Biofuels in ships

A project report and feasibility study into the use of biofuels in the Norwegian domestic fleet

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Olav Andreas Opdal and Johannes Fjell Hojem

ZERO

Zero Emission
Resource Organisation

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About ZERO

ZERO Emission Resource Organisation is a Norwegian organisation dedicated to working for solutions that provide zero emissions and no damage to the environment. ZERO is a non-profit foundation. ZERO are not consultants, the battle against climate change is ZERO's only mission. However ZERO participates in partnerships financed by third parties.

More info about ZEROs work is enclosed in Appendix 5 of this report and on our website; www.zero.no

Questions regarding this report may be directed to:

Olav Andreas Opdal
Olav@zero.no
+ 47 99 64 59 75

ZERO – Zero Emission Resource Organisation
Maridalsveien 10
0178 Oslo
www.zero.no

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Abbreviations

BTL – Biomass-To-Liquids
CTL – Coal-To-Liquids
CNG – Compressed Natural Gas
CO_2 – Carbon Dioxide
FAME – Fatty Acid Methyl Esther
GHG – Greenhouse Gas
GTL - Gas-to-liquids
HFO – Heavy fuel oil
LBF – Liquid biofuel
LNG – Liquefied Natural Gas
MDO – Marine Diesel oil
MGO – Marine Gas Oil
NGO – Non Governmental Organisation
N_2O – Nitrous Oxide
NO_x – Nitrogen Oxides
OEM - Original Equipment Manufacturer
PAH – Polycyclic Aromatic Hydrocarbon
PM – Particulate Matter
PSV – Platform supply vessel
REE – Rapeseed Ethyl Esther
RME – Rapeseed Methyl Esther
SME – Soy Methyl Esther
SO_2 – Sulphur dioxide
TTW – Tank-To-Wheel
WTT – Well-To-Tank
WTW – Well-To-Wheels

Preface

This report is made by Olav Andreas Opdal M.Sc. and Johannes Fjell Hojem of the Norwegian environmental NGO ZERO.

Other contributors include Vegard Hole who has written parts of Chapter 12 and Dagfinn Bakke who has translated parts of this report from Norwegian.

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The authors would like to thank all those involved with providing information on the use of biofuels in ships. This includes engine manufacturers, ship owners, biofuel producers and public institutions. We would like to pay special thanks to Terje C. Gløersen of the Norwegian Shipsowner's Association, Kai Juoperi of Wärtsilä and Thomas Knudsen of MAN B&W Diesel. This report could not have been made without their help.

With this report it is the authors hope that all those involved in marine transport will see new possibilities in renewable energy and that this report can shed light on biofuels as a viable fuel for ships. It is also our hope that this report will be an inspiration for all those willing to find new solutions to combat the severe threat of global warming.

Oslo, 18.12.2007
Olav A. Opdal

Abstract

The increased awareness of human induced global warming has created an interest in using renewable energy instead of fossil fuels. Marine transport is one of the least energy intensive way of transporting goods, however, it is also one of the sectors with the fewest available alternatives to fossil fuels. To combat global warming, all industrial sectors should take measures to cut emissions; biofuels can help achieve this in marine transport.

The Norwegian domestic fleet consists of a wide variety of different sized vessels employed in a range of sectors from fishing ships to supply ships for the offshore industry. Major engine manufacturers are MAN, Wärtsilä, Rolls Royce/Bergen Diesel and Caterpillar.

Although not currently used commercially in any part of the world, there have been a limited number of projects using biofuels in ships. For example in the Great Lakes Region in USA there have been a number of successful projects with biofuels. These and more projects demonstrate that existing engines can be modified to operate on biofuels.

Also the extensive use of crude plant-oil in the land-based power generating industry is interesting as these plants use engines similar to those in large ships.

Some technological challenges exist when converting to biofuels from petroleum based fuels. 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.

Low blends of biofuels in marine diesel oil and heavy fuel oil (MDO/HFO) may be a way of implementing biofuels for ships based on the model used for automotive transport. Switching between fuels may be done without major problems to the engine; however the fuel system may need some adjustment.

The most promising biofuels for use in ships are biodiesel and crude vegetable oil, however pyrolysis oil and other biofuels may prove to be potential alternatives. The preferred choice of raw material is rape oil or soya oil, but residual oils (waste cooking oils), palm oil, sunflower oils and others can be alternatives. Biodiesel is most suitable for replacing marine distillate and vegetable oil is most suitable for replacing residual fuels.

The production of vegetable oils is growing and production in 2006 was 100 million tonnes. Only a small percentage of this production volume is used for biodiesel production. In 2006 the production of biodiesel reached 6.4 million tonnes. The major part of biodiesel production being in Europe: in 2006, 4.9 million tonnes biodiesel were produced, which was a 54 % increase from the previous year. Nevertheless the production capacity for biodiesel in the world is much bigger. A larger demand for biodiesel will increase levels of production. Second generation biofuels made out of biomass like wood and algae-diesel will further boost production.

Biofuels are more expensive than fossil fuels, calculations show that a typical supply ship for the Norwegian petroleum industry using MDO will almost double its fuel expenses when changing to biodiesel. Carbon dioxide-taxes could however increase in the future and by using lower priced biofuels, such as pyrolysis-oils, the price gap could be significantly reduced.

Biofuels are sulphur-free, thus the use of biofuels will remove the SO_2 problem from shipping. Also the emissions of particulate matter will be significantly reduced resulting in a reduced health risk. Only renewable CO_2 will be emitted during combustion, and even though there are some greenhouse gas emissions during production of the biofuel, the climate change gas reductions will be substantial when changing from fossil fuels to biofuels.

NOx-emissions may increase slightly though the technology is available to deal with this problem. Carcinogenic Polycyclic Aromatic Hydrocarbons emissions are reduced so are the emission of Carbon Monoxide emissions.

Because biologically derived fuels are biodegradable, in the unfortunate event of a fuel spill, there will be a reduced impact on the local marine environment compared to a spill involving petroleum fuels.

Increasing production of biofuels grown on agricultural land will have an impact on the price of agriculture products, such as food. However the increase in food prices is not expected to be dramatic.

It is estimated that even with the foreseen increase in use of biofuels, the overall prices on food will have a more moderate development than the average cost on other products. It is also important to bear in mind that this increase comes after almost 40 years of a steady decrease in prices of agricultural products on the world market.

A more steady increase of prices of agricultural products will benefit many of the poorest people in the world whose main source of income is linked to agriculture. Higher priced food will on the other hand be negative for the urban poor.

Some countries, both poor and rich, will benefit from an increase in food prices whilst others will loose. This is dependant upon on how much food these countries import and what proportion of the exports are made up of agricultural products.

Biofuels also open up new opportunities for many poor countries, both to become less reliant upon imported oil and to produce an agriculture product which will have an almost permanent demand from the rest of the world.

However as development on new biofuels technologies evolve, biofuels that not affect foodprice at all will be available. For instance biofuels produced from agricultural waste and from residues from the forest industry will be available.

Sammendrag

Økt bevissthet omkring menneskeskapt global oppvarming har ført til at interessen for å bruke fornybar energi også har økt. Sjøtransport er en av de mest energieffektive måtene å transportere varer på. Samtidig er det også en av de sektorene der det finnes færrest tilgjengelige alternativer til fossile drivstoff. For å bekjempe global oppvarming må alle sektorer iverksette tiltak for å kutte utslippene; biodrivstoff kan hjelpe til for å oppnå dette i den marine sektoren.

Den norske innenriksflåten består av en stor variasjon av større og mindre skip i forskjellig operasjon. Flåten inkluderer alt fra fiskefartøy til forsyningsskip for offshore-sektoren. Store motorprodusenter representert i den norske innenriksflåten er MAN, Wärtsilä, Rolls Royce/Bergen Diesel og Catarpillar.

Bruken av biodrivstoff i skip har vært begrenset internasjonalt og bruken er ikke kommersialisert. Likevel har det vært et begrenset antall prosjekt med bruk av biodrivstoff i skip. For eksempel ser det ut som Great Lakes området i USA har hatt et stort antall prøveprosjekt som har vært vellykket. Den omfattende bruken av planteoljer til stasjonære anlegg for kraftproduksjon er interessant siden det i disse anleggende brukes tilsvarende motorer som i skip.

Det eksisterer noen tekniske utfordringer med konvertering av motorer og motorsystemer til bruk av biodrivstoff. Syrenivået i biodrivstoffet setter krav til syrebestandig materiale, biodrivstoff trenger også omhyggelig temperaturkontroll. Likevel er ikke den tekniske konverteringen spesielt avansert. Lavinnblanding av biodrivstoff i HFO/MDO kan være en mulig innpassing av biodrivstoff i det marine markedet slik som det er gjort på landtransport. Bytting mellom bio- og fossile drivstoff kan også gjøres uten store problem for motoren, dette kan imidlertid medføre noe modifikasjon av systemet.

De mest lovende biodrivstoffene for bruk i skip er bioolje og biodiesel, men også bioetanol og pyrolyseolje kan vise seg å bli mulige alternativ. Anbefalt råstoff for produksjon av biodrivstoff er rapsolje eller soyaolje, men også vegetabilsk restolje, palmeolje, solsikkeolje eller andre råstoff kan brukes. Biodiesel er mest tilpasset som erstatning for MDO, mens bioolje kan tenkes erstatte HFO.

Verdens produksjon av palmeolje er økende og nådde i 2006 100 millioner tonn per år. Bare en liten del av denne produksjonen brukes til biodieselproduksjon. I 2006 var produksjonen 6.4 millioner tonn. Brorparten av biodieselproduksjonen er i Europa, i 2006 ble det produsert 4,9 millioner tonn biodiesel i Europa. Det var en økning på 54 % fra året før. Produksjonskapasiteten er mye større, et større marked vil kunne utløse denne produksjonen. I tillegg vil algediesel og annen generasjons biodrivstoff laget av skog kunne øke råstoff grunnlaget betraktelig.

Produksjon av biodrivstoff er dyrere enn fossile drivstoff, beregninger viser at et typisk forsyningsskip med bytte av MDO til biodiesel vil omtrent doble utgiftene for drivstoff. Det kan tenkes at rammevilkårene endres, for eksempel at CO2-skatten økes. Dette kan gjøre at billig biodrivstoff slik som pyrolyseolje kan bli konkurransedyktig med fossile marine drivstoff.

Biodrivstoff har ikke noe innhold av svovel, noe som gjør at utslippene av svoveldioksid kuttes helt ved en overgang til biodrivstoff i skip. Utslipp av svevestøv vil også bli drastisk redusert og gi et bedre arbeidsmiljø for skipets personell. Bare fornybar CO_2 slippes ut ved bruk av biodrivstoff, og selv om det er noe drivhusgassutslipp ved dyrking av biodrivstoff vil utslippene av drivhusgasser reduseres betraktelig ved en overgang fra fossile drivstoff til biodrivstoff. NOx-utslippene økes sannsynligvis litt; teknologi er tilgjengelig for å behandle disse utslippene. Utslippene av polysykliske aromatiske hydrokarbon som kan forårsake kreft blir kraftig redusert, det samme gjelder karbonmonoksidutslippene.

Biodrivstoff er biologisk nedbrytbart og ved en oljesølulykke vil biodrivstoff ha en bedre innvirk-

ning på det lokale maritime miljøet enn fossile drivstoff.

Økt forbruk av biodrivstoff dyrket på jordbruksland vil ha en effekt på prisen på landbruksprodukter som for eksempel matprisen. En slik økning av matprisen vil ikke bli dramatisk. Det er antatt at selv med den økte bruken av biodrivstoff som er forutsett i verden vil ikke matprisen ha mer en moderat utvikling i forhold til prisøkningen på andre produkter. Det er også viktig å tenke på at prisøkningen på mat kommer etter nesten 40 år med stødig prisnedgang på landbruksprodukter på verdens markedet.

En stødigere utvikling av prisene på landbruksprodukter vil gavne mange av de fattigste menneskene i verden, som baserer størstedelen av inntekten sin på landbruksprodukter. Høyere pris på matvarer vil på den andre siden være negativt for de fattige i byen. Noen land, både fattige og rike vil tjene på prisutviklingen, andre vil tape. Dette avhenger av hvor mye matvarer de importerer og hvor avgjørende del landbruksprodukter utgjør av eksporten.

Biodrivstoff åpner nye muligheter for fattige land. Både til å bli mer selvforsynt av energi og å produsere et landbruksprodukt med nesten uendelig etterspørsel på verdensmarkedet.

1. General Introduction

«Biofuels in Ships» is a feasibility study conducted by the environmental NGO ZERO. It addresses the potential of using biofuel in the Norwegian domestic fleet and in ships in general. The report consists of three parts; Part I Technical Factors, Part II Market and commercial issues, Part III Environmental and social considerations.

1.1 Background

Awareness of global warming has increased markedly in recent years. Alarming new reports tell of increasing concentrations of CO_2 in the atmosphere and higher temperatures as shown in figure 1:

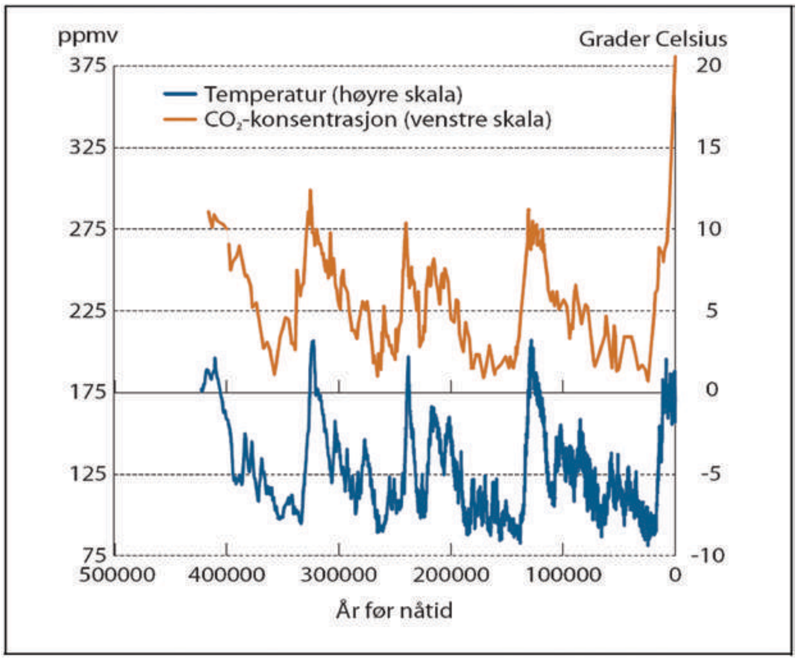


Figure 1: Historic temperature variation and CO_2 concentration in the atmosphere (Norsk offentlig utredning No. #18, 2006)

Sea transport is one of the least energy intensive modes of transport, thus the emissions are relatively low compared to other modes. Figure 2 shows emissions from different types of transport:

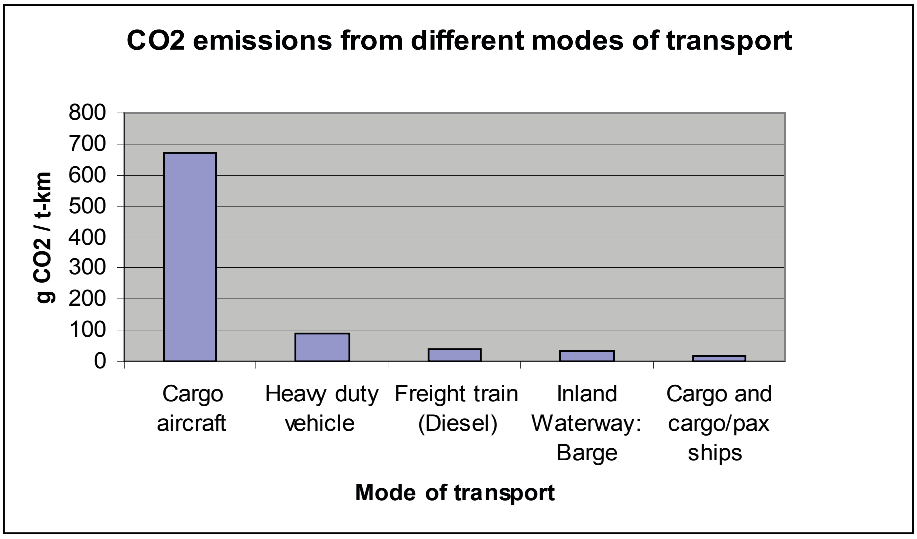


Figure 2: CO2-emissions from different modes of transport (TRT 2007)

However, the fuels currently in use in marine transport are residual fuels from petroleum, a very impure product resulting in large emissions of SO_2, NOx and Particulate Matter (PM) emissions. Furthermore the international shipping industry is not subject to any CO_2-regulation and no practical measure is currently available for switch from fossil fuels to renewable alternatives.

More energy-efficient designed ships together with fuel-efficiency technologies could help reduce greenhouse gas emissions, but there is a limitation on how far this can go. Therefore, it is necessary to develop systems and utilise renewable energy sources in ships and thus reducing the CO_2-emissions further to carry out a given transport work. Biofuels could be the fuel of choice in this regard.

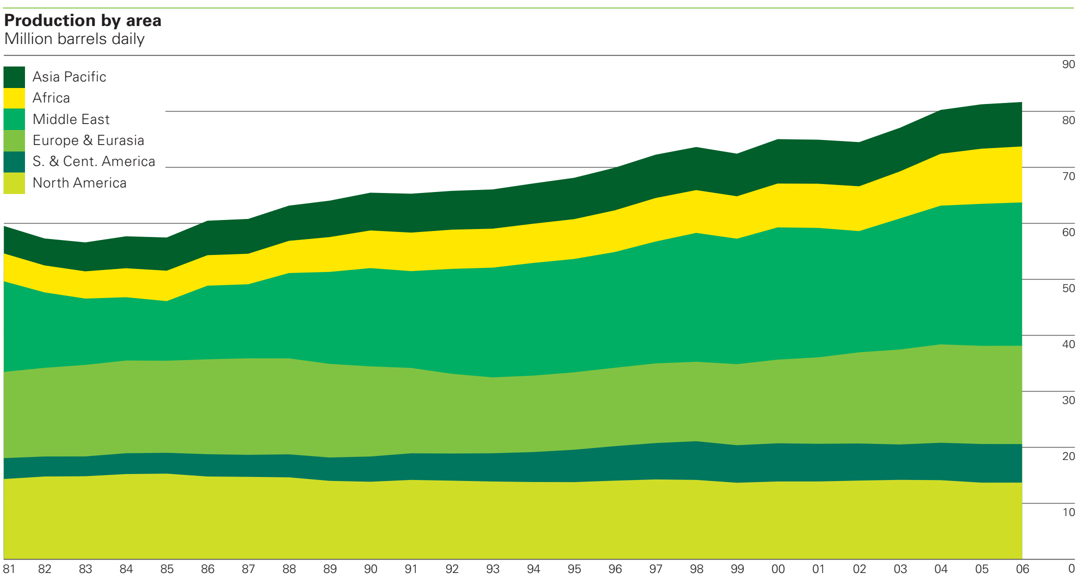
Norwegian domestic fleet is one of the major emitters of greenhouse gases in Norway and in 2006 the fleet released greenhouse gases corresponding to 3.8 million tonnes CO_2-eq, corresponding to about 7 % of the total Norwegian GHG-emissions. (Statistics of Norway 2007). In this figure, coastal traffic accounted for 2,5 million tonnes CO2-eq, the fishing fleet about 1.3 million tonnes of CO2-eq.

Global oil production and consumption continues to grow and is expected to continue increasing well into the future (BP 2007). Global oil production is rapidly reaching peak production in some parts of the world leading to higher prices. In Norway for example the peak production of oil has been already been reached.

Industrial development in India and China are two of the most important reasons for a higher crude oil demand in the world. To achieve the millennium goals put forward by the UN for development in Third World countries, energy has to play an important role. Thus, this development will put further pressure on the global oil market.

Unrest in some parts of the oil producing world, as in Iraq and Iran, is also leading to increased uncertainty of oil production. All these factors have contributed to boost the oil price over the past few years. This boosts the possibility of using other alternative transport fuels previously considered unrealistic due to low oil prices. Figure 3 shows the development in oil production over the last 25 years:

Figure 3: Oil production historical overview (BP 2007)



World oil production rose by 400,000b/d in 2006. Former Soviet Union output rose by 450,000b/d, driven by Russia and Azerbaijan. OECD production fell by 430,000b/d, with declines in Norway, the UK and Mexico offsetting growth in Canada. Other non-OPEC production increased due to rising Angolan output. OPEC output edged up by 130,000b/d.

World shipping, heavily dependent on fossil fuels, also feels the increased tension in this market and is thus affected by the availability and price of marine fuels. Alternative fuels can help ease this pressure and be beneficial for the sector in the long run. In this report one alternative is examined; the potential of using biofuels in ships' engines.

1.2 Limitations of study

The study focuses on the Norwegian domestic fleet since a possible introduction of biofuels will most likely start in the domestic fleet in order to guarantee reliable supply of compliant biofuels in their bunkering ports, but the findings may be transferable to other countries and international sea transport.

This is a feasibility study only; and to realise the potential of using biofuels in ship engines further research should be made on an experimental basis. Development is needed, both in relation to the production of suitable and low-cost biofuels in sufficient quantities and with respect to the operational aspects of using such biofuels in ship-engines. Also incentives from the Government will be needed to stimulate this development and switching to biofuels.

Part I: Technical Factors

2. Technical factors - introduction

Initially we present a synopsis and evaluation of existing biofuel-testing, ongoing research and other relevant projects. Later we take an overview and assessment of anticipated ship compatible installations using biofuels. In chapter 6 we outline potential technical challenges in the wake of applying biofuels in ship engines.

2.1 The Norwegian domestic fleet

The Norwegian domestic fleet is indeed diverse consisting of a wide range of marine vessels; ranging from fishing ships vessels to cargo vessels. As an illustration, table 1 displays Norwegian ships operating domestically (DNV, 2004), covering vessels with propulsion machinery above 750 kW engines only, hence, excluding most recreational boats and some fishing vessels.

Table 1: Domestic fleet (Norwegian). Engine power > 750 kW (DNV 2004)

Vessel category	Number of vessels
Fishing vessel	212
Ferries	125
Speed boats	50
Passenger boats	58
Research vessel	111
Offshore supply ships	20
Stand-by ships	50
Cargo ships	61
Total	**687**

According to The Statistics of Norway (SSB), a comprehensive study of the Norwegian fleet is being carried out at the time of writing and is expected to be available in early 2008. (Terje A. Gjertsen, SSB).

