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Eco-Efficient Transport

Interim report: Overview of potentials for an increased eco-efficiency in maritime shipping

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STOA

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Interim Report

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Abstract

The report gives a brief overview of the approaches of the most promising technologies and concepts for the increasing of eco-efficiency in maritime shipping.

Executive summary

A transition to a more eco-efficient transport system is needed to cope with recent challenges and anticipated future developments in the transport sector. The STOA project on eco-efficient transport will look at established, emerging and more visionary technologies and concepts supporting eco-efficient transport. The basic idea behind the project is to conduct technology assessment complemented by consultations of stakeholders; scenario building is used as an integrative element. In principle, all modes of transport are treated in the project. However, since the transport sector is a highly complex and broad field, it is unavoidable that the scope be narrowed. Therefore, for the maritime sector, it was decided to give only a brief overview of selected technologies and concepts for reducing the ecological footprint of this sector—as opposed to the more detailed analysis carried out in regard to some of the other sectors and sub-sectors. It was further specified that the literature-based overview should particularly consider the following issues:

- fuels and propulsion technologies to reduce energy consumption and emissions (e.g. improving the efficiency of conventional engines; using hydrogen, biomass, or supportive sails);
- using land-based electricity in shipping (e.g. in ports and locks);
- additional technologies to reduce the quantity and impact of emissions;
- and changes in operation (driving at lower speeds to reduce fuel consumption).

The overview is given in the present report. First, the importance of the maritime sector for globalization and for economic growth in Europe is highlighted. Globalization and related developments in international trade have led to impressive growth in the field of maritime shipping. More than 80% of international trade in goods is carried by sea, 40% of intra-European freight is carried by short-sea shipping. The level of seaborne trade has quadrupled in the past four decades and is predicted to increase significantly in the coming years.

Shipping is often recognized as an energy-efficient and relatively environmentally friendly form of transport. Shipping is using roughly one tenth of the fuel (per ton mile) used by road transport. But the emissions of greenhouse gases (GHG), sulphur dioxide (SO_2), nitrous oxide (NO_x) and particulate matter (PM) are comparatively high, due to the use of unrefined bunker oil. It is estimated that the maritime transport industry accounts for up to 8% of global SO_2, for up to 15% of global NO_x emissions and for about 3.3% of global carbon dioxide (CO_2) emissions. Apart from the release of these pollutants, maritime shipping has many other impacts on the environment (e.g. vessel oil spills, ballast-water disposal, anti-fouling pollution, vessel scrapping and waste disposal at sea). However, these are only mentioned briefly in this report.

The International Maritime Organization (IMO) has passed regulations and standards to reduce the ecological impacts of shipping. A crucial issue in this context is the reduction of SO_2. Sulphur oxide (SO_x) emissions are directly proportional to the sulphur content of fuel; they are not related to engine design, operations or combustion conditions. Therefore, reducing the content of sulphur in fuel represents an important approach for the reduction of SO_x emissions.

However, due to the effects of the low-sulphur and low-viscosity characteristics of this fuel, difficulties may occur during the fuel-switching process and during sustained operation on marine distillates.

For the reduction of NO_x, a broad range of measures can be used. Several of these measures aim at cutting NO_x emissions by reducing peak temperature and pressure in the cylinders. Lower temperatures lead to less NO_x emissions, but generally decrease efficiency as well. For example, direct water injection into the cylinder can be used to reduce the combustion temperature. The disadvantages are higher fuel consumption and smoke emissions as well as a reduction in lifetime.

Most diesel engines are optimized for NO_x reduction—at the expense of fuel efficiency. Therefore, advanced NO_x after-treatment retrofit technologies could enable a re-optimization of engines. After-treatment systems (e.g. exhaust gas scrubbers) have been developed which succeed in cleaning 99% of SO_x and also 80% of soot particles from the exhaust gases. Retrofitting the existing fleet would be much faster and less costly than, for example, distilling the fuel.

A promising alternative to conventional fuels seems to be liquefied natural gas (LNG). The advantage of LNG is its significantly lower emissions: the exhaust gases are practically free of SO_x and soot particles, NO_x can be reduced by almost 90%. Many countries already run shore-based gas infrastructures; however, the development of an adequate maritime gas infrastructure is still considered challenging and expensive.

Other alternative fuel and power sources, such as biofuels, solar photovoltaic cells and fuel cells, are often considered to be more uncertain, longer-term options. In regard to biofuels, it is unlikely that the biomass available for energy and transport will be used in the maritime sector. For the use of hydrogen in fuel cells, the environmental benefits strongly depend on how the hydrogen is produced. Electric drives are interesting for ships that regularly switch speeds and for ships that need a lot of generation capacity when the ship is not moving fast (e.g. cable-laying ships). Obstacles and disadvantages relate to the size, weight and cost of the equipment involved in electric propulsion. For electric drives and also for fuel cells, further research and demonstration activities are needed to improve and test feasibility. The competitiveness of such approaches might be increased in the future. Furthermore, auxiliary propulsion technologies to support engine-driven propulsion systems are being discussed. Prominent examples are skysails and Flettner Rotors. Other approaches mentioned in this report include "weather routing", improved hulls and slow steaming. In particular the latter offers highly interesting potentials for the reduction of fuel consumption.

The expected growth rates in maritime shipping illustrate that—particularly when it comes to combating climate change—immediate action is urgently needed. This includes retrofitting existing ships, since a strong inertia is characteristic of the shipping sector. Ships are used for decades: New developments implemented today might still be in use in the year 2050 and beyond. These facts, together with the expected growth rates, underpin the argument that there is a strong need for action in a sector that is of the utmost importance for the daily life of European citizens.

General information

An affordable, efficient and clean transport system is a basic pillar for economic growth and the quality of life in European countries. However, transport is still accompanied by a broad range of negative impacts on human health and the environment. It is still using huge amounts of finite resources. Congestion is increasingly hampering the efficiency of the system. Transport volumes are expected to further grow in the future. So, a transition to a more eco-efficient transport system is needed to cope with recent challenges and anticipated future developments in the transport sector. Against this background, the STOA Project on "Eco-Efficient Transport" aimed at assessing to what extent different concepts and approaches can help to increase the eco-efficiency of the transport system.

This interim report is Deliverable 2b of the project. It offers an overview of the approaches of the most promising technologies and concepts for increasing eco-efficiency in maritime shipping. In the project specifications, it was decided that this report should particularly consider issues such as

- fuels and propulsion technologies to reduce energy consumption and emissions (e.g. improving the efficiency of conventional engines; using hydrogen, biomass or supportive sails)
- using land-based electricity in shipping (e.g. in ports and locks);
- additional technologies to reduce the quantity and impact of emissions;
- and changes in operation (driving at lower speeds to reduce fuel consumption).

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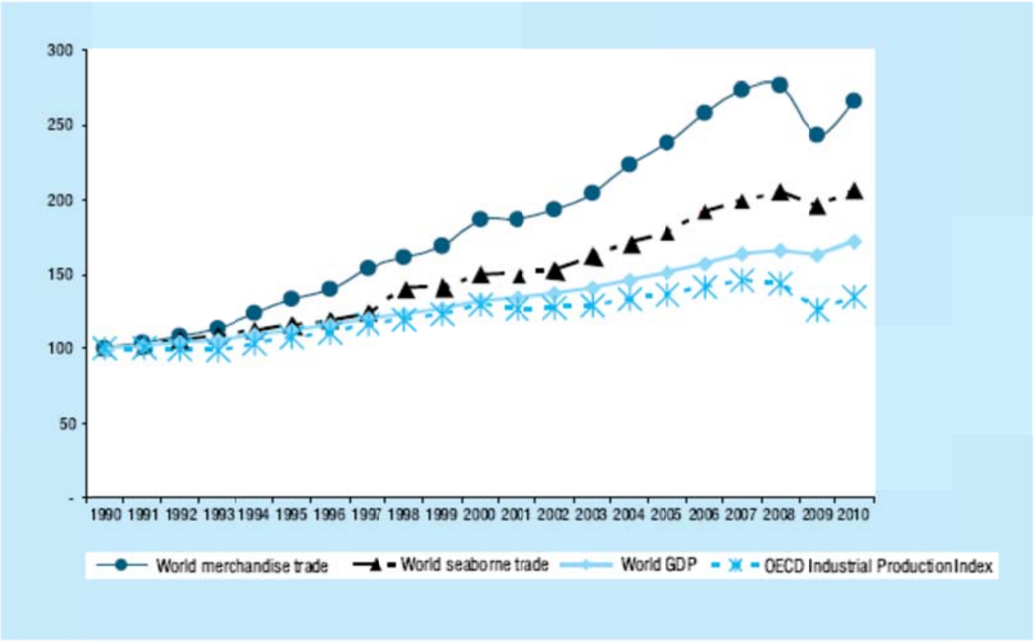
1. Trends and challenges in maritime shipping

1.1. Maritime shipping: economic relevance and ecological footprint

For centuries, maritime shipping was the most important mode for the transport of goods and people over very long distances. It connected Europe to countries such as India, Indonesia and China, and it permitted the exchange of goods with the American continent. In the Mediterranean area as well, shipping was a basic pillar of economic prosperity for several thousand years.

