: Ecofys]

Fuels	Cetane number	Higher Heating value (MJ/kg)	Kinematic viscosity (mm2/s at 40 °C)	Cloud point (°C)	Pour point (°C)	Flash point (°C)	Density at 15 °C (kg/m3)
IFO 380 (ISO8217-RMG)	**not specified**	**not specified** (~ 42,8) [41]	***<380***	**not specified**	***<30*** *(~ 6-18)* [41]	***>60*** *(~90)* [41]	***< 991*** *(~963)* [41]
Straight Vegetable Oil	37 – 42	39.5 -39.7	32 – 37	-4 - +7	-32 - -12	246 - 274	900
Raw pyrolysis bio-oil	10	22.7	14.5	-21	-33 - -12	40-100	1100-1250
HDO pyrolysis bio-oil	"high"	45.2	2.8	unknown	unknown	35-39 [42]	900
MDO (ISO8217 DMB)	***> 35***	**not specified** (~45,3 [43])	***2 – 11***	**not specified**	***0 - +6***	***> 60***	***< 900***
MGO (ISO8217 DMA)	***> 40***	**not specified** (~45,3 [44])	***2 – 6***	**not specified**	***-6 - +0***	***> 60***	***< 890***
Biodiesel	49 - 58	37.3 –39.8	4.2 - 4.5	-1 – +8	-4 – +6	110 - 195	880-920
Di-methyl ether (DME)	55 – 60	29.8	0.2 – 0.25 [45]	unknown	unknown	-41	665 (5 bar)
Bio-methane	0 [46]	55	n/a	n/a	n/a	-188	0.66
Bio-ethanol	8	29.8	- - 1.2	n/a	n/a	12	791

Based on these general specifications, it can be concluded that biodiesel and straight vegetable oil are the options closest to marine fuels, looking at the green ( ) bars indicating compliance with the ISO standard. ( ) shows no or uncertain compliance with the reference marine fuel ISO standard. Bio-methane and bio-ethanol are not to be compared with the given fuel specifications from the ISO standard, while they will be applied in different type of engines.
Table 6 also makes clear that for several biofuels information could not yet be given, or not applicable due to the type of biofuel, or values are in such a wide range that only a reference like "high" or "low" could be made.

[41] SL Ross Environmental Research LTD., 2004, spill related properties of IFO380 fuel oil, for minerals management services

[42] Wildschut J., 2009, Hydrotreatment of Fast Pyrolysis oil using Heterogeneous Noble Metal Catalysts

[43] Le Calvez P., 2006, oily waste management on board of vessels, lecture to air spotters cadets on training course with CEDRE

[44] Le Calvez P., 2006, oily waste management on board of vessels, lecture to air spotters cadets on training course with CEDRE

[45] Chapman E.M. e.a, 2003, Annual Technical Progress Report for Project Entitled "Impact of DME-Diesel Fuel Blend Properties on Diesel Fuel Injection Systems", Pennsylvania State University

[46] Komatsu K. e.a., 2011, A Study of an HCCI Engine Operating on a Blended Fuel of DME and Methane

The cloud point of a fluid is the temperature at which dissolved solids are no longer completely soluble, precipitating as a second phase giving the fluid a cloudy appearance. This term is relevant to several applications with different consequences.
In the petroleum industry, cloud point refers to the temperature below which wax in diesel or biowax in biodiesels form a cloudy appearance. The presence of solidified waxes thickens the oil and clogs fuel filters and injectors in engines. No reference for a cloud point is given in the fuel ISO standard.

The pour point of a liquid is the highest temperature at which it could become semi-solid and loses its flow characteristics.

The flash point of a volatile material is the lowest temperature at which it can vaporize to form an ignitable mixture in air. Liquids with a flash point less than 60.5 °C or 37.8 °C —depending upon the standard being applied— are considered flammable, while liquids with a flash point above those temperatures are considered combustible.
Gasoline (petrol) is a fuel for use in a spark-ignition engine. The fuel is mixed with air within its flammable limits and heated above its flash point, then ignited by the spark plug. In order to avoid pre-ignition by dint of the hot combustion chamber, the fuel must have a low flash point and a high auto-ignition temperature.
Diesel fuel flash points vary between 52 and 96 °C. Diesel is suitable for use in a compression-ignition engine. Air is compressed until it has been heated above the auto-ignition temperature of fuel, which is then injected as a high-pressure spray, keeping the fuel-air mix within flammable limits. There is no ignition source. The fuel is, therefore, required to have a high flash point and a low auto-ignition temperature.

In Table 7 below an overview is given of the different flash points of the fuels, in relation to their auto-ignition temperature.

Table 7 **Overview of fuel flash points and their auto-ignition temperature**

Fuel	Flash point	Auto-ignition temperature
Ethanol (70%)	16.6 °C (61.9 °F) [3]	363 °C (685 °F) [3]
Gasoline (petrol)	−43 °C (−45 °F)	246 °C (475 °F)
Diesel	>62 °C (144 °F)	210 °C (410 °F)
Jet fuel	>60 °C (140 °F)	210 °C (410 °F)
Kerosene (paraffin oil)	>38–72 °C (100–162 °F)	220 °C (428 °F)
Vegetable oil (canola)	327 °C (621 °F)	
Biodiesel	>130 °C (266 °F)	

Aside to these parameters presented and discussed above, the water content of the fuels is of importance, the acidity and possible toxicity.

In the sections below the selected biofuels will be discussed individually on their technical performance, and compatibility with marine engines.

4.2.1 Biodiesel/ FAME

The application of biodiesel as marine fuel has been tested in several research programs and by several companies (see also section 2.4.3). Two technical bottlenecks that are potentially problematic are often found in this applied tests:

- Biodiesel acts as a solvent and has a tendency to soften and degrade certain rubber and elastomer compounds which often are used in older engines. Therefore at higher blends, rubber hoses and seals and other materials used in delivering and transporting the fuel through the ship may need to be replaced with synthetic, biodiesel resistant material.
- Biodiesel potentially removes deposits in the fuel system left by petroleum diesel, which could then clog filters. Filters should thus be checked and cleaned regularly. Alternatively, the fuel tanks should be cleaned prior to using biodiesel filling.

Furthermore, the technical standard ISO8217 lists some concerns/challenges around biodiesel or FAME (fatty acid methyl esters):

- A tendency to oxidation and long-term storage issues;
- Affinity to water and risk of microbial growth;
- Degraded low-temperature flow properties;
- FAME material deposition on exposed surfaces, including filter elements.

Interviews with shipping and bunker fuel industry revealed that FAME could probably be mixed without adaptations up to about 7-10% in the current supply chain. The IMO 2007 study[47] even concludes that low blends of biodiesel up to 20% (B20) could be used without any fuel system degradation, i.e. without occurrence of the above discussed problems.

For higher blends, the ISO concerns could be partially realistic. Significant amounts of water will only be attracted, if there is a continuous open connection with the ambient air, This could be easily avoided if the fuel tank is closed (only allow in air to fill the space left by the consumed fuel). The low temperature flow properties are similar to those of marine fuels. Oxidation could indeed occur, but long time biodiesel storage should not be a problem, as long as the fuel is consumed within several months.
Also, existing oil/water filters could help in reducing the issue of higher water content in biodiesel compared to marine fuels.

Application of low blends of biodiesel in distillate marine fuels could be introduced relatively easily. Bunker fuel suppliers can decide to include a small fraction of biodiesel, if accepted by the client. This blend could be prepared at the moment of bunkering. If biodiesel blends become accepted, whether or not endorsed by the ISO standard, the blending could take place at the bunker fuel terminal or even earlier in the supply chain. As stated in section 3.2.2 in board blending of biofuels as main option, seems less attractive due to the administrative hurdles of ship owners in ECA's (Emission Control Area's) and the additional handling on board of the ship.

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[47] IMO 2007, *Feasibility study into the use of biofuels in the Norwegian domestic fleet*, Marine Environment Protection Committee, 57th session, Agenda item 4

Application of high blends of biodiesel require small on-board adaptations to counteract the above discussed problems. This means that a small investment may be necessary to modernize hoses and seals, and that the personnel must be instructed to check filters more often. This is only useful if the ship uses the high blend on a very regular basis. Therefore, high biodiesel blends should not (yet) be applied in the mainstream sector, but only in dedicated fleets.

4.2.2 DME

For the last 20 years DME (di-methyl ether) has been a known substitute for diesel. It has been tested on small engines but this is no guarantee for its suitability for use in larger engines.[48]

Based on interviews with parties in the shipping sector the following items are of importance concerning DME as a possible alternative shipping fuel.[49] On vessels, leakages are a bigger problem than for road transport, as the engines and fuels are operated in closed spaces, where leakages from fuel pumps can lead to explosions. There are safety issues that need attention because of the high vapour pressure. Fuels like DME, LNG and methanol that have a low flashpoint require a lot of attention in order to manage and prove their safe use and are therefore probably more suited for new build ships and engines.

Infrastructure is missing to introduce DME in ships. Industry proposes to produce DME onboard from methanol, by means of a relatively simple chemical installation.[50] This would not make the case for *biogenic* DME easier, since the global production of biomethanol is currently very small, with only one plant producing 200 ktonne in the Netherlands. Biomethanol could potentially be produced from many different feedstocks in large volumes, but the real prospects are highly uncertain due to the link of biomethanol production with the technological development and commercial upgrading of biomass gasification (see also section 2.2).
Furthermore, the on-board chemical installation, however simple, will require operation by dedicated and skilled personnel. In view of decreasing manpower onboard of ships, this option may not be realistic.

4.2.3 Straight vegetable oil

Vegetable oil is suitable for replacing residual fuels[51]. It is unknown if the vegetable oil has been tested for marine application, but there is some experience with land-based power stations that replaced HFO with vegetable oil, e.g. with engines from Man B&W and Wärtsilä.

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[48] Presentation by P.E. Højlund Nielsen from company Haldor Topsøe: *OBATE: an upgraded alcohol fuel for efficient & clean Diesel engine application*, Marine Days, Göteborg, April 5th 2011

[49] Based on personal communications and interviews with bunkering parties in the market, ship owners, classification body, and the International Bunkering Industry Association (IBIA) between September and December 2011, plus a workshop ECSA with ship owner assocations on November 22nd 2011.

[50] Presentation by P.E. Højlund Nielsen from company Haldor Topsøe: *OBATE: an upgraded alcohol fuel for efficient & clean Diesel engine application*, Marine Days, Göteborg, April 5th 2011

[51] IMO 2007, *Feasibility study into the use of biofuels in the Norwegian domestic fleet*, Marine Environment Protection Committee, 57th session, Agenda item 4

Man B&W state that diesel engines designed for heavy fuel oil can be run on vegetable oil without problems, whereas engines designed for marine diesel or gas oil may have problems though due to higher density and viscosity of the vegetable oil.[52] Wärtsilä has approved its engines to run on vegetable oils (within certain specifications). See also section 3.3.2.

It is unlikely that vegetable oil could be blended with HFO. ECSA members[53] think this would lead to emulsions rather than blends. Occurrence of significantly different phases in one fuel is harmful for the engine operation. Even the application of very fine emulsions may lead to cavitation in the fuel system, at the point where the fuel is heated.

Rather, vegetable oil would be applied as a pure replacement (100% blend) of HFO. In that case, the biofuel temperature has to be closely monitored to keep the correct viscosity levels. This ensures circulatory ability, optimal engine injection and efficient atomisation and combustion. For soybean and rapeseed oil, the viscosity is fine, palm oil needs to be heated before application to ensure a lower viscosity.

An advantage of the application of vegetable oil is that less energy is needed for the preheating of fuels. This would result in a net fuel saving (on energy basis).

As discussed above, the application of vegetable oil does imply some adaptations in the ship's fuel system and operation. Therefore, vegetable oil can, at first, only be applied to dedicated fleets with well-informed personnel and small operational changes.