Table 2 gives a statistical distribution of engine makes installed in Norwegian vessels in domestic operation. Some of the listed manufacturers have merged while others have been subject to takeovers. Caterpillar and Wärtsilä are the most influential companies with regards to domestic ship-engine market share. As a footnote Wärtsilä and MAN possess the most knowledge on the operation of biofuels in their engines.

Table 2: Installed engines in the Norwegian domestic fleet

Engine	Share of fleet
Wärtsila/Wichmann	25 %
Deutz	7 %
MWM	4 %
Rolls Royce/Bergen Diesel	12 %
MAN B&W (inkl. Alpha)	9 %
MTU (inkl. Detroit)	7 %
Caterpillar/MAK	25 %
Mitsubishi	3 %
NOHAB	2 %
Others (At least 20 different)	7 %

2.2 Conventional Marine fuels

The international standard organization (ISO) list 19 different marine fuels which meet the requirements for marine fuels supplied world wide onboard ships. Out of these 19 fuels, the 4 most important marine fuels are IFO180, IFO380, MDO and MGO. These relate to the ISO grades RME25, RMG35, DMB and DMA respectively as specified in ISO 8217:2005 (ref. Appendix 1 and 2). MDO stands for Marine Diesel Oils and MGO stands for Marine Gas Oils (Bunkerworld 2007).

In the Norwegian domestic fleet MDO and MGO represent the biggest share of fuel use, but there is also some use of HFO. According to the Statistics of Norway only about 20 % of the fuel sales in Norwegian harbours is heavy fuel oil (Statistics of Norway 2007)

To some extent also natural gas is being used as fuel for marine transport. For instance a lot of new ferries in Norway use natural gas.

Image below: The supply vessel «Viking Dynamic». Photo: Norwegian Shipowners' Association.

3. Biofuels in the marine sector - Experience

The evidence suggests that biofuels are only used on a limited basis within the marine sector. However, we have identified some projects where biofuels have been tested. Both the short and long term effects of operating biofuels on machinery have been examined.

Interestingly, a great number of projects involving biofuels in marine vessels have been conducted in the region of the Great Lakes in North America. Most of these projects are triggered by a need to reduce local emissions such as smog and sulphur emissions and are focussed on smaller recreational boats. A summary comprising various biofuel-projects is given below:

3.1 Great Lakes Biodiesel Market Development Program

In 1998 a feasibility study was initiated focussing on biodiesel in recreational boats within the Great Lakes. Simultaneously, the study aimed to explore how a regional biodiesel distribution net could be developed. The fuel of focus in this study was soya biodiesel.

The study concluded that biodiesel may very well replace fossil fuels in recreational boat engines. It also stated that if biodiesel became price-competitive with fossil fuels, some retailers would start selling it (Great Lakes Market Development Program 1999).

3.2 Great Lakes Environmental Research Laboratory (GLERL)

As part of their research on environmental improvements in the marine sector, GLERL have initiated a project and converted their research ships to run on biodiesel. The project was started in 1998 and over the past nine years the project has been successful in switching from petroleum fuels to biofuels.

In addition also all the onboard mechanical and hydraulic systems have been converted to run on vegetable oils to complete the objective of petroleum-free vessels. NOAA R/V Huron Explorer, one of the ships in the program, was awarded the U.S. Department of Energy's Federal Energy Management Program during an Earth Day Week event on the shores of Lake Michigan in 2006. It was the first US vessel with a combustion engine to operate totally free of petroleum products.

Figure 4: The first US research vessel to operate completely free of petroleum products (NOAA, 2007)

The fuel of choice in this program has been soya based biodiesel. The programme is ongoing with particular focus on reducing NOx-emissions, monitoring long-term effects of using biodiesel and also the possible use of ethanol in small recreational boats (NOAA, 2007).

3.3 Great Lakes Maritime Research Institute

In 2006 The Great Lakes Maritime Research Institute carried out a large research project aimed at determining the technical and economic viability of using biodiesel in marine vessels. In this project the focus was on soya biodiesel.

Technically the study addressed some potential problems concerning the use of biodiesel in marine vessels.

The fact that biodiesel acts as a solvent is considered potentially problematic as there is a tendency for biodiesel to soften and degrade certain rubber and elastomer compounds which often are used in older engines. These issues could be resolved by switching to system components with synthetic hoses and seals that are biodiesel resistant.

In addition, the study claims that new engines are often are biodiesel compatible but that the OEM (Original Equipment Manufacturer) should be consulted before use.

Another concern was that biodiesel could potentially remove deposits left in the fuel system by petroleum diesel which could then clog filters. Filters should thus be checked and cleaned. Low blends of biodiesel up to B20 was said to be observed without any fuel system degradation (Hasan et al. 2002).

3.4 Annis Water Research Institute

Another research programme in the same area conducted by the Annis Water Research Institute and Grand Valley State University aimed to investigate Biodiesel compatibility in two research ships on Lake Michigan.

These boats were powered by a Cummins engine and a Detroit diesel engine. Again the project used soya based biodiesel. The motivation for this project was to reduce the damage to the local environment and the problems of exposing passengers to the diesel exhaust. Some tests were conducted and the study concluded that using B20 would involve a minor risk only for the engine. During the conducted tests no damage to machinery was noted (Annis Water Resource Institute et al. 2003).

3.5 BioMer Canada

The BioMer project was a joint undertaking by Maritime Innovation Sine Nomine Group and Rothsay (biodiesel manufacturer). The four Montrèal cruise companies Croisères AML, Bateau-Mouche, Lachine Rapid Tours and Lachine Canal Cruise provided 12 boats for biofuel trials (BioMer 2005).

The BioMer project ran from mid-May to mid-October 2004. The project's objectives were to:

- Test the use of pure biodiesel (B100) as an alternative fuel to tour boats of various sizes;
- Assess the economic viability and benefits of biodiesel in the routine operations of the marine industry;
- Measure the environmental impact of biodiesel.

The 12 boats used in the project were all passenger boats of which the biggest had a capacity of 750 passengers. The biofuel used was biodiesel made from offal and waste cooking oils. Biodiesel made from used cooking oil and offal is of poor quality but could also potentially be very cheap.

Table 3: Fuel consumption results from the BioMer project (BioMer 2005)

	Difference in Biodiesel Energy Content per Unit Volume	Difference in Engine Performance	Difference in Fuel Consumption
B5	-0.3 %	+2.3 %	-1.8 %
B20	-1.4 %	+2.3 %	-0.8 %
B100	-7.2 %	+3.3 %	+3.3 %

In the project report there are a few recommendations regarding the operation of biodiesel in boats. Below some of the most important recommendations are summarized:

- In order to reduce release of build-up due to the Biodiesel's solvent effects it is necessary to thoroughly clean onboard and dockside fuel tanks before switching from petroleum fuels

to biofuels. Even at blends as low as 5 % biodiesel cleaning of tanks most be made. If the cleaning of storage tanks prior to the fuel switch is not possible, schedule three or four additional fuel filter changes during the cleansing period.
- Tune diesel engines e.g. by adjusting injection timing and duration, to optimise efficiency and performance before any use of B100. Note that after such tuning, the engine must run on B100 exclusively and should be readjusted before returning to petrodiesel.

The study concludes that the BioMer project yielded very promising results for using biodiesel in maritime transport (BioMer 2005).

3.6 Biodiesel in recreational boats (UK)

A joint research study aiming to investigate the positive and negative sides with regards to the introduction and use of biodiesel in recreational boats in the United Kingdom was undertaken in 2003.

The institutions behind this study were The Department of Naval Architecture and Marine Engineering, University of Strathclyde Glasgow, The Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology, Trondheim and the Norwegian Maritime Directorate, Oslo.

The study aimed at investigating whether biodiesel could be used in recreational boats in order to reduce the impact on the local marine environment. It concluded that fuelling recreational boats in UK with biodiesel could be feasible if rapeseed cultivation reached a certain level. The study claims the most obvious obstacle to using biodiesel is the price of biodiesel compared to that of fossil fuels (Zhou et al. 2002).

Rapeseed based biodiesel (RME) was used in this study.

3.7 Earthrace

In 2008 a new speedboat record attempt is planned. A group lead by engineer Pete Bethune will set out from New Zealand to try and set a new speed record for circumnavigating the globe. The aim is to do this in 65 days with a boat fuelled by 100 % biodiesel. The project called Earthrace, is aimed at raising awareness about environmental issues and the sustainable use of resources.

The Earthrace boat is powered by two Cummins Mercruiser engines, both with a power output of 350 kW.

Captain of the ship, Pete Bethune, states that they hope to demonstrate that biofuels are a possible alternative to fossil fuels. Bethune started the project in 2002 and has tried to raise funds from investors who believed in his project. It has not been possible to obtain information about how the engine and fuel system of the Earthrace boat were adapted in order to use biodiesel.

More information about the Earthrace project can be found on the projects webpage, www.earthrace.net.

Figure 5: Earthrace boat fuelled by biodiesel. Photo: earthrace.net

3.8 RCCL

RCCL undertook testing on some of their Caribbean-based cruise ships, «Jewel of The Seas» among others, by using biodiesel in their GE LM2500 gas turbines. (Trond Are Berg, RCCL). Until recently the turbines have been run on petro-diesel exclusively. RCCL started out with 5 % blends and eventually fuelled the turbines with a 100 % biodiesel.

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

3.9 BV energi

During the summer 2007, a biofuel manufacturer and a private recreational boat owner tested biofuel for use in a luxury yacht. A Sunseeker 75 yacht powered by two MAN diesel 1300 hp (975 kW) engines was tested by running on biodiesel all summer without any engine or fuel system modifications prior to testing.

Ingar Vatndal of BV energi says that no major problems were detected during the test period but stresses the fact that one should change fuel filters often to begin with when switching from MDO to biodiesel. Deposits from MDO are likely to clog fuel filters as the biodiesel has dissolving properties. According to Mr Vatndal, cleaning fuel tanks prior to using biodiesel would be a useful exercise. (Vatndal 2007).

Image below: The cruise ship «Jewel of the Seas». Photo: Royal Caribbean International.

4. Biofuels in applications comparable to ship engines

The use of biofuels in marine vessels is rather limited, but widely used for in engines designed for inland transport and power plants. The versatility of diesel engines allows a variety of fuels to be used. Indeed, Rudolf Diesel, the inventor of the diesel engine actually ran the first diesel engine on peanut oil.

Although today's engines differ significantly from the first diesel engines, biofuels may be used in engines as well as in gas turbines.

The world's biofuel consumption is steadily increasing, creating new markets and opportunities. The global shipping industry is regarded as one of these potential new markets.

4.1 Diesel engines and biofuels

Biofuels for power generation is a well known and growing market. The market situation for green power generation is very attractive in some parts of the EU, this has enhanced the use of biofuels in stationary power generation. Engine manufacturers like MAN and Wärtsilä make engines designed for biofuel use, these low and medium speed engines are also considered suitable for ships.

MAN B&Ws experiences with biodiesel dates back to 1994 and although their research has mainly been focused on non-marine applications, the company has a great deal of knowledge on biofuel compatibility in their engines.

They commenced research and tests on of a wide variety of biofuels in order to figure out which were most suitable. In 2001 a pilot plant for biofuels with an installed power of 750 kW was delivered. Since then they have developed a lot of know-how on how to operate low and medium speed engines using biofuels (MAN B&W Diesel press release 2007).

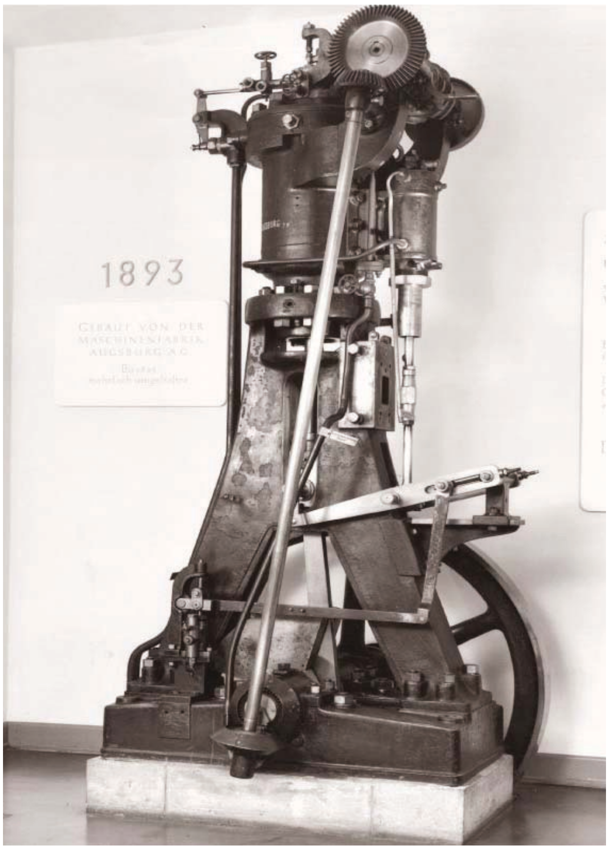


Figure 6: The first diesel engine from 1893 used peanut oil (25/40, 20 HP, 172 rpm (MAN Diesel B&W 2006)

From these early pioneering days, MAN now confirm 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 (MAN B&W Diesel 2007).

MAN B&W has delivered engines to a number of biofuel plants. For instance 18 large medium speed engines, ranging in size from 2.6 to 8.7 MW have been ordered for Italian biofuel power generation. In Italy, MAN cooperates with the Italian engineering company Termoindustriale who claim that the MAN diesel engine is well suited for vegetable derived oils. However, they state that 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. Their experiences on this matter were related to the use of palm oil, which has poor winter characteristics (MAN B&W Diesel 2007).

A new milestone was reached in 2007 for MAN'sMANs biofuels efforts when a large 2007 cogeneration plant employing a bio-fuel version of the highest powered four-stroke medium speed engine in MAN Diesel's range commenced operation at Mouscron in Belgium. The Belgian plant is based on an 18 cylinder configuration type 18V48/60 engine.

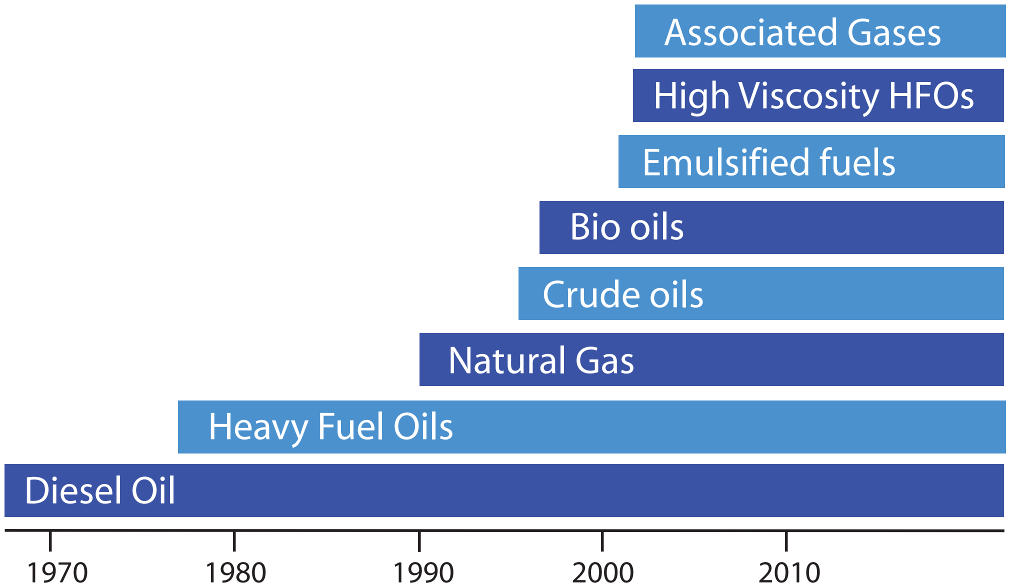


Figure 7: Fuel versatility of Wärtsilä engines (Juoperi et al. 2007)

A paper presented at the CIMAC Congress 2007 in Vienna sums up Wärtsilä's biofuel work (Juoperi et al. 2007). Since the 1980's Wärtsilä has been working within the area of alternative fuels. In the early 90's Wärtsilä started to investigate whether biofuels could be a fuel compatible to their engines. The first test was done with wood-based pyrolysis oil and showed that acidity was critical to the fuel system. Throughout the 1990's a number of tests were carried out. In 1995 rapeseed oil was labelled engine compatible by Wärtsila, 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 (Wärstilä press release 2007). Records of these power plants have been good, time between overhauls being about the same as for HFO engines.

Many operational plants are situated in Italy due to the favourable renewable energy market. Italy is investing heavily in renewable energy because 18 % of their energy is imported. All energy companies must use at least 3 % renewable energy. The market for biofuels in power generation in Italy is booming (Stenger 2007).

Biodiesel can also be used for power generating purposes. For example in 2007 Oslo's annual Øya summer festival was powered by units that run on biodiesel supplied by the Norwegian power rental company Aggreko.

Backup and emergency power units can also make use of biofuels. Mobile container solutions for power generation exist up to 3 MW.

Another example is that of University of California (Riverside), which has installed a 6 MW backup-system in three modules fuelled by biodiesel (National Biodiesel Board 2007).

5. Engine manufacturers

A dialogue with the most important engine manufacturers has been established in order to investigate to what extent the various companies have undertaken testing of biofuels and whether they issue a biodiesel warranty with engines destined for the marine sector.

5.1 MAN B&W Diesel

As described above MAN B&W Diesel along with Wärtislä, are the engine manufacturers with the most experience on biofuels for stationary power generation as well as being the largest engine suppliers to the Norwegian domestic fleet. MAN B&W have an important role to play in the adoiption of biofuels in shipping.

MAN Diesel manufactures a number of different biofuel compatible engines. According to the Senior Vice President of Research and Development, MAN Diesel A/S, Thomas S. Knudsen, there is a high demand for two-stroke biofuel engines at the moment. Below is a figure of the different engines tailored for biofuels:

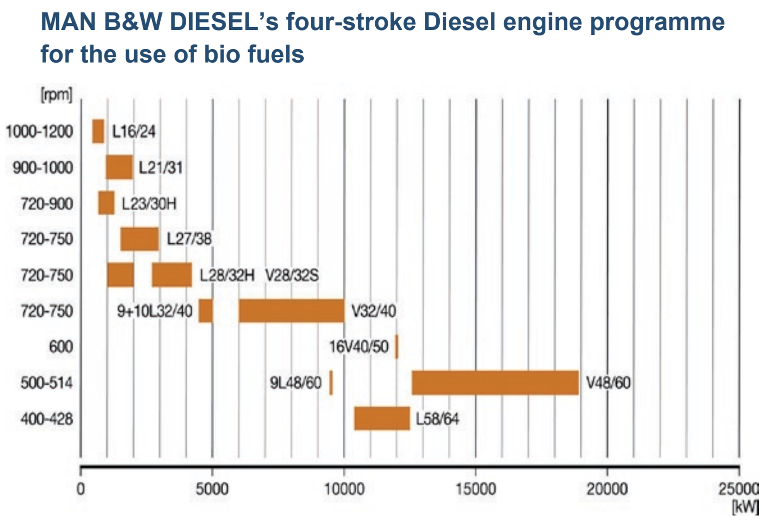


Figure 8: MAN Diesel engine for the use of biofuels (MAN Diesel B&W 2006)

According to Knudsen, MAN low speed engines can be ordered for biofuels. This relates to the market situation and may in future be an interesting area for MAN. 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. When considering the cold flow properties, MAN also points out that HFO is a residual fuel which needs a lot of preparing treatment prior to use. Once these modifications have taken place, a switch to biofuels is deemed rather uncomplicated (MAN B&W Diesel Press Release 2007). MAN has received inquires regarding use of biofuels in ships from Indonesian ship owners (Thomas Knudsen, MAN B&W Diesel 2007).

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, Thomas S. Knudsen 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. Knudsen assumes that conversion also could be made on ships, but that no retrofit projects for ships have been initiated.

Nevertheless he gives a rough estimate that an existing ship engine can be converted to run on biofuels for less than 5 % of the engine cost. Due to the corrosiveness of biofuels, the major cost of the conversion according to MAN will be the retrofitting of the storage tank (Thomas Knudsen 2007).

According to Michael Finch Pedersen in MAN, they don't have any experience of uising biofuels in their two 2-stroke marine engines, however Finch , expects them to approach the subject in a similar way as with stationary engines. Some knowledge of biofuels in two-stroke stationary engines exists. A vegetable oil fuelled MAN diesel two-stroke is set to operate in a plant near Bremen, Germany by autumn 2008 (Michael Finch Pedersen 2007).

MAN reports that the difference in price between heavy fuel oil relative and liquid bio fuels is the main obstacle for further research.

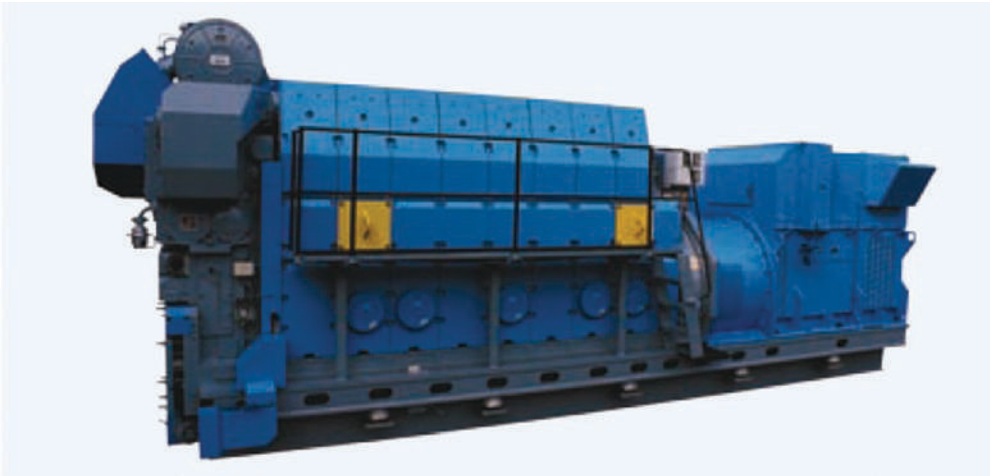


Figure 9: MAN B&W Diesel generating-set type 8L27/38 for 2.6 MW output operating with biofuel (MAN B&W Diesel 2007)

5.2 Wärtsilä

On Wärtsilä's website it is stated that every third ship sailing the seas runs on Wärtsilä power. Wärtisiä is thus a very important player in the shipping sector. It is also one of the engine manufacturers with the most biofuels know-how.

Biofuels are regarded «one» of three main fuels that can be used in Wärstilä engines, see Table 4.

Within the area of marine vessels Wärtsilä have not performed specific research regarding biofuels. Kai Juoperi, from Wärtsilä, explains that the lack of research by pointing at the present market situation. There are no limitations from the engine technical point of view. In the wake of an increased interest Wärtsilä is likely to increase their work on biofuel for marine vessel. Leif Meland in Wärtsilä, Norway says that in order for such a project to be initiated there must be a financial foundation in place (Leif Meland 2007).