In modern times, maritime shipping remains a crucial element of the global transport system. “It is impossible to imagine today’s Europe without waterborne transport and its related operations. Waterborne industries underpin our way of living by facilitating the supply of goods, food and energy as well as personal mobility and leisure on the water”[1]. Maritime shipping is the backbone of globalization; it enables the increasing global exchange of goods and the increasing international division of labour that is characteristic for economies in industrialized and emerging countries. These trends are expected to continue, and a further increase in maritime freight transport is thus to be expected.

Figure 1: Indices for world gross domestic product (GDP), the OECD Industrial Production Index, world merchandise trade and world seaborne trade, 1990–2010 (1990=100) (Source: UNCTAD 2010, p.4).[2]



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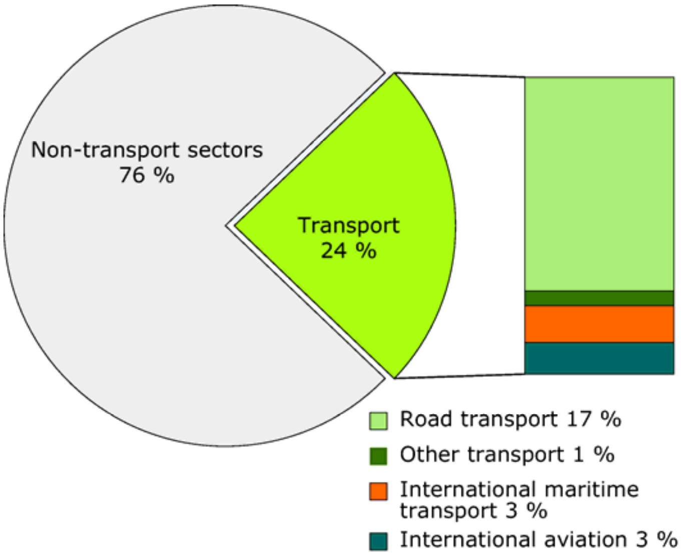
[1] Waterborne TP (2008), p.6.

[2] On the basis of OECD Main Economic Indicators, May 2010; the UNCTAD Trade and Development Report 2010; the UNCTAD Review of Maritime Transport, various issues; the WTO International Trade Statistics 2009, Table A 1a, and the WTO press release issued in March 2010, entitled “World trade 2009, prospects for 2010”. WTO merchandise trade data (volumes) are derived from customs values deflated by standard unit values and adjusted to the price index for electronic goods. The 2010 index for seaborne trade is calculated on the basis of the growth rate forecast by Clarkson Research Services.

In its 2009 report, the International Maritime Organization (IMO)[3] estimates that more than 80% of international trade in goods is carried by sea, with an even higher percentage of developing-country trade. 40% of intra-European freight is carried by short-sea shipping.[4] Figure 1 illustrates the growth rates in maritime shipping and their close correlation with developments in global GDP. The recession in 2008/2009 lead to a decline in growth rates, but the overall trend is that growth rates will continue. The level of seaborne trade has quadrupled in the past four decades and is predicted to further increase in the coming years.[5]

Shipping is the dominant transport mode for overseas freight and, at the same time, is often recognized as a sustainable, energy efficient and relatively environmentally friendly form of transport.[6] Shipping is using roughly one tenth of the fuel (per ton mile) used by road transport.[7] However, the emissions of greenhouse gases (GHG), sulphur dioxide (SO_2), nitrous oxide (NO_x) and particulate matter (PM) are comparatively high, due to the use of unrefined bunker oil. It is estimated that the maritime transport industry accounts for up to 8% of SO_2 and up to 15% of NO_x emissions.[8] Other authors estimate that shipping's contribution to global NO_x emissions could be as much as 30%.[9] The European transport sector is responsible for around 24% of GHG emissions in the European Union (EU) (see Figure 2), 15% of this amount comes from shipping.[10] It is estimated that shipping contributes about 3.3% of global carbon dioxide (CO_2) emissions.[11]

Figure 2: Transport sector's contribution to total GHG emissions (Source: EEA 2011, p. 23).



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[3] The IMO is the United Nations' specialized agency responsible for improving maritime safety and preventing pollution from ships.

[4] See CEC (2009).

[5] See CEC (2011a).

[6] See DfT (2004), quoted in Chapman (2007).

[7] See CEC (2011a), p. 7.

[8] See CEC (2011a), p. 7.

[9] See Corbett et al. (2007), quoted in Jürgens et al. (2011).

[10] See CEC (2011a), p. 7.

[11] See Eyring et al. (2005a), quoted in Jürgens et al. (2011).

Maritime shipping has many other serious impacts on the environment, such as vessel oil spills, ballast-water disposal, air pollution, anti-fouling pollution (tributylin), dredging, vessel scrapping and waste disposal at sea.[12]

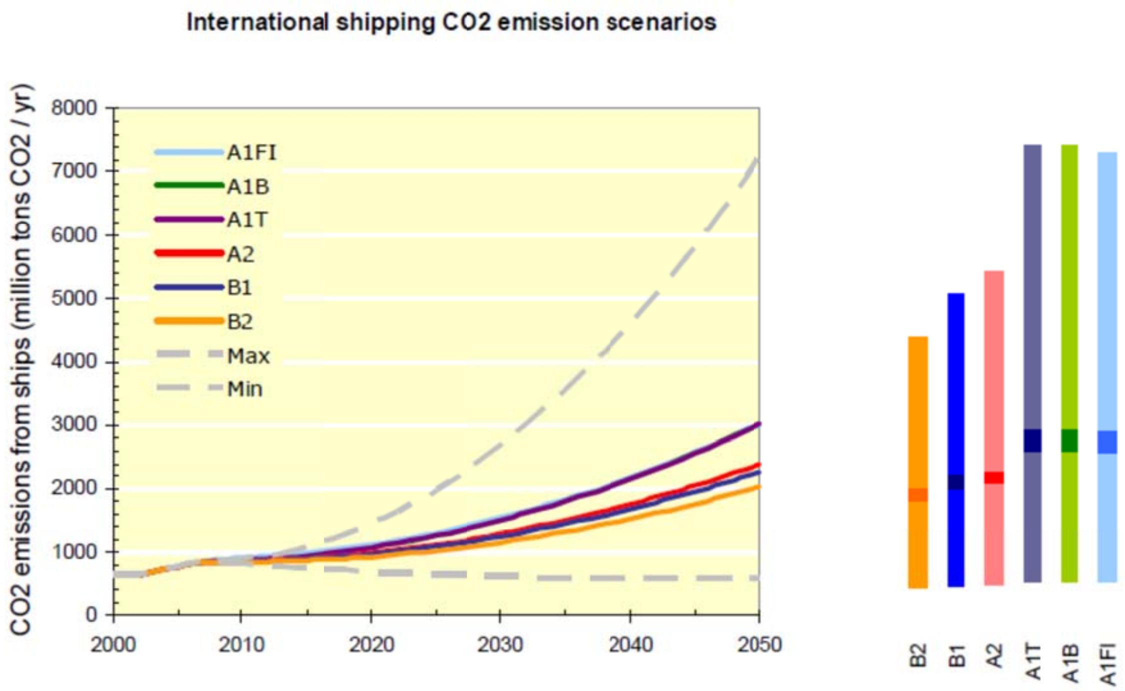
The impacts are diverse in character. For example, ballast water disposal has been responsible for the spreading of invasive species.

When ships take on ballast water to provide stability, numerous species are in that water. Once the water is released at a distant location, the species that have survived the journey are also released into the local eco-system.

However, it was agreed to put the focus of the report on improving the energy balance and on reducing the emissions of pollutants such as CO_2, SO_x, NO_x, PM and volatile organic compounds (VOC). These pollutants are closely related to the use of heavy fuel oil (HFO) with a high sulphur content.