4.2.4 Bio-methane

Bio-methane or bio-LNG could be an alternative to LNG (liquefied natural gas) which gains increasing interest in the shipping sector. It could connect to existing and upcoming LNG terminals in Europe, currently in Belgium (1), the Netherlands (1, with several others under development), UK (4), Denmark (1), Sweden (1), Norway (>40), and with plans for about 20 additional LNG terminals in North West Europe.

Bio-methane would be applied in exactly the same way as bio-LNG and therefore not lead to any additional challenges.

In principle bio-methane could also be applied as CNG (compressed natural gas). This would have the following disadvantages:

- High pressure of 200-250 bar in gaseous form;
- Bulky storage (3 times LNG);
- Very expensive storage (strong, heavy vessel);
- High pressure fueling difficult and slow;
- And requires a bunker station with at least 10 times storage to avoid large pressure drops.

[52] MAN Diesel 2006, quoted by IMO 2007

[53] ECSA workshop with ship owner assocations organized on November 22nd 2011

Application as LNG would imply the following measures:

- Storage is at very low temperature (minus 162 °C) at elevated pressure;
- In practice, the actual volume required for LNG storage compartments is usually some four times that of diesel tanks which provide an equivalent quantity of energy;
- Continuous use is necessary, because LNG evaporates slowly, but instantly;
- Application can be as a dual fuel in main engine, or as a mono/dual fuel in auxiliary engines.

LNG-tankers use the boil off of loaded LNG as fuel. LNG is also used on ferries and coastal ships. Norway is a major innovator in this regard and 16 of their ships currently run on natural gas stored on board as LNG. These include car/passenger ferries, passenger ferries, supply ships, coast guard ships, and small coastal LNG tankers (NGV, 2009). Another five vessels are currently under construction.

To switch from LNG to bio-LNG investments and technological development is needed to produce the demanded amount of biogas (see also section 2.2.10). Biogas is currently produced mainly through digestion of agricultural residues (food and manure) in small scale widely spread installations, but in long term could switch towards biomass gasification of woody residues. At this point in time the scattered availability of biogas in Europe would be limiting the introduction of bio-LNG, as long as no intra-European biogas certification scheme allows local biogas production facilities to introduce their biogas at central LNG terminals within Europe.

4.2.5 Bio-ethanol

Bio-ethanol is produced all around the world in very large volumes, larger than biodiesel (see also section 2.4). In some locations, bio-ethanol is cheaper than gasoline (without incentives). In South America and South Asia it is produced from sugar cane, in the USA from maize and in Europe from wheat, maize and sugar beet. The final product quality is rather independent from the feedstock.

Bio-ethanol is not a logic option for diesel engines. It is a poor diesel fuel, with low cetane number, low energy content, it is corrosive and has a poor lubricating ability.

Nevertheless, it is possible to apply ethanol in diesel engines, as a neat fuel. There is much experience in Swedish busses (Scania engines) running on ethanol. This option requires modification of the engine, namely the introduction of a glow plug ignition, and an ignition improver must be added to the ethanol. For introduction into shipping, it would therefore be recommended to introduce bio-ethanol in blends only and for high speed, auxiliary engines.

4.2.6 Pyrolysis oil

Pyrolysis oil is potentially very cheap, because it can be produced from any biomass/ residue and anywhere around the world. Several Wärtsilä heavy fuel engines are running on pyrolysis oil, with a combined capacity of 680 MW (see also section 3.3.2).

Pyrolysis oil is a poor quality product. It consists of an emulsion with 20–30% water. The high oxygen content leads to low pH values, which makes the fuel acidic and corrosive, low heating values and high viscosities. As a result, it is difficult to store and transport, and can damage engines and boilers. It is immiscible in petroleum oils and not auto-igniting in a diesel engine.

It is possible to upgrade the oil to fossil fuel quality, but that may undo the cost advantage. The pyrolysis oil should than be introduced at refinery level in order to be introduced to the fuel supply of (amongst others) ships.
All interviewed parties do not see pyrolysis oil as a viable option.[54]

4.2.7 Biofuel supply chain and use on the ship

Because of the different storage and engine type requirements of the selected biofuels, the supply chain for fuel as well as fuel use on board of the ship is different from conventional marine fuels. The following Table 8 shows the differences in investments to the fuel infrastructure per step in the supply chain for the selected biofuels. Also, a comparison is given to the differences between mass and volume needed for the selected biofuels to reach the same energy content as for marine fuels. Biofuels in general have a lower energy density than marine fuels, and also a different overall density differing per type of biofuel. So, all fuels are compared on a 100% fossil reference in terms of how much more volume and mass is needed both in energy output as in on board storage facilities.

While pyrolysis oil is not seen as a viable option by interviewed market parties (see section 4.2.6), it is not included in the overview below.

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[54] Based on personal communications and interviews with bunkering parties in the market, ship owners, classification body, and the International Bunkering Industry Association (IBIA) between September and December 2011, plus a workshop ECSA with ship owner assocations on November 22nd 2011.

Table 8 Supply chain changes for biofuels in ships

Biofuel	Relative fuel comparison		Storage					Engine type
	Mass needed	Volume needed	Bunkering Shore	Bunkering Ship	Onboard storage	Mass needed	Volume needed	
	energy ouput (fossil = 100%)					onboard fuel storage (fossil=*100%)*		
DME	150%	200%	DME filling station Ambient temperature, low pressure	DME in cylinder, Ambient temperature, low pressure	DME in cylinder, Ambient temperature, low pressure	180%	400%	Mono fuel
(bio)-LNG	86%	200%	LNG station, connected to (bio) gas grid. Cryogenic temperature, low pressure storage.	LNG in cylinder, Cryogenic temperature, low pressure	Cryogenic storage, either on deck (retrofit) or in the hull (newly build)	144%	400%	Dual fuel or monofuel
(bio)-CNG	86%	450%	Large number of heavy CNG cylinders. Available in standard containers.	CNG cylinders in standard containers.	CNG in cylinders, either in standard containers (retrofit) or in racks (newly build).	240%	900%	Dual fuel or monofuel
Biodiesel B5 (5% blend)	102%	100,5%	Blended with regular fuel	Standard, minor adjustments	Standard, minor adjustments	102%	100,5%	Mono fuel
Biodiesel B100 (pure biodiesel)	116%	110%	Separate tanks with minor modifications (e.g. right paint and correct fuel lines)	Separate tanks with minor modifications (e.g. right paint and correct fuel lines)	Separate tanks with minor modifications (e.g. right paint and correct fuel lines)	116%	110%	Mono fuel
Bio-ethanol E100 (pure ethanol)	160%	200%	Separate tanks with minor modifications (e.g. right paint and correct fuel lines)	Separate tanks with minor modifications (e.g. right paint and correct fuel lines)	Separate tanks with minor modifications (e.g. right paint and correct fuel lines)	213%	200%	Mono fuel

Engine manufacturers claim that the engines are suitable for biofuels (see also section 3.3.2), but do not yet give guarantees. Engine manufacturers provide warranties for certain specifications of fuels. Therefore, engine manufacturers will be essential stakeholders in the process of setting new fuel specification standards. As long as the ship engine manufacturer does not take responsibility for accepting biofuels, the risk is for the ship owner.

A current trend in shipping is a reduction of staff on board ships, and with that a decrease in availability of knowledge and skills in different people, or rather condensation of knowledge and skills in fewer people. For biofuels and other new fuels to be introduced, new knowledge and skills are needed. Interview market parties warn for a possible organizational threat or hurdle for the introduction of biofuels, to properly train few shipping staff on board. Aside to the needed training and setting up new onboard procedures for handling, the MSDS safety sheets need to be updated to the introduced alternative fuels.

Conclusion

From a technical integration point of view, small percentage biodiesel blends (up to 20%) with MDO/MGO seem the most promising fuel for shipping, aside to 100% replacement of HFO by straight vegetable oils, due to best compatibility with current engines and supply chain.

Aside to the limited application of bio-ethanol in diesel engines, the investments needed to the supply chain seem manageable, although less favourable than for biodiesel and SVO.

DME and bio-LNG are still upcoming technologies, with at this point limited biomass feedstock availability. Also, more investments are needed to the fuel supply chain in order to introduce these fuels. For new build ships these fuels seem more promising.

Pyrolysis oil is not seen as a viable option as an alternative fuel for ships at this point.

The issue remains of the responsibilities and ownership in the supply chain. All risks now lie with the ship owners, both for fuel quality as engine guarantees.

4.3 Sustainability analysis

The selected biofuels were analyzed on their sustainability compared to marine fuels. Two main items are discussed here: the greenhouse gas balance of biofuels compared to the fossil reference, and the emissions to air.

4.3.1 Greenhouse gas balance

For every selected biofuel the greenhouse gas balance was determined for the different biomass resources which could lead to the selected type of biofuel. The full greenhouse gas balance overview per biofuel type are presented in Appendix A.

Below in Figure 15 the highest and lowest values of the selected biofuel types are presented in a comparison with the fossil reference fuel (grey). The liquid fossil reference is the average of the life cycle greenhouse gas emissions of both gasoline as diesel, as mentioned in the Renewable Energy Directive. To compare bio-methane with a fossil reference, the LNG greenhouse gas emission is stated in the left grey bar on the right.

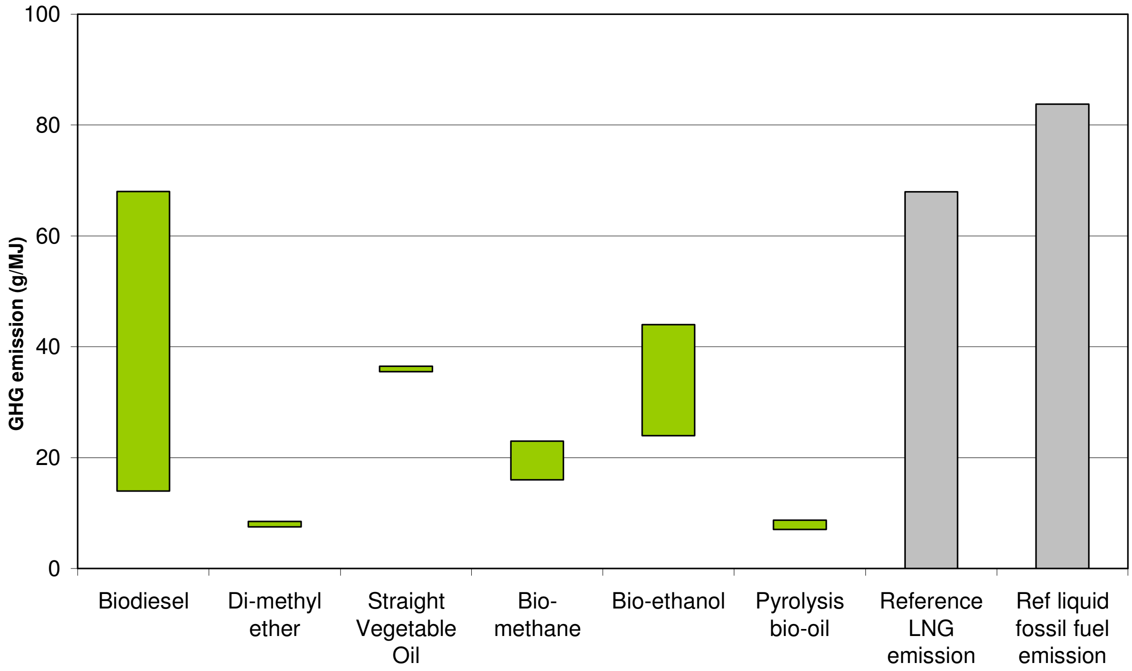

Figure 15 Overview of GHG balance comparison between selected biofuels and fossil reference

As discussed in section 2.5, obliged parties within the RED can only comply with the obligation if they fulfill the set sustainability criteria. One of these criteria is a minimum reduction of greenhouse gas emissions. Currently, until 2017, that minimum reduction should be 35% compared to the fossil reference.