Table 4: Fuel versatility in Wärtsila engines (Wärtsilä 2007)

Liquid, oil-based fuels	Gaseus fuels	Biofuels (examples)
Liquid fuel oil (LFO)	Natural gas (NG)	Rapeseed oil
Heavy fuel oil (HFO)	Liquified natural gas (LNG)	Palm oil
Crude oil (CRO)	Compressed natural gas (CNG)	Coconut oil
High-viscosity base oils	Associated gas	Biodiesel
Ormulusion ®	Coal bed gas (methane)	
Water-fuel emulsions		

From the power plants in operation a lot of useful experience can be noted. Some of this experience is directly transferable to marine vessels. Wärtsilä claim problems have been few, but some issues have been noted. The main problems have been in connection with cavitations on fuel injection pumps, blocking of fuel pipes and material choice for rubber seals.

In the next chapter we discuss further the problems and solutions to using biofuels in engines.

Figure 10: Pentesilea power plant running on 100 % biofuel in Monopoli, Italy (Juoperi et al. 2007)

5.3 Caterpillar

Caterpillar has done some work on biofuels in their engines though not to the same extent as Wartsila. Jannik Stranger points out that their engines should operate without trouble using biofuels. They have done some tests internationally in this field and may start more testing. Stranger also underlines their positive approach with reference to more use of biofuels in their engines (Jannik Stranger 2007).

Caterpillar verifies the use of biofuel blends. Caterpillar C7 and bigger engines can use 30 percent biodiesel. It is likely that higher blends can also be used in Caterpillar engines, but Caterpillar does not yet warrant such use (Caterpillar 2007).

5.4 Rolls Royce/Bergen Diesel

Lutz Liebenberg of Rolls Royce Norway states that they have had no experience with biofuels on their marine engines but that they are planning to give it more attention after having received several enquiries from customers.

Currently they are waiting for results of some samples sent to DNV (Det Norske Veritas) of rapeseed oil to see whether the fuel characteristics are suitable for use in ship engines. The tests are aimed at collecting useful information on the fuel's combustion qualities. Based on the results of the tests, Rolls Royce may want to initiate engine tests and hopefully be able to accept biofuels as a viable fuel for their ship engines. On a general basis, Libenberg says that biofuels should be well suited for use in ship engines (Lutz Liebenberg).

6. Technical review: Shipping Biofuel compatibility

6.1 Engines

There are two main types of diesel engines used as main and auxiliary engines in ships, the low speed two-stroke engine and the medium speed four-stroke engine. Low speed engines generally drive the propeller shaft directly while medium speed engines may drive the shaft via a gear or via a generator/electrical motor (diesel-electric propulsion). As summarised in the previous chapter biofuels are suitable for marine engines. However, there can be certain challenges connected to the use of biofuels. In this chapter these challenges will be addressed.

The use of biofuel in these engines is well documented from the use of biofuel in land-based power plants. As previously stated, the two leading engine manufacturers in this emerging market are MAN B&W Diesel and Wärtsilä.

Diesel engines designed for heavy fuel oil can be run on vegetable oil without problems, engines designed for marine diesel or gas oil may have problems though due to higher density and viscosity of the vegetable oil (MAN Diesel 2006). In these engines an alternative fuel could be biodiesel.

A report from Wärtsilä (Juoperi et al. 2007) evaluates what kind of issues are the most difficult when running medium speed engines on biofuels; cavitation on fuel injection pumps, blocking of fuel pipes and material choice for rubber seals.

The Juoperi et al. review focuses on the most problematic issues concerning medium speed engines, but also low speed engines can use biofuels (MAN B&W Diesel 2006)

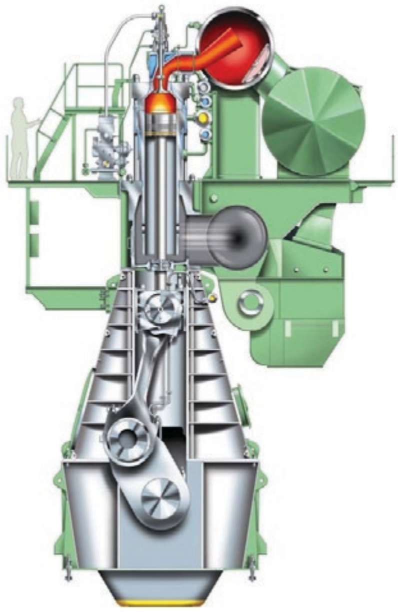


Figure 11: Two stroke engine in ship (Henningsen 2007)

6.2 Cavitation on injection pumps

When using vegetable oil in engines one relevant problem tends to be the cavitation of injection pumps. Cavitation on injection pumps is mainly due to the increased temperature of the fuel, this reduces the viscosity and locally the fuel starts to boil.

Cavitation is in most cases very isolated, but deep, most probably it is due to the fact that power plants are running all the time at same load. In contrast to land based power plants, marine engines run much more on different loads, this is due to shifting of running speed, for instance when entering a harbour. This issue may need closer review. Figure 12 illustrates the cavitation on the fuel pump caused by palm oil.

The cavitation problem can be solved by using a more cavitation resistant pump. Both the outlet and inlet flow need to be regulated by restricting the outlet flow vs. the inlet flow, this has shown to clearly improve the situation. Figure 13 shows how the fuel injection pump can be adjusted. Such pumps are installed in vegetable oils power plants delivered by Wärtsilä.

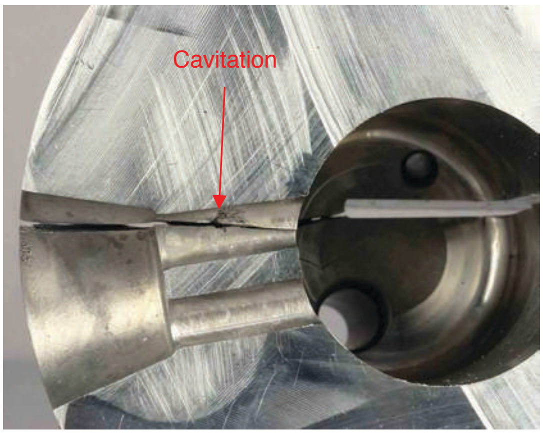


Figure 12: Cavitation of so called double spill port of injection pump, cavitation mark in picture opened up for inspection (Juoperi et al. 2007)

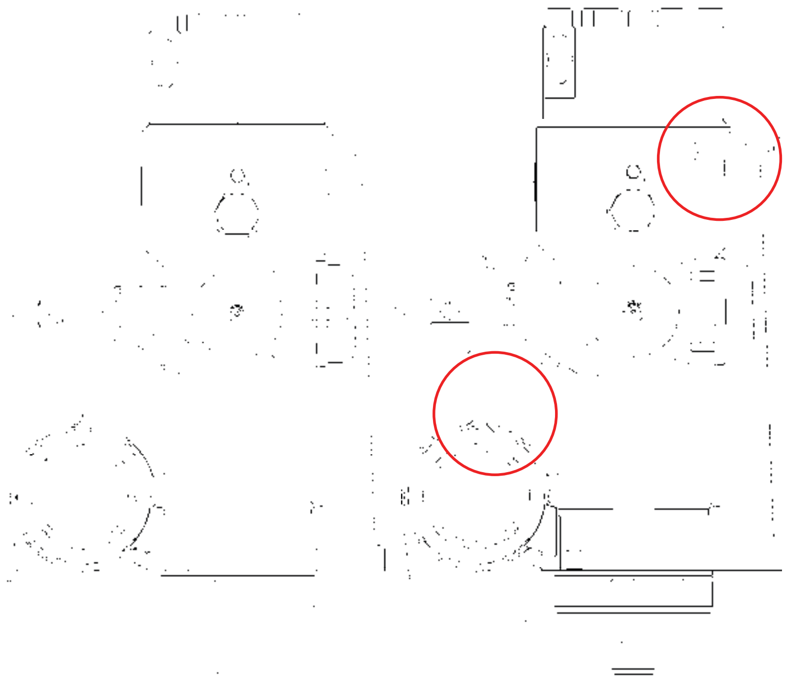


Figure 13: Original pump vs. modified pump (Juoperi et al. 2007)

6.3 Blocked leak-fuel oil pipes

Temperature control is imperative when running an engine on biofuels to ensure proper viscosity. As reviewed in the previous chapter, it is essential that the fuel temperature is regulated. If the fuel temperature goes to high locally in the return line, the fuel properties will change and the fuel will polymerise making the fuel more like a plastic mass as the example in figure 14 shows.

Figure 14: Polymerised biofuel in return line where temperature has been too high (Juoperi et al. 2007)

This problem is usually seen as a leakage through the fuel rack, this is due to the pressure build up from the blocking of the return line.

The best way to avoid this problem is to ensure fuel leakage lines/piping should have:

- Correct heating/cooling for avoiding wax plugs /polymerisation
- Increased drainage capacity so that the biofuel more easily runs away
- Larger size to cope with increased flow

6.4 Corrosion of elements

The acidity of liquid biofuels is highlighted as a potential problem in relation to biofuel in diesel engines. Wärtsilä has a limit of total acid number (TAN) of 5 mgKOH/g (Juoperi et al. 2007) whereas MAN specifies a TAN limit of 4 mgKOH/g (MAN Diesel 2006). Figure 15 shows the importance of keeping the TAN number within the limits, already after 48 hours of running on biofuels with high TAN number the problems of cavitation appears.

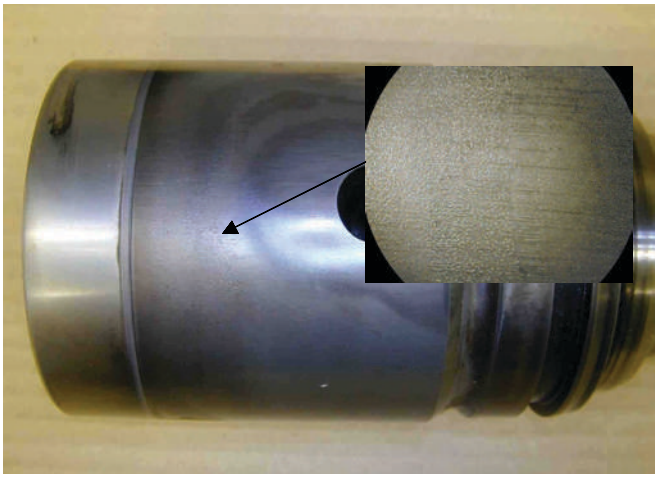


Figure 15: Injection pump element after 48 hours on high acidity fuel.
Acid number > 100 mg KOH/g (Juoperi et al. 2007)

6.5 Rubber seals

As biofuels are more acid than HFO and MDO, the load on seals is increased. Wärtsilä states that they have switched to different solutions for seals (Juoperi et al. 2007). Figure 16 shows the improvements in seals for injection pump on biofuel operated engines:

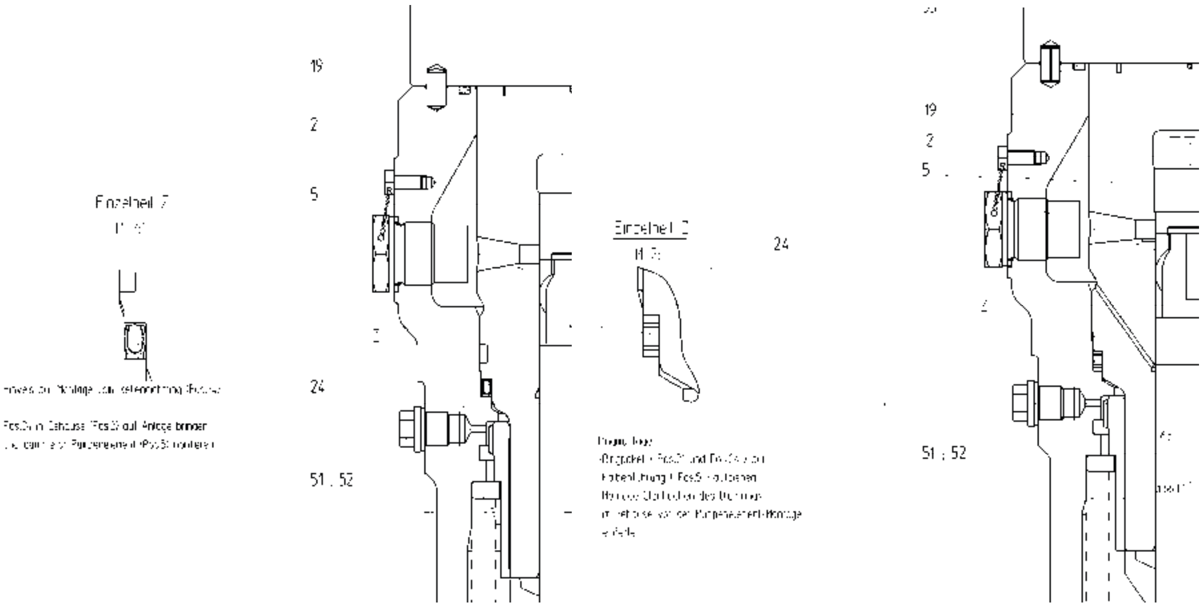


Figure 16: Seals improvements for injection pump for biofuel operated engines
(Juoperi et al. 2007)

The fact that biodiesel acts as a solvent is stressed as potentially problematic. There is a tendency to soften and degrade certain rubber and elastomer compounds which often are used in older engines. These problems can be resolved by switching to system components with synthetic hoses and seals that are resistant (Abu R. Hasan et al. 2002).

6.6 Fuel system

An important issue is the winter qualities of biofuels. Biofuels such as biodiesel could have poorer cold weather performance than petroleum fuels. Biodiesel has been processed so that it has a lower viscosity than vegetable oil, but the level of viscosity varies with the content of esters in the fuel which again corresponds to the raw material used. The viscosity of the fuel needs to be checked against the design parameters of the most vital part of a ships fuel system, namely the fuel pump and the fuel injection.

HFO is a very viscous fluid, so ships which use HFO oils need preheating to lower the viscosity so that it can be operated by pumps, centrifuges etc. The pump design sets the limits for maximum and minimum viscosity, if the viscosity is lower than the design, the flow rate of the fuel will be higher than the capacity of the pump. The two most important HFO fuels, IFO 180 and IFO 380 have a viscosity of 180 and 380 cSt at 50 °C while MDO generally ranges from 1 – 10 cSt at 40 °C. Table 5 shows how different biofuels compare with HFO and MDO.

Table 5: Comparison of biofuels and marine fuel properties (MAN Diesel 2006)

	Vegetable oil treated, non transesterified	Bio Diesel EN 14214	Automotive diesel EN 590	Marine diesel ISO 8217 DMB	Heavy Fuel Oil ISO 8217 RM ..
Density/15 °C	920 - 960 kg/m³	860 - 900 kg/m³	820 - 845 kg/m³	< 900 kg/m³	975 - 1010 kg/m³
Viscosity at 40 °C/ 50 °C	30 - 40 cSt	3.5 – 5 cSt	2 – 4.5 cSt	< 11 cSt	< 700 cSt /50 °C
Flashpoint	> 60 °C	> 120 °C	> 55 °C	> 60 °C	> 60 °C
Cetane no.	> 40	> 51	> 51	> 35	> 20
Ash content	< 0.01 %	< 0.01 %	< 0.01 %	< 0.01 %	< 0.2 %
Water content	< 500 ppm	< 500 ppm	< 200 ppm	< 300 ppm	< 5 000 ppm
Acid no. (TAN)	< 4	< 0.5	-	-	-
Sulphur content	< 10 ppm	< 10 ppm	< 350 ppm	< 20 000 ppm	< 50 000 ppm
Calorific value	ca. 37 MJ/kg	ca. 37.5 MJ/kg	ca. 43 MJ/kg	ca. 42 MJ/kg	ca. 40 MJ/kg

There is more information on fuel properties in appendix 1 – 4.

The information given about viscosity suggests that with preheating as for HFO, biofuels should be suitable.

Another important aspect is the cloud point, pour point and cold filter plugging point.

- Cloud Point: The temperature at which small solid crystals are first visually observed as the fuel is cooled. Most fuels can still be used below the cloud point (NREL 2004).

- Cold Filter Plugging Point (CFPP): The temperature at which fuel crystals have agglomerated in sufficient amounts to cause a test filter to plug. This point is generally considered to be more useful when considering the cold flow properties of a fuel.

- Pour Point: The temperature at which the fuel contains so many agglomerated crystals that it is essentially a gel and will no longer flow. At this point the fuel no longer can be used without heating. Long before reaching this point the filters will be clogged and the fuel would have stopped flowing. Nevertheless it can be used in a blending situation. In addition the so-called Pour Point may well be used as a factor in comparing one fuel to another.

The pour point of HFO (IFO180, IFO380) is not to exceed 30 °C (ISO 8217) and the pour point of the biooil with least flow properties is palm oil with a pour point of about 21 °C (Juoperi et al., 2007). For biodiesel, the EN14214 (see appendix 4) sets different limits of the CFPP value depending on seasonal variations, 0,-10, -20. The upper limits for the pour point for various distillate fuels range from -6 to 6 °C according to ISO8217:2005(see appendix 1).

Table 6: Cold flow properties of different biofuels (NREL 2004)

Test method	Cloud point ASTM D3500		Pour point ASTM D97		Cloud filter plug point ASTM D4539	
B100 Fuel	˚F	˚C	˚F	˚C	˚F	˚C
Soy Methyl Ester	36	2	30	-1	28	-2
Canola Methyl Ester	27	-3	25	-4	25	-4
Lard Methyl Ester	57	14	52	11	52	11
Edible Tallow Methyl Ester	68	20	55	13	57	14

Additives can be added to improve the fuels cold flow properties. Wintron XC30, Arctic Express Biodiesel Antigel and Lubrizol are some of the examples of additives. By adding 1000 ppm the cold properties would normally be improved by 3 °C. Cold flow properties can best be improved for biofuels with a low level of saturated fatty acids like rapeseed based biodiesel (RME). The Norwegian biofuel producer BV energi claims to have biodiesel with satisfactory cold flow properties at temperatures as low as -27 °C (Ingar Vatndal BV energi). At sea such low temperatures will not be frequent, if at all occurring.

Fuel systems need careful temperature control. Too high temperature can cause polymeric compounds. Temperature control is thus essential for use of biofuels. The fuel feed system may then be equipped with extra components like heaters, coolers, additional trace heating etc. in order to ensure correct fuel temperature (Niklas Haga).

The most frequently reported problem with biofuels in the fuel system is the potential clogging of filters in a start-up phase when switching to biodiesel. Biodiesel's solvent properties can potentially cause clogging of fuel filters from HFO deposits in the storage tanks. This is normally only reported to happen in a start-up phase when switching from HFO to biofuels. A possible remedy is to thoroughly clean the storage tanks.

Thoroughly clean onboard and dockside fuel tanks before starting to use biodiesel blends stronger than 5 % in order to reduce the release of build-up due to the fuel's solvent action. It's also recommended to schedule three or four additional filter changes during the cleansing period if prior cleaning is not feasible (BioMer 2005).

6.7 Storage tanks

Due to the corrosiveness of biofuels, there has been raised question if the fuel tanks could manage the biofuel. Based on the information from use of biofuels for other applications some information can be summarized.

Normal acid proof storage tanks can be used with biodiesel without any major problems. Nevertheless, by switching from HFO, deposits in the storage tanks can cause clogging of filters as mentioned in the previous section.

The storage tanks onboard a ship are regulated with a temperature based on the applied fuel used. The fuel temperature should always be kept at least 10 – 15 °C above the fuel's cloud point (Juoperi et al. 2007). Giving the above section on flow properties, this should not pose a problem when converting from HFO or MDO.

Biofuels will degrade faster than conventional diesel. Ageing and oxidation of biodiesel can lead to increases in the TAN value, increase of the corrosion activity and the formation of sediments that can clog filters. High temperatures, sunlight and atmospheric oxygen can speed up the ageing process (NREL, 2004).

Biodiesel with high levels of saturated fatty acids are more stable with respect to oxidation. Rapeseed based biodiesel is an example of this type of biodiesel. Oxidation preventive agents can be added to the biodiesel to increasse the storage time of biodiesel. The American ASTM D4625 standard suggests that the least stable biodiesel can be stored up to eight months, whereas the National Biodiesel Board recommends a maximum of six months storage. Longer storage than this would need adding of oxidation preventive agents.

Biodiesel absorbs water and the biodiesel producers are very careful so that the level of water content in the biodiesel is at an acceptable level. Water in biodiesel can lead to biological growth as the fuel degrades. When the water content is within the standards this problem is not documented (UFOP 2004). The control of water content in biodiesel is therefore of great importance.

7. Low blends of biofuel

Based on the issues given above, it can be interesting to establish a low blend of biodiesel in petroleum diesel which can be used in marine engines without any modifications.

Low blends are blends of biodiesel for which the manufacturer guarantees the performance of in engines. In most cases this is 5 %, but some manufacturer's guarantees operation up to 20 % or even 100 % biodiesel. A document from the National Biodiesel Board suggests that the blending of 20 % biodiesel and 80 % petroleum diesel should be acceptable. (National Biodiesel Board 2005). This conclusion is based on a project that aimed at evaluating higher blends than B5 and based on experiences with blends in a number of vehicles in different climate over several years.

The low blend of biodiesel in the transport sector is currently B5. The technical background is that blends up to 5 % are regarded as additives and thereby accepted by engine manufacturers.

There are many indications however that blends of biodiesel could be higher without any problem. The experiences in the marine sector is however limited. According to a study conducted by the Great Lakes Maritime Research Institute low blends of biodiesel up to B20 were said to be observed without any fuel system degradation. (Abu R. Hasan et al. 2002).

8. Multifuel aspect

Biofuels and HFO can be used in the same engine and switching between fuels does not pose any problem with respect to the engine. The potential problems can be found in the fuel system and storage of the fuel. As shown previously in this chapter, some changes may have to be done to the fuel system. The vegetable oil needs to be heated to another temperature than HFO, thus HFO and biofuel might need separate storing facilities and different pre-treatment (Thomas Knudsen, MAN Diesel).

Based on information from Wärtsilä, a switch between vegetable oils and MDO should be possible without any problems to the engine. The fuel system and preheating may, however, need some adjustment (Kai Juoperi 2007).

Part II: Market and Commercial Issues

This section will aim to portray the present bio-fuel market and its anticipated development according to Market and Commercial aspects of introducing biofuels into the Norwegian domestic fleet.