The ranges indicated above are already enough to illustrate the difficulties involved in obtaining data[13]; however, it is clear that the shipping sector makes a substantial contribution in this area. This presents a particular challenge as soon as one considers the expected growth rate. In a report by Miola et al. (2010), it is expected that CO_2 emissions will already be increasing by 10-20% in 2012. Based on IMO work, the International Council for Clean Transportation (ICCT) recently illustrated different scenarios for the growth in CO_2 emissions from shipping (see Figure 3). The 2011 White Paper of the European Commission has set a target that 30% of road freight over 300 km should shift to other modes (such as rail or waterborne transport) by 2030 and more than 50% by 2050[14]; this illustrates that the importance of shipping for European transport is expected to grow.

Figure 3: Trajectories of the emissions from international shipping. Columns on the right-hand side indicate the range of results for the scenarios within the individual families of the scenario (Source: IMO 2009, p. 14).



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[12] See Talley (2003).

[13] See Miola et al. (2010).

[14] See CEC (2011b).

There is potential for improving the eco-efficiency of waterborne transport. Innovations supporting such a development are an important element of the research and development strategy as well as the Vision 2020 of the European waterborne technology platform.[15]

“A 'zero emission' approach, notably on substances like SO_x, NO_x, CO_2, PM and VOCs, is an enormous technological challenge. Reducing one pollutant may well have a negative effect on other pollutants, while no single option will be suitable for all types of ships. Economically viable processes, systems and equipment have to be developed under a holistic approach, ensuring a balanced long term solution”.[16]

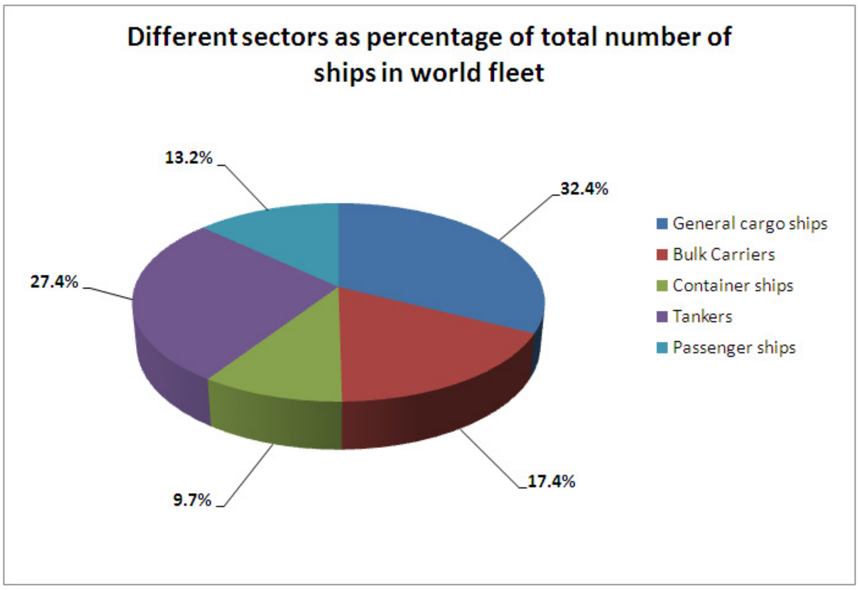
Europe and the European waterborne sector have the potential to play a significant role in increasing the eco-efficiency of maritime shipping. “Around 40% of the world merchant fleet is beneficially controlled by European companies, approximately 25% are flying the European EEA [European Economic Area] flag”.[17]

Against this background, it is not astonishing that a range of studies exists, which focus on technical and political measures for reducing the ecological footprint of the maritime sector.[18] The implementation of several of these measures would increase the investment cost but reduce the cost of operation in those cases where they lead to savings in energy consumption. Therefore, in many of the studies, the cost-effectiveness of measures is part of the analysis. This cannot be done in a systematic way within the brief overview given in this report, but will be mentioned where it is of particular importance.

1.2. Common classifications of sea-going vessels

In order to better understand the potential for reducing the ecological footprint of maritime shipping, it is important to be aware of the fact that different types of ships exist.

Figure 4: Shipping Facts (Source: “Shipping Facts” 2010).



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[15] See Waterborne TP (2008); Waterborne TP (2011).

[16] See Waterborne TP (2008), p.13.

[17] See Waterborne TP (2008), p.6.

[18] See IMO (2009); ICCT (2011); Miola et al. (2010); McCollum, Gould, & Greene (2009); CEC (2011a).

Apart from classifications by classification authorities (German Lloyd or its British counterpart Lloyd's Register), which publish construction parameters, control the construction and issue a so-called class (relevant for safety and insurance) to ocean-going vessels, ships can be grouped by size and by type of freight. The main categories are divided as described in Figure 4.

Shipping between the world's economic centres along the usual sea trade routes requires passing through channels in order to avoid longer distances. This has led to a characterization by maximum size, particularly in regard to fitting into the lock chambers of these channels. It is defined by the vessel's deadweight (measure of weight a ship can safely carry) and its dimensions. Malaccamax, Panamax and Suezmax are examples of these ship-size definitions.[19]

1.3. Legal aspects and regulations in maritime shipping

The IMO, a sub-organization of the United Nations, establishes international legislation in terms of maritime safety and—with increasing emphasis—in terms of environmental protection. In the International Convention for the Prevention of Marine Pollution from Ships (MARPOL), the IMO´s Marine Environmental Protection Committee (MEPC) has achieved international agreements on harmful ship coatings, the treatment of ballast water and wrecking. In the field of air pollution and GHG reduction, the MARPOL annex VI was formulated; it went into force in May 2005.

Existing in a state of competition with regional regulations and the United Nations Framework Convention on Climate Change (UNFCCC), it was a major challenge for the IMO to convince developing countries to cooperate, because of their privileged position in the UNFCCC. As the IMO always works on the principle of equal rights and obligations, privileges for developing countries presented a severe obstacle to insuring competitiveness, because of the fact that the majority of ocean-going vessels already flies under the flags of these countries. Some inter-trade organizations, on the other hand, have brought forward the argument that the stricter emissions and sulphur content limits expose the shipping industry to inhomogeneous competition from road transport and may cause a shift to the road.[20] The avoidance of such a backshift is also considered, for example, in the European Commission's communication on strategic goals and recommendations for the EU's maritime transport policy. In this document, one high-priority area is described as follows: "Oversee the smooth implementation of the amendments adopted by the IMO in October 2008 to MARPOL Annex VI to reduce SO_x and NO_x oxides emissions from ships. This includes assessing which European sea areas qualify as Emission Control Areas, the availability of the adequate fuels and the impacts on short-sea shipping. The Commission's proposals should ensure that modal 'back-shift' from short-sea shipping to road is avoided."[21] The Emission Control Areas (ECAs) are mapped in Figure 5.

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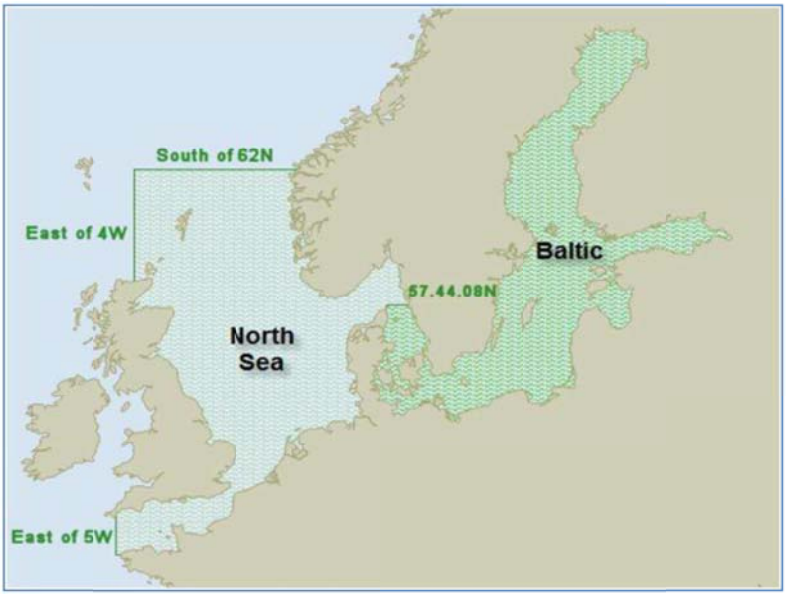
[19] Cf. Lloyd's Register (2010).

[20] See Lemper et al. (2010).

[21] See CEC (2009), p.6.

Figure 5: ECAs (Source: Jürgens et al 2011, p. 26).