Figure 15 shows that in case of biodiesel the GHG emission could be still so high (almost 70 g/MJ) that the 35% threshold will not be reached compared to the GHG emission of the fossil reference (around 80 g/MJ). The GHG emission will depend strongly on the type of feedstock used to produce biodiesel and the production processes (e.g. appendix A-1 shows that using palm oil as a feedstock for biodiesel could lead to higher GHG emissions).

4.3.2 Emissions to air

There have not been many published tests of biofuels on slow speed marine engines on biofuels. Therefore, lessons should be drawn from general trends of engine-out emissions of high-speed engines on biofuels, as compared to fossil fuels. Table 9 below shows the typical change in emissions for the selected biofuels. Note that for ethanol, there is very limited information about its performance in diesel engines. Therefore, for comparison, the relative performance of bio-ethanol in an Otto engine is given at the bottom of the table.

Table 9 **Typical change in emissions when fossil fuels are replaced with biofuels in diesel engines and gasoline engines**

Blends	NOx	PM10	SOx	HC
Diesel engines				
B100	+10%	-50%	-100%	-65%
B20	+2%	-12%	-20%	-20%
DME	-	-	-	+
BTL	-	-		
Gasoline/ otto engines[1)]				
E85	-60%	-		+30%
M85	-30%	-		+25%
CNG	-33-97%	-95%	-100%	+

1) Gasoline is the reference fuel for ethanol and methanol (E85 and M85) in Otto engines, Otto engines are generally speaking much cleaner than diesel engines. Although the CNG is technically used in a Otto engine, this concerns a modified diesel engine and the reference fuel is diesel.

Since the biofuels do not contain sulphur, there are no emissions of sulphuric acid.

When diesel is replaced by pure biodiesel (B100 in Table 9 above), the NO_x emission generally increases with about 10%[55]. This increase is linear, so that the use of a 20% biodiesel blend results in an increase of about 2%. NO_x emissions are not depending on the chemical composition, but rather on the combustion conditions. The combustion of biofuels in ship engines will be slightly different from marine fuels, but actual performance for large quantaties of biofuels is unknown at this point.[56] This issue needs further research in order to use biofuels in large quantities. In road transport, NO_x emissions are reduced by post-treatment or injection of urea (adblue). Reduction of PM10 and HC emissions was measured in a test with biodiesel in Amsterdam tourist boats.

A study of dimethyl ether (DME) as an alternative fuel for diesel engine applications[57] showed a reduction in regulated exhaust emissions with the exception of total hydrocarbons (THC), which were primarily in the form of unburned DME.

Tests on the application of synthetic diesel (BTL, GTL) generally show reductions of both NO_x and particulate matter.

Use of CNG in heavy duty vehicles leads to a 65% to 85% lower emission of NO_x compared to the baseline. Note that these vehicles use a modified diesel engine, with spark ignition, so that it effectively operates as a gasoline engine. [58]

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[55] EPA 2002, *A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions*, Draft Technical Report, EPA420-P-02-001, October 2002

[56] Based on personal communications and interviews with bunkering parties in the market, ship owners, classification body, and the International Bunkering Industry Association (IBIA) between September and December 2011, plus a workshop ECSA with ship owner assocations on November 22nd 2011.

[57] TP 13788E; Natural Resources Canada, 2000

Wärtsilä dual-fuel engines in gas (from LNG) mode produce roughly 80% less NO_x compared to IMO Tier I levels and practically zero SO_x and particulates.[59]

4.3.3 (Sulphur) emission reduction measures

For medium speed diesel engines, if reductions of 80% are to be achieved by 2020, the only feasible option is Selective Catalytic Reduction (SCR). Other options like double stage turbo charging, exhaust gas recirculation, water in injection may lead to only 50-60% reduction in emissions.[60]
Ship owners are investigating still the possibility of sulphur scrubbers as a way to reduce end-of-pipe sulphur emissions. Main objection currently is the space and weight requirements for such a technical installation, which takes up precious cargo space and therefore reduces the economic potential.[61]

4.3.4 Particulate Matter

Particulates are mainly PM10s and PM2.5. PM10s being of maximum 10 micrometers in aerodynamic diameter and PM2.5 being of maximum 2.5 micrometers in aerodynamic diameter. The particulates can cause serious health problems to the respiratory system of human beings. It is documented that there is a reduction of particulate matter emissions when using biodiesel instead of automotive diesel.[62] According to an American study, soya based or rapeseed based biodiesel could reduce particulate emissions by 35 % compared to automotive diesel.[63] Although no direct data were found on effects in shipping, experience from land-based power plants using palm oil instead of HFO shows that the reductions of particulates have been significant.

The emitted particulates from engines consist of organic and inorganic constituents. Organic compounds include unburned fuel, while inorganic constituents include soot, sulphates and metallic compounds.[64] In biofuels, these inorganic constituents are not present. As a result there are minimal PM emissions from these engines which use biofuels.

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[58] TNO 2008, G. Kadijk, *Praktijkemissies EEV Stadsbussen*, 14th of May 2008 and TNO 2010, W.A. Vonk, R.P. Verbeek, H.J. Dekker, Emissieprestaties van jonge Nederlandse personenwagens met LPG en CNG installaties, 21 mei 2010

[59] Karlsson 2010, *Enabling the safe storage of gas onboard ships with the Wärtsilä LNG*

[60] Based on ECSA workshop with ship owner assocations on November 22nd 2011

[61] Based on personal communications and interviews with bunkering parties in the market, ship owners, classification body, and the International Bunkering Industry Association (IBIA) between September and December 2011.

[62] ZERO 2007, Biofuels in ships - A project report and feasibility study into the use of biofuels in the Norwegian domestic fleet

[63] ZERO 2007 quoting Strong et al. 2004

[64] Munack et al. 2005.

4.3.5 Other emissions

In general, biofuels are biodegradable, and when leaked to the environment they do not cause as much concern as with fossil fuels. If biofuels were to be introduced in pure blends, this could be an advantage in reducing HSE costs.

Conclusion

The selected biofuels can be of major positive influence on both the reduction of GHG emissions as on the improvement of local air quality due to no sulphur content.

If used in 100% blends biofuels can have an HSE advantage in case of spills to the marine environment, due to their biodegradable nature, compared to marine fuels.

It is possible to produce the selected biofuels in a sustainable way, as long as sustainability is made mandatory within a clear framework and linked to the incentives for bio energy in the RED.

4.4 Cost-economic analysis

The operational shipping costs are for a large part dominated by fuel costs (up to 50%). While fuel costs are so important in the operational costs (OPEX) the focus in this paragraph lies on comparison between marine fuel and biofuel costs.

Figure 16 shows the market prices for biodiesel and several fossil derived diesel fuels over the past two years. The trend of future prices is impossible to predict. After the oil record of 145 USD/barrel in July 2008, prices have gone up and down between 35 and 100 USD. Nevertheless, it is widely assumed that oil prices will increase in the next decades and that they will be increasingly more volatile.

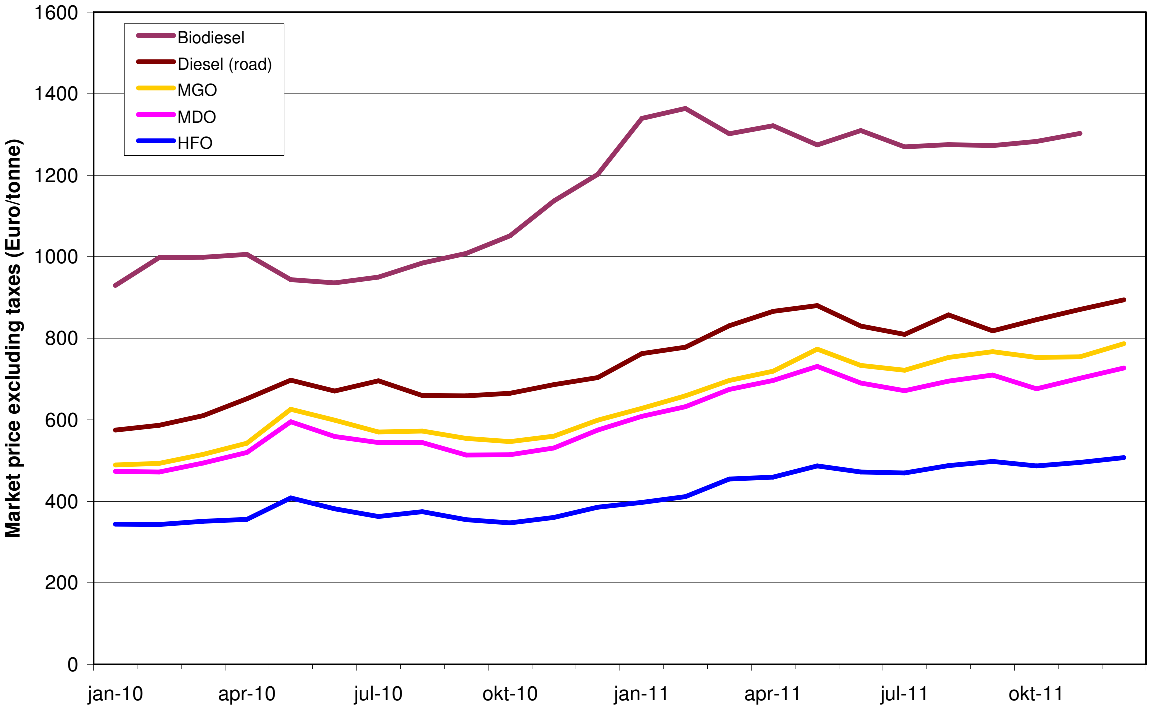

Figure 16 **Historical prices for shipping fuels [www.bunkerindex.com], biodiesel (UFOP) and diesel for road applications, all excluding taxes**

High oil prices directly lead to high fossil fuel product prices, which means that the shipping fuels will get more expensive. The future price of biofuels is also impossible to predict. Some argue that better agricultural management practices and future conversion technologies will lead to lower biofuels prices. Others point out that an increasing competition for agricultural feedstock will counteract this effect. Moreover, high fossil fuel prices increase the energy and fertilizer costs in agriculture. Finally, as long as the biofuels market is smaller than the fossil fuels market, it will follow the price setting in the fossil fuels market. In other words, even if biofuels could be cheaper than fossil fuels, they would not be cheaper in the general market.

4.4.1 Production costs of biodiesel

The production cost of biodiesel, in the past two years, is considerably higher than the cost of fossil fuels. This is reflected in the market price, although it must be understood that the market price also reflects the value of biodiesel on an incentivized market.

Different qualities of biodiesel are traded at different prices. This is especially related to the cold flow properties. The biodiesel shown in Figure 16 above has a low Cold Filter Plugging Point (CFPP) of -10 °C. This means that it will perform well at low temperatures, a characteristic that is important for high blends in road transport in northern Europe in winter. Biodiesel with a CFPP of 0 °C and furthermore the same quality costs about 30-40 Euro/tonne less. Low blends of such biodiesel still tend to perform the same as diesel fuel in cold weather. Blends up to at least 5% have no measurable effect on the cold-flow properties. Yet cheaper qualities of biodiesel are also traded incidentally, but they are probably mixed with higher qualities to meet the market demands. The prices of lower quality biodiesel are not listed.

From Figure 16 above, it can be seen that the gap between the biodiesel price and the diesel specified for road applications (EN 590) has been about 300 to 600 Euro over the past 2 years. In the road fuels consumer market the gap was initially, several years ago, mainly bridged by tax exemption measures. Nowadays, in most EU Member States the fuels are sold simply because the fuel supplier has an obligation to deliver renewable energy, and biofuels are the most logical choice.

The price gap between biodiesel and shipping fuels (MDO, MGO and HFO) is consistently larger, as these fuels are cheaper than road diesel. MDO has been about 100-200 Euro cheaper than road diesel for the past 2 years.

If also cheaper qualities of biodiesel could be used in the shipping sector than what is required in the roadside sector, it could be attractive for fuel suppliers to (partially) fulfill their obligation in the shipping sector. This is allowed according to the Renewable Energy Directive, but not (yet) by the Member States' legislation. In such a case, the gap that must be bridged should be equal to the price differential between road diesel and MDO. This is demonstrated in the following Figure 17.