9. Ship compatible Biofuels

At the time of writing a number of different bio-fuels are manufactured globally. However, the most widespread types are bio-ethanol and biodiesel with the latter regarded most similar to today's ship fuel. Pure plant oil (unfinished biodiesel) might also be an avenue to explore as it is suitable for machinery running on heavier diesel oils. Furthermore, some sorts of wood based products, such as pyrolysis oil and synthetic biodiesel, are viewed as relevant fuel alternatives in the too near future. Therefore, we have decided on putting the said fuels' market aspects in the centre of attention in this report and take just a brief look at ethanol as its fuel characteristics are relatively dissimilar to existing ship fuel.

9.1 Vegetable oil

Oil plants play an important role as sources of protein and fat to both humans and animals. A wide range of oil rich plants are grown and used for a variety of purposes. Plants like rapeseed, soybeans, palm, peanuts and sunflower cover most of our worldwide need for plant based fat.

Vegetable oils are used in numerous foodstuff products but act as ingredients in other areas as well. Processed oils can be found within product groups as cosmetics, plastic, candles, soaps, paint, industrial adipose, leather tanning products, solvents, wax, rubber, bio-fuels to name but a few.

The global bio-oil production is based on oil seeds where the oil is extracted. The leftovers, which are regarded surplus to requirements in the oil extraction process are later transformed into a protein rich mix and used as livestock feed.

Rapeseed (Europe) and soya (USA) are the most common raw materials in bio-oil designated for fuel production, with oil content (seeds) of 40 % and around 20 % respectively. The rest of the seeds are converted to either food or livestock feed.

Basically all types of plant oils may be used in energy production; however, diverging characteristics lead to some oils being more suitable than others. Refined vegetable oils used for light and heating are one of the earliest forms of processed energy we have identified.

Unkown to many is that biofuel in engines has a history as old as the diesel engine itself. Rudolf Diesel who invented the diesel engine, actually used peanut oil as fuel in his first engine tests. In his patent document of 1912 he wrote: «The use of plant oils as fuel may today be insignificant, but exploiting these products might become as essential as today's petroleum and coal products.»

9.1.1 Soya oil

Soy is runner-up with regards to today's biodiesel production worldwide. The plant is mainly grown in America and Asia, but the EU is also a major producer. Soya is used in innumerable foodstuffs and plays an important role as livestock feed. The plant is the key raw material in US biodiesel production.

9.1.2 Rapeseed oil

Rapeseed is almost exclusively farmed in the northern hemisphere, with China, India, Canada and the EU as the main producers. Spring rapeseed (Canola) is most common in Canada while winter rapeseed is dominating the European market due to mild winters. Rapeseed is undoubtedly the main raw material in European biodiesel production. This biodiesel is called Rapeseed Methyl Esther (RME).

9.1.3 Palm oil

Palm oil is the number one vegetable oil judging by annual manufactured volume, with the food and cosmetics industry absorbing most of the production. Production is mostly located in Asia where Malaysia and Indonesia are the largest manufacturers.

The oil palm (Elaeis guineensis) originates from Africa and was imported to Asia in the early 1800's. The palm's fruit, in which the oil is stored, may weigh up to 50 kg and contain a stunning 30 % oil.

Due to its poor winter qualities though, palm oil is unsuitable as a raw material in traditional European biodiesel. The European biodiesel standard EN 14214 allows only a very limited palm oil volume.

Therefore palm oil in European energy production is mainly found in stationary heat and power where the use of this oil is possible through a pre-heating process.

A Finnish company, Neste Oil, recently presented a new biodiesel production technique called NExBTL, which is described as «Generation 1 ½». This technique paves the way for an increased palm oil level in biodiesel without abating its winter qualities.

The palm oil may be a potential threat to the rainforest in the sense that it requires the same conditions for growth as the rainforest. Malaysia and Indonesia, as the key producers of palm oil, are responsible for a substantial level of deforestation. However, palm oil production in itself is not accountable for negative effects on rainforest and biological diversity; though palm oil plantations may be a driving force behind deforestation. There are issues concerning production of palm oil in South East Asia that prompts the need for careful consideration before using palm oils from this area. Deforestation of the Rainforest is one of the major causes of greenhouse gas emissions in the world.

Only about 1 % of the world's biodiesel production use palm oil as a feedstock (FAO 2007).

9.1.4 Jatropha oil

Jathropha is a poisonous shrub plant which can be found in arid areas. It is exceptionally drought resistant, hence, very suitable for areas incompatible to other crops. The oil gained from the Jatropha nuts is, like the rest of the plant, toxic; therefore, it is apt for energy purposes only.

Despite Jatropha's rather insignificant position as an oil plant today, it is widely expected to play a crucial role in tomorrow's energy and fuel production. The large plantations and Jatropha projects popping up in both Asia and Africa are leading to an anticipated rise in Jatropha production the coming years.

Table 7 shows the yields of vegetable oils from different raw materials:

Table 7: Oil yields of different oil plants

Plant	Latin	Kg Oil/hectare
Soy	*Glycine max*	375
Rapeseed	*Brassica napus*	1000
Jatropha	*Jatropha curcas*	1590
Oilpalm	*Elaeis guineensis*	5000

9.1.5 Refining of pure Vegetable oil

In order to extract the vegetable oil it first needs to be pre-treated. The oil rich seeds or beans are cleaned and dried. The extraction of the oil is usually mechanical from heated raw material. When all the oil is extracted there is a residual product which can be used as animal feed. Figure 17 shows the different steps of refining crude vegetable oil to purified vegetable oil:

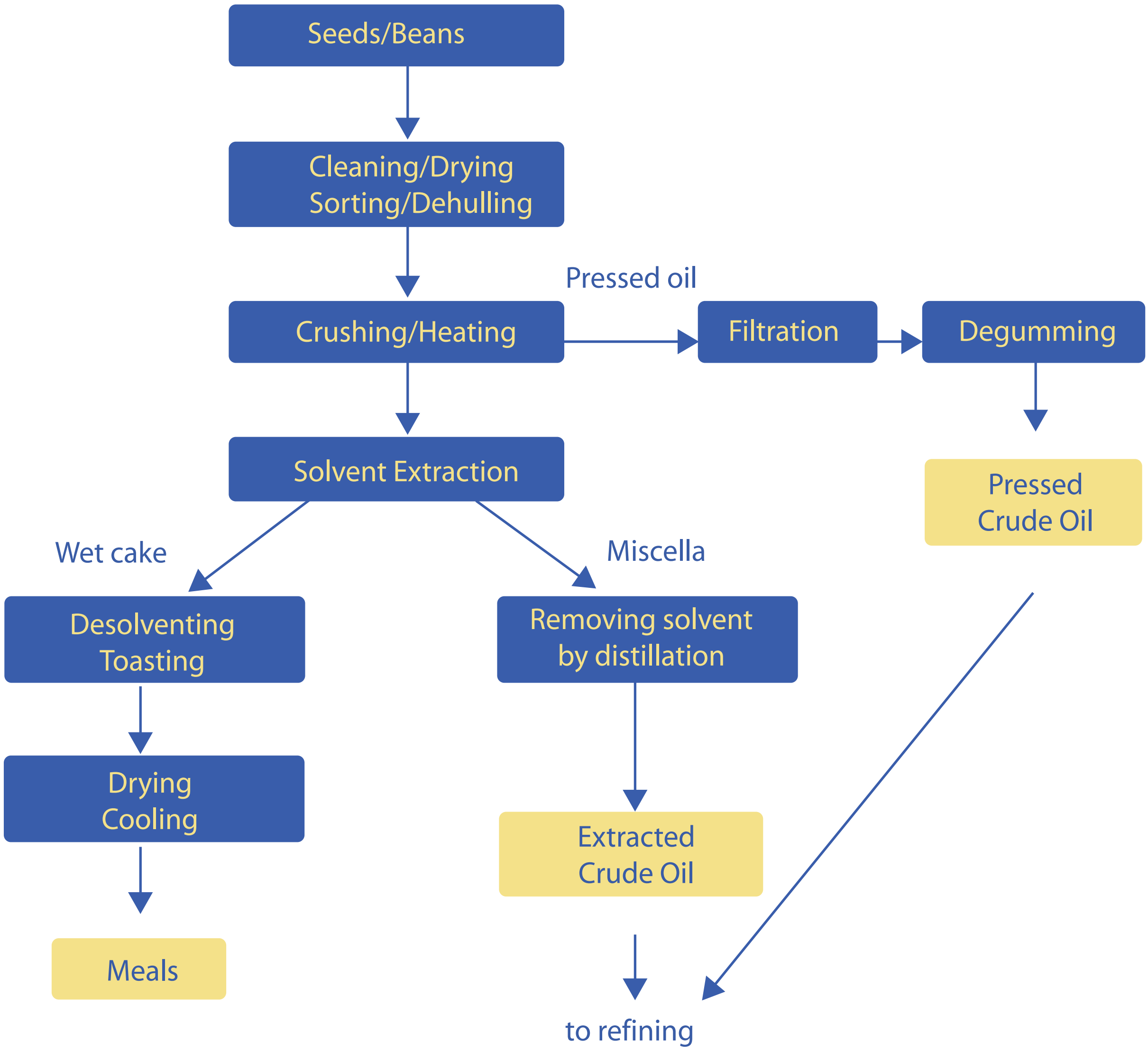


Figure 17: Refining crude vegetable oil to purified vegetable oil (Fediol 2007)

9.2 Pyrolysis Fuel Oil

Pyrolysis oil is oil produced from biomass such as trees, straw or waste wood. The biomass is treated in an oxygen free environment at high temperatures (400-500 °C) to form a dark brown liquid. Pyrolysis oil is often thought of as a poor quality product and its applications are therefore limited, although perhaps ships engines which are capable of handling HFO can manage pyrolysis oil. Pyrolysis oil can prove to be very economical beneficial compared to other biofuels (Dynomotive energy systems, 2007).

Figure 18: Mobile pyrolysis plant in Canada (ZERO 2006)

9.3 Biodiesel

Biodiesel may be produced from plant oils or animal fat. In Europe rapeseed (canola) is the most frequently used product in biodiesel manufacturing.

The biodiesel is usually produced by a chemical process where alcohol (usually methanol) is added to the crude vegetable oil. This process is named Transestherfication which tears the fat molecules in the oils apart and leaves only the combustible hydrocarbons.

The end result is a fuel called «Methyl Esther or «biodiesel». The word «Methyl» indicates that Methanol has been used in the process, while the result of employing ethanol is Ethyl esther – leading to a bi product called Glycerine. The latter method was patented in 1940 when glycerine was crucial in the making of explosives.

Biodiesel is sometimes referred to as «Transestherified Vegetal Oil» and was initially used in heavy vehicles during World War II in South Africa.

Biodiesel based on rapeseed is called Rapeseed Methyl Esther (RME) while biodiesel derived from soya is labelled SME. FAME (Fatty Acid Methyl Ester) is often used as a name for the entire group of biodiesels made from plant and animal fat.

10. Biofuel production volumes

10.1 Bio-oil production

Biodiesel is made from vegetable oil which in turn determines the level of the biodiesel production. In addition, vegetable oil may be used directly as unprocessed fuel. The annual vegetable oil production globally is in excess of 100 million tonnes. The 2005/2006 production overview can be found in figure 19:

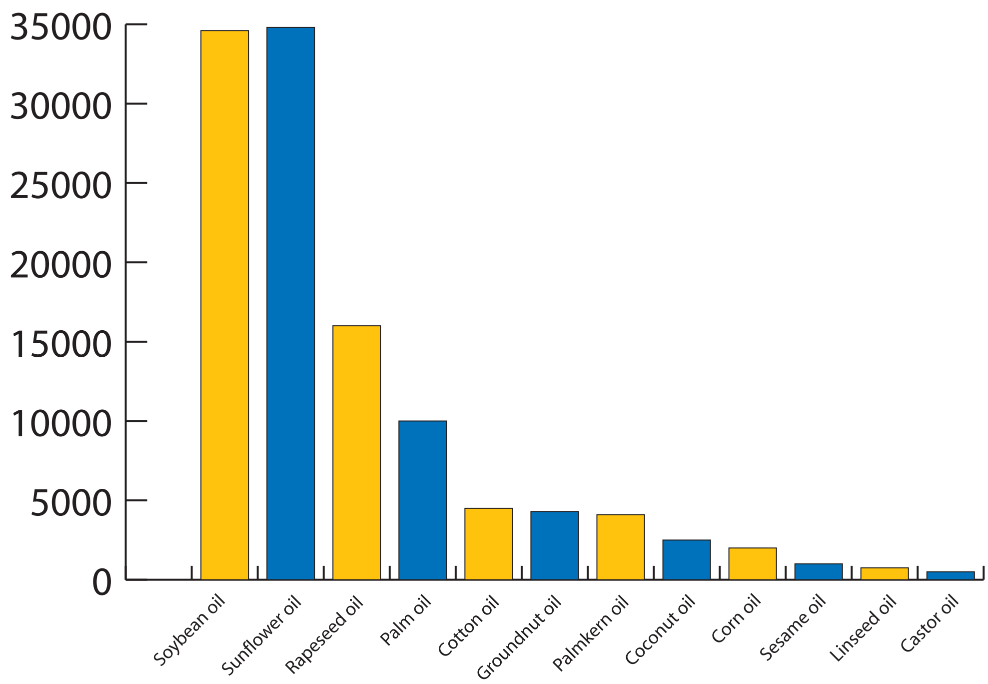


Figure 19: Worldwide vegetable oil and fat production 2005/2006 (1000 tonnes) (Fediol 2006)

The last decade has seen a doubling of soya and palm oil production. At the same time rapeseed and sunflower oil have lost market share despite a growth in production.

The worldwide growth in production volumes (1993 – 2006) is displayed in figure 20:

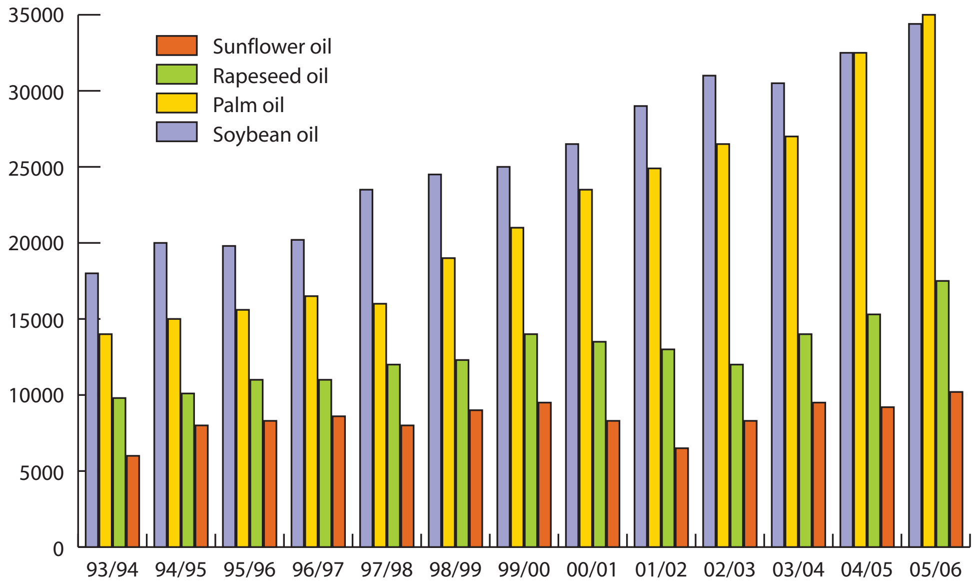


Figure 20: Global production – 1993-2006 (1000 tonnes) (Fediol 2007)

Total worldwide production distributed to regions and countries is shown in figure 21.

Palm oil is mainly manufactured in Malaysia and Indonesia, China find themselves in the driver's seat with regards to while The US, China, Argentina and Brazil are the key soya producers. Europe and China are the world's leading rapeseed producers.

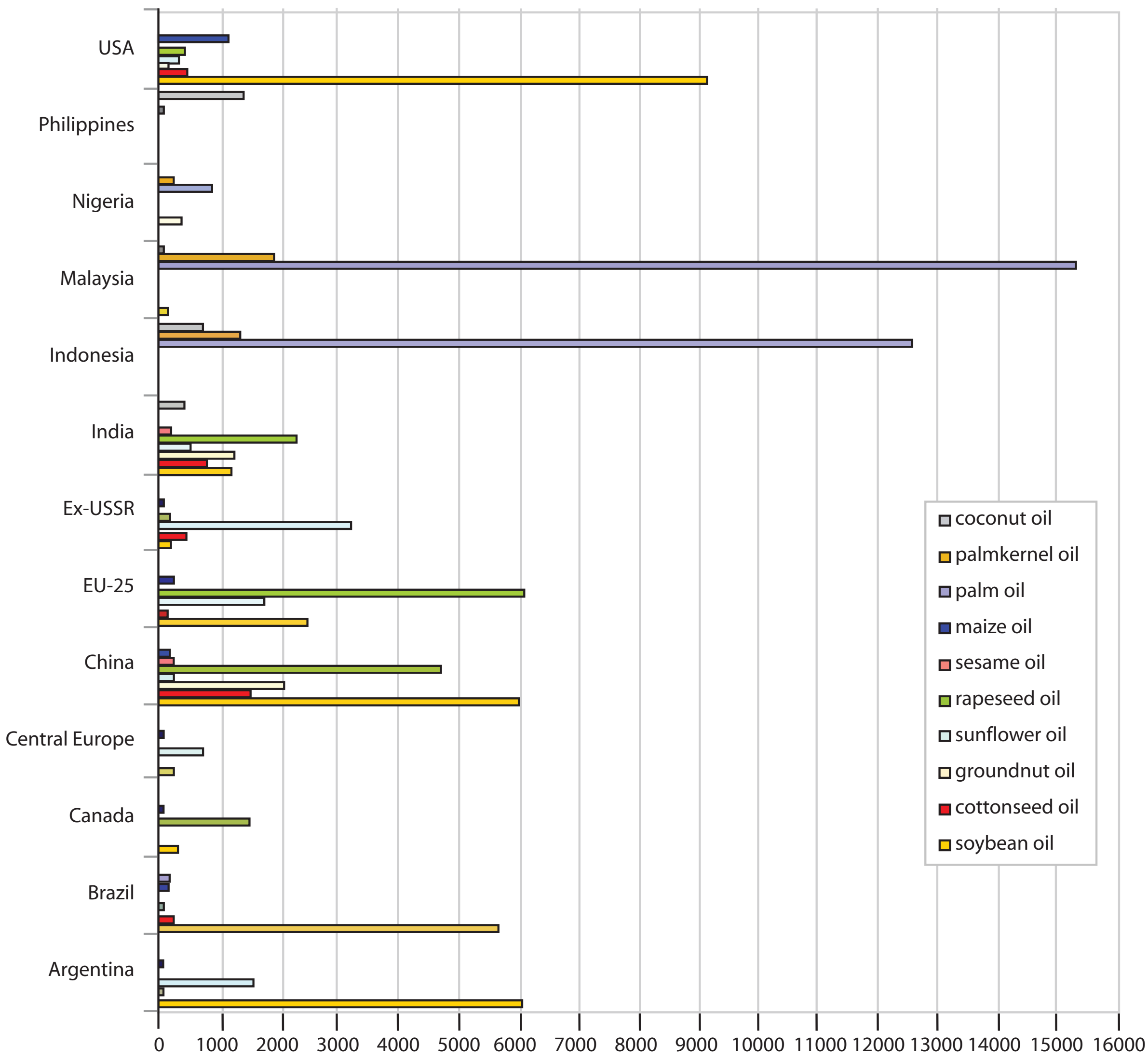


Figure 21: Oil and fat production 2005/2006 country wise in 1000 tonnes (Fediol 2006)

Development in European vegetable oil production from 1970 is shown in figure 22 (next page).

Vegetable oil production is dominated by a small number of multi-national companies who control the entire chain of production from oil extraction to refining and ultimately the end product itself. Three quarters of the European capacity is shared by four large major companies: A.D.M, CARGILL, BUNGE and SAIPOL (ranked by size). In addition, a number of smaller companies operate in the market (Fediol 2006).

EU plant oil business include a total of approximately 150 production plants and 20,000 employees. Fediol, the Europoean organization of oil producers has a combined total vegetable oil production capacity of around 30 million tonnes annually.

The annual European vegetable oil production is 8.6 million tonnes while 3.7 millions tonnes are imported and later processed.

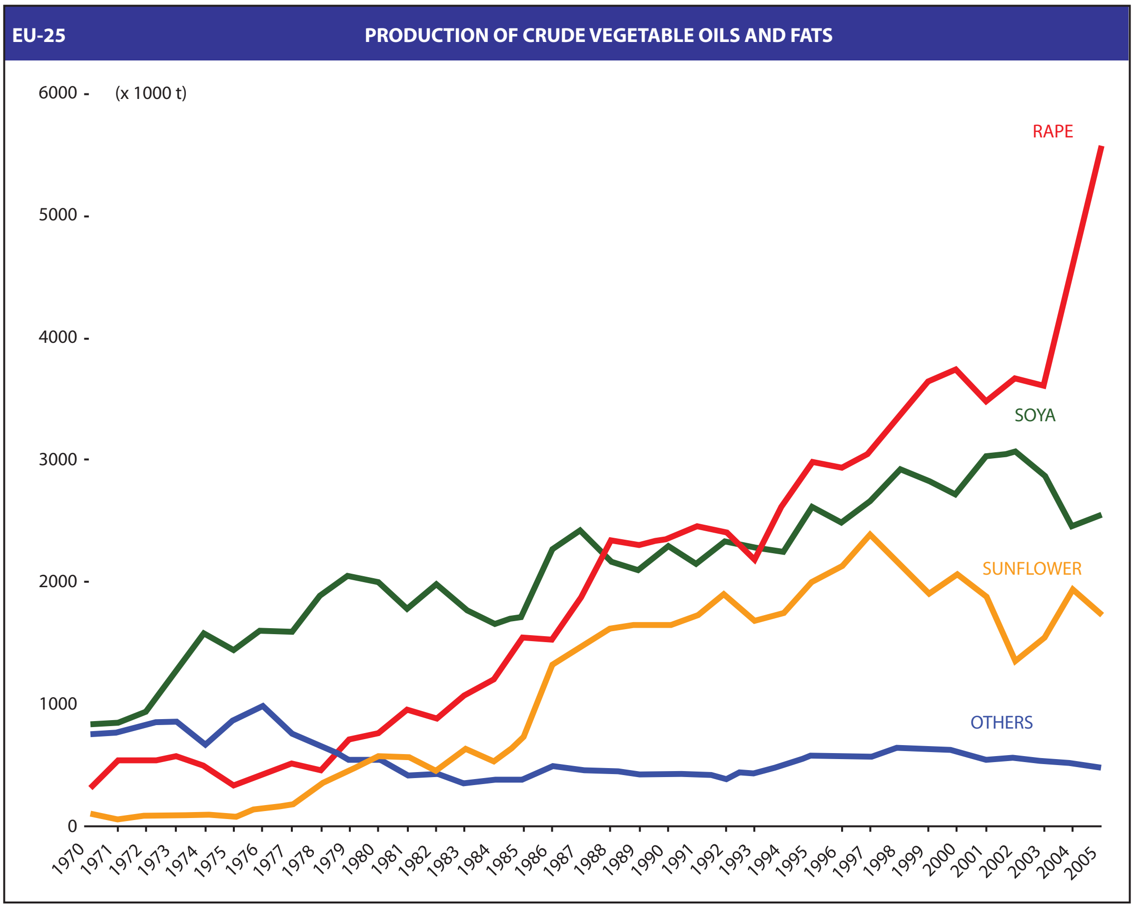


Figure 22: Development in European vegetable oil production since 1970 (Fediol 2007)

10.2 Biodiesel production

10.2.1 European Union

The majority of global biodiesel production is based in the European Union which produces 4.9 million tonnes of world's 6.4 million tonnes of biodiesel (2006 figures). This is equivalent to 77 % of global production.