The above-mentioned Annex VI applies to all ships (and fixed or floating drill rigs) of 400 or more gross tons. Beginning in January 2015, it will restrict the sulphur mass friction to 0.1% in so-called ECAs[22] and to 0.5% worldwide by the year 2020 (2025 at the latest),[23] and is thus intended to reduce SOx emissions. Furthermore, within the designated ECAs, this act limits the amount of NOx emissions according to IMO Tier I to Tier III, which are valid for newly built ships. NOx emissions will be reduced by 80% compared to 2010.

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[22] Cf. Miola et al. (2010), p.35.
Note: The Baltic Sea and North Sea are designated ECAs for SOx only, therefore they are named 'Sulphur Emission Control Areas' (SECAs).

[23] See Bethge (2011), p. 3.

2. The basis: a standard ship propulsion system

In general, modern ships use reciprocating diesel engines for propulsion. For marine application, and especially for their commercial use, they must meet several requirements. One crucial issue is that ships may become disabled if the propeller does not flow against the rudder. Therefore, reliability is of the utmost importance in the maritime sector. Due to the engine mass, the engine house is generally located in the lower decks. Thus, high durability is needed, because replacement would be complex and costly. On the other hand, a high continuous output is required for long distances to be covered. In addition to low investment costs, owners demand low consumption—not least because of space consumption by fuel, which reduces the space available for cargo.

Today, diesel engines are broadly classified according to their operating cycle (two or four stroke), their construction and their speed. Slow-speed engines have a maximum operating speed of up to 300 revolutions per minute (rpm), although most large, two-stroke, slow-speed diesel engines operate below 120 rpm. In addition, there are very long stroke engines that have a maximum speed of around 80 rpm. The largest, most powerful engines in the world are slow-speed, two-stroke crosshead diesels, which are also used as power plants in developing countries and in remote locations. They are additionally used as emergency backup aggregates.

Medium-speed engines have a maximum operating speed in the range of 300 to 900 rpm. Many modern, four-stroke, medium-speed diesel engines have a maximum operating speed of around 500 rpm. Finally, there are high-speed engines, with a maximum operating speed of more than 900 rpm. Most modern, larger-sized merchant ships use slow-speed, two-stroke crosshead engines, or medium-speed, four-stroke trunk engines. Only smaller vessels, such as interior merchant ships or sport vehicles ever use high-speed diesel engines.

Modern diesel engines can use diesel fuel, gas oil, HFO or gas for combustion; diesel only describes the process of air intake and compression, heating and the auto-ignition after fuel injection. HFO, which is more or less a refuse material from the petrochemical industry, is most common for large, low-speed engines; it requires onboard refinement because of its low preparation degree. Before combustion, it is clarified and skimmed and must then be heated in service reservoirs in order to increase pumpability. Onboard modern ships, the waste heat from exhaust gases is used for this purpose.

Reciprocating marine diesel engines replaced steam-based systems because they offered greater efficiency than the steam turbine; however, for many years, the reciprocating engines had an inferior power-to-space ratio. The size of the different types of engines is an important factor in selecting what will be installed in a new ship. Slow-speed, two-stroke engines are much taller, but the area needed, in terms of length and width, is smaller than that required by four-stroke, medium-speed diesel engines.

Because modern ships' propellers are at their most efficient at the operating speed of most slow-speed diesel engines, ships with these engines generally do not need gearboxes. Usually, such propulsion systems consist of either one or two propeller shafts, each with its own direct-drive engine. Ships propelled by medium- or high-speed diesel engines (such as passenger ships) may have one or two (or sometimes more) propellers, commonly with one or more engines driving each propeller shaft by means of a gearbox. Where more than one engine is geared to a single shaft, each engine will most likely drive through a clutch; this allows engines that are not being used to be disconnected from the gearbox while others keep running. This arrangement permits maintenance to be carried out while under way.

3. Innovations in fuels and combustion

Engine efficiency is of the utmost importance not only in environmental terms, but also in economic terms, since fuel costs are responsible for a large portion of total costs in the shipping sector. Depending on the type of vessel, fuel costs can account for more than 50% of operating costs.[24] Diesel and turbo engines have already achieved a degree of efficiency of around 50%; it is not expected that this degree will be greatly increased in the near future.[25]

Compliance with the NO_x emissions requirements of IMO Tier II can be achieved through moderate changes to engine management and through the application of modern turbochargers with high pressures and efficiency. Subsequently meeting the limits of IMO Tier III is going to be more challenging. The emission of SO_x is primarily influenced by the fuel's sulphur content. Also the emission of particulate matter strongly depends on the sulphur content. When discussing the potential to reduce pollutants from shipping, it should be taken into account that engines of higher complexity demand more skilled personnel. Modern engines are probably more comparable to a small power plant than to a larger-scaled automotive engine. The low qualification of workers may therefore hinder an efficient development.

In this chapter, options for alternative fuels and improved combustion processes are described. Most of these measures are potentially available from a technical point of view.

3.1. Low sulphur fuels (LSF)

Marine oils are classified into distillates (marine gas oil [MGO] and marine diesel oil [MDO]) and fuel oil, also called HFO or bunker oil.[26] The latter are residues of the refining process and responsible for the high sulphur content. Limits in sulphur content will result in a switch to distillate fuels / low sulphur fuels (LSF)[27] – at least when entering ECAs.

Still, a majority of the maritime ships will run on HFO in the near future. Its low quality and high sulphur content are accompanied by low costs, high energy density and a distinctive infrastructure. For the longer term, limited availability and rising prices need to be taken into account.

SO_x is a serious pollutant; it is produced during the combustion process. The emissions of SO_x are directly proportional to the content of sulphur in fuel, and are not related to engine design, operations or combustion conditions[28]. Therefore, the main method for the reduction of SO_x emissions is to reduce the content of sulphur in fuel. The sulphur content of standard maritime oil is 2,700 times higher than that of conventional diesel for cars.[29] However, the production costs of low sulphur fuels are high.

In the TEFLES project, it is pointed out: "The desulphurization process consumes high amounts of energy in the form of temperature, steam and pressure as well as huge quantities of Hydrogen (H_2), which also requires enormous amounts of energy during its production process."[30]

One option for reducing the sulphur content in heavy oil is the hydrodesulphurization of heavy oils. According to the TEFLES report, direct sulphur removal from crude oil by some

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[24] See Jürgens et al (2011), p. 38.

[25] See Eyring et al. (2005b); McCollum, Gould, & Greene (2009).

[26] See Jürgens et al. (2011), p. 34.

[27] Commonly, maritime bunker fuels (heavy or residual oils) with the prefix of "LS" refer to <1.5% or >0.5%, respectively, content of sulphur on the fuel distillates.

[28] See Gregory (2010); Jürgens et al. (2011).

[29] See Miola et al. (2010), p. 12.

[30] See Jürgens et al. (2011), p. 39.

hydrodesulphurization methods can remove up to 90% of the sulphur with an associated fuel loss of about 5%.[31]

To improve this process, ionic parts of the fuel are also removed. These components are relevant for the lubrication of internal parts of engines and fuel pumps. But even fuels that exceed the sulphur limit may also fail to provide sufficient lubrication. As a corrective, a medium to improve lubrication can be applied to the fuels.[32] However, this process can induce additional PM emissions. Up to now, there is no maritime legislation in the European ECAs that explicitly sets limits on particulate emissions of ships.[33]

A maritime conference held in Tacoma (US) in 2012 addressed issues around the implementation of ECAs.[34] In general, ships switch from HFO to LSF when entering ECAs. This switch from HFO to LSF is not a simple procedure. For example, temperature fluctuations during the switching process in the engine can lead to short-term variations in viscosities, energy contents as well as fuel flows in the engine system. Potential consequences are alterations in the combustion process that may even cause the main engines to stop. Situations with slow speed or speed reduction operation, linked to low main engine rpm values, are particularly susceptible to this effect. The engines may work unstable or even stall. On the other hand, it is also essential that the process of switching does not take place too fast, in order to prevent heat shock to the engine parts.[35]

To ensure adequate marine fuels quality, and thereby to prevent damage and maintain manufacturer liability, the International Organization for Standardization (ISO) published a new version of ISO 8217 in July 2010.[36] This norm regulates the requirements for marine fuels and, in this capacity, sets a stability limit for distillate oils as well as a specific lubricity for fuels of less than 0.05% sulphur content of mass.