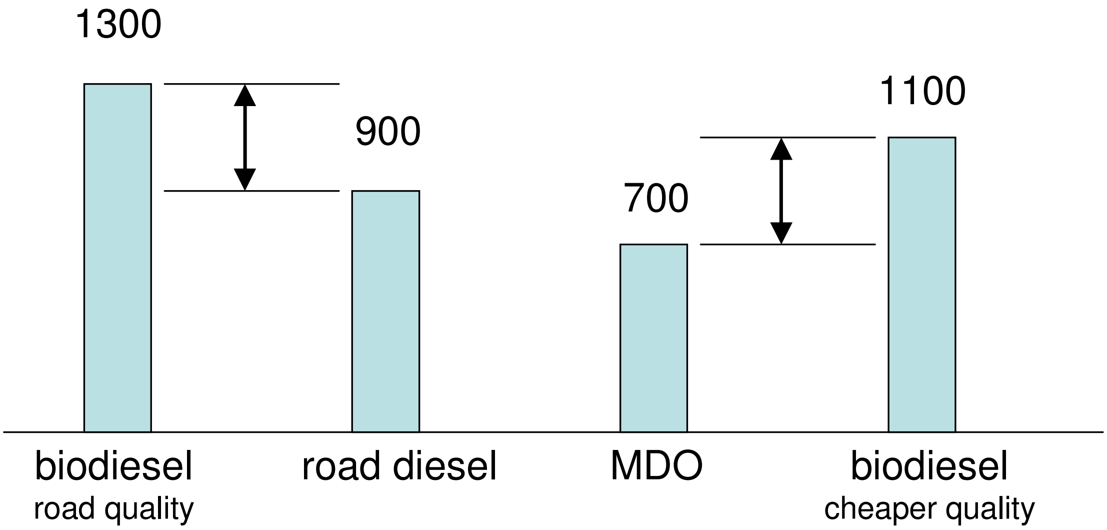

Figure 17 Price differential between biodiesel and diesel for the road sector (left hand side) and between MDO and biodiesel for the shipping sector in case the same price differential is pursued.

When a fuel supplier sells biofuels to the road sector, in order to fulfill his obligation, he would basically make a loss of 400 Euro per tonne of diesel replaced with biodiesel in the example above. In case of a 5% biodiesel blend, this would effectively mean a loss of 20 Euro for each tonne of resulting fuel (0.95 times the diesel price plus 0.05 times the biodiesel price gives a new product price of 920 Euro/tonne). The fuel supplier may recover this loss by increasing the price of all his fuels with 2 eurocents, even if some fuels contain higher fractions of biofuels than others.

If fuel suppliers with an obligation to market biofuels (because of their sales of road fuels) would sell biofuels to the shipping sector, they would probably not increase the MDO price with 20

Euro/tonne as per the example above, because they would then loose precious customers. Rather they would recover the loss in their road fuel sales where the small price rise goes unnoticed.

4.4.2 Other biofuels

An overview of the prices for all evaluated biofuels is given in Figure 18. The prices are expressed on energy basis, to allow a more fair comparison. The bandwidth of prices of fossil shipping fuels, as well as of biodiesel and bio-ethanol of the past 2 years are taken from the earlier discussed Figure 16 above. Also the historical bandwidth of palm oil available on the EU market (thus including the international import costs) and rapeseed oil of the past two years is used. For bioDME and pyrolysis oil, projections of future production costs are taken. Since there is no practical experience, the cost estimations are based on the developers' reports and are likely to be optimistic. For bio-methane, experience costs in different EU Member States give a very broad bandwidth, which is probably caused by the large variation in incentives. The real costs of large scale bio-methane production can be expected at the lower end of the given range.

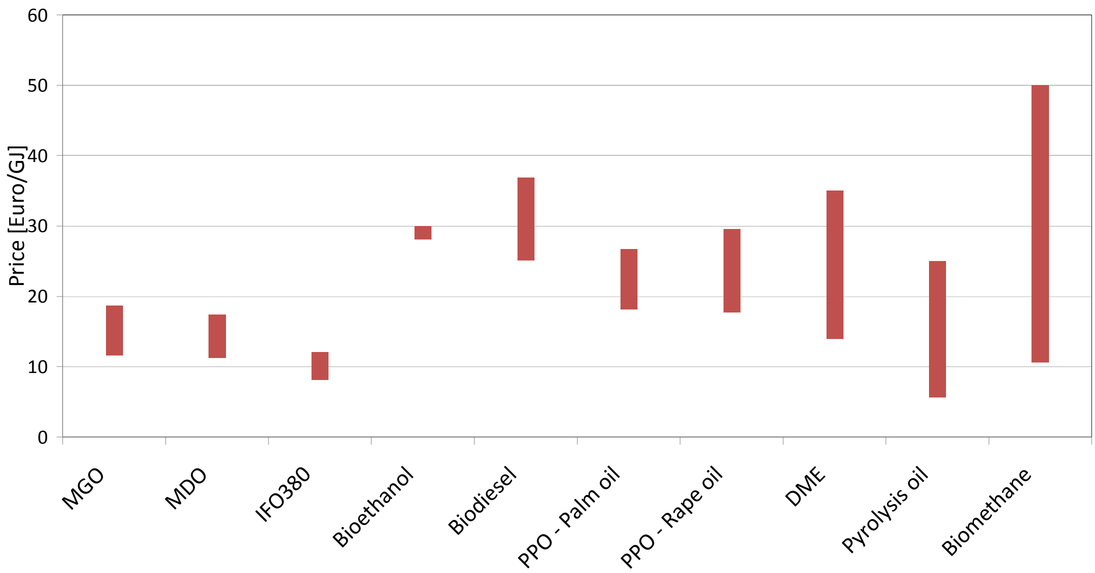

Figure 18 Historical and expected price ranges for selected biofuels.

Figure 18 shows that most biofuels could have a more attractive in price than biodiesel. This means that the gap between the price of marine fuels and biofuels could be smaller than discussed in the previous section. Application of these biofuels require small to significant adaptations in the on-board fuel system, as was discussed in the technical section.

Vegetable oils are structurally cheaper than biodiesel. Currently the price differential is between 380 Euro/tonne (rapeseed oil compared to biodiesel) and 560 Euro (palm oil compared to biodiesel). HFO is cheaper than road diesel, but the price difference is in the same range about 400 Euro over the past two years. This means that it may be economically attractive for bunker fuel suppliers with an obligation to market biofuels if they could sell biofuels to the marine market (see also the same discussion at the end of section 4.4.1). In the far East (Indonesia, Malaysia) palm oil will even be cheaper, but as there would be no incentive (no obligation for renewable fuels in transport), it would not directly be as attractive.

Also the increasing need for the ship owners to shift towards low sulphur fuels, will have impact on the marine fuel prices. Either they buy a more expensive low sulphur fuel, or install equipment on deck (consuming precious storage space) for cleaning the flue gasses, or they shift towards biofuels.
Due to the many uncertainties in prices and market developments concerning this item, it was not possible to make an quantitative analysis on this dilemma for ship owners for investing in end-of-pipe solutions or an overall switch to alternative fuels. Note that investments in sulphur end-of-pipe solutions will realize the growing sulphur restrictions in ECA's for ship owners, but will not contribute to lower carbon emissions.

Certainly, when high sulphur HFO will be phased out in 2020 or 2025, there will be a need for alternative heavy fuels, and vegetable oil or biodiesel blends could be an attractive option.

Marine fuels are sold mostly through spot market, and for a smaller amount through long-term contracting. Drop-in biofuels that do not require adaptations to the fuel system or engine, could be sold via either contract. However, biofuels that require onboard adaptations will only be sold via long-term contracts, since both buyer and seller need a long-term certainty to justify their investments. Possible lock-in of type of biofuels and their technological implications, related to the needed on board investments as well as needed production facilities, is a risk for the flexibility of the (marine) fuel market.

Conclusion

Production costs of biofuels are still more expensive than fossil marine fuels. However, the uncertainty in technological development, scaling and therefore cost reduction could lead to a competitive situation, if marine fuels are to be increasing in price, and if the obligation incentive for biofuels remains within the RED.

Operational costs are of major importance to ship owners and are largely dominated by the fuel costs (up to 50%). If Member States allow in their translation of the RED that biofuels can also be introduced to the shipping sector to meet the obligation, biodiesel in ships would be evenly cost-effective as introduction in the road sector, based on the perspective of the obligation owner.

It could also be the case that biofuels are cost-economic beneficial if sulphur restrictions are increasing for marine fuels, especially the cheaper and widely available biofuels like straight vegetable oils and biodiesel.

4.4.3 Investment costs (CAPEX)

Generally speaking, all alternatives require an investment compared to business as usual. Investments could be at different levels:

- Fuel infrastructure: new filling stations and bunker ships in for instance the case of LNG. The costs of the fuel infrastructure will probably be translated into the fuel price. See also Table 8, for changes in current supply chain.
- Retrofitting: for instance in the case of the installation of sulphur scrubbers for continuation of HFO use and low sulphur limits; or conversion from HFO to LNG.
- New-build: Change to different technology combination (engine and fuel) when purchasing new build ships. The choice for a main engine running on DME is than more costly than a standard HFO engine, at this point, but could lead to economic benefits through lower operational costs.

Based on interviews with stakeholders in the market, it is very difficult at this moment to estimate the actual investment costs, since they depend on size, availability and market maturity.[65] For ship owners the most attractive investments are those where the operational costs shows a large saving compared to business as usual, based on lower fuel prices or other incentives, while their investment costs are depreciated over such a long time period (the technical lifespan of a ship could be over 50 years).

4.4.4 Niche market potential to enhance introduction of biofuels

There are some selected biofuels that seem fitted for so-called niche market application, making an introduction with additional stimulation possible at a shorter period in time.

Based on interviews with the market[66] the following niche market potentials were defined:

- Introduction of biofuels in the passenger segment, such as large cruise ships and ferries. These ships have a major electricity consumption (see also Appendix C for the average fuel consumption per type of engine), much larger than fuel consumption for propulsion. Also, they will spend much more time in the ECA's with growing sulphur limitations giving them (economic) incentive to reduce sulphur content in fuels, and they are assumed to be more sensitive for green imaging (i.e. participation in the WWF Climate Savers programme). Bio-ethanol for their auxiliary engines, biodiesel to be blended with MDO/MGO, or straight vegetable oil to replace HFO are viable options.
- Introduction of biofuels for coastal shipping. Ships with regular scheduled routes within EU, in port areas only (supporting vessels) or for inland shipping will also spend much more time in ECA's, forcing them within the set policy time frame to reduce their fuel sulphur content. Also, these logistical ship patterns take place only or mostly within the EU linking strongly to the RED targets for renewable fuels. Aside to the sulphur incentive and the biofuels obligation, it could also be possible for port authorities to make certain biofuels more attractive by reducing the port costs under certain conditions. This will greatly benefit the operational costs of a ship owner (i.e. at Rotterdam port costs are around 25k Euro per hour) and will directly connect to these intra-EU ships.
- Intrdocution of biofuels in the ships connected to the offshore activities. In the last few years a strong growth has taken place in the introduction of offshore wind farms in

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[65] Based on personal communications and interviews with bunkering parties in the market, ship owners, classification body, and the International Bunkering Industry Association (IBIA) between September and December 2011, plus a workshop ECSA with ship owner assocations on November 22nd 2011.

[66] Same as previous footnote 65.

Europe. Major developments occur in UK, Germany, Belgium, Denmark and the Netherlands. For this offshore renewable special purpose vessels are active in both the construction as the operational phase. From an EC level it would be easy to set additional policy to introduce biofuels for the propulsion of these ships.

Conclusion

Several niche market options are identified and could lead to faster introduction of biofuels in ships, if additional policy would be implemented.

5 Conclusions and recommendations

In this report the potential of biofuels for possible introduction into ships was investigated. To determine this potential three main questions need to be answered:

- Is there currently a market for biofuels to be used in ships?
- Is it possible to use biofuels in ships?
- What is restraining the market to use biofuels in ships?