The EU has been making biodiesel on an industrial scale since 1992. From, 1998 there has been rapid growth in biodiesel production with a 54 % increase in growth between 2005 and 2006.

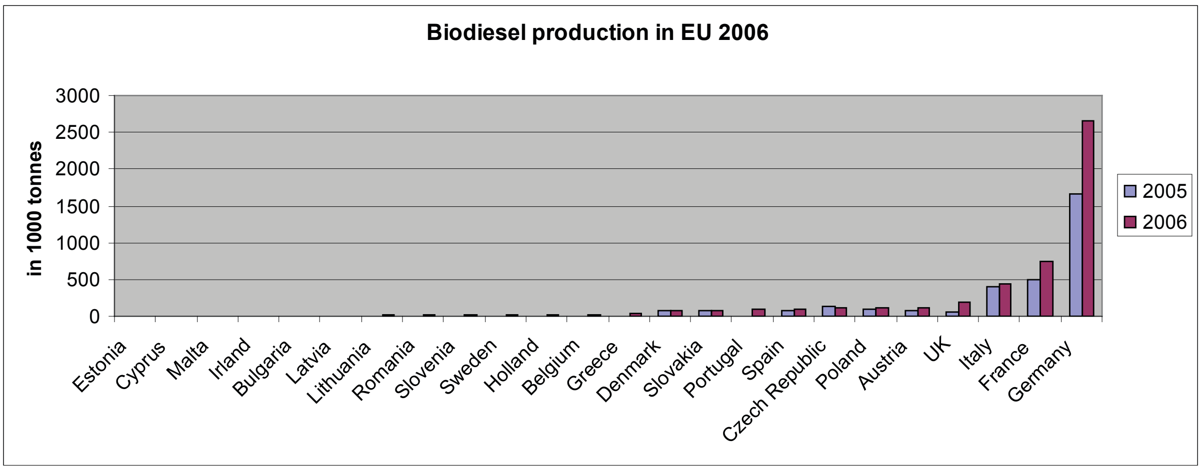


Figure 23: Production in the EU 2006 (European Biodiesel Board 2007)

Biodiesel production is rapidly increasing and with production capacity higher than production, if demand is increased there is sufficient spare capacity to allow for higher levels of production. By 2007 the European Biodiesel Board (EBB) reports of a production capacity of 10.3 million tonnes only in the EU. This illustrates a great potential of increased production. Where market development is concerned, there are a number of different potential future scenarios of biodiesel production.

Biofuel Market Worldwide predicts a 30 % annual growth from 2006 and an estimated global biodiesel production in the region of 11 million tonnes by 2010 (RNCOS 2006). The International Energy Agency (IEA) expects a doubling of annual biofuel production by 2011 (International Energy Agency 2006). Biodiesel production correlates with demand, higher demand triggering higher production as the production capacity is in place.

There is a huge amount of fallow land in Europe, in 2005 – 2006 there was 7.7 million ha of fallow land in the EU (Eurostat 2005). This land can be potentially used to produce biofuels and substantially increase its production.

10.2.2 Germany

In 2006 Germany had a biodiesel production capacity of two million tonnes. This is expected to reach nearly 4.5 million tonnes in 2007 (UFOP, 2007). Germany's domestic biodiesel market began slowly, but production figures rocketed in the late 1990's. Production has gone from a tiny 5000 tonnes in 1992 to 100,000 tonnes in 1997 reaching 2.66 million tonnes in 2006. In 2005 biodiesel made up 6.3 % of Germany's total diesel consumption (Association of German Biofuel Industry 2007).

There is now a growing interest in Germany to use pure vegetable oil to fuel vehicles.
Up to 30 % rapeseed oil may be blended with conventional diesel, but the oil can also be used as fuel in a pure form. Several thousand cars already run on pure rapeseed oil with an increasing number of heavier vehicles such as HGVs following the trend. Approximately 10 % of the German filling stations (1900) offer biodiesel to customers (Association of German Biofuel Industry 2007).

10.2.3 USA

According to the National Biodiesel Board (NBB) 85 companies have their own production plants and actively promote biodiesel. The map in figure 24 indicates where these plants are located:

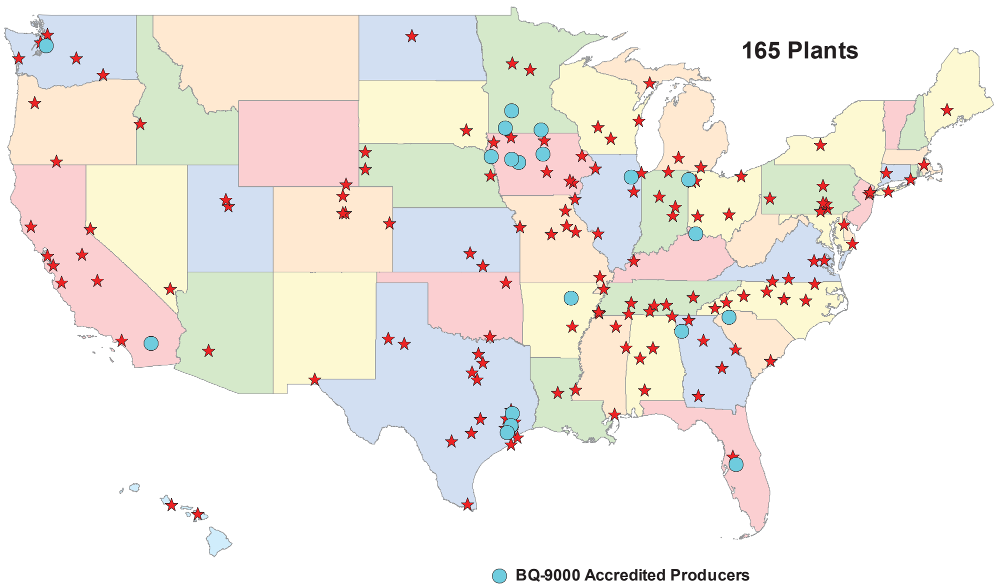


Figure 24: Commercial biodiesel plants in USA (National Biodiesel Board 2007)

The sale of biodiesel in the US was 250,000 tonnes in 2005, and the estimate for 2006 was about 750,000 tons as shown in figure 25:

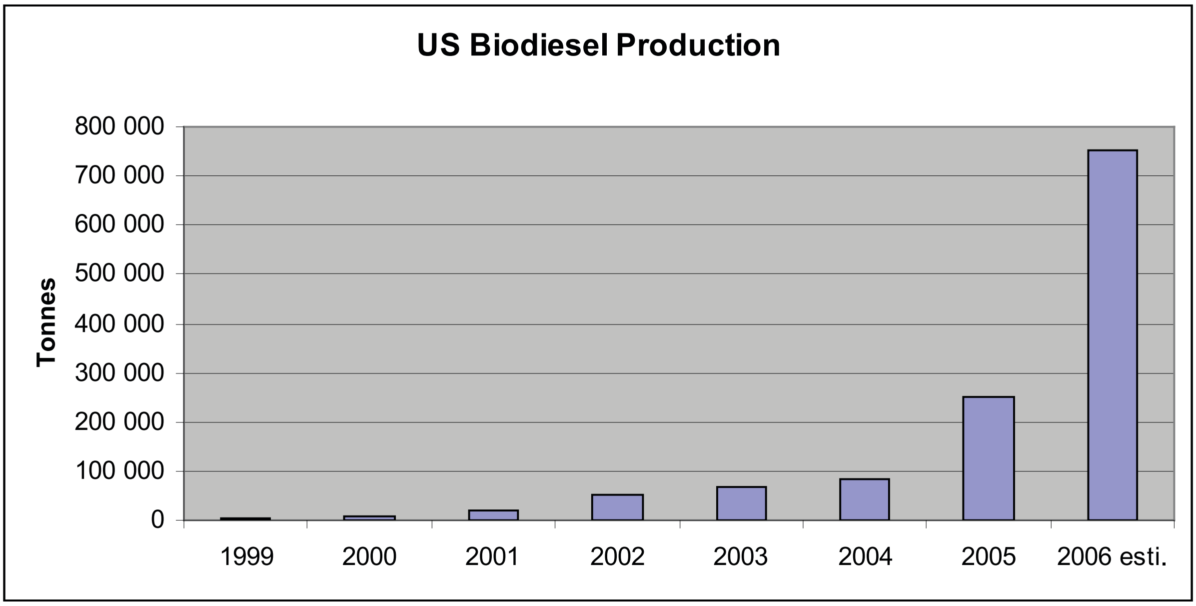


Figure 25: US Biodiesel production development (National Biodiesel Board 2007)

In 2005; 250,000 tonnes of biodiesel were sold in the U.S. with an estimate for 2006 in the region of 750,000 tonnes. Production capacity is rapidly increasing in the U.S. with current production capacity reportedly being 1.9 million tonnes (National Biodiesel Board 2007).

According to the NBB 78 biodiesel producing companies are planning to expand their existing plants or build new operations within the next 18 months (see the map below in figure 26) this would increase production capacity dramatically to an estimated 5.5 million tonnes per annum.

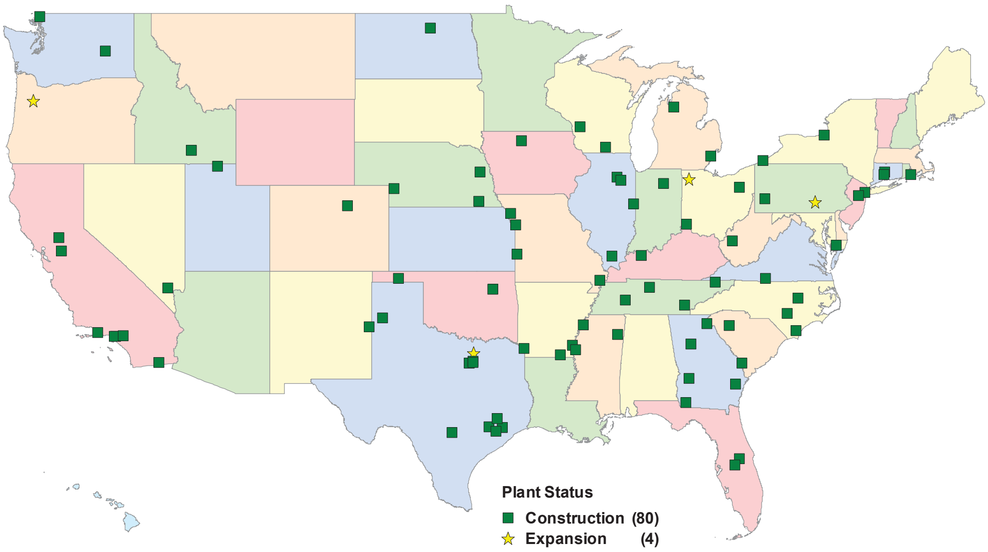


Figure 26: Biodiesel plants under construction in USA (National Biodiesel Board 2007)

10.2.4 Norway

Up until the present day, biodiesel production in Norway has largely been insignificant amounting to an output of just 8.500 tonnes by the end of 2006. Production has been mainly based on fish oils but some small companies also offer biodiesel made from used cooking oil.

From thjs small beginning we are now witnessing a transformation towards bigger production plants and a shift to using imported rapeseed oil in the manufacturing process. In 2007 a larger production facility opened at Hurum aiming at producing 150,000 tons a year, but if demand materialises up to 300,000 tonnes a year could be produced.

Another plant is scheduled to be built over the next two years and looks set to boost the annual production volume up to 400,000 tonnes a year. This estimated volume equates to approximately 20 % of Norway's auto diesel consumption. The Norwegian production is mainly based on imported rapeseed oil from Europe.

A low-blend biodiesel (B5) is now being widely introduced by oil companies. To aid further development of the biodiesel market, the Norwegian government recently announced a new fixed fuel standard, with the aim of gradually increasing the proportion of biofuels used in cars from two percent (measured by volume) in 2008 to five percent in 2009. In the same announcement, the government also set a seven percent-goal to be reached by 2010. Measured in energy content the goal for 2010 is approximately 5.75 percent (State Pollution Control Agency 2007)

10.3 Ethanol production

Global ethanol production was more than 16 million tonnes by the end of 2005, an increase of almost 80 % from 1995 (see figure 27):

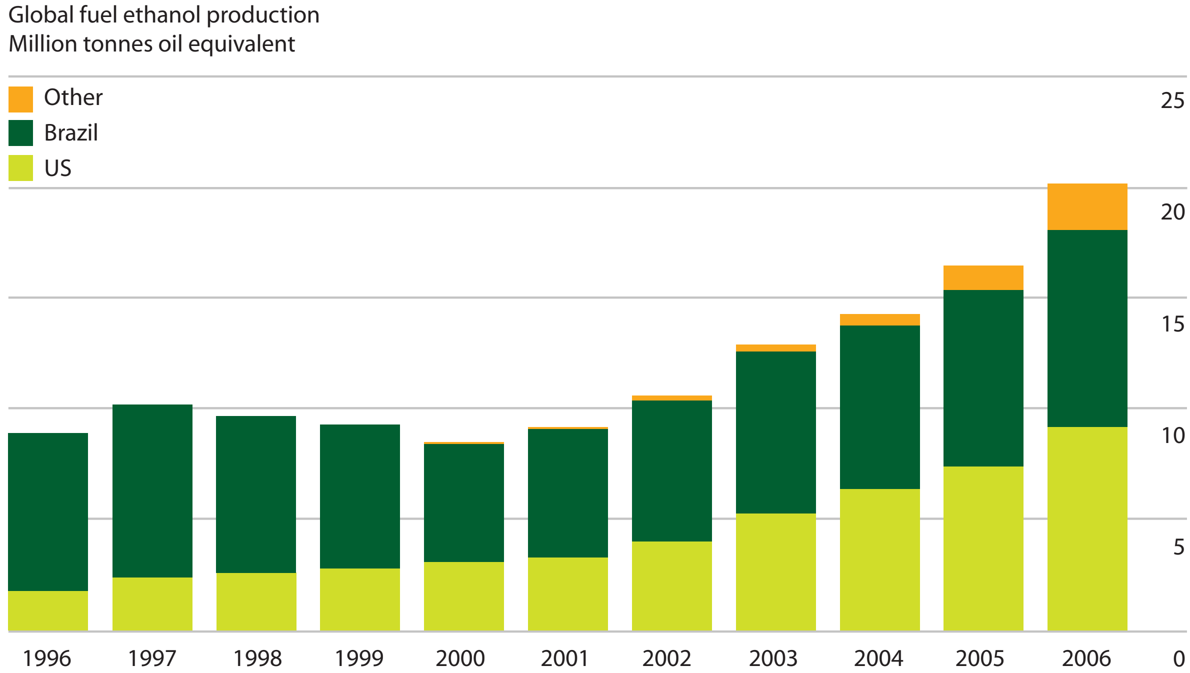


Figure 27: Global Ethanol Production (BP 2007)

Currently Brazil and the USA are responsible for 92 % of the world's total ethanol production. Traditionally Brazil has been the world's most important ethanol producer, however, in the past five years US production has increased dramatically. Apart from Brazil and the USA, China is the world's third biggest producer of ethanol, producing 643,000 tonnes oil equivalents in 2005.

10.4 Next generation biofuels

10.4.1 «Generation 1½»

«Generation 1½» biodiesel is called so, because it uses a technology in between conventional biodiesel and second generation biofuels. «Generation 1½» biodiesel is an avenue to explore with regards to fish oils and other types of animal fat or vegetable oils. These are oils which results in a poor quality final biodiesel product when using traditional first generation technology.

The raw material used may be upgraded by adding hydrogen, as shown in figure 28. This process is more energy demanding compared to traditional biodiesel production but the resulting product has the benefit of having improved winter qualities (-5 to -30 º°C) and is easier to blend with conventional biodiesel compared to conventional biodiesel. The Finnish oil company Neste Oil was aiming to start large scale commercial production (170,000 tonnes p.a.) in of 2007. Neste Oil will promote «Generation 1½» fuel under the label NExBTL (NesteOil 2007).

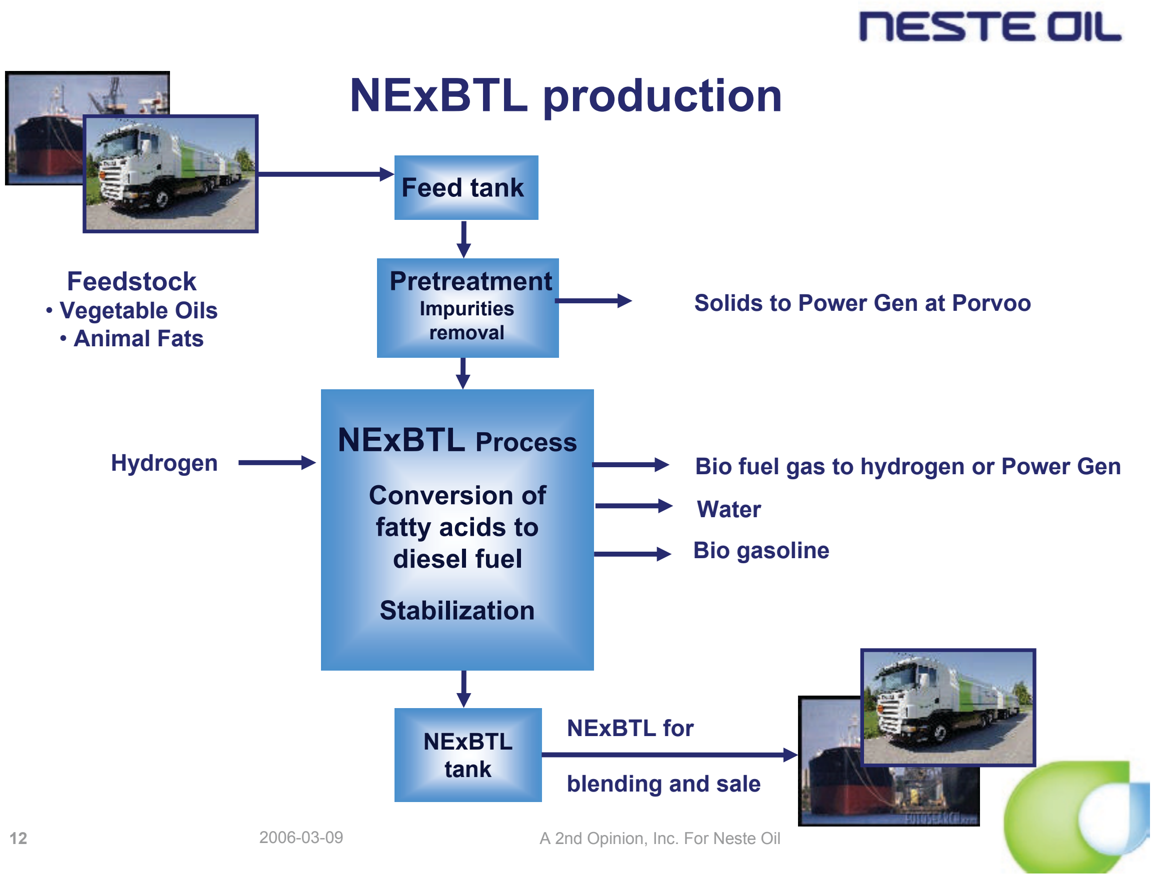


Figure 28: Neste Oil Production Process scheme (NesteOil 2006)

10.4.2 2nd Generation Biodiesel

The production of synthetic biodiesel is called 2nd generation biodiesel, the, so-called Btl process (Biomass-To-Liquid). The generation leap is based on the fact that 2nd generation biofuels use the whole plant as feedstock and not only the «fruit» of the plant as done in first generation biofuels.

Production is typically a three-step process: gasification, gas purifying and ultimately hydrocarbon construction in a Fisher-Tropsch (FT) reactor. This process is identical to the process for producing GtL (Gas-To-Liquids) and CtL (Coal-To-Liquids), the only difference relies on the feedstock used.

This technology has yet to become commercially available, though, the German biodiesel company Choren has developed a technology whjch is considered to be the next major development in the industry. A large-scale demonstration plant being built was scheduled to open in 2007. At the time of writing though, it has still not opened. Norsk Hydro and Norske Skog are carrying out a feasibility study with regards to a potential Norwegian full-scale plant. Figure 29 on the next page shows how the process flow is of such a plant.

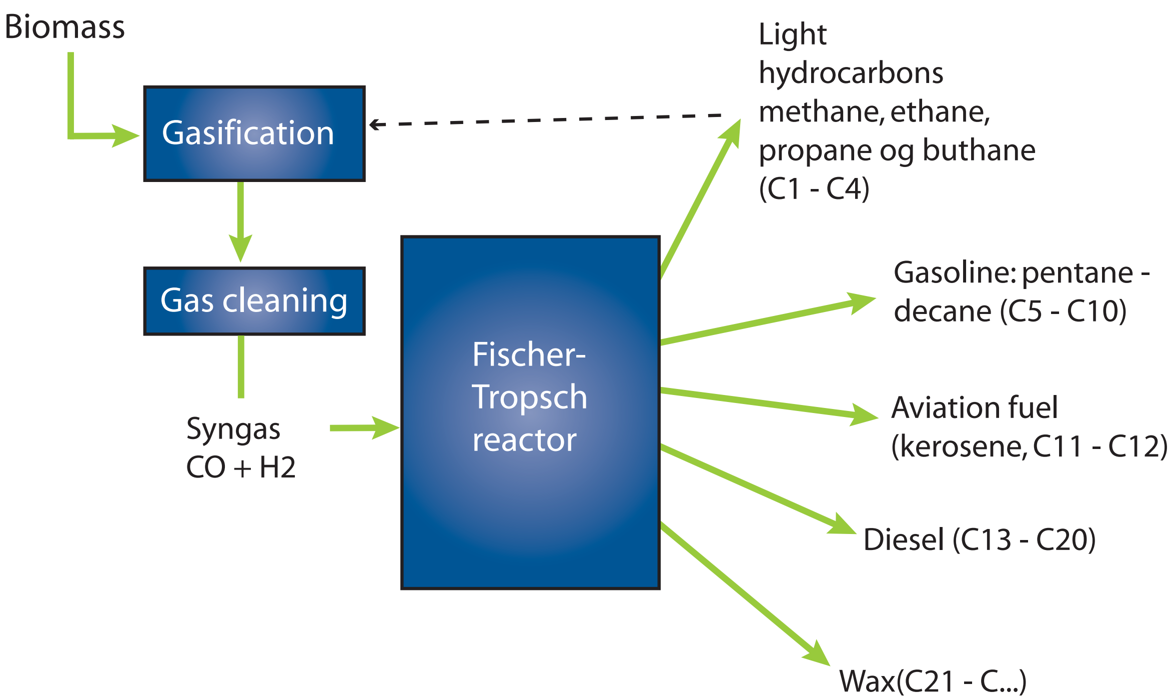


Figure 29: Fischer-Tropsch technology process scheme

10.4.3 Biofuels from algae

Biofuel production based on oil extraction of algae is technically feasible. Algae are fatty single-celled plants with an astonishing growth rate and may be cultivated in desert areas and other relatively sunny but unproductive sites.