3.2. Combustion process and exhaust after-treatment

Most diesel engines are optimized for NO_x reduction—at the expense of fuel efficiency. Therefore, advanced NO_x after-treatment retrofit technologies could enable a re-optimization of engines.[37]

In-engine improvements help to reduce NO_x; however, a conflict must be regarded at this point. In general, higher combustion temperatures lead to higher efficiency; but, at the same time, an increase in combustion temperature also leads to an increase in the emissions of NO_x. A compromise must be found regarding the specific operation speed, which also has an impact on slow steaming, for instance. There are many different options for reducing NO_x. Many of these aim at cutting NO_x emissions by reducing peak temperature and pressure in the cylinders.[38] Slow-speed, two-stroke engines can easily be fitted with low-NO_x valves; it is thought to be standard for new engines of this type to have these valves fitted. More advanced measures include retarding injection (about 30% NO_x reduction), raising the compression ratio (up to 35% NO_x reduction), increasing turbo efficiency and common rail injection.[39]

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[31] See Jürgens et al. (2011), p. 41.

[32] See Crutchely (2010).

[33] See Jürgens et al. (2011), p. 62; cf. also Crutchely (2010) and European Parliament, Council of the European Union (2008).

[34] See “Preparing for the ECA” (2012).

[35] Cf. Tama (2012); Harbor safety Committee (2012).

[36] See Crutchely (2010); cf. also DNV (2010).

[37] See McCollum, Gould, & Greene et al. (2009), p. 20; Eyring et al. (2005b); MARTINEK (2000).

[38] See Miola et al. (2010), p. 53.

[39] See Miola et al. (2010), p. 53.

In addition, the combustion of emulsions of water and fuel can reduce PM, NO_x and CO_2 emissions. As this facilitates an adaption of the engine specifications, a consumption reduction of five to eight percent is also possible, as claimed by the manufacturer.[40]

To reduce the combustion temperature, direct water injection into the cylinder is used. In order to reach a 50-60% reduction in NO_x, a 40-70% water-to-fuel ratio is required.[41] The disadvantages are higher fuel consumption and smoke emissions as well as a reduction in lifetime.[42] An alternative is the Humid Air Motor (HAM), which uses seawater to add water vapor to the combustion air. It is connected with high initial costs, but its lower consumption of both fuel and lubricating oil reduce its operating costs.[43] Exhaust gas recirculation (EGR) is another way to lower NO_x emissions by reducing peak cylinder temperature. Its main drawbacks are that thermal efficiency is reduced and costs, as well as space requirements, heavily increased.[44] Proven in the case of heavy-duty trucks, this system is about to be applied to marine use. It requires low sulphur fuels and is highly complex, because a common rail injection and optimized engine management are inherent to the system.

Selective catalytic converters (SCR) are also known from the road sector and can be applied to shipping. They can lead to a reduction in NO_x emissions of up to 90 to 95%. Apart from the high investment and operation costs, the main problems are the space requirements for the catalytic elements and the storage of ammonia or urea.[45] A less efficient alternative is Selective-Non-Catalytic-Reduction (SNCR).

SO_x content is solely dependent on the sulphur quantity in the fuel; therefore, it cannot be influenced by in-engine measures, but only by after-treatment (secondary measures) or a change to a low sulphur fuel (primary measures). Life cycle assessments of the CO_2-equivalent of primary measures appear to be less favorable than those of secondary measures. After-treatment systems have been developed, which succeed in cleaning 99% of SO_x and also 80% of soot particles from the exhaust gases.[46] Also, scrubbers are able to reduce SO_x by 99% and NO_x and PM by 85% without increasing CO_2 emissions.[47] The water can be filtered to remove PM and released back into the sea. The report argues that retrofitting the existing fleet would be much faster and less costly than, for example, distilling the fuel. In principle, seawater and fresh water can both be used as a scrubber agent.

Until the infrastructure of refineries is able to produce the required amounts of low sulphur fuels, this may be a promising alternative. Nevertheless, technical requirements need to be taken into account. The alignments of the facilities have an impact on conversion rates in the catalyzer (NO_x reduction) and the effectiveness of turbochargers. Furthermore, SCR systems are huge in size, as they also require space for urea tanks as well as fresh and wasted scrubber material.

Regardless of the contents of the exhaust gases, waste heat recovery (WHR) systems have been developed, which can be combined with almost every type of combustion.

The higher the engines' output, the better the WHR-systems' potential, and therefore the better the operating efficiency, as claimed by some manufacturers. For example, up to 10% of the maximum

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[40] See "Emissionsreduzierung durch Kraftstoff-Wasser-Emulsion" (2010); Schnack (2009), p. 15; cf. also FMC Fiedler Motoren (2013).

[41] See Sarvi (2004), quoted in Miola et al. (2010).

[42] See Eilts & Borchsenius (2001), quoted in Miola et al. (2010).

[43] See Miola et al. (2010), p. 54.

[44] See Miola et al. (2010), p. 54.

[45] See Miola et al. (2010), p. 54.

[46] See Knüppel & Jürgens (2010).

[47] See Miola et al. (2010)

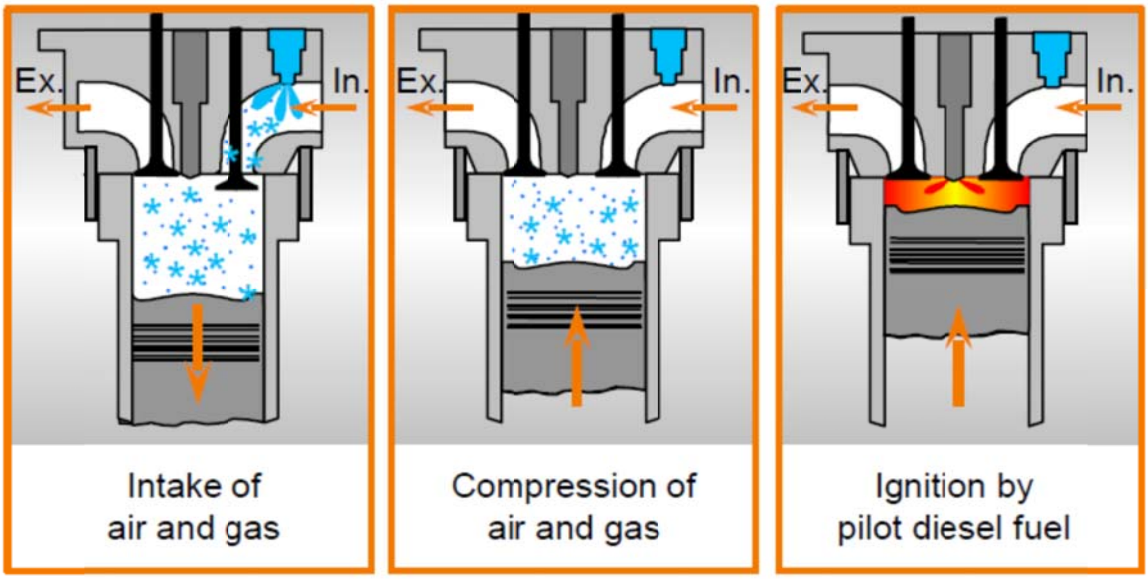
continuous rate (MCR) can be achieved by using exhaust gas turbines (located parallel to the turbochargers) to supply the board grid via generators.

3.3. LNG and other alternative fuels

The combustion of liquefied natural gas (LNG) appears to be a practical and low-cost alternative for complying with the more stringent limits on air pollution—especially in combination with exhaust after-treatment. The advantage of LNG is its significantly lower emissions: The exhaust gases are practically free of SO_x and soot particles, and NO_x can be reduced by almost 90%.[48] LNG currently presents a potential price advantage. From a technical perspective, it has in its favour the facts that many countries already run shore-based gas infrastructures (e.g. Norway) and that the corresponding technologies of stationary gas engines and heat production are mature and would therefore benefit a maritime application. Until know, technically it is possible to use LNG as marine fuel in the most types of ships. It requires a modification or a new construction of the main engines, like the dual-fuel (DF) concept.

The dual-fuel concept offers several opportunities. Taking into account the chemicals limits of the fuel (gas/oil ratio) as well as technical limits, the DF offers the advantage to run on alternative fuels (e.g. LNG) inside the ECAs and on other marine fuels (e.g. HFO) outside these areas. A seamless switch between the fuel modes is possible without losing power or speed. An approach that is increasingly getting commercialised is the DF principle. The US shipping company TOTE has ordered two containerships with DF engines systems.[49] Maritime engines manufacturers notify new orders in DF ships. At the same time it can be observed that further developments in DF techniques take place, which offer more flexibility for the usage of alternative fuels (e.g. Methanol, LPG, Dimethyl Ether (DME)).[50]

Figure 6: DF engine characteristics (Source: Thijssen 2006, p.15).



The main operation principle of a DF engine (in LNG mode) can be explained by the specific process of ignition. In the example in Figure 6 the engine works basically on the diesel principle, but contains

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[48] See "Gas-powered engines for marine applications" (2011).