From these questions and their answers as described below in the conclusions (see section 5.1), main recommendations are drafted towards the shipping sector in order to realize the potential of biofuels in ships (see section 5.2).

5.1 Conclusions

Is there currently a market for biofuels to be used in ships?

Yes, there is a market for biofuels to be introduced in ships based on current policy and support schemes, high operational costs and environmental benefits. The conclusions below support this answer.

- The market for biofuels for transport is created mostly by national and European policies, setting targets for renewable fuels and energy within the Renewable Energy Directive (RED). Almost all biofuels are currently consumed within the road transport sector.
- Within the RED the biofuels obligation can be met by implementing biofuels in ship transportation sector for oil companies delivering fossil fuels to both road and marine transport. This will differ per Member State, depending on the Member State translation of the RED in their legislation. Member States are not obliged to directly translate the RED in their national legislation, as long as they comply with the overall obligation.
- Within the shipping sector targets are set to gradually reduce the emissions to air caused by ship engines by international MARPOL legislation.
- The use of biofuels not only is a strong option to realize lower carbon intensity in the propulsion of ships, but also shows potential to reduce the pressure of ship emissions on local air quality. 100% biofuels show no sulphur content.
- Biofuels, in 100% blends, can even have a Health, Safety, Security and Environment (HSSE) advantage in case of spills to the marine environment due to their biodegradable nature, compared to conventional fossil marine fuels.
- So, biofuels are good sustainable alternative for fossil marine fuels. The sustainability of the biofuel does need to be accounted for within the sustainability framework of the European Commission as mentioned in the RED.

- Operational costs are of major importance to ship owners and are largely dominated by the fuel costs (up to 50%). Biofuels are in most cases more expensive than fossil fuels, due to higher production costs and lower economies of scale. The obligation within the RED forces the fuels market to buy and introduce biofuels anyways. The higher costs (difference between the higher production costs per energy content of biofuels, minus the normal market price of the fossil fuel) are integrated within the overall fuel price in a transport market segment. If Member States allow in their national translation of the RED that biofuels can also be introduced to the shipping sector to meet the obligation, biodiesel in ships could be evenly or even better cost-effective as to be introduced in the road sector, based on the perspective of the obligation owner.
- It could also be the case that biofuels are cost-economic beneficial if sulphur restrictions are increasing for marine fuels, especially in case of the cheaper and widely available biofuels like straight vegetable oils and biodiesel, due to their no-sulphur content.
- Several niche market options are identified and could lead to faster introduction of biofuels in ships, if additional policy would be implemented, such as for passenger and cruise ships, intra EU ships and offshore supporting vessels within the EU.

Is it possible to use biofuels in ships?

Yes, it is technically possible to replace marine fossil fuels with biofuels for use in ship engines. The conclusions below support this answer and elaborate on the most relevant parameters limiting the potential of biofuels: availability, technological development, technical integration, and operational consequences.

- There are many biofuel types in different stages of technological development. Historical developments and current trends show the technological potential for biofuels is far from fully exploited and shows a large potential as a sustainable fuel for the future.
- The major European bunkering locations in North West Europe and Gibraltar have in principle good access to biofuels, especially to biodiesel, based on current production facilities. Also for inland shipping the availability of biofuel production facilities near bunker stations and ports is considered not a bottleneck (see Figure 6 in section 2.4.5).
- Current availability of biofuels though is limited though to traditional production technologies from agricultural crops for biodiesel and bio-ethanol. This could contain a potential threat of lock-in of these types of biofuels and technologies for introduction into ships. Other biofuel types and their resources could be more interesting for this transport segment, based on costs, technical integration into the marine fuel supply chain and overall environmental performance (on greenhouse gas emissions).
- The availability of biofuels in general (aside to their geographical production distribution) is probably not a bottleneck for the introduction of biofuels in the shipping sector. Current underused production facilities in Europe show potential for taking up a possible demand by the shipping sector. The aviation sector is exploring options and could in potential take up a large amount of biofuels, but are aiming on higher quality fuels and therefore new to built production capacity.
- Depending on the type of biofuel they can be easily (drop-in fuels) or with huge modifications (new-build, long term) used in the shipping sector.

- Although not many practical experiences of using biofuels in ships have taken place, technical compatibility of biofuels with marine engines seems high and integration manageable.
- The position of biofuel blending (with the bunker parties or on board of the ship) is still in debate. From an organizational point of view, it would be best at this point to blend the biofuels at the bunker level, in order to have one Bunker Delivery Note per fuel supply with all specifications. Ship owners are not in favour of on board blending, as an extra activity on board of the ship that needs their attention. Current practice in sampling (and lack of guidelines on onboard blending) does not allow the ship owner to harvest the environmental benefits of biofuels to the best potential if they would execute on board blending (as a no-sulphur fuel). Blended (low sulphur) bio/ fossil marine fuels bought at the bunker station can easily follow the current sampling practice and little to no alteration (depending on the type of biofuel) are needed to the supply chain. Also, within the Renewable Energy Directive it will be the bunker parties that would have an obligation to deliver biofuels to the market. Furthermore, the technical integration at the bunker station will be easier and would benefit an economy of scale if on bunker level.
- From a technical integration point of view, small percentage biodiesel blends (up to 20%) with Marine Diesel Oil or Marine Gas Oil (MDO/MGO) seem the most promising fuel for shipping, aside to 100% replacement of Heavy Fuel Oil (HFO) by straight vegetable oils from plants (SVO), due to best compatibility with current engines and supply chain. chain. It can easily replace Marine Diesel Oil or Marine Gas Oil (MDO/MGO). As shown in chapter 4 blending a percentage of 5% biodiesel in current MDO/ MGO fuels would be the easiest introduction looking at technical alteration to the supply chain, availability of the biofuel, and cost price of the biofuel.
- Aside to the limited application of bio-ethanol in diesel engines, the investments needed to the supply chain seems manageable, although less favourable than for biodiesel and SVO. It remains an attractive option as alternative fuel with better environmental performance for auxiliary engines in ships with higher on board energy consumption (such as cruise ships and passenger ferries).
- Di-methyl ether (DME) and bio-liquid natural gas (bio-LNG) are still upcoming technologies, with at this point limited biomass feedstock availability due to the technological immaturity. Also, more investments are needed to the fuel supply chain in order to introduce these fuels. For new build ships these fuels seem more promising.

What is restraining the market to use biofuels in ships?

Market incentives are there, it is technological possible, but still the introduction of biofuels is limited to a few applied test projects and local initiatives. The following conclusions were drafted by Ecofys on market barriers that need to be addressed in order to accelerate the introduction of biofuels in the shipping sector.

- The main market barrier that should be addressed is the fact that the market incentives in place (obligation within the Renewable Energy Directive, and the sulphur restrictions within the MARPOL legislation) are affecting different market parties in the marine fuel supply chain. Bunker parties could be affected in the fuel obligation, where ship owners are responsible for meeting the lower sulphur content in their used fuels and for other environmental impacts of their shipping (such as spills, waste etc) and also will have the exposure benefits of green imaging or profiling.
- Introducing biofuels to the shipping sector will have both opportunities and threats to the current market players in the fuel supply chain. The major opportunity would be the ability to shift position in the supply or rather value chain (upstream – downstream) if i.e. ship owners would produce biofuels themselves or cooperate with new biofuel entries in the marine market. This could be a threat to the larger players in the conventional market which have position in both fossil fuel supply as well as shipping.
- There is no large experience of biofuels use in ship engines. Known R&D projects that investigate the possibilities are all private company initiatives, and applied in operational ships. Public information is limited in availability.
- So, there are still some uncertainties around a full scale introduction of biofuels concerning the technical aspects. Current research and stakeholder interviews show contradicting arguments and only small scale test results are available, as a clear indication of first orientations by current market players. Especially the Health, Safety, Security and Environment aspects in the operational situation should be investigated further for introduction of biofuels on a substantial scale (e.g. a fixed percentage for every ship to use biofuels).
- The known restraints from the market concerning biofuels (long term storage related to unstable fuel quality and micro biological growth, water content leading to acidity, degraded low-temperature flow properties) are based on unfamiliarity with biofuels in this sector. Data collection from literature, the current R&D projects, and interviews with stakeholders have not led to recognition of these technical restraints. All restraints seem manageable with mitigation measures such as limited to larger retro fitting adjustments, good housekeeping and set-up of clear fuel specifications for biofuels, depending on the blend percentage. Still, proof of principle on larger scale is missing.
- To comply with the expectations on higher environmental performance of biofuels, sustainability of biofuels is of strong importance and affects the production of biofuels and with that the market. In the aviation sector a clear preference is shown towards biofuels from new, more sustainable resources such as algae to prevent potential exposure and liability on using non-sustainable biofuels. As the shipping sector is still in an orientation mode, this aspect and lessons learned from other industries can be taken into account with a head start (e.g. by setting references in fuel standards for marine market to the sustainability criteria mentioned in the Renewable Energy Directive).

- Current practice and stakeholder opinion would lead to blending of biofuels at the bunker station. This means the blending initiative will lie with the bunker parties, although current ownership and responsibilities in the fuel supply chain lie fully with the ship owners. The current sampling practice could be amended with better guidelines within MARPOL on compliance with presenting sulphur content in their fuels. This way, the biofuel in its own tank and fuel supply system can be contained and monitored better on board of the ship, and the ownership on fuel quality and its environmental benefits remains with the ship owners.
- The consequences of using biofuels for the operational side seem limited if lower blends are used. Biofuels do need special attention if used in higher or 100% blends (mainly due to the higher water content which needs frequent monitoring). This asks for training and integration within the stringent HSSE management on board of ships.
- Legislation for shipping is limited to a low level of detail, and not so much EU dominated and highly detailed as for road transport which operates more local/ national. For shipping the International Maritime Organization (IMO) is of major importance and acts on a global scale where a worldwide level playing field is of strong importance. This could be a hurdle for the introduction of biofuels, if the RED for example would be prolonged actively towards the shipping sector.
- Production costs of biofuels are still higher than for fossil marine fuels. However, the uncertainty in technological development, scaling and therefore cost reduction could lead to a competitive situation, if marine fuels are to be increasing in price, and if the obligation incentive for biofuels remains within the RED. This remains an unpredictable factor in the future marine fuel market with strong effect on the introduction of biofuels.

5.2 Recommendations

1. EMSA is recommended to stress for more focus in the Renewable Energy Directive (RED) on the obligation at the bunkering parties and not only the general supplying market. This way also obliging bunker parties supplying only to the marine sector with could have a biofuels target. EMSA could focus on a clear proposal for the review of the RED, scheduled for 2014. The coming two years could be used for extended research into the technical uncertainties and the new fuel supply chain (see recommendation 5) should be worked out, with a focus on the European shipping market.
2. To accelerate the introduction of biofuels in the shipping sector, it is recommended to introduce a separate fuel standard for biofuels to use in ship engines. Experiences in road transport and aviation show that such a dedicated fuel standard accelerates market acceptance and introduction of the fuel. There are several ways to introduce such a fuel standard, in which EMSA could play an encouraging role:

- Through an EC initiative, focusing on the European market such as inland shipping, intra-EU and dedicated offshore maintenance ships. This way the standard could be made binding, and will stimulate fuel quality in general in the shipping market. Alignment with an adjusted RED (with separate ambitions or stronger focus on alternative fuels for shipping) as well as the benefits of accelerate biofuels introduction into ships for air quality should support the EC initiative.
- Through the works of the IMO. The current version of the ISO8217:2010 technical fuel standard for marine fuels does not facilitate the introduction of biofuels. Based on more practical experience (see recommendation 5) the international fuel standard could be altered and could be made legally binding within the MARPOL legislation.

This way the international shipping market is targeted to introduce biofuels. With a good biofuel standard IMO would give the market concrete new tools and means to comply with MARPOL legislation on sulphur content.