Some algae contain up to 60 % triglyceride in addition to a range of other carbohydrates which can be converted into ethanol, methane, hydrogen, synthesis gas (gas consisting of H_2 and CO) or desiccated solid bio-mass. Algal oil production can be up to 30 times greater than an equivalent area used for the production of other oilseed crops. The oil content of algae can be up to 70 % of their dry weight and an astonishing 200 to 400 tons oil/hectare/year can be produced from algae. The Dutch company AlgaeLink offers complete solutions for algae growing for biodiesel production. The photo-bioreactors, glass tubes in which the algae is grown, are of sizes up to 100 tons biomass production per day (AlgaeLink 2007).

Extensive research on outdoor algae cultivation took place in the 1980's and 1990's focusing on shallow ponds exposed to sunlight.

More recently there has been a shift towards growing algae in bio-reactors which are in effect giant test tubes. The benefits of bio-reactors are that temperature and pH can be carefully monitored and adjusted as well as allowing the elimination of undesirable micro organism.

In order to improve growth rate, algae have been placed in waste water from industrial processes which simultaneously works as water decontaminant. In U.S. Algae cultivation in exhaust from coal based power plants has been tested (GreenFuels Technology 2007).

10.5 Norwegian biofuel production – Present and Future

Norway's current biofuel production potential based on domestic agricultural products is estimated to be 15,000 tonnes of biodiesel and 37,000 tonnes ethanol (ZERO et al. 2007). It is thought unlikely that Norway will use this potential for biofuel from food crops as the country is heavily dependant upon food imports and unlike the E.U. and U.S. does not have large areas of set-aside farmland.

The adoption of new technologies though could enable Norway to take advantage of any form of biomass, notably wood, which would massively boost Norway's biofuel potential.

Measured in energy, Norway's annual output of raw materials from agriculture and forest is in the region of 55 TWh. 16 TWh are designated for energy purposes and the remaining 39 is dispersed on building materials, pulp and paper, food and livestock nutrition (Norges Vassdrags- og Energidirektorat 2003).

Norwegian theoretical annual biomass potential is 425 TWh whereof 64 TWh is wood. Present annual logging level is approx 12 million m^3 (A quantity equal to around 24 TWh). This means that there is still an annual increase in the order of 40 TWh of energy in Norwegian forests. It has been estimated that about half of this energy could be utilized, possibly for biofuels production (ZERO et al. 2007).

As a result, wood make up a considerable part of the unutilized biofuel raw material potential. Depending on fuel quality specification, between 50-70 % of the 20 TWh available for biofuels production can with existing and soon available technology, be converted in to fuel for ships. This would correspond to1-1.,4 billion litres of diesel fuel.

In addition, 5 TWh of fat and/or carbohydrate-rich residual from households, industry and agricultural activity may be utilized for production of biofuels. 1.8 TWh solid firewood from straw may also hold a potential 0.9 TWh biodiesel content (100 million litres) (ZERO et al. 2007).

11. Biofuel cost

The Central-Europe (Germany, Austria, Benelux and Scandinavia) RME-biodiesel spot price was 6.60 NOK/litre by mid-Nnovember 2007 (€ 925/ton) (Dagens Næringsliv 2007). While Rotterdam pure-oil price was 5.50 NOK/litre rapeseed oil, 5.10 NOK/litre soy-oil and 4.20 NOK/litre palm oil (FAO 2007). Compared to petroleum based fuels, the price of biofuels are is very high. The cost for HFO 380 was per November 2007; 3.88 NOK/liter (Including the Norwegian national tax on CO_2 and SO_2) and MDO 4.42 NOK/litre (Bunkeworld 2007). However as these fuels has different energy content, the relative price differences can best be seen when reviewing per energy cost, as in table 8:

Table 8: Comparison of biofuel and marine fuel prices (Nov. 2007)

Fuel	NOK/MJ
HFO 380	0,095
IFO 180	0,100
MDO	0,115
Biodiesel	0,200
Palm Oil	0,124
Soya Oil	0,154
Rape Oil	0,166

We have looked at two different cases for comparing prices for fuels in the Norwegian domestic fleet. First we have taken a standard platform supply vessel (PSV) for the Norwegian offshore industry, using 2000 tonnes of fuel per year as basis. This type of ships uses generally MDO in Norwegian domestic operation. Substituting MDO with biodiesel would increase fuel costs in this ship from about 9.8 million NOK to 17 million NOK, an increase of fuel cost of 73 %. The cost of CO2-reduction will be in this calculation 920 NOK/tonne. If one assumes this ship initially used 2000 tonnes HFO instead and intends to replace this fuel with rape oil, it would be an increase of 75 % from 7.8 million NOK to 13.7 million NOK. This is of course large figures, both cases shows almost a doubling of yearly fuel costs.

Cheaper crude plant oils can be used instead of rape oil. As seen in table 8; both palm oil and soya oil are cheaper. Table 8 shows the price differences of different fuels with case 2, switching HFO with crude plant oil:

Table 9: Cost of different fuels for a ship consuming energy equal to 2000 tonnes HFO

Fuel (equa. 2000 tonn HFO)	Annual fuel costs (NOK)	Increase in %
HFO	7 826 500	
Rape oil	13 665 500	75
Soya oil	12 725 100	63
Palm Oil	10 249 400	31

The cost of crude vegetable oil has risen considerably the past few years and if the current high crude vegetable oil prices are reduced as a result of increased production, this could change the profitability of introducing biofuel.

The taxation of fossil fuels like MDO and HFO can, however, over the next few years be increased from the national level at 0.54 NOK/litre and this could balance out the cost gap. The SO_2 taxation is currently more important to the total equation than the CO_2 tax, because of high levels of sulphur in HFO. Figure 30 shows the projected price of vegatable oils in the coming years. In part III of this report, these issues are debated more closely.

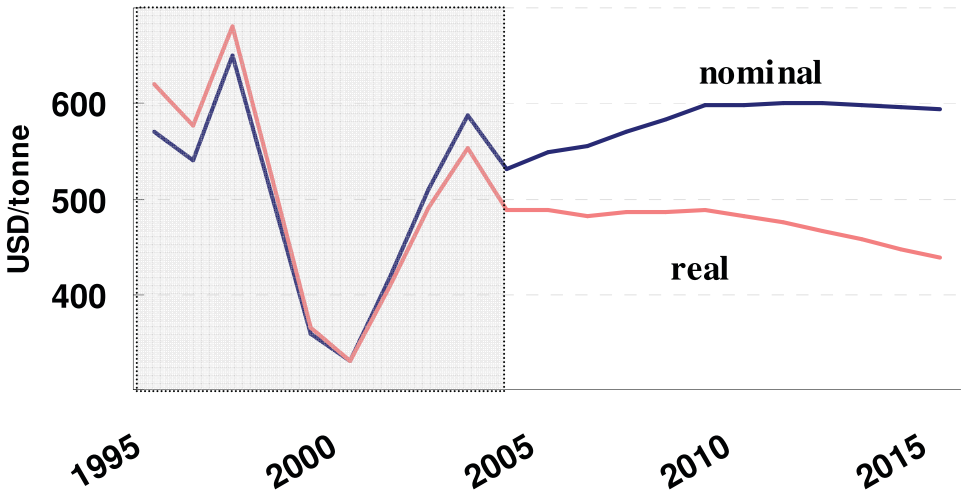


Figure 30: Vegetable oil price projection (Thoenes 2005)

The fuel cost with regards to biofuels from biomass (2nd Generation) will be determined by both technology and quality specification, however, at present it is impossible to predict whether it will be cheaper or more expensive compared to today's vegetable oil fuels.

Part III: Environmental and social considerations

12. Environmental concerns

As sea transport is a very energy effective form of transport, greenhouse gas emissions from sea transport is lower than other modes of transport. Nevertheless, as the importance of facing the threat of global warming is becoming more urgent, sea transport needs to face this problem. In addition use fossil fuels in ships leads to other emissions such as SO_2, NOx and particulate emissions which can lead to serious environmental and health issues.

Use of biofuels can reduce these emissions, but the combustion of carbon-based material suich as biofuels will always lead to some level of emissions. The combustion reactant with biofuel will for instance be air which consists of 79 % Nitrogen and 21 % Oxygen leading to NOx-emissions from combustion.

Combustion results in a number of very complicated reactions and the products formed are depending on many factors. The degree of mixing of the biofuel and air can regulate the reactions happening once the biofuel is ignited. In an ideal scenario with complete combustion there would be no emissions of carbon monoxide or unburned hydrocarbons, but this would increase emissions of NOx which is heavily influenced by the combustion temperature. (Moran & Shapiro 2000).

12.1 Greenhouse Gas Emissions

The total GHG-emission from the Norwegian domestic fleet in 2005 amounted to 3.8 million tonnes CO2-eq, corresponding to about 7 % of the total Norwegian GHG-emissions, see Figure 31 (Statistics of Norway 2007). In this figure, coastal traffic accounted for 2.5 million tonnes and the fishing fleet about 1.3 million tonnes of CO_2-eq.

Under the Kyoto protocol Norway has to stabilize its greenhouse gas emissions to only one percent above 1990 level. Figure 31 shows the contribution of emissions from domestic shipping including fishing vessels compared with other sectors. Domestic shipping is one of the major groups of greenhouse gas emissions in Norway (Statistics of Norway 2007).

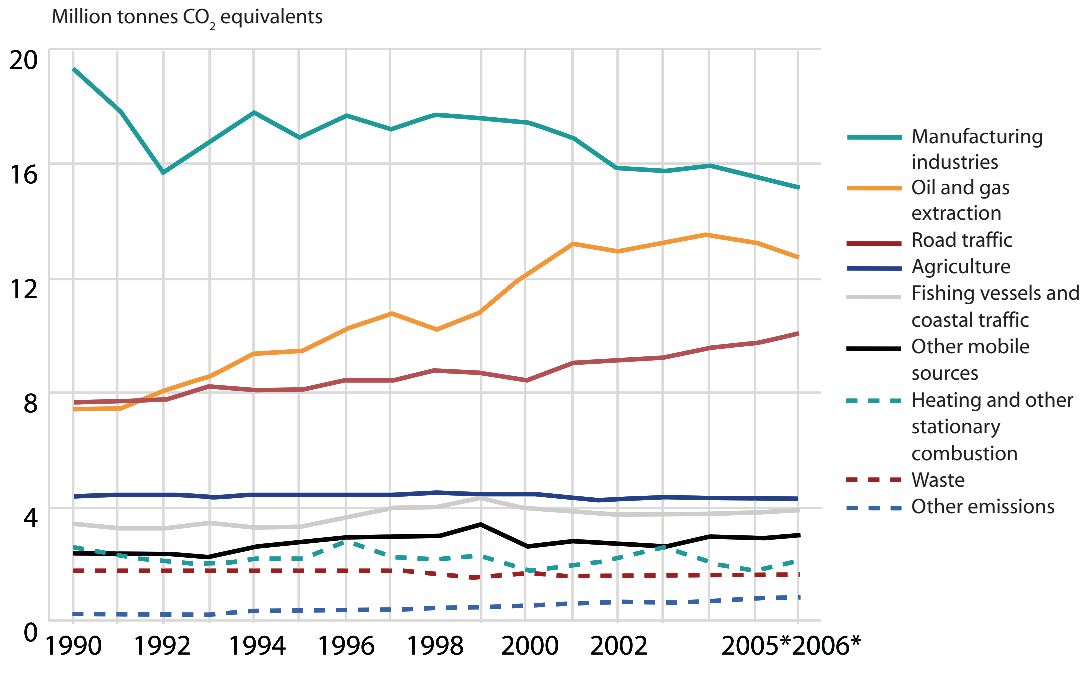


Figure 31: Emissions of greenhouse gases by source 1990 - 2006.
Million Tonnes CO2 equivalents (Statistics of Norway 2007)

Biofuel can be considered to be a renewable energy because the same amount of CO_2 that is released from combusting biofuels has previously been taken up from the atmosphere as the plant grows, thus not leading to any net increase in the concentration of CO_2 in the atmosphere.

However some fossil-fuel energy is used when producing the raw material for biofuels. The picture is further complicated by the fact that the fertilizer used to help biofuel crops itself releases nitrous oxide, a very potent greenhouse gas. Consequently it is necessary to consider the broader picture of greenhouse gas emissions for biofuels.

The best study of comparing conventional fuels and biofuels is made in the automotive sector.

A joint research study conducted by the European Council for Automotive R&D (EUCAR), The oil companies' European association for environment, health and safety in refining and distribution (CONCAWE) and The Institute for Environment and Sustainability of the EU Commission's Joint Research Centre (JRC) compares conventional automotive fuels and biofuels (EUCAR, CONCAWE, JRC 2007). According to this study rapeseed based biodiesel could save 53 % of greenhouse gas emissions compared to conventional diesel. This figure includes nitrous oxides (N_2O) and fossil-fuels used in production. Figure 32 is derived from this study. The black line over the graph outlines the possible error margin of the study:

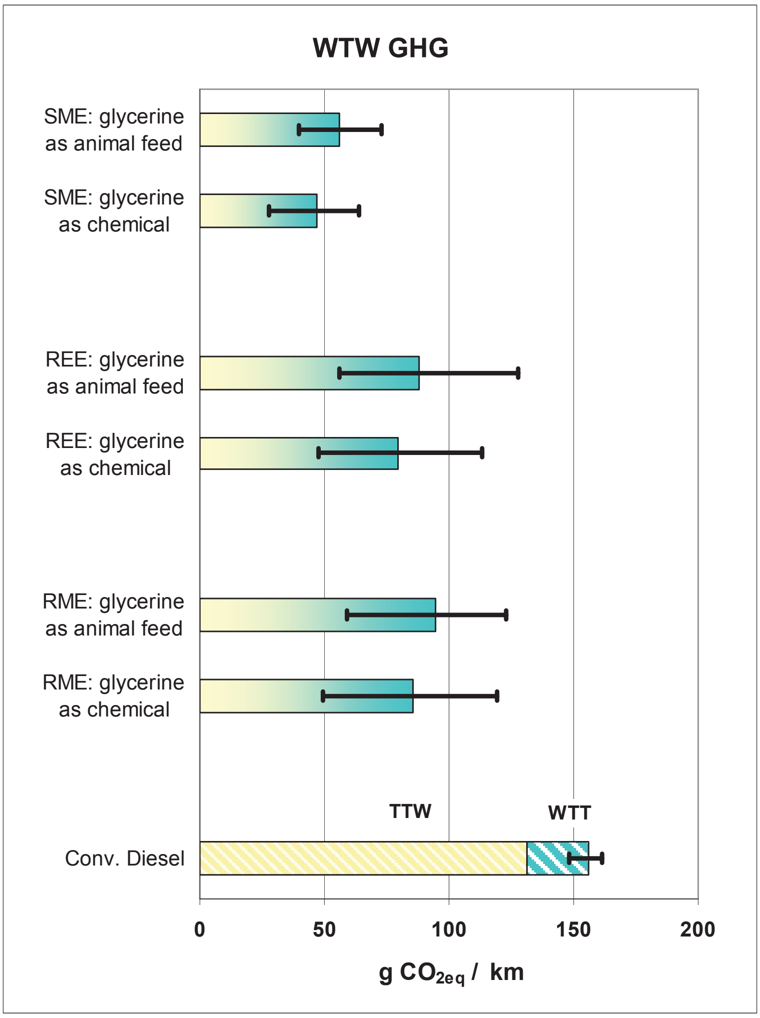


Figure 32: Well-To-Wheels greenhouse gas emissions from different pathways of biodiesel and conventional diesel (EUCAR, CONCAWE, JRC 2007)

Combusting most marine fossil fuels produce about the same amount of CO_2, namely about 3.17

tonnes CO2 per tonne of fuel, as conventional diesel. This leaves the EUCAR report as a satisfactory baseline for comparison (EUCAR, CONCAWE, JRC 2007).

As seen from Figure 31, RME (rapeseed based biodiesel) generates more greenhouse gas emissions than SME (soya based biodiesel). Rapeseed based biodiesel is, however, the most common type of biodiesel in Europe and Norway. As indicated in figure 31, the fate of the by-products is of high importance for the final GHG-balance.

The big uncertainty in Figure 31 is due to nitrous oxides (N_2O) emissions from cultivation of the vegetable oil plants used for biofuels production which is not well accounted for. The nitrous oxide emissions also vary with different feedstocks. Crutzen et al. suggest that production of palm oil for instance may have less emission than rapeseed oil and soybean oil (Crutzen et al. 2007). Ligno-cellulosic 2nd generation biofuels have considerably less N_2O-emissions during production (EUCAR, CONCAWE, JRC 2007).

While the fossil energy inputs to the production of biodiesel is higher than for production of petroleum fuels as can be seen in figure 33, still the fossil energy inputs in production is not nearly half of energy output (EUCAR, CONCAWE, JRC 2007).

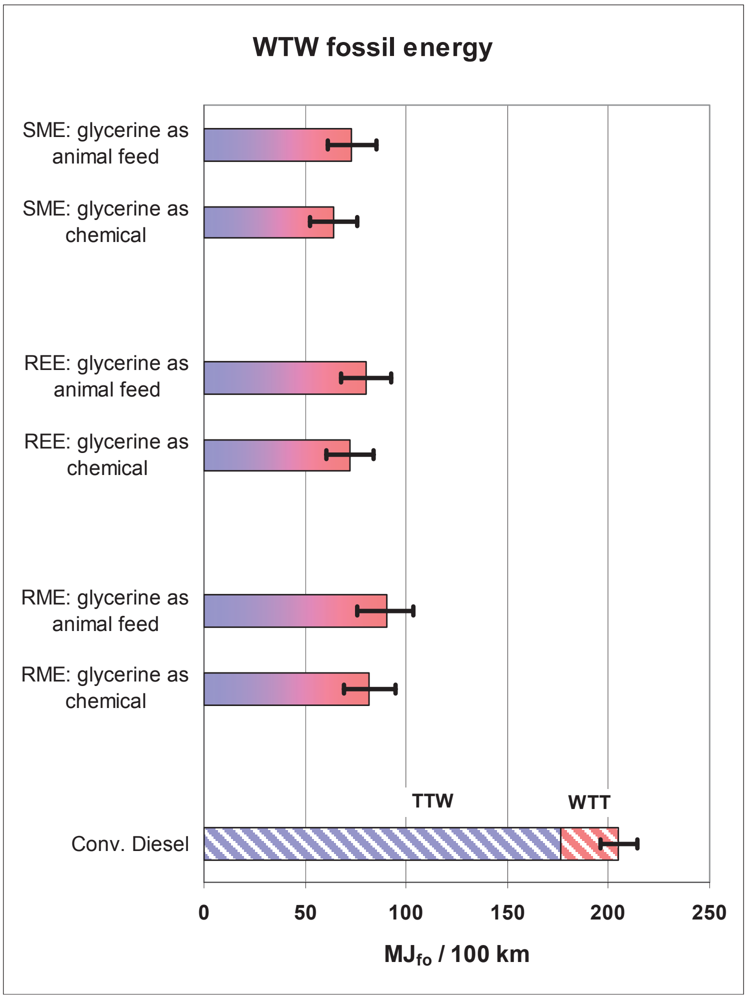


Figure 33: Fossil energy inputs to biodiesel production (EUCAR, CONCAWE, JRC 2007)

In chapter 11 we reviewed an example of how much a change to renewable biofuels would cost. It is also interesting to review how much CO2-emissions that can be cut by implementing biofuels in ships. By a switch to biofuels, the same ship reviewed in chapter 11 will save about 6.300 tonnes of

CO_2-emissions annually (well-to-wheels perspective not reviewed).

12.2 NOx emissions

Nitrogen monoxide (NO) and nitrogen dioxides (NO_2) are by-products of the combustion process. NOx gases are not greenhouse gases but contribute to acidification that causes acid rain which is a major environmental problem for Scandinavia and Northern Europe and eutrophication.

The NOx emissions from biofuels in engines are generally slightly higher than NOx-emissions. Several theories exist on the reason for this increase. For instance the increased flame temperature caused by reduced concentration of carbon soot is believed to cause increased emissions of NOx. However there are several factors that affect the NOx-emissions.