[49] See The Motorship (2013a).

[50] See The Motorship (2013b); The Motorship (2013c).

an additional gas injector. The incoming fuel mixture (air and gas) is ignited by a small amount of diesel fuel, typically 1%, instead of a spark like in the Otto-principle.[51]

A further advantage is that the DF principle can be used in slow and medium speed engines. This allows applications for both maritime and inland ships. The development of an adequate maritime gas infrastructure will be challenging. In the Baltic Sea — a designated ECA — a considerable market penetration and terminal development seems to be most likely, particularly because of the natural gas reserves of some neighbouring countries.[52] The Commission's alternative fuel strategy addresses this issue.[53] It may be a further step to establish an innovation-friendly environment in order to offer the possibility to introduce alternative fuels and propulsion systems in inland water transport (IWT). Finally, it should not be underestimated that IWT will surely benefit from getting the image of a clean and environmental friendly option for freight transport.

Since LNG is nearly sulphur-free, the system can tolerate higher temperatures. As a consequence, the use of WHR systems becomes more feasible, which in turn will make systems more energy efficient.[54] However, it was mentioned above that sulphur usually serves as a lubricant in engine combustion. Depending on the design of the engine, alternative lubricant solutions might be needed and further research might be required in this field.[55]

From an economic point of view, the higher investment costs (about 20% more for a system with integrated EGR and WHR)[56] for a gas or diesel fuel engine should be recovered by the financial advantages; LNG's lower energy density (and thus greater space requirements) as compared to diesel fuel have been taken into account in this calculation.

In terms of gas usage, the industry faces a limited availability of adequate infrastructure. Until now, only LNG carriers have been using the so-called boil-off gas, which results from heating during transport, as a fuel alongside the usual HFO. Projects with container-based tanks for independent bunkering have also been set up.[57] For implementation, suitable solutions for filling up and storing must still be found—as well as a safe onboard location for tanks and reliable cooling. The IMO is setting up appropriate rules, formulated in the International Code of Safety for Gas-Fuelled Engine Installations (IGF-Code), which is expected to be finalised in 2015.[58] Due to the high pressure, gas tanks need a solid structure and must therefore be compact in form: This limits the space available for cargo.

When burning methane, which is about twenty times more harmful to the atmosphere than CO_2, as the main constituent of LNG, the discharge of unburned parts into the exhaust gas via the discharge valves appears to present a problem.

Other options than LNG are discussed as well for the shipping sector, but seem to be less promising. In the transport sector in general, biofuels are being discussed as an alternative to conventional, oil-based fuels.[59] The IMO states that the use of biofuels on ships is, in principle, technically possible.[60]

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[51] See Thijssen (2006), p.14.
Note: Depending on the manufacturing, the field of application (speed/size of vessel), the engine design or the technological design of the DF concept may vary.

[52] See Maddox Consulting (2012), pp. 49f; DMA (2012), pp. 60f; MAGALOG (2008).

[53] See CEC (2013a); CEC (2013b).

[54] See CEC (2011a), p. 26.

[55] See CEC (2011a), p. 26.

[56] See "Attraktive Brennstoffalternative" (2010).

[57] See "LNG-Motorenkonzept für Containerschiff" (2010).

[58] See Germanischer Lloyd (2013), p. 131.

[59] See STOA (2007); STOA (2011).

[60] See IMO (2009), p. 11.

However, the use of first-generation biofuels involves some technical challenges and could increase the risk of losing power, e.g. due to the plugging of filters. The IMO does not consider biofuels to be a realistic alternative for the maritime sector in the near future—mainly because of their limited availability and unattractive prices. In order to assess the impacts of biofuels in terms of eco-efficiency, it is necessary to consider the total life cycle of the fuels, including the production of the feedstock.[61] One interesting option might be Methanol, which can be produced from a variety of feedstock, as well as from biomass. Methanol can be burned directly, or it could be used in a fuel cell (see chapter 5.1.).

3.4. Electric propulsion

In principle, electric propulsion systems are also an option in the shipping sector, but they are not widespread. They are used, for example, in some cruise ships and in specialized vessels. Electric drives are interesting for ships that regularly switch speeds and for ships that need a lot of generation capacity when the ship is not moving fast, e.g. cable-laying ships.[62] The use of diesel electric machinery can be very beneficial to the ship's overall efficiency.[63] Obstacles and disadvantages relate to the size, weight and cost of the equipment involved in electric propulsion.

Hydrogen and fuel cells are another option that is being tested in the road sector. However, in terms of environmental performance, the production of hydrogen needs to be examined. The storage and handling of the hydrogen would be a challenge in itself.[64] Methanol could be an alternative fuel for fuel cells. For example, the European Commission has reported that the METHAPU project explored the feasibility of using solid oxide fuel cells (SOFC) that run on methanol.[65]

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[61] See Eyring et al. (2010), p. 4761.

[62] See CEC (2011a), p. 27.

[63] See Miola et al. (2010), p. 53.

[64] See Kollamthodi et al. (2008), p. 46.

[65] See CEC (2011a); METHAPU (2008).

4. Auxiliary propulsion technologies

Until the rise of combustion engines, wind power had been the only option for ships' propulsion besides human power. When covering long distances, ships routed to follow prevailing winds. In order to use wind energy nowadays, routes in the northern Atlantic and northern Pacific provide the best conditions for the adoption of towing kites, for example, because predominantly abaft winds occur for either outward- or inward-bound vessels.[66] On the other hand, modern systems for loading and clearing require space on deck; thus, traditional rigs could interfere, and telescopically reefed hard-wing sails might offer a solution for the future (cf. Figure 7).[67]

Figure 7: Huge Hard Wing Sails (Source: Ouchi, Uzawa, & Kanai, 2011, p. 2).

4.1. Skysail

The installation of towing kites could be a solution applicable to most ships sailing long distances. The system consists of a flying system with a kite, a control pod and a towing rope (cf. Figure 8). The tractive force is transmitted to the ship through a rope made of high-strength synthetic fiber. A special cable integrated into this rope secures the supply of power to the control pod and the communication with the control system on the ship. The main advantage of this solution, as opposed to conventional sails, is its ability to capture the stronger, steadier winds at higher altitudes. Furthermore, it generates more power relative to wind force, because of the acceleration of the kite. Finally, it can be retrofitted on most types of vessels.

On the other hand, this system demands winds abaft or crosswinds; the point of application at the front of the ship may affect the course in a negative way. Also, the intrusion in the airspace may conflict with regulations. Depending on the wind regime as well as weather conditions, course and speed, the potential fuel savings of a single ship could amount to 20% or even 30%.[68] Considered globally, this could lead to a reduction of approximately 5%.[69]

Recently, fields trails indicated that savings induced by the Skysails are lower than it was expected (e.g. 5-12% vs. 20-30%).[70] Together with the economic crisis this hampers the market penetration of the approach. Nevertheless some shipping companies decided to follow this approach and to use the entire system or other products, like the 'SkySails' Performance Monitor'.[71] The 'Performance Monitor'

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[66] For a detailed analysis of the predominant wind conditions in relation to the existing routes, cf. e.g. Aschenbeck et al. (2009a).

[67] Cf. Ouchi, Uzawa, & Kanai (2011).

[68] See Aschenbeck et al. (2009b).

[69] See Aschenbeck et al. (2009a).

[70] See WINTECC (2009).

[71] See SkySails (2013a).