- Through a market initiative: the market could set up a standard themselves. To have an optimal effect it would be best if both ship owners and bunker associations would align in drafting such a standard. EMSA for example could organize a meeting with ECSA and IBIA to discuss the frameworks of such an initiative.

3. Much could be learned from the current developments in the aviation industry. EMSA could lobby with IMO to take example of the IATA approach, to set up ambitious targets for biofuel introduction. This way a clear signal to the market is given on how to make the industry more climate neutral and with a better environmental performance in terms of air pollution and spills. IMO this way would motivate ship owners as well as bunker parties to change their supply chains and take position
4. Some "quick wins'" in addressing market barriers are identified in current MARPOL legislation. A change in Energy Efficiency Design Index for ships is a way to stimulate the introduction; now there is only focus on carbon content without making distinction between fossil carbon and biogenic carbon produced by biofuels. Also, guidelines for the blending of biofuels, either on bunker level or on board of ships, could help the shipping sector to switch to biofuels in order to comply with lower sulphur restrictions. EMSA has a good position to facilitate these changes within the IMO.
5. More R&D research is required on the technical uncertainties and efficiency potential of biofuels for ships. To prevent scattered market initiatives in R&D trials and to upgrade the test results to a larger perspective, it would be recommended to create a special Framework Programme on the innovation potential and uncertainties of biofuels in ships. This way the knowledge and experience is also disseminated properly throughout the market. Article 4C of directive 2005/33 regarding the sulphur content of marine fuels states that European Member States can be exempted from marine fuel sulphur requirements laid out in article 4A and 4B for emission abatement techniques testing purposes. The requirements for testing are that the EC and all involved port states are notified of these tests and that the results are provided to the Commission and made publically available. EMSA could use this possibility for tests together with a cooperation with Department of Research of the EC to fundamentally investigate the effects of larger scale biofuel introduction into ships. Focus areas for research would be the use and limitations of 100% blends of biodiesel and straight vegetable oil for full operation and for longer storage, and the use of bio-ethanol in the auxiliary engines.
6. Engine manufacturers and classification bodies should anticipate more on the introduction of biofuels in the marine sector and expand their terms & conditions, guarantees and so on to include biofuels. EMSA could motivate these parties to develop energy labels for ships together with them that not only take into account energy efficiency in current and new ships but also look at environmental impact of alternative fuels in mono fuel or dual fuel engines. Lessons from other e-labeling methodologies and implementation schemes (build environment, cars) can be integrated. First initiatives for e-labeling of ships have started, the Dutch government for example has recently asked Ecofys to investigate the e-labeling possibilities for inland shipping.
7. An overall benchmark of the performance of the different ship types and their emissions with ETS or levy kind of system could lead to incentives for the market.

The aviation sector for example will be submitted to European Emission Trading Scheme for carbon emissions as of 2013. EMSA could investigate the effects of this decision by the EC together with IATA or other aviation branch organizations as to define if this measure would also be possible and effective for the shipping sector.

8. Ship owners and bunker parties in their turn should define their strategic pathway in the coming changes in the bunker fuel market. Long term vision and strategy in this is of strong importance. An important role in this re-positioning and set up of new supply chains is given to the port authorities as clusters of the different fuel industries. EMSA could play a mediating role in this multi stakeholder debate and encourage the market towards a sustainable transition. It is recommended to start with the larger market groups where introduction of biofuels could also have green profiling benefits, such as the cruise and passenger ships and large container carriers.

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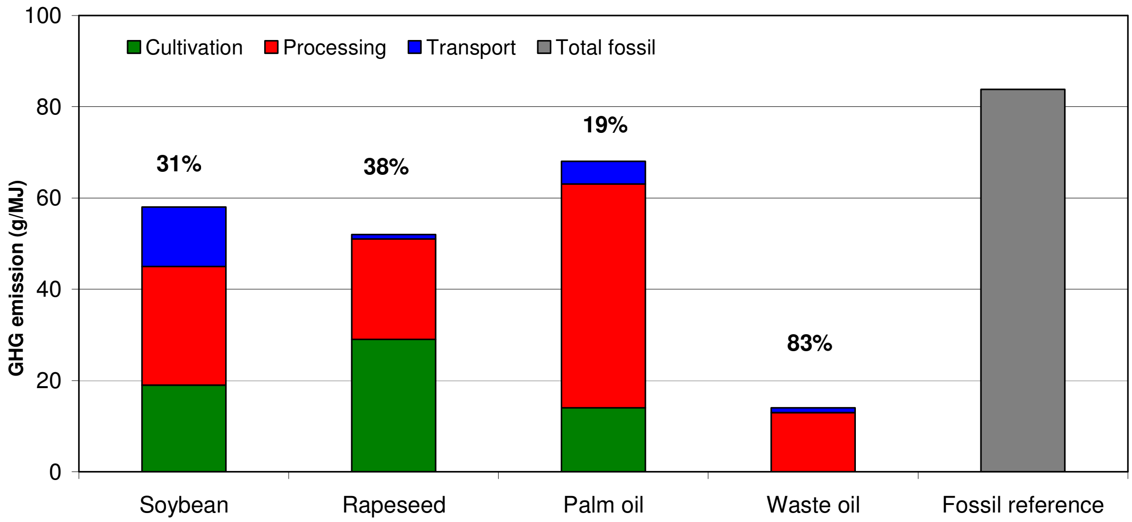
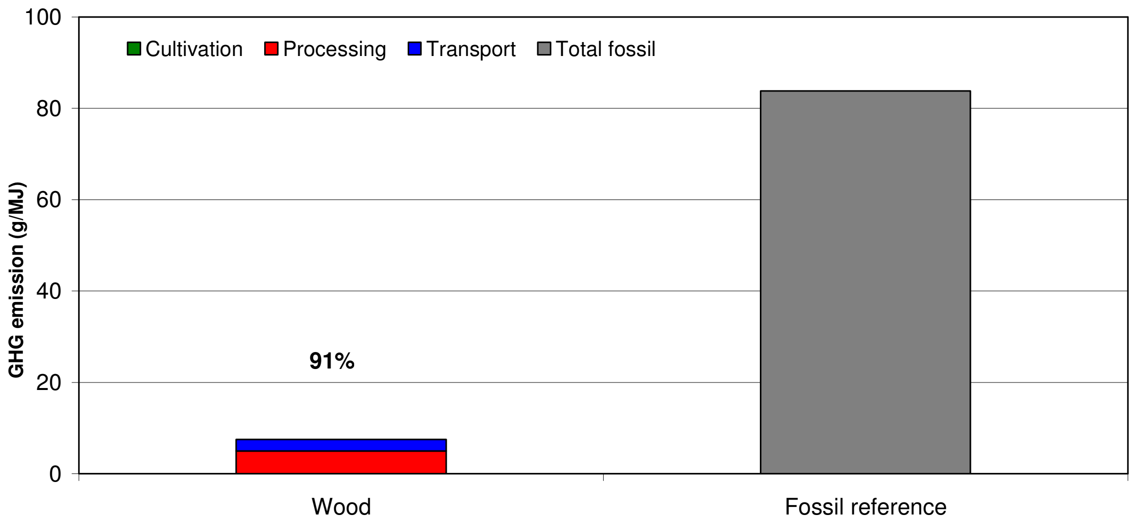
Appendix A GHG balance of selected biofuels

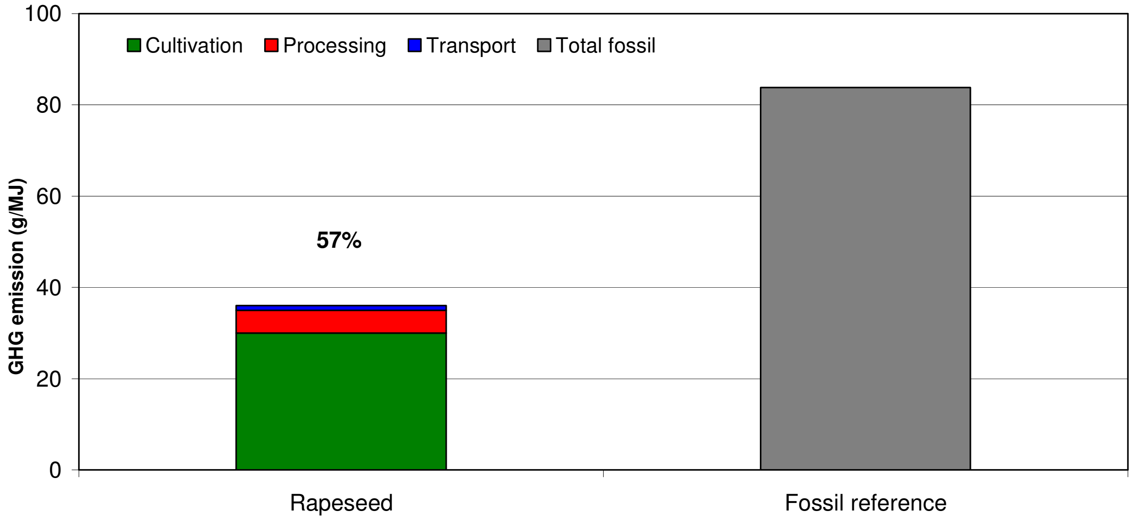
A-1 Biodiesel



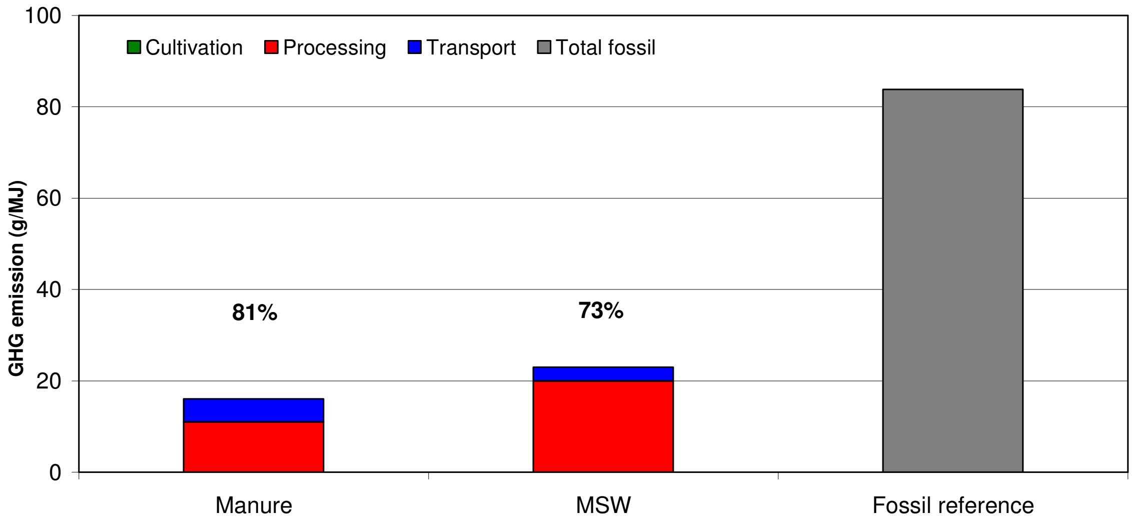
A-2 Di-methyl ether (DME)