In 2002 the US Environmental Protection Agency released a report based on a number of tests on engines using biodiesel. Large truck engines were used and soya-based biodiesel was compared against petroleum diesel. Figure 34 shows the results from the tests:

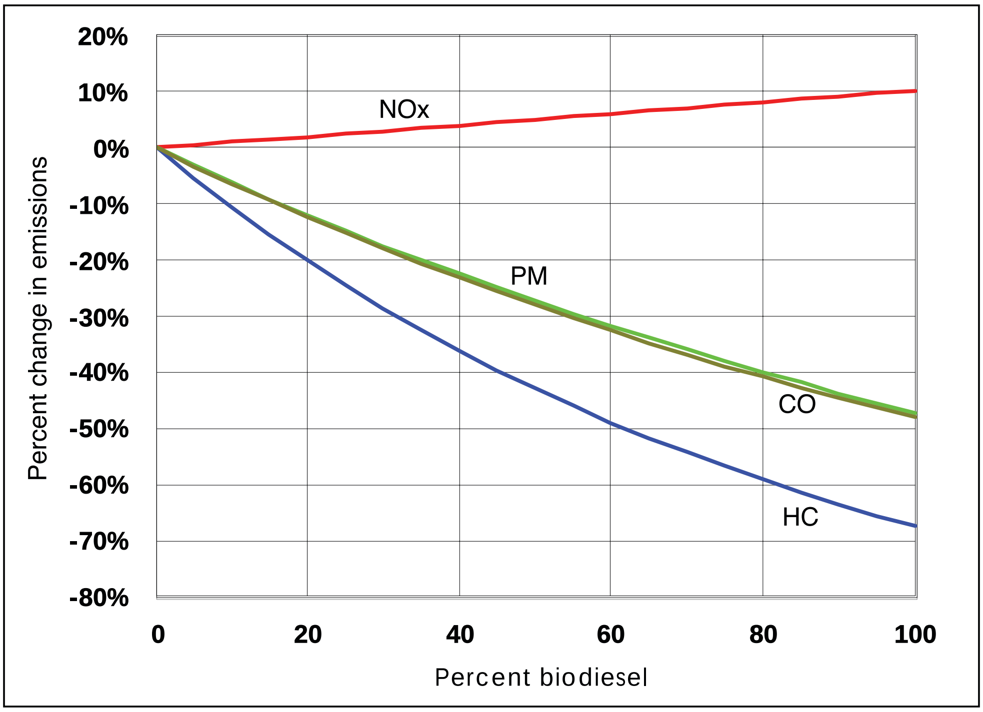


Figure 34: Emissions related to different blends of biodiesel in autodiesel on a truck engine (EPA 2002)

In another study conducted by several US research institutions, rapeseed oil was also examined, with the results showing the same NOx emissions as for petroleum diesel (Krahl et al. 1996). Wärtsilä however reports of a slight increase in the NOx emissions when using palm derived vegetable oil instead of HFO (Juoperi et al. 2007).

Based on these findings, it seems that crude rapeseed oils may have similar NOx emissions from a ship engine compared with HFO. However the results are not directly transferable, since the engine design is essential for NOx emissions. Figure 35 on the next page shows how palm oil compares with HFO in land-based power plants.

In the Norwegian inshore waters, a NOx-tax was introduced on 1 January 2007 for many NOx-emitters, including vessels whose installed power is greater than 750 kW. There are several ways of dealing with the NOx problem, the most widely used for ships engines being Selective Catalyst Reduction (SCR) but also HAM-technology and water emulsion are potential technologies. (Det

Norske Veritas 2007). Using biofuel, in these engines are not documented to affect the level of NOx-reduction when using these technologies (Juoperi et al. 2007).

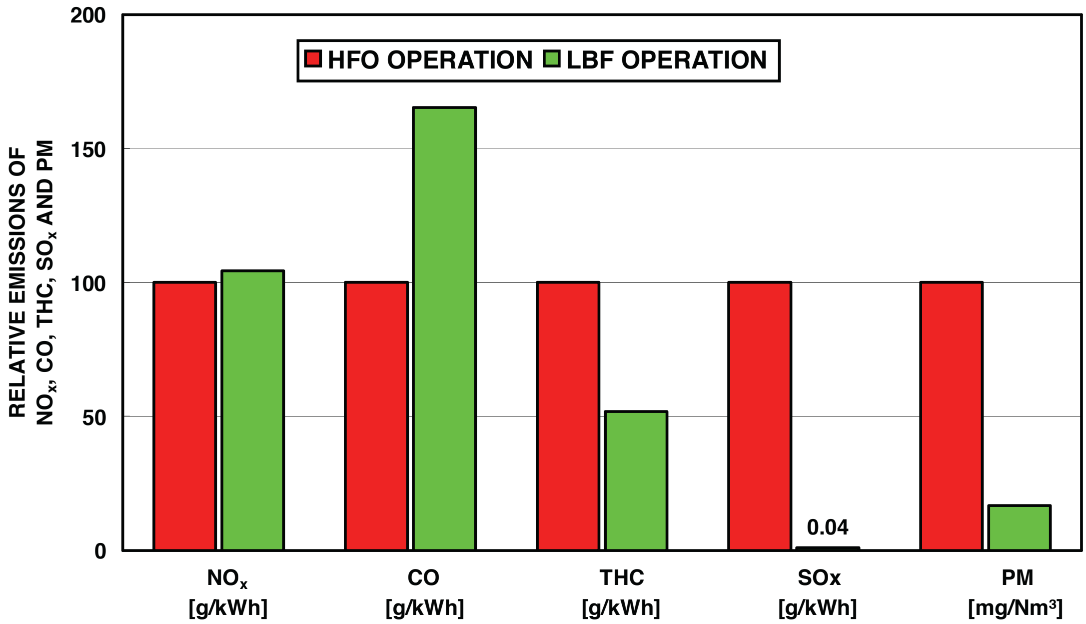


Figure 35: Liquid bio fuels (LBF) local emission (Juoperi et al. 2007)

12.3 Sulphur emissions

Introducing biofuels in ships will significantly reduce emissions of sulphur compounds such as sulphur dioxide ($SO_{2)}$ from ships because of the minimal presence of sulphur in biofuels.

Norwegian domestic shipping accounts for 16 % of Norways SO_2 emissions (Miljøstatus 2005).

Table 10: Sulphur content of different fuels (MAN B&W Diesel, 2006)

	Vegetable oil, treated, non transesterified	Biodiesel EN14214	Marine Diesel ISO 8217 DMB	Heavy Fuel Oil ISO 8217 RM ..
Sulphur content (PPM)	<10	<10	< 20 000	<50 000[1]

[1]MARPOL Annex VI limit the max permissible sulphur content to 45,000 ppm

SO_2 reacts with atmospheric water and creates a weak solution of H_2SO_4 (Sulphuric acid) which in turn leads to the formation of acid rain which acidifies water bodies such as lakes and rivers and soil leading to serious environmental damage.

When there is no sulphur present in the fuel there will not be any SO_2 from combustion, thus this problem does not arise when using biofuels.

In Norway there is a fuel tax on fuels containing sulphur for domestic use. For each 0.25 weight percent sulphur in the fuel, the tax is 0.07 NOK/litre fuel (Lovdata 2007).

12.4 Particulates

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. According to an American study, soya based or rapeseed based biodiesel could reduce particulate emissions by 35 % compared to automotive diesel (Strong et al. 2004).

It has not been possible to find a comparable study for ship engines. However, experience from land-based power plants using palm oil instead of HFO shows that the reductions of particulates have been significant.

Levels of PM in Oslo and Trondheim have been higher than set limits , mainly due to heavy traffic. High levels increase risk of health problems and authorities are trying to use different measures to cut emissions, such as reduced speed limits in periods og high concentrations.

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 (Munack et al. 2005). In biofuels, these inorganic constituents are not present. As a result there are minimal PM emissions from these engines which use biofuels.

12.5 Carbon Monoxide

CO emissions derive from the incomplete combustion of the fuel. CO is oxidized to CO_2 in the atmosphere or eliminated by soil bacteria. However, in spite of this carbon monoxide is not considered as important a polluting substance as particulates, SO2 or NOx (Munack et al. 2005).

The increased level of CO in figure 39 suggests an increase of CO emissions when using vegetable oil instead of HFO, however this does not correspond with figure 38 where biodiesel significantly reduces emissions in comparison with automotive diesel.

12.6 Polycyclic Aromatic Hydrocarbons (PAH)

There are over 500 different PAH-compounds and usually PAH exist in mixtures of substances.

PAH is found in crude petroleum. Incomplete combustion of organic material is the most important source of PAH. Inhaling air polluted with PAH can cause serious health problems such as cancer, a lowered immune system and an increased risk of skin diseases (Norwegian Institute of Public Health, 2007).

A study conducted by the U.S. Environmental Protection Agency shows a reduction of PAH in the region of 75 % to 85 % when petroleum is substituted with biodiesel (National Biodiesel Board, 2007). HFO has a higher content of PAH than auto-diesel leading to the assumption that biofuels in ship engines using HFO would result in even greater reductions of PAH emissions (Janhäll 2007).

Bunker handling can be made safer by using biofuels. According to a Swedish study, people in direct contact with HFO have been found to have traces of PCA (polycyclic aromatics, including PAH) in their urine (Prosjekt Grön Kjemi 2007).

12.7 Marine environment

Huge spills of oil from ships have been shown to be disastrous for marine environment.

In 1989 the oil tanker Exxon Valdez spilled an enormous amount of crude oil in the Prince William Sound in Alaska, creating the one of the worst environmental disasters the world has ever seen. This and other oil spills is represent a continuing environmental threat all over the world.

Because they are biodegradable, a spill involving biofuels would be much easier to cope with. The US Environmental Protection Agency concludes that biofuels have less impact on aquatic and marine organisms than petroleum oils. An Idaho study in the U.S. examined the biodegradability of biodiesel and petroleum diesel in water. It was found that rapeseed biodiesel was 95 % degraded after 23 days while petroleum diesel was only 40 % degraded.

Biodiesel is classified as food in many countries and the demands for handling and transport are less strict.

Low blends of biodiesel could also improve biodegradability of the petroleum based fuel; this is therefore another reason for using low blends of biofuels in marine fuels (Von Wedel, 1999).

13. Social considerations

13.1 Biofuels in ships – A sensible use of natural resources?

Biofuels are relatively limited resources and, therefore it is important to consider where they should be used to ensure maximum environmental effects. For example would it be better to run cars on biofuels rather than ships? And are there other, maybe more advantageous ship-compatible fuels besides biofuels? Furthermore, the increasing demand for biofuels has an effect on food-prices and what are the consequences of this, in particular for developing countries?

13.2 Alternative ship-fuels

Several available alternatives to HFO, MGO and MDO can be found today. Gas (CNG or LNG) is regarded the most commercially available fuel. The SOx-emissions of these fuels are very small, which is also the case for particulate matter. The NOx-reductions may also be significant. Fossil fuel, either in the shape of LNG or CNG, does to some extent solve some challenges with regards to local emissions and NOx, however these fuels can only prompt slight reductions in CO_2 emissions in a well-to-wheel perspective. Production of LNG is energy intensive and leads to significant emissions of CO_2. Also there are some emissions of non-combusted Methane that will further reduce the climate benefits of using LNG in ships.

Today's available CO_2-neutral and emission-free vehicle solutions are first and foremost biofuels, electric- and hydrogen operated cars.

Electricity and hydrogen may to some degree be possible alternatives for some ships, such as ferries. However, the installation of the said technologies is likely to demand extensive refitting, alterations or even replacement of present engines. One should also keep in mind that this is not commercially available technology. Biofuels and its compatible technology, on the other hand, can be ordered and delivered fairly hassle free.

It should be noted that sails are also an emission free ship-alternative. Such a seemingly retrograde step for shipping may seem irrelevant to today's modern shipping fleets. However there are currently a number of projects whose aim is to develop kite-like sails for major cargo ships.

Whether this will be a relevant substitute or supplement to engine power remains to be seen. Also hybrid technologies involving sails, solar, waves and hydrogen solutions may become more relevant in the future. However interesting this may be, for the time being we should focus attention on existing alternatives.

Consequently the introduction and use of biofuels stands out as the most appropriate action to bring about in order to obtain rapid reduction in levels of CO_2 from shipping.

13.3 Biofuel applications

To determine whether biofuel in ships is a sensible use of energy, one should also consider other issues than merely looking at other possible energy purposes. Should biofuels be used as food rather than fuel, is an issue that need to be considered.

13.3.1 Biofuels for inland transportation

With regards to biofuels for other energy purposes than ships, there are two areas in particular that stand out; inland transportation including buses, cars and trains and stationary energy generation. Generally speaking, inland transportation employs the same engine technology and comparable fuel as ships. In both cases one energy unit of biodiesel will replace one energy unit of fossil fuel. Despite better energy efficiency in larger ship engines as compared with smaller diesel engines, the CO_2-reductions will be the same regardless whether the biofuel is used in ships or in land-based application.

The local pollution such as sulphur and PAH-emissions is another point of difference between fossil fuels and biofuels. In general biodiesel contains far less sulphur and other carcinogenic compounds such as PAH compared with marine distillate fuels. Due to the higher content of sulphur in fossil marine fuels than in the autodiesel used for cars, a greater reduction in SO2 emission is expected when introducing biofuels in shipping than for inland transportation.

13.3.2 Stationary biofuel uses

Biodiesel may also play a role as a substitute in oil-to-heat processes. However, if the intention is solely heat generation it is far more effective to grow other plants rather than oil succulent crops, e.g. rapeseed. For example a 1000 m^2 of grown rapeseed can produce an equivalent to 1000 kWh biodiesel (1000 litres) p.a. The same area though could produce seven times as much energy through wood pellets produced from salix (willow trees). Obviously; wood pellets are rather impractical as fuel for transport, but serves as a fully fledged alternative to heating oil given necessary alterations to equipment are carried out.

Growing vegetable oil plants for biodiesel production also generates a considerable amount of residual products which are suitable for food or livestock feed. In addition the same area is often used for food production in an annual rotation with energy crops. Fast growing salix is not very well suited for that kind of use and would represent a complete change in the use of land.

13.4 Biofuels versus food production

To what extent does the production and use of biofuels affect the price of foodstuffs and what impacts may it lead to on poor people of the world?

A joint report from The UN's Food and Agriculture Organisation (FAO) and for the Organisation for Economic Co-operation and Development (OECD) indicates that increased demand for biofuels is unlikely to have had any significant impact on the steep rise in wheat prices in 2006. The report outlines other explanations; like failed crops in 2006 and due to bad weather and, the growing populations and booming economies of developing countries, most notably China and India (FAO/OECD 2007)

Yet another report published by the Washington based think-tank The International Food Policy Research Institute (IFPRI), the same conclusions were reached.

The IFPRI analysis forecasts that we will experience a very different price growth between the various types of vegetable oil plants. They also assume that productivity within African agricultural sector is set to pick up along with an expected area-effective second generation biofuel manufacturing. This, according to the institute, will lead to a more steady increase in commodity prices.

13.4.1 Increased prices –effects on the poor communities

A possible increase in prices on agricultural products may have both negative and positive effects. In particular families with net export of foodstuffs benefits from increased foodstuff prices and net exporting countries will enjoy increased revenues on exported foodstuff.

The poor communities may also be helped with locally produced energy (biofuels) which in turn can lead to local economic development and less dependency in on more expensive imported fossil energy.
However, the poor in urban areas and net importing countries should expect tougher times in the wake of higher food cost.

13.4.2 Poor countries and households – consequences
Any change in prices of agricultural commodities is likely to have different effects on different groups of people. The last years' price increase on agricultural products has been substantially lower than other products. Now it looks as agricultural products price increase is set to come in line with the general price growth on products and services. Thus the price of food is not expected to become cheaper relative to other goods. Naturally, the effect will vary from foodstuff net producers to consumers, and further depend on how much of the total economy agricultural products represent.

In this context large-scale net importers of food like Senegal are more vulnerable than for example Russia as Senegal's agricultural products import represents a larger part of the country's total economy. Correspondingly, those households that spend the best part of their income on food are worse off than households where food expenditure amounts to a smaller part of the total income if prices are to go up.

13.4.3 Net exporting countries – benefits
As long as a country falls in the category of net exporter, higher prices of agricultural products results in more resources for distribution. Whether, and how, these resources are distributed depends on who owns the natural resources in the first place and what kinds of reallocation mechanisms are present in the country.

Among the least developed countries we find both net exporters and importers, hence, it is hard to conclude whether a price increase may be a benefit to developing countries in general.
Some countries with a net export of agricultural products is destined to benefit from increased prices on agricultural prices just as other countries have benefited from declining prices in the past

Table 11 lists net exporters and importers in all continents, and total value of export surplus or deficit.

Table 11: Number of net exporting and importing countries of agricultural products, ranged after continent (FAO/OECD 2007)

	Number of net exporters	Number of net importers	Export- return / deficit, mill US$
Africa	17	32	-5 979
Asia & The Middle East	11	32	-65 330
Europe	11	30	-21 462
Latin-America & Caribbean	14	17	39 547
North-America	2	1	878
Oceania	5	6	20 916
Total	63	118	-31 430*

* Due to incomparable statistics from many countries

On the whole; Africa, along with Asia / Middle East and Europe, are net importers of agricultural products. Latin-America can show for the biggest profit from agricultural trade while Oseania and North-America is also net exporters. Both rich and poor countries are to be found as net exporters and net importers. Even the least developed countries are represented on both sides in the overview. From the 38 countries classified by the UN as «Least developed countries»; 8 were net exporters and 30 net importers in 2003/2004.

For example Malawi could show for an impressive $322 million trading profit in average (2003/04), Mali with $180 million and finally Zambia with $55 million trade return. The not so fortunate list are topped by Bangladesh with a staggering $1800 million deficit, which alone represent close total of first and second runners-up Yemen's and Angola's $917 and 902 million trade shortfall (FAO/OECD 2007).

Based on FAO's net trade overview we may draw the conclusion that increased prices on agricultural products is likely to be beneficial to both rich and poor countries. However, we find more losers among the already poor countries as pointed out by in a study conducted by Arvind Panagariya (Panagariya 2005).

13.4.4 The majority of poor in developing countries are producers of agricultural products

Who benefits from increased food prices depends on land ownership and, if present, the processing industry.

If a household can be regarded as an agricultural net producer and produces agricultural products to a higher value than it consumes, a price growth will thus give the household an increased income. The same goes for poor farmers if land is well distributed as in Vietnam. This is not, however, the case with Brazil where land is disproportionately distributed.

In general we know that 70 % of the populations of poor countries are engaged in the primary industry, mainly in agricultural production (Norwegian Ministry of Foreign Affairs 2004). They are likely to benefit from increased prices on agricultural products. However, the urban populations in poor countries are growing rapidly and few of these will benefit from these price rises.

Even though a large number of the citiy's poor population have connections to rural districts, and may to some extent benefit from increased income there, they can largely be characterised as net consumers. Trends show that a growing number of people move to urban areas, therefore, increased prices will affect an increasing number of people in poor countries. See table 12 below:

Table 12: Population distribution, urban areas (Potter et al. 1999)

Region	Percent of population in urban areas		
	1970	2000	2025*
Globally	37,2	46,7	60,5
Africa	22,9	41,3	57,8
Latin-America	57,3	77,2	84,8
Asia	23,9	35,0	53,0

In other words, poor groups have conflicting interests with regards to prices on agricultural products. Urban population and other net consumers have profited from an average below market price increase on food (FAO World Agricultural Outlook 2007), while producers have experienced a plunging purchasing power. As a result, their ability to invest in capital goods in order to boost production has been negatively affected. Prices have relatively declined due to high availability of agricultural products.

According to the FAO report 'The State of Agricultural Commodity Markets' (SOCO) 2004, the impact of commodity price fluctuations is greatest in the poorest countries of the developing world. «An estimated 2.5 billion people in the developing world depend on agriculture for their livelihoods,» the report points out (FAO 2004).

The report adds that lower food prices mainly benefits consumers in developed countries or consumers living in urban areas of developing countries whilst net food importing countries benefit from savings in foreign exchange. However the vast majority of the world's poor and hungry live in rural areas of developing countries and depend upon agriculture for their primary source of income. It is these groups who will suffer losses in income and employment as a result of declining commodity prices. For this reason the FAO concludes that the benefit of lower food prices will be outweighed by these losses (FAO 2004).

13.5 Will increased prices lead to a new industry?

If prices of agricultural products should go up in the wake of an increased demand for biofuels, it will make these products relatively more expensive than goods from other sectors, leading to a possible redistribution of income from other sectors to the agricultural sector.

Emerging biofuel demand will pave the way for new and related industries which will benefit from increased commodity prices.

This is also something which was highlighted in an UN report on biofuels and development (UN-Energy 2007). The UN underline that bioenergy production is more labour intensive than fossil fuel production and as a result this could be a source of employment. Brazil is used as an example in the report where it is assumed that small scale industry will evolve in forage and after processing, as well as in support businesses like transport and agricultural machines. In the long-run this industry can mature and also contribute to activities on a higher technological level.

The report summarizes: successful biofuel industries bring significant job-creation potential with positions that include highly skilled science, engineering, and business-related employment, medium-level technical staff, low-skill industrial plant jobs, and unskilled agricultural labour.

Because the vast majority of bioenergy employment occurs in farming, transportation, and processing, most of these jobs would be created in rural communities where underemployment is a common problem (UN-Energy 2007).

Increased prices on agricultural products could also lower the drive to urbanization. In many developing countries the growing urbanization is an increasing problem, both because of high unemployment in the cities and the negative environmental impacts of densely populated cities. One of the classical models of economics of developing countries is the Lewis-model. This model discusses how increased income in the countryside will make city life relatively less attractive and counteract urbanization.

A more advanced version of this model, the Todaro-model, shows how people in the countryside consider the chances of getting a job and its expected salary in the city up against the income they can expect to earn locally. If income increases more locally as a result of higher price of agricultural products, the model predicts that fewer people will move to the city. Also it suggests that people may start to move from the cities and out to the countryside. Less pressure on the labour market in urban areas may in turn also contribute to higher salaries to the workers in the city.

13.6 Concluding remarks on prices and distribution

Depending on the economy of each individual country a price increase for agricultural products will have different effects. In some countries such a price increase will have a positive outcome, whereas for other countries, depending on import of agricultural products, the outcome will be negative. As for a household that produces more agricultural products than it consumes, a price increase of agricultural products would benefit the household's economy. The poorest countries in the world are net importers of agricultural products, whilst the poorest families in these countries are net agricultural products producers.

Poor countries and poor households are both winners and losers when the cost of agricultural products increase making any definite conclusions is thus hard to make.
Concerns about biofuels' effect on food prices have among other things been triggered by high prices on crops in 2006. The food price increase appears, however, to have been a result of failing harvests in many parts of the world this year (OECD/FAO 2007). Australia also experienced failing harvests in 2007 (Reuters 2007).

- Poor climatic conditions and draught resulted in failing harvest for grain and corn in 2006 which decreased by 50 % in Australia this year. The USA, EU, Canada, Russia and Ukraine also experienced lower production than usual in 2006. This combined with small reserves in store paved the way for record prices of these products world wide. Production was 60 million tonnes lower than expected.

- Unexpected high demand for biofuels in North-America and Europe contributed to an even higher price. This demand amounted to 17 million tonnes of grain and corn products.

- Also the price of oilseed increased in part because of higher demand for cheap substitutes for corn and wheat and partially because of changed production patterns of oilseeds production, particularly in the USA. This was because of the increased revenue from corn and crops.

- Reduced use of export subsidies as a result of policy change can also have contributed to increased price on diary products and sugar.

Even though the price hike in 2006 mainly seems to rely on other factors than biofuels production, both the FAO/OECD report and a report from the Washington based think-tank the International Food Policy Research Institute (IFPRI 2007), points out that biofuels production in long-terms will affect the price of agricultural products.