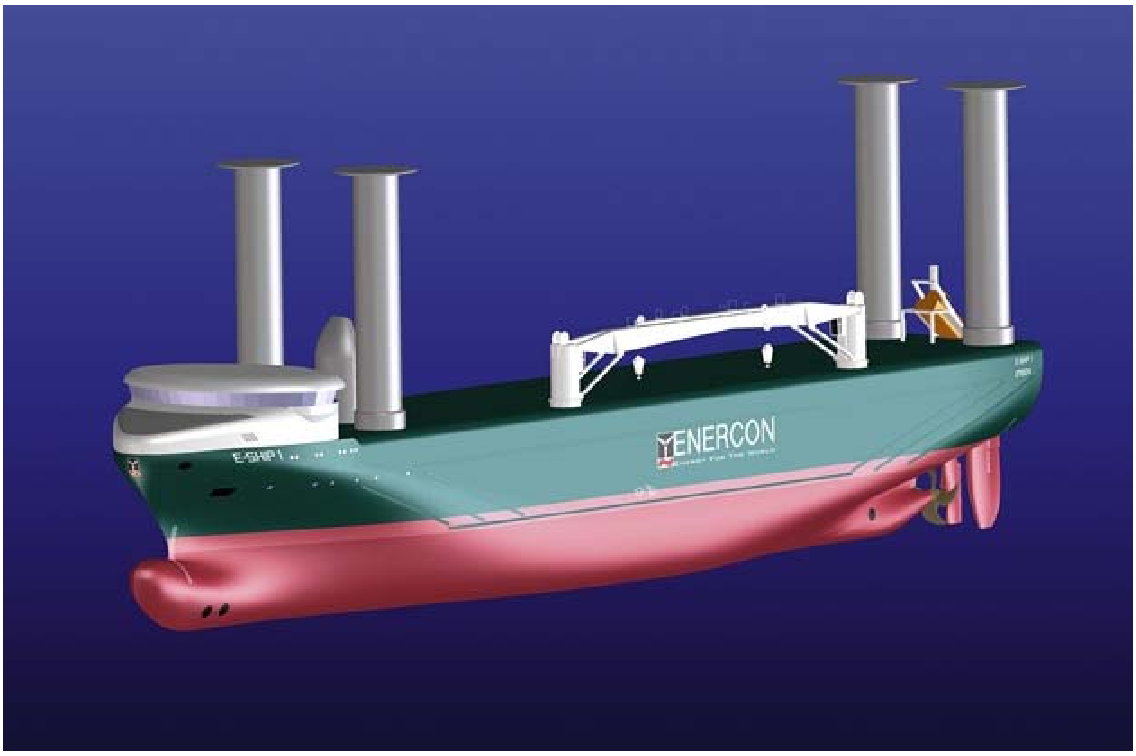
is an information system. Via sensors it continuously collects and displays all relevant data about the operating conditions of the ship. On that basis optimisation of operation parameters (speed, fuel composition) is enabled. Advanced navigation systems like this will help shipping operators to increase efficiency of the ships in an economic- and environmental friendly manner (Cf. chapter 5.2 Operational Changes).

Figure 8: Ship equipped with SkySail (Source: Skysails, 2013b).

4.2. Flettner Rotors

The Flettner Rotor, named after its inventor Anton Flettner, uses the so-called Magnus effect for propulsion (cf. Figure 9). This effect describes a force perpendicular to the line of motion of a spinning object. On ships, upright cylinders were used; they were usually driven by electric motors in order to control their rpm values and direction and to provide for their initial start. Aside from sail-assisted vessels, there are some projects that exclusively use this force. As in common sailing, there are favorable courses in relation to wind direction. For a rotor-equipped ship, these are rectangular to the wind, whereas the effect disappears either when sailing downwind or the opposite. To realize savings in terms of fuel consumption, it is preferable that the rotors be flowed against freely; therefore, superstructural parts need to be low-ceilinged. Clearance on deck is also constricted.

Figure 9: E-Ship 1 (Source: ENERCON, 2008).



E-Ship 1 is a cargo ship for hybrid purpose. Ramps serve vehicle decks while other cargo decks are accessible only by crane. Completed in 2010 at a German Shipyard it is owned by a wind turbine manufacturer it will be used for transport of components. The *E-Ship 1* is equipped with nine Mitsubishi marine diesel engines with a total output of 3.5 MW. The ship's exhaust gas boilers are connected to a Siemens downstream steam turbine, which in turn drives four Enercon-developed Flettner rotors. These rotors, resembling four large cylinders mounted on the ship's deck, are 27 meters tall and 4 meters in diameter. The Flettner drive allows for projected fuel savings of 30-40% at a speed of 16 knots.

5. Further developments

5.1. Electric power supply

Beside the main drive, the electric power supply on board consumes energy, e.g., produced by the main machine/generator, and, thus, emits harmful substances. These negative effects are highly relevant in port areas in particular when residential areas are nearby. For safety reasons as well as for enabling maintenance, usually, more than one generator is installed. The generators could be assisted by fuel cells or by steam turbines of a WHR system. Whereas the main engine can be turned down in ports, the electric power grid on board still must be sustained. In order to reduce the air pollution in ports, land based power supply is implemented partially. The feasibility is strongly dependent on the local situation.

This is why, for instance, the port of Hamburg promotes onboard generation with clean fuels such as LNG[72] while the port of Lübeck focuses on connection to the land based grid.

In both cases, offshore or ashore, the ecological footprint of power supply strongly depends on a life-cycle analysis of the power generation. For example, in case of old ships using comparatively old generators it can be highly beneficial to turn them off and connect the ship to the shore-side grid which might be based on an efficient combined heat and power station (CHP, gas, biomass). In other ports like tourist destinations it is more likely that cruise ships and ferries are in place. These new ships can produce relatively "clean" electricity, in particular if they are upgraded with fuel cells or multi-fuel (oil/LNG) power generators on board.

In the meantime, fuel cells are becoming increasingly competitive in the field of auxiliary power for electricity supply. For example, a hybrid auxiliary power generation will be able to produce electricity by fuel cells efficiently, to store it by battery, and, therefore, to balance the electricity consumption (net grid) of different engine components, e.g. machine and navigation control systems or air condition. In addition, security relevant systems like control or communication systems become less vulnerable if they are powered by an extra engine. Due to the higher efficiency, a two-digit percentage reduction in GHG emission is reported to be feasible by the usage of a fuel cell.

Further, fuel cells offer short payback periods and they can be implemented in most types of new ships.[73] Still, the investment costs are up to four or five times higher compared to diesel generators.

Besides the advantages of low or zero on-site emissions (overall emissions depend strongly on the life cycle of the fuel) and its higher degree of efficiency of over 50 percent the modular system provides interesting options in hull construction, and produces neither acoustic noise nor vibrations.[74] Until now, several tests have been made with fuel cells for board grid assistance as well as for propulsion technology and it was proven that, in principle, they can operate under special maritime conditions. Experts claim that it is most likely that fuel cells will be applied for board grid assistance on private yachts and passenger ships.[75]

5.2. Operational changes

It was described above that new technologies offer interesting potentials to reduce the ecological foot print of shipping. Experts argue that also non-technical operational changes offer interesting options. An option that is often referred to is the so-called 'weather routing': it means choosing a route that is

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[72] See Maass (2009).

[73] See Miola et al. (2010).

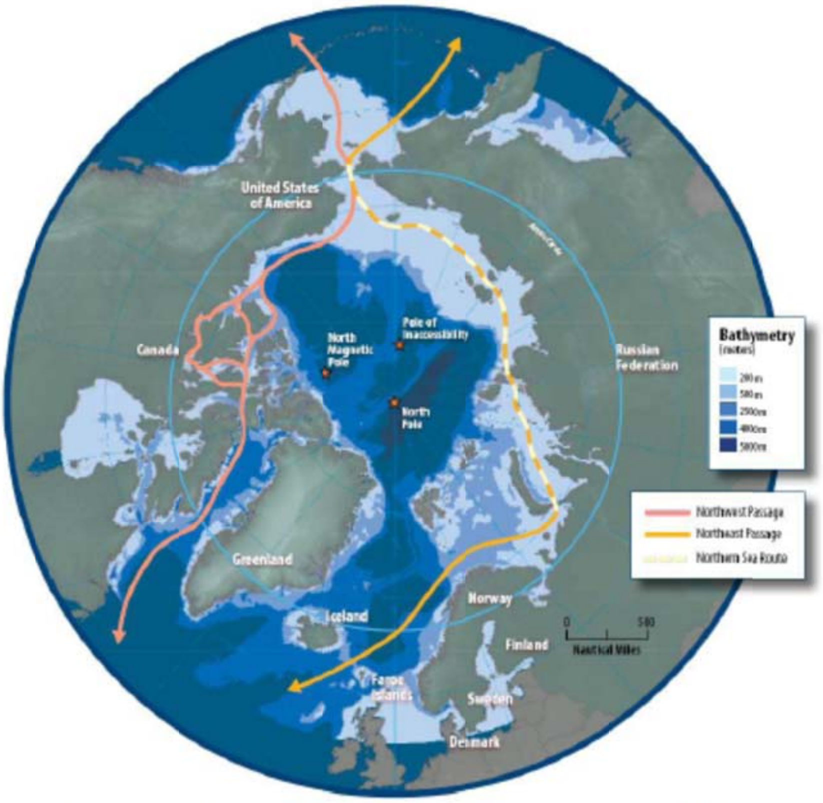
[74] See "GL veröffentlicht Brennstoffzellenstudie" (2010).