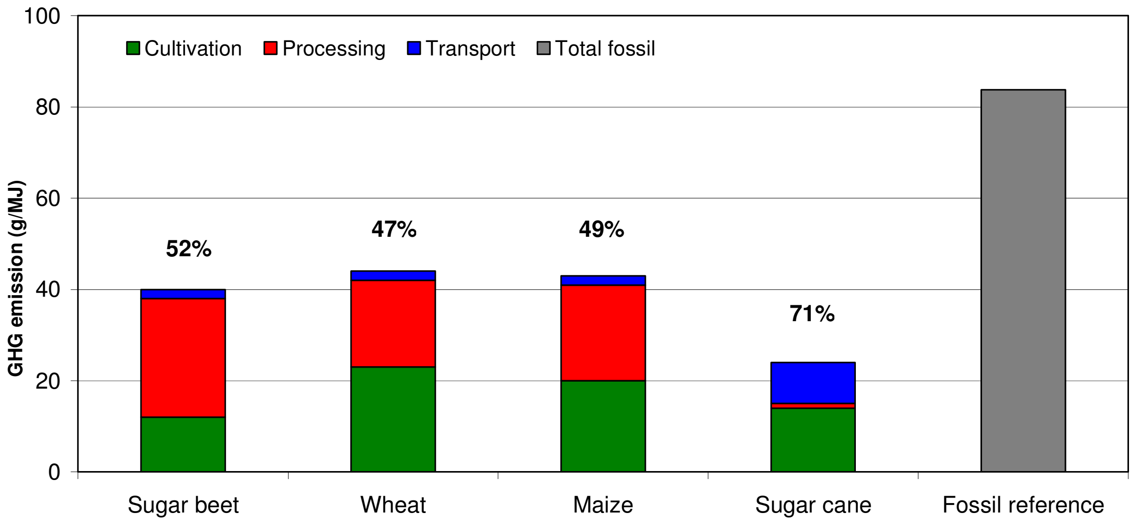
A-3 Straight vegetable oil (SVO)



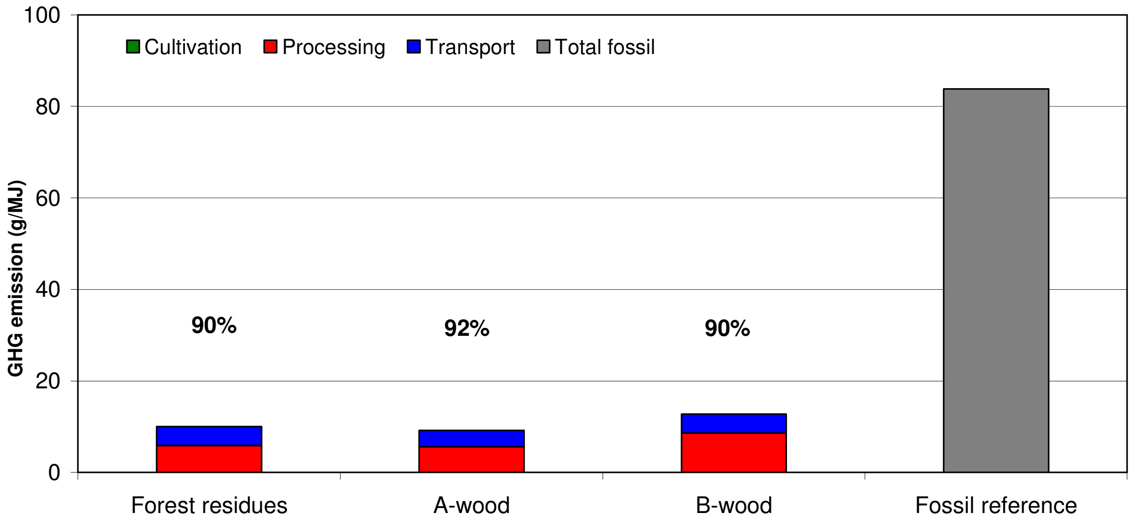
A-4 Bio-methane



A-5 Bio-ethanol



A-6 Pyrolysis bio-oil



Appendix B ISO8217:2010 IMO Standard for marine fuels

Table 1 — Distillate marine fuels

Characteristics	Unit	Limit	Category ISO-F- DMX	DMA	DMZ	DMB	Test method reference
Kinematic viscosity at 40 °C[a]	mm^2/s	max.	5,500	6,000	6,000	11,00	ISO 3104
		min.	1,400	2,000	3,000	2,000	
Density at 15 °C	kg/m^3	max.	—	890,0	890,0	900,0	see 7.1 ISO 3675 or ISO 12185
Cetane index	—	min.	45	40	40	35	ISO 4264
Sulfur[b]	mass %	max.	1,00	1,50	1,50	2,00	see 7.2 ISO 8754 ISO 14596
Flash point	°C	min.	43,0	60,0	60,0	60,0	see 7.3 ISO 2719
Hydrogen sulfide[c]	mg/kg	max.	2,00	2,00	2,00	2,00	IP 570
Acid number	mg KOH/g	max.	0,5	0,5	0,5	0,5	ASTM D664
Total sediment by hot filtration	mass %	max.	—	—	—	0,10[e]	see 7.4 ISO 10307-1
Oxidation stability	g/m^3	max.	25	25	25	25[f]	ISO 12205
Carbon residue: micro method on the 10 % volume distillation residue	mass %	max.	0,30	0,30	0,30	—	ISO 10370
Carbon residue: micro method	mass %	max.	—	—	—	0,30	ISO 10370
Cloud point	°C	max.	–16	—	—	—	ISO 3015
Pour point (upper)[d] — winter quality	°C	max.	–6	–6	–6	0	ISO 3016
Pour point (upper)[d] — summer quality	°C	max.	0	0	0	6	ISO 3016
Appearance	—	—	Clear and bright[j]			e, f, g	see 7.6
Water	volume %	max.	—	—	—	0,30[e]	ISO 3733
Ash	mass %	max.	0,010	0,010	0,010	0,010	ISO 6245
Lubricity, corrected wear scar diameter (wsd 1,4) at 60 °C[h]	µm	max.	520	520	520	520[g]	ISO 12156-1

Table 2 — Residual marine fuels

Characteristic	Unit	Limit	RMA 10[a]	RMB 30	RMD 80	RME 180	RMG 180	RMG 380	RMG 500	RMG 700	RMK 380	RMK 500	RMK 700	Test method reference
			Category ISO-F-											
Kinematic viscosity at 50 °C[b]	mm^2/s	max.	10,00	30,00	80,00	180,0	180,0	380,0	500,0	700,0	380,0	500,0	700,0	ISO 3104
Density at 15 °C	kg/m^3	max.	920,0	960,0	975,0	991,0	991,0				1010,0			see 7.1 ISO 3675 or ISO 12185
CCAI	—	max.	850	860	860	860	870				870			see 6.3 a)
Sulfur[c]	mass %	max.	Statutory requirements											see 7.2 ISO 8754 ISO 14596
Flash point	°C	min.	60,0	60,0	60,0	60,0	60,0				60,0			see 7.3 ISO 2719
Hydrogen sulfide[d]	mg/kg	max.	2,00	2,00	2,00	2,00	2,00				2,00			IP 570
Acid number[e]	mg KOH/g	max.	2,5	2,5	2,5	2,5	2,5				2,5			ASTM D664
Total sediment aged	mass %	max.	0,10	0,10	0,10	0,10	0,10				0,10			see 7.5 ISO 10307-2
Carbon residue: micro method	mass %	max.	2,50	10,00	14,00	15,00	18,00				20,00			ISO 10370
Pour point (upper)[f] – winter quality	°C	max.	0	0	30	30	30				30			ISO 3016
Pour point (upper)[f] – summer quality	°C	max.	6	6	30	30	30				30			ISO 3016
Water	volume %	max.	0,30	0,50	0,50	0,50	0,50				0,50			ISO 3733
Ash	mass %	max.	0,040	0,070	0,070	0,070	0,100				0,150			ISO 6245
Vanadium	mg/kg	max.	50	150	150	150	350				450			see 7.7 IP 501, IP 470 or ISO 14597
Sodium	mg/kg	max.	50	100	100	50	100				100			see 7.8 IP 501
Aluminium plus silicon	mg/kg	max.	25	40	40	50	60				60			see 7.9 IP 501, IP 470 or ISO 10478
Used lubricating oils (ULO): calcium and zinc; or calcium and phosphorus	mg/kg	—	The fuel shall be free from ULO. A fuel shall be considered to contain ULO when either one of the following conditions is met: calcium > 30 and zinc > 15; or calcium > 30 and phosphorus > 15											see 7.10 IP 501 or IP 470 IP 500

Appendix C Ship specifications

IMO GHG Study			Average fuel oil consumption (thousand tonnes per year)				Ave. GT	Fuel Type
Category	Size	number of ships in 2007	Main Engine	Aux Engine	Boiler	Total	2007	
Crude oil tanker	200,000+ dwt	494	21.8	1.2	1.3	24.3	155,685	HFO
Crude oil tanker	120,000–199,999 dwt	353	16.5	1.5	0.9	18.8	80,711	HFO
Crude oil tanker	80,000–119,999 dwt	651	12.2	1	3	16.1	56,921	HFO
Crude oil tanker	60,000–79,999 dwt	180	8.2	0.8	3	12	39,498	HFO
Crude oil tanker	10,000–59,999 dwt	245	6.2	0.8	1.5	8.5	24,290	HFO
Crude oil tanker	0–9,999 dwt	114	1.1	0.2	0.5	1.8	2,085	DO/HFO
Products tanker	60,000+ dwt	198	7.7	1	3.6	12.2	46,775	HFO
Products tanker	20,000–59,999 dwt	456	4.5	0.9	3	8.4	24,262	HFO
Products tanker	10,000–19,999 dwt	193	2.9	0.6	1.8	5.3	9,723	HFO
Products tanker	5,000–9,999 dwt	466	1.8	0.3	0.9	3	4,264	MDO/HFO
Products tanker	0–4,999 dwt	3,959	0.6	0.1	0.3	1	1,056	DO/HFO
Chemical tanker	20,000+ dwt	1,010	8.5	1	0	9.5	24,917	HFO
Chemical tanker	10,000–19,999 dwt	584	4.7	0.7	0	5.4	9,357	HFO
Chemical tanker	5,000–9,999 dwt	642	3	0.5	0	3.5	4,651	DO/HFO
Chemical tanker	0–4,999 dwt	1,659	0.7	0.2	0	1	1,331	DO/HFO
LPG tanker	50,000+ cbm	138	12.1	1.2	0	13.3	43,784	HFO
LPG tanker	0–49,999 cbm	943	1.9	0.5	0	2.3	4,834	DO/HFO
LNG tanker	200,000+ cbm	4	28.5	3.8	0	32.4	135,846	HFO
LNG tanker	0–199,999 cbm	239	31.1	2.8	0	33.8	90,933	HFO
Other tanker	Other	402	0.9	0.2	0	1.1	2,030	DO/HFO
Bulk	200,000+ dwt	119	15.2	1.2	0	16.4	114,519	HFO
Bulk	100,000–199,999 dwt	686	13.1	1	0	14.1	83,619	HFO
Bulk	60,000–99,999 dwt	1,513	8.8	0.8	0	9.6	39,568	HFO
Bulk	35,000–59,999 dwt	1,864	7	0.8	0	7.8	27,596	HFO
Bulk	10,000–34,999 dwt	2,090	5.4	0.7	0	6.1	15,351	HFO
Bulk	0–9,999 dwt	1,120	0.9	0.3	0	1.2	1,942	MDO/HFO
General cargo	10,000+ dwt	674	5.8	0.6	0	6.3	11,382	HFO
General cargo	5,000–9,999 dwt	1,528	3.1	0.3	0	3.5	4,704	DO/HFO
General cargo	0–4,999 dwt	11,006	0.5	0.1	0	0.6	1,061	MDO/HFO
General cargo	10,000+ dwt, 100+ TEU	1,225	5.8	0.7	0	6.5	15,641	HFO
General cargo	5,000–9,999 dwt, 100+ TEU	1,089	2.1	0.4	0	2.6	5,294	MDO/HFO