The FAO/OECD report is based on historical price development and projections of future supply and demand for agricultural products. These projections are based on the following assumptions that the report repeats clearly:

- Continued high economic growth in the world, especially in countries like China, India, Brazil and Russia. This will result in higher demand for meat and diary products and by implication to input factors in this production such as grain

- Projected oil price scenarios are connected with uncertainties, but are based on the International Energy Agency publication 'The World Energy Outlook 2006'. This publication assumes a price decline for oil to about $55 a barrel in 2012 and then a price increase toward $60 a barrel around 2016.

- The custom duties are important for how international trade with agricultural products evolves. The FAO/OECD has not incorporated any expectations for the outcome on the negotiations in the World Trade Organisation and assumes that todays framework will be applicable for the whole period. The big bilateral free trade agreement is also included.

- The European Union sugar reform came into force in the summer of 2006 and implies progressive price support cuts of 36 % over four years to the sugar industry in EU.

The FAO/OECD report of 2007 does for the first time include explicitly assumptions on the development of biofuels. The price of grains and corn, sugar, and also increasingly oilseeds and palm oil are affected by biofuel production. The following assumptions are made in the analysis:

- USA: Strong increase in ethanol production, mainly based on corn as a feedstock. Doubling of the ethanol production from 2006 to 2016, with a 50 % of the increase in 2007. While 20 % of the corn production is used for ethanol in the start of the period, it is assumed that about 32 % of the corn production will be used as feedstock for ethanol production by the end of the period.

- European Union: Bioethanol mainly based on crops and corn will be important in the EU in addition to the production of biodiesel. It is assumed that the European Union will not achieve its goal on of 5.75 % biofuels by 2010. However it is assumed that only 3.3 % of the fuel consumption in 2010 will be biofuels. Further, it is assumed that the consumption will continue to grow until 2016. The major part of the production will be covered by increased production within the EU, especially by wheat. It is also assumed some increase in oilseed and corn production.

- Canada: Canada is assumed to achieve the national target of 5 % ethanol blend in gasoline by 2010 and 2 % biodiesel blend in autodiesel and heating oils by 2012

- China: The production of ethanol will continue to increase steadily from 1.18 million tonnes in 2006 to 3.0 million tonnes in 2016, mainly with corn as feedstock.

- Brazil: It is assumed an increase in ethanol production of 145 % from 2006 to 2016. In 2016 it is assumed that the yearly production will be 34.7 million tonnes per year.

Figure 36 is derived from the FAO/OECD report and shows the expected increase in use of biofuels.

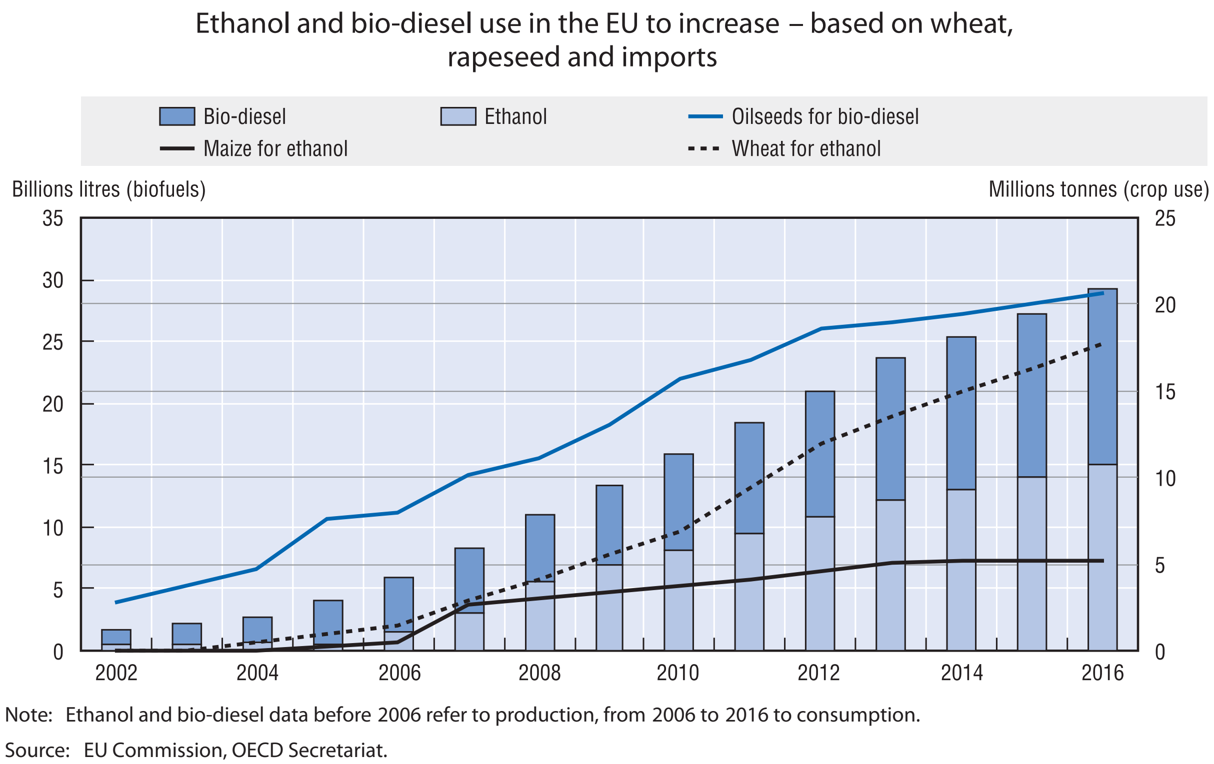


Figure 36: Expected increase in use of biofuels in the EU (FAO/OECD 2007)

The report from OECD/FAO accounts for the low production of 2006, but was written too early in 2007 to have taken in to consideration that also 2007 was a year of low agricultural production, especially in Australia. Most likely FAO/OECD has estimated the projected price development for the coming ten years without considering the failing harvest of 2007. FAO/OECD discuss this price estimates as a useful basis for comparison to discuss what will happen if certain assumptions does not materialise.

Towards 2016 it is assumed that food prices will decline from the high levels of 2006, but demand for biofuel will result in higher prices in this time-frame than what has been expected previously. The OECD/FAO report emphasizes that the role biofuel will play is bound with uncertain aspects:

- Agricultural and trade policy development in the field
- How fast 2nd generation biofuels can be implemented
- Oil price development

The price estimates of agricultural product shows a moderate increase, however, the increase is not expected to be higher than the inflation for most countries. In fact this implies a decline in food prices.

The moderate development of prices on agricultural products is shown evidently when one look at which level of price development is expected on other consumer goods. The price increase on consumer goods in general over the next ten years is assumed to be 2 % per year in OECD 5 % in South-Africa and Turkey and 3.1 % in Mexico (OECD/FAO 2007). For comparison the expected increase on prices for agricultural products will be relatively low. Since the prices for 2006 where unusually high as a result of failing harvests it can be more useful to review the average price of agricultural products for the first half of the period 2000-2010 as shown in tables 13 and 14:

Table 13: Measured price increase for the period 2006 – 2016, based on FAO/OECDs assumption of increased demand for biofuels and other important economical prospects (FAO/OECD 2007)

	Calculated increase in price up to 2016 in comparison to the mean price for 2001-2006**	Calculated increase in price up to 2016 in comparison with the price level of 2006
Wheat	2,1 %	-1,2 %
Corn*	3,3 %	-0,2 %
Rice	3,5 %	0,5 %
Oilseeds	1,3 %	0,4 %
Veg.oil**	1,8 %	0,4 %
Crude Sugar	1,2 %	0,5 %

* Mainly corn, but includes also barley, Indian millet and oat

** Mean increase of price from 2006 to 2016, 2006 prices assumed to be a mean for the period 2001-2006.

Table 14: Historical and calculated level of prices for different agricultural products (FAO/OECD 2007)

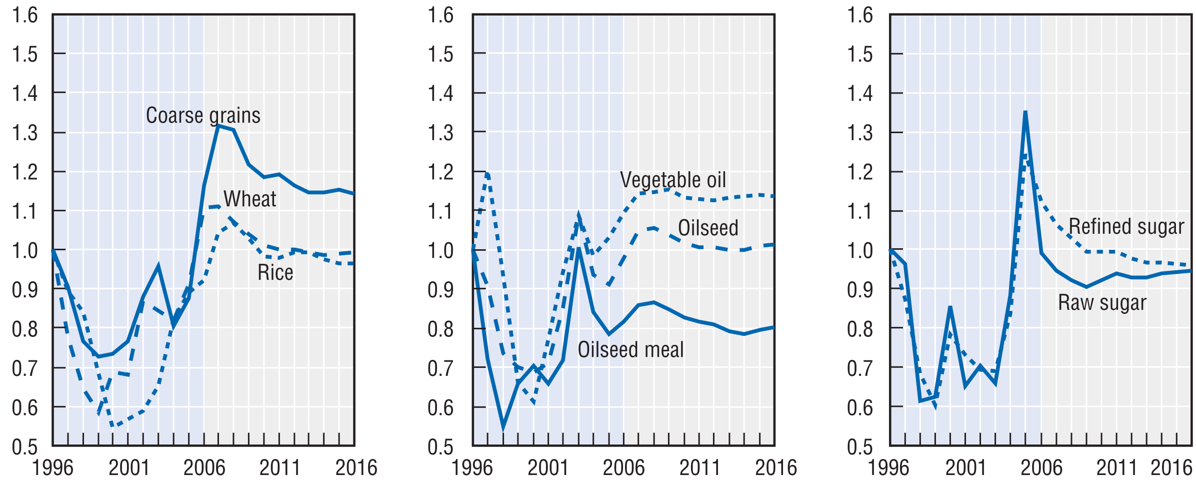
	Historical prices (US$/tonne)		Calculated future price (US$/tonne)
	Mean 2001-2006	2006	2016
Wheat	152,0	204,0	183,2
Corn*	103,6	140,4	138,2
Rice	238,4	311,4	326,0
Oilseeds	266,0	289,8	299,6
Veg.oil	520,6	590,7	613,9
Crude Sugar	217,6	253,5	242,5

* Mainly corn, but includes also barley, Indian millet and oat

As seen from these prices, it can be assumed that the prices will not be much higher than today. Still it can be assumed that the prices will be somewhat higher than the average for the period 2001-2006. Figure 37 shows how the FAO/OECD report estimates the development of prices of agricultural products.

Outlook for world crop prices to 2016

Index of nominal prices, 1996 = 1



Source: OECD and FAO Secretariats.

Figure 37: Estimate of the development of prices on agricultural prices (FAO/OECD 2007)

The figure shows a price level for different agricultural products compared with the price level in 1996, which have been normalised to 1. For example it can be seen that the category of «coarse grains» which is mainly corn, was 20 % more expensive than in 1996 (FAO/OECD 2007).

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Communication:
Kim Juoperi
Head of Fluids Technology, Engine Performance 4-stroke
Research & Development
Industrial Operations
Wärtsilä Finland
Kim.juoperi@wartsila.com

Leif Meland
Wärtsilä Norway
+47 53 42 25 00
Conversation

Ingar Vatndal
BV energi
ingar@bvenergi.no
+47 90 11 97 68
Conversation

Jannik Stranger
Catarpillar
Norway
+47 23 17 05 00
Conversation

Thomas Knudsen
Senior Vice President of Research and Development
MAN Diesel A/S
Thomas.Knudsen@man.eu

Trond Are Berg
Chief Engineer
GTV Jewel of the Seas
Royal Caribbean International
JW_ChiefEngineer@rccl.com

Terje A. Gjertsen
Statistics of Norway
+47 62 88 56 16
Terje.Gjertsen@ssb.no

Lutz Liebenberg
Rolls Royce/Bergen Diesel
Norway
+47 55 53 60 00

Niklas Haga
Senior Development Engineer
Plant Technologies, PPT, Power Plants
Wärtsilä Finland Oy
+ 358 10 709 1528
niklas.haga@wartsila.com

Michael Finch Pedersen
R&D Emission, Dept. LDF4
MAN Diesel A/S
Teglholmsgade 41, DK-2450 Copenhagen SV
+ 45 3385 1372
MichaelF.Pedersen@man.eu

15. Appendices

Appendix 1: Fuel specification – Marine residual fuels

ISO 8217:2005(F) fuel quality standard for RESIDUAL marine fuels

Parameter	Unit	Limit	RMA 30	RMB 30	RMD 80	RME 180	RMF 180	RMG 380	RMH 380	RMK 380	RMH 700	RMK 700
Density at 15 °C at 15 °C	kg/m^3	Max	960.0	975.0	980.0	991.0		991.0		1010.0	991.0	1010.0
Viscosity at 50°C	mm^2/s	Max	30.0		80.0	180.0		380.0			700	
Water	% V/V	Max	0.5		0.5	0.5		0.5			0.5	
Micro Carbon Residue	% m/m	Max	10		14	15	20	18	22		22	
Sulphur [1 1]	% m/m	Max	3.5		4.00	4.50		4.50			4.50	
Ash	% m/m	Max	0.10		0.10	0.10	0.15	0.15	0.15		0.15	
Vanadium	mg/kg	Max	150		350	200	500	300	600		600	
Flash point	°C	Min	60		60	60		60			60	
Pour point, Summer, Summer	°C	Max	6	24	30	30		30			30	
Pour point, Winter, Winter	°C	Max	0	24	30	30		30			30	
Aluminium + Silicon	mg/kg	Max	80		80	80		80			80	
Total Sediment Potential	% m/m	Max	0.10		0.10	0.10		0.10			0.10	
Zinc [2]	mg/kg	Max	15									
Phosphorus [2]	mg/kg	Max	15									
Calcium [2]	mg/kg	Max	30									

1: A sulphur limit of 1.5% m/m will apply in SOx Emission Control Areas designated by the International Maritime Organization. In addition, ports and port states may specify more stringent requirements.

2: The Fuel shall be free of ULO (Unused. Lube Oil)
A Fuel is considered to be free of ULO if one or more of the elements are below the limits. All three elements shall exceed the limits before deemed to contain ULO.

Appendix 2: Fuel specification – Distillate marine fuels

ISO 8217:2005(F) fuel quality standard for distillate marine fuels

Parameter	Unit	Limit	DMX	DMA	DMB	DMC
Density at 15 °C at 15 °C	kg/m^3	Max	-	890.0	900.0	920.0
Viscosity at 40 ° C	mm^2/s	Max	5.5	6.0	11.0	14.0
Viscosity at 40 ° C	mm^2/s	Min	1.4	1.5	-	-
Micro Carbon Residue at 10% Residue at 10% Residue	% m/m	Max	0.30	0.30	-	-
Micro Carbon Residue	% m/m	Max	-	-	0.30	2.50
Water	% V/V	Max	-	-	0.3	0.3
Sulphur [1] [1]	% (m/m)	Max	1.0	1.5	2.0	2.0
Total Sediment Existent	% m/m	Max	-	-	0.10	0.10
Ash	% m/m	Max	0.01	0.01	0.01	0.05
Vanadium	mg/kg	Max	-	-	-	100
Aluminium + Silicon	mg/kg	Max	-	-	-	25
Flash point	°C	Min	43	60	60	60
Pour point, Summer, Summer	°C	Max	-	0	6	6
Pour point, Winter, Winter	°C	Max	-	-6	0	0
Cloud point	°C	Max	-16	-	-	-
Calculated Cetane Index		Min	45	40	35	-
Appearance			Clear & Bright		-	-
Zinc [2]	mg/kg	Max	-		-	15
Phosphorus [2]	mg/kg	Max	-		-	15
Calcium [2]	mg/kg	Max	-		-	30

1: A sulphur limit of 1.5% m/m will apply in SOx Emission Control Areas designated by the International Maritime Organization.. In addition, ports and port states may specify more stringent requirements.

2: The Fuel shall be free of ULO (Unused Lube Oil).
A Fuel is considered to be free of ULO if one or more of the elements are below the limits.All three elements shall exceed the limits before deemed to contain ULO.

Appendix 3: Fuel specification – Vegetable oil

2006-03-09

PRODUKTSPECIFIKATION
VEGETABILISK BIOOLJA
Aska max 0,05 %
Art.nr. 309

Analysis	Unit	Method	Result
Calorific Value (Gross)	MJ/kg	ASTM D240-92	38.7
Calorific Value (Net)	MJ/kg	ASTM D240-92	36.1
Elementary Analysis (A)	%mass		
Hydrogen Content			12,0
Carbon Content			75,8
Oxygen Content		Calculation	12,1
pH on waterphase at 25^{0}C	pH		3,9
Sulphur(S)	mg/kg		109
Viscosity at 50^{0}C	mm^2/s	EN ISO 3104	21,8
Flash point	^{0}C	SS EN 22719-93	180
Density at 50^{0}C	kg/l	ASTM D 1298-85	0,8906
Water (Karl Fisher)	%		0,76
Nitrogen	%		< 0.10
Ash	%	SS-EN-ISO 6245-94	0,042
Total Acid Number (TAN)	mgKOH/g	ASTM D664-89	92
Lead (Pb)	mg/kg		0,22
Cadmium (Cd)	mg/kg		< 0,02
Boron (B)	mg/kg		4,7
Copper (Cu)	mg/kg		0,32
Zinc (Zn)	mg/kg		2,3
Chromium (Cr)	mg/kg		0,11
Nickel (Ni)	mg/kg		0,07
Vanadium (V)	mg/kg		< 1
Mercury (Hg)	mg/kg		< 0,05
Arsenic (As)	mg/kg		< 0,1

Smältpunkt ca 30-35 ^{0}C.

ENERGILOTSEN SVERIGE

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Sweden	e-mail stefan.persson@energilotsen.se		SWIFT	HAND SE SM
	e-mail magnus.johansson@energilotsen.se		**Bankgiro**	**5302-1432**
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Appendix 4: European biodiesel standard EN14214

Property	Units	lower limit	upper limit	Test-Method
Ester content content	% (m/m)	96,5	-	pr EN 14103d
Density at 15°C at 15°C	kg/m^3	860	900	EN ISO 3675 / / EN ISO 12185..
Viscosity at 40°C at 40°C	mm^2/s	3,5	5,0	EN ISO 3104
Flash point	°C	> 101	-	ISO CD 3679e
Sulfur content content	mg/kg	-	10	-
Tar remnant (at 10% remnant (at 10% distillation remnant) remnant)	% (m/m)	-	0,3	EN ISO 10370
Cetane number	-	51,0	-	EN ISO 5165
Sulfated ash content content	% (m/m)	-	0,02	ISO 3987
Water content content	mg/kg	-	500	EN ISO 12937
Total contamination	mg/kg	-	24	EN 12662
Copper band corrosion (3 hours at 50 °C) (3 hours at 50 °C)	rating	Class 1	Class 1	EN ISO 2160
Thermal Stability	-	-	-	-
Oxidation stability, 110°C, 110°C	hours	6	-	pr pr EN 14112k
Acid value	mg KOH/g	-	0,5	pr pr EN 14104
Iodine value value	-	-	120	pr pr EN 14111
Linolic Acid Methylester	% (m/m)	-	12	pr pr EN 14103d
Polyunsaturated (>= 4 (>= 4 Double bonds)) Methylester	% (m/m)	-	1	-
Methanol content content	% (m/m)	-	0,2	pr pr EN 14110l
Monoglyceride content content	% (m/m)	-	0,8	pr pr EN 14105m
Diglyceride content content	% (m/m)	-	0,2	pr EN 14105m
Triglyceride content content	% (m/m)	-	0,2	pr EN 14105m
Free Glycerine	% (m/m)	-	0,02	pr EN 14105m / pr pr EN 14105m / pr EN 14106
Total Total Glycerine	% (m/m)	-	0,25	pr EN 14105m
Alkali Metals (Na+K) (Na+K)	mg/kg	-	5	pr pr EN 14108 / pr / pr EN 14109
Phosphorus content content	mg/kg	-	10	pr EN14107p

Appendix 5: ZERO Emission Resource Organisation

www.zero.no

Our vision

A world where carbon emissions cause no threat to nature and environment.

Our mission

ZERO will contribute to limiting the threat posed by climate change by promoting carbon-free energy solutions. In our view, emission-free alternatives exist for all energy use, and ZERO works continuously for their realisation.

We therefore:

- urge companies to choose carbon-free energy solutions and cooperate to put them into use
- seek contact with policy makers to favour such solutions
- collect and distribute information to contribute to their realisation.

Our method

In order to make emission-free solutions prevail, ZERO pursues a constructive role in the fight against climate change: Instead of negative campaigning, we prefer to advocate the solutions which we support.

ZERO aims to possess first class knowledge of carbon-free energy technology. We co-work with companies and industrial researchers to secure the know-how necessary to maintain that position.

ZERO views environmental problems from a broad perspective. Our technological and political knowledge enables us to identify areas where renewable energy solutions should be preferred to polluting ones, thereby acting as meddlers between companies, policy makers and industrial researchers.

ZERO seeks influence wherever decisions affecting climate change are made. We seek contact with policy makers, whilst protecting our integrity to ensure that our advice is reliable and our information is to be trusted.

ZERO also acts as guardian and watchdog when carbon-free energy solutions are abandoned, or framework for use of such technology is weakened.

Finally, in addition to lobbying towards industry and policy makers, ZERO informs the general public of renewable and carbon free energy solutions. We aim for our website www.zero.no to be a preferred source for news and information on the subject.

Our position

...towards companies

ZERO is a non-profit foundation.

ZERO is an environmental organisation. We are not consultants, the battle against climate change being our only mission. However, we participate in partnerships financed by third parties.

ZERO cooperates with companies who are polluters, in order to urge them to choose non-emission solutions, and with companies who make such solutions, in order to widen their use.

…towards other organisations

ZERO is the only Norwegian environmental organisation solely committed to fighting climate change. We never accept the use of fossil fuels without carbon dioxide burial.

As environmentalists, we demand that Norway cut carbon emissions by a minimum of 90 per cent. Still, ZERO's role is to be constructive and pragmatic, cooperating even with big polluters, if it can help obtain our goals.

We do not believe in moralization. Rather than urging people to reduce their standard of living, ZERO advocates solutions that enable people to maintain their current way of life.

…towards researchers
ZERO is not a research institute. We work with industrial researchers to help develop and promote new carbon-free technology.

Our income
In addition to general sponsors, ZERO's sources of income include financial support to specific projects, as well as endowments. Contributions come from companies, individuals and Norwegian authorities.

ZERO is a foundation with no supporting members. Neither are we paid consultants for companies or authorities.

ZERO has full intellectual property rights to its work. Sponsors to our reports and publications are highlighted.

Our fields of focus
ZERO works with a wide range of sources for greenhouse gas emissions. Below follows a list of our major fields of focus:

- CO2-capture and storage
- Electric power for the offshore sector
- Biofuels for road transport, ships and heating
- Wind energy
- Hydrogen
- Electric vehicles
- Other renewable energy

www.zero.no

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