IMO GHG Study			Average fuel oil consumption (thousand tonnes per year)				Ave. GT	Fuel Type
Category	Size	number of ships in 2007	Main Engine	Aux Engine	Boiler	Total	2007	
General cargo	0–4,999 dwt, 100+ TEU	1,486	1.1	0.4	0	1.4	2,724	DO/HFO
Other dry	Reefer	1,239	4.3	0.7	0	5	4,998	DO/HFO
Other dry	Special	228	4.1	0.6	0	4.8	12,201	MDO/HFO
Container	8,000+ TEU	118	46.4	5.9	0	52.3	100, 082	HFO
Container	5,000–7,999 TEU	417	37.5	4.6	0	42.1	70,290	HFO
Container	3,000–4,999 TEU	711	25.2	2.8	0	28	45,317	HFO
Container	2,000–2,999 TEU	667	15.6	2.2	0	17.7	29,363	HFO
Container	1,000–1,999 TEU	1,115	9.7	1.4	0	11.1	16,438	HFO
Container	0–999 TEU	1,110	3.1	0.8	0	3.9	6,967	DO/HFO
Vehicle	4,000+ ceu	398	13.2	1.1	0	14.4	51,549	HFO
Vehicle	0–3,999 ceu	337	7.3	0.7	0	8	20,561	HFO
Ro-Ro	2,000+ lm	194	10	1.2	0	11.2	25,725	HFO
Ro-Ro	0–1,999 lm	1,517	1.7	0.4	0	2.1	3,557	DO/HFO
Ferry	Pax Only, 25 kn+	984	2.6	0.1	0	2.7	302	DO/HFO
Ferry	Pax Only, <25 kn	2,108	1.2	0.1	0	1.3	392	DO/HFO
Ferry	RoPax, 25 kn+	177	18.3	1.1	0	19.4	12,119	DO/HFO
Ferry	RoPax, <25 kn	3,144	4.5	0.7	0	5.2	4,723	DO/HFO
Cruise	100,000+ gt	24	47.5	2	0	49.5	119,041	HFO
Cruise	60,000–99,999 gt	69	32.6	4.3	0	36.9	79,541	HFO
Cruise	10,000–59,999 gt	130	12.5	2.4	0	14.8	29,559	HFO
Cruise	2,000–9,999 gt	74	3.2	1	0	4.2	4,851	HFO
Cruise	0–1,999 gt	202	0.5	0.2	0	0.7	664	MDO
Yacht	Yacht	101	0.6	0.2	0	0.8	560	DO/HFO
Offshore	Crew/supply vessel	607	0.7	0.1	0	0.8	246	MDO/HFO
Offshore	Platform supply	1,733	0.7	0.4	0	1.1	1,127	DO/HFO
Offshore	Tug/supply ship	550	0.5	0.3	0	0.8	905	MDO/HFO
Offshore	Anchor handling T/S	1,190	1.6	0.7	0	2.3	1,545	DO/HFO
Offshore	Support/safety	487	0.8	0.3	0	1.1	1,486	DO/HFO
Offshore	Pipe (various)	246	1.2	0.9	0	2.1	6,657	MDO/HFO
Service	Research	895	1.1	0.4	0	1.5	1,641	MDO/HFO
Service	Tug	12,330	0.8	0.1	0	0.9	281	MDO/HFO
Service	Dredging	1,206	1	0.5	0	1.5	2,191	DO/HFO
Service	SAR & patrol	992	0.6	0.2	0	0.8	523	MDO/HFO
Service	Workboats	1,067	0.4	0.2	0	0.6	1,559	MDO/HFO

IMO GHG Study			Average fuel oil consumption (thousand tonnes per year)				Ave. GT	Fuel Type
Category	Size	number of ships in 2007	Main Engine	Aux Engine	Boiler	Total	2007	
Service	Other	813	1.1	0.2	0	1.3	1,360	MDO/HFO
Miscellaneous	Fishing	12,849	0.3	0.2	0	0.5	313	MDO/HFO
Miscellaneous	Trawlers	9,709	0.8	0.4	0	1.2	601	DO/HFO
Miscellaneous	Other fishing	1,291	1.3	0.3	0	1.6	1,296	DO/HFO
Miscellaneous	Other	667	4.2	0.9	0	5.1	11,497	DO/HFO

Appendix D Project overview of biofuels in ships

This appendix provides an overview of existing R&D projects, where biofuels have been tested onboard ships as well as.
Practical R&D projects on fuelling ships on DME are not yet existing to our knowledge.

D-1 Royal Caribbean Cruises (RCCL) testing on biodiesel

RCCL tested the use of biodiesel on some of their Caribbean-based cruise ships, amongst which the “Jewel of The Seas”, in their GE LM2500 gas turbines. Until recently, the turbines ran on petro-diesel exclusively. RCCL started out with 5% blends and eventually fuelled the turbines with a 100% biodiesel.

Contrary to earlier projects in the Great Lakes area where environmental protection was in the focal point, RCCL initiated biodiesel testing shortly after the US biofuel tax scheme was introduced. Shortly after the tests finished RCCL tabled a report in favor of biodiesel which also stated that reduced soot emissions in the fuel system along with the obvious positive effects on the environment. RCCL is signaling biodiesel availability as the main challenge with regards to an increased use of biodiesel.

	RCCL biodiesel testing project
Consortium partners	RCCL, Imperium Renewables
Contact details	JW_ChiefEngineer@rccl.com (Trond Are Berg, Chief Engineer GTV Jewel of the Seas)
Year	2006-2007 (project was scheduled for 5 years, but RCCL stopped in 2008)
Budget	n/a
Type of fuel	Biodiesel
Blend rate	Started with 5% blend, eventually used 100%
Engine Specs	GE LM2500 gas turbines
Sponsors	None

D-2 Bioship project - Anna Desgagnes (2006)

From mid June to mid October 2006 the maritime freight ship Anna Desgagnes was powered by B20 biodiesel. The project was undertaken in collaboration with Transport Canada and Environment Canada, Maritime Innovation and the Sine Nomine Group. The project aimed to demonstrate the viability of biodiesel for maritime transport and evaluated the economic, technical and operational advantages of biofuel for the maritime industry.

	Bioship project - Anna Desgagnes
Consortium partners	Maritime Innovation (Canadian) ($ 42.500), Transport Desagnes Inc. ($ 225.000), Sine Nomine Group ($ 10.000), Canada Environmental Technology Centre ($ 10.000)
Contact details	Richard Lavoie, Maritime Innovation, 418-725-3525 Carole Campeau, Transport Desagnes, 418-692-1000 Website: http://www.imar.ca/en/
Year	2006
Budget	$487.500
Type of fuel	Biodiesel: blend of rendered animal fats and cooking oils
Blend rate	1 of the four generators powering the ship ran on biodiesel
Engine Specs	n/a
Sponsors	Canada Transport ($200.000)

D-3 Maersk and Lloyd's marine engine biofuel test (2010-2011)

Maersk and Lloyd's ran a biofuel feasibility test in 2010 and continue to access batches of biofuels in their Kalmar freight vessel during 2011.
In 2010, the biodiesel FAME (fatty acid methyl esters) used for the test were based on sustainable crops grown in (temperate) regions or reused oils, and supplied by Shell. Blends were tested on increasing blends up to 100% FAME. Note that the tests were only performed on secondary diesel engines (for electricity production) as use of biodiesel is not allowed in the drive engines for safety reasons if Maersk wishes to comply with the fuel standard ISO 8217.

The outcome of the FAME test shows that FAME use in marine diesel engines is possible, but requires elevated attention to housekeeping. No negative impacts were detected on the engine, but the amount of test hours may not be sufficient to draw significant conclusions (160 hours). Tests confirmed that the engine was easier to start when fed on FAME, which was to be expected because of its higher cetane number (measure of a fuel's ignition delay, similar to octane number for gasoline) so engine was easier to start. Although emission tests were performed, the (poor) quality of the measurement data did not allow for meaningful conclusions. Major outcomes of the test were that no microbiological growth in the FAME tanks occurred in the period from April to November 2010.

	Suitability of biodiesel in use for powering marine engines
Consortium partners	Maersk (Line, Tankers, Supply Service, Drilling, Ship Management), Lloyd's Register's Strategic Research Group, Consortium of Dutch subcontractors
Contact details	Maersk: Lasse Kragh Andersen, Senior Environmental Specialist, tosoheenv@maersk.com, +45 33634495 Lloyd Register's Strategic Research Group: Kim Tanneberger, Biofuel Research specialist, kim.tanneberger@lr.org, +44 (0)20 7423 1923
Year	2010
Engine Specs	The MAK 8K32 engine dedicated to the project is powering a 3.5 MW generator. Ship name: Maersk Kalmar
Budget	n/a
Type of fuel	FAME
Blend rate	5-7%. Engine supplier has indicated that up to 20% blend is possible.
Sponsors	Dutch Government (GAVE program)

D-4 Deen Shipping bio-LNG for inland shipping (2011)

Deen Shipping has a Dual Fuel ship "Arganon" for inland shipping. Consortium partners Deen, PON Power (Caterpillar), Cryonorm Projects, Shipyard Trico, CBRB worked on the project. Recently the first agreement to deliver bio-LNG was made with Deen Shipping by Holland Innovation Team (HIT). They import bio-LNG from Chive, a UK company that distributes LNG and bio-LNG.

	Deen shipping building Dual Fuel ship "Arganon" for inland shipping
Consortium partners	Deen, PON Power (Caterpillar), Cryonorm Projects, Shipyard Trico, CBRB
Contact details	Deen Shipping: info@arganon.nl , +31 (0)78 619 0084 Pon Power: power.nl@pon-cat.com , +31 78 6420 420 Shipyard Trico: info@tricobv.nl , +31 10 294 0800 Cryonorm: info@cryonormprojects.com, T +31 172 41 80 80 CBRB: cbrb@binnenvaart.nl, T +31 10 798 98 00
Year	2011
Budget	n/a
Type of fuel/blend rate	80% LNG, 20% Diesel
Sponsors	European Regional Development Fund, AgentschapNL, Province of Zuid-Holland

D-5 STX Europe Group orders ship that runs on biofuels (2011)

This will be the first installation ever where a European commercial shipping operation is going to permanently use liquid bio-fuel. The ship is currently being built in Finland and will be delivered in spring 2012. It can use different types of liquid biofuel.

D-6 Wärtsilä conversion of tanker from heavy fuel oil to LNG

In November 2011, Wärtsilä Corporation has completed the conversion of the 25,000 dwt product tanker *Bit Viking* from heavy fuel oil to liquefied natural gas (LNG) operation. The conversion enables the *Bit Viking* to qualify for lower nitrogen oxides (NO_x) emission taxes under the Norwegian NO_x fund scheme. The conversion involved changing the 6-cylinder in-line Wärtsilä 46 engine running on heavy fuel oil to 6-cylinder in-line Wärtsilä 50DF dual-fuel engines that operate on LNG. When gas is used in a dual-fuel engine, CO_2 emissions are reduced by about 20% compared to liquid fuels[67]. The vessel's classification certificate was also updated. The engines are connected directly to the propeller shafts through a reduction gearbox, thus avoiding the electrical losses that are an unavoidable feature of diesel-electric configurations. This enables a significant improvement in propulsion efficiency, reduced fuel consumption, and corresponding reductions in emissions. This is also the first LNG fueled vessel to be classified by Germanischer Lloyd.

The Bit Viking utilizes Wärtsilä's new LNGPac system, which enables onboard storage of LNG. The two 500 cubic meter LNG storage tanks are mounted on the deck to facilitate bunkering operations and permit the bunkering of LNG at a rate of 430 cubic meters per hour. The storage tanks provide the vessel with 12 days of autonomous operation at 80% load, with the option to switch to marine gas oil if an extended range is required. When visiting EU ports, which have a 0.1% limit on sulphur emissions, the vessel operates on gas.

Figure 19 Tanker Bit Viking, converted to run on LNG [Source: Karlsson 2011]

67 [Karlsson 2011]

	Earthrace/Ady Gill
Consortium partners	The vessel was designed by LOMOcean Design (formerly Craig Loomes Design Group Ltd.) and built by Calibre Boats in Auckland, New Zealand.
Contact details	http://www.lomocean.com/ tel. +64 (0)9 360-9799 fax. +64 (0)9 360-9795 Email. andre@lomocean.com
Year	2005-2010 (Reported as sinking on January 7, 2010)
Budget	$2.5 million for the construction of the ship
Type of fuel	animal fat and vegetable oil mix biodiesel
Engines	two 540 horsepower Cummins Mercruiser engines
Range	12,000 nautical miles (22,224 km) from 12,000 litres (2,640 imp gal) of fuel capacity
Blend rate	diesel, biodiesel or blends
Sponsors	n/a

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