[75] See Hillmer (2010).

avoiding fuel consuming weather conditions such as storms and windy weather. But one of the most effective ways to reduce fuel consumptions and emissions is the reduction in speed.[76]

The hull's water resistance increases exponentially with higher steaming speed. Trials were made with slower velocities in order to find new optimum values. Shipping operators state that fuel savings of 50 percent can be achieved by a 20 percent speed reduction.[77] Further it is estimated that a 10% reduction of fleet average speed can lead to a 19% reduction of $C0_2$ emissions.[78] As a reaction to high fuel prices shippers have adapted fleet average speeds themselves.[79]

Figure 10: Map of the Arctic and main sea routes (Northwest passage, the Northeast passage and the Northern Sea Route) (Source: Faber et al., 2012, p. 81).



Source: Arctic Council, 2009: Arctic Marine Shipping Assessment 2009 Report.

However, it can be rather difficult to identify a company-specific solution regarding slow steaming. Ongoing discussions about scientifically based mathematical formulas for calculating an optimised speed were published in 2010 in Schiff und Hafen ('Ship and Harbour') and even before.[80,81] For minimum fuel consumption a ship is advised to sail at constant speed at a level that allows for

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[76] See Eyring et al. (2010).

[77] See "Focus on green technology" (2011).

[78] See Faber et al. (2012), p. 107.

[79] See McCollum, Gould, & Greene (2009); Meyer, Stahlbock, & Voß (2012); Hautmann (2011); Faber et al. (2012), p. 12.

[80] See Gudehus (2010a).

[81] See Gudehus (2010b).

reaching the recommended time of arrival. However, remarkable cost reduction can be achieved by cost-optimized operation compared to maximized speed.[82]

Nevertheless, speed reduction will not be useful for all categories of ships; for example, older ship types/engines, which already drive slowly, do not offer high potentials without 'slow steam kits'. As engines as well as turbochargers are optimized for full load operation, part-load operation requires technical adaption. This can be provided by retrofit solutions of the engine manufacturers which, for instance, cut off one of a row of turbochargers. In addition to the benefits of slow steaming, fuel consumption could be brought down another 3 to 7 percent.[83]

Aside from reductions by slow steaming, fuel consumption can also be lowered by better trim; this shows reductions of up to 5 percent.[84] Parameters like speed, draught, water depth, and the hulls form have an effect and can be optimized with certain software solutions.

It is further discussed that climate change and its impact on ice coverage in the northern hemisphere might open new routes (see Figure 10), and, thus, lead to fuel savings. As an alternative to the route through the Mediterranean and the Suez channel or around the Cape of Good Hope to Asia the Northeast Passage could be navigated.

This would reduce, for instance, the range from Hamburg to Yokohama by 40 percent, and, hence, the fuel consumption would be reduced as well.[85] Because of the ice coverage, the season is shortened from June to the end of September. Moreover, there are safety requirements to be met regarding the hull's stability and ice breakers must escort passing vessels as the northern sea route administration claims. This increases the costs. Furthermore, it shall be taken into account that in the very northern region (Arctic) the highest impact of climate change is assumed.

It must further be stressed that the arctic region is one of the last virtually undisturbed areas and a highly sensitive ecosystem. Additional future changes as well as the already described ones, will support climate feedback mechanisms.[86]

5.3. Other approaches: air lubrication, propeller, hulls and service (cleaning)

The following paragraphs give a brief overview of innovations in important shipping components which support reduced fuel consumption and increased efficiency.

5.3.1. Air lubrication

The basic idea is to use the different friction properties of water and air to reduce the friction of ships in the water. The hull construction is designed in a way that enables it to cover or create a very small layer of air between the hull of the ship and the water (see Figure 11).[87]

Depending on the type of ship and on the way of usage (ferries/tankers), possible fuel reduction is discussed in the range between 3, 5 percent and 15 percent. This increase in efficiency would lead to a relatively short payback time.[88]

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[82] See Gudehus (2010a).

[83] See "Slow-Steaming Upgrade für Maersk-Schiffe" (2010).

[84] See "Senkung des Brennstoffverbrauchs durch Trimmoptimierung" (2010).

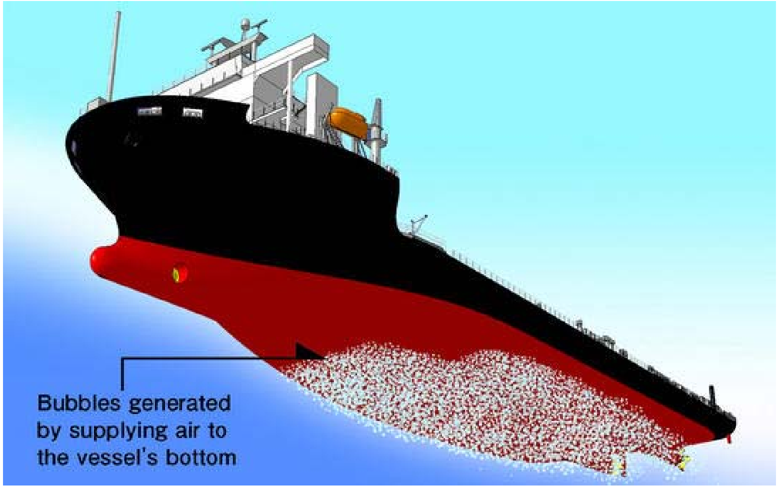
[85] See Knudsen (2010).

[86] See Eyring et al. (2010), p. 4763; Faber et al. (2012), p. 7, p. 10.

[87] See Miola et al. (2010), p. 50.

[88] See Miola et al. (2010), p. 50.

Figure 11: Example Air-Lubrication System (ASL) module carrier YAMATAI (Source: NYK Line, 2013).



5.3.2. Propeller systems

In order to improve the water flow at the propeller, special ducts were developed that can be installed in front of the propeller (cf. Figure 12).

Figure 12 Example for a duct construction (Source: Skipsrevyen, 2010).

These modifications can cause two positive measures: a pre-swirl stabilization as well as a duct-effect. Therefore, non-movable stator fins change the angle of flow towards the propeller in such a manner that it operates as a counter-rotating device for a more favourable angle of attack.

The effect of the duct increases the flows velocity towards the propeller which also enhances the propeller's working conditions[89]. Furthermore, systems like this have proven to upgrade course-stability, and both reduce cavitation occurrence and vibrations. This modification is optimized for significant hull-coefficients and floating characteristics. Thus, it comes into operation on tankers, bulk carriers or smaller container vessels. Trials have shown fuel savings of 6 % on average.

Another comparable system uses so-called propeller bulbs in combination with hydro-dynamically optimized propeller wings and rudders, and a special connector bulb. Depending on the hull's form, and on the number of propellers the system can also be retrofitted, and it has shown saving potentials from 3 percent up to over 10 percent for comparatively slow vessels with one propeller. This also yields in a better manoeuvrability.[90] Developments with a system called Side by Side–Propeller have also been made. It consists of at least two counter rotating propellers that are located closely to each other. Although it seems as if rather no practical trials have been undertaken, the manufacturer quotes

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[89] See Gustafsson & Werner (2010).

[90] See "Optimierung der Propulsionseffizenz" (2010).

up to 40 percent more impulse with equal engine output to be used for the manoeuvre propulsion as well as for the main propulsion.[91]

Further, the utilization of carbon fibres is in the state of on-board tests. It reduces the weight of certain rudder components which results in an easier handling during manufacturing and transportation. Its main benefit is the provision of optimal surface properties for reducing the hydro-respistivity.[92]

Significant fuel savings potentials are expected by combining and improving propeller and lubrication systems together, like the Air Cavity System (ACS). Its hovering cushions are integrated in the hull's structure. A constant line of 'micro-bubbles along' the hull up to the propeller system is injected. Different research projects have shown that reduction potentials between 15 up to 30 percent are feasible.[93]

5.3.3. Propeller and hull cleaning

A very easy way to save fuel and minimize the water resistance is to optimize the ship's surface below sea level by cleaning and coating. In the following paragraph two approaches will be presented.

Over the time, aquatic plants like micro algae begin to grow, and, thus, enlarge the surface. As a result, the water resistance is steadily deteriorating. This process depends on a variety of factors like water temperature, the hull material, and waiting times in ports. Especially the propeller's efficiency will be affected because its surface is relevant for the friction in water. It is assumed that with an increased frequency of propeller polishing and hull cleaning (around 5 years interval) fuel savings in the range of some percentages can be achieved.

5.3.4. Hull coating

This approach has the same goal as the propeller, and the hull cleaning: to reduce friction and optimize water resistance. Fine-textured surfaces, e.g., fish surfaces (bionic), and tough materials in general lead to a better hull performance and to less fuel consumption. Both approaches in combination could offer fuel saving capacities in a double-digit range.[94]

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[91] See "Verbesserte Schubausbeute bei gleicher Motorleistung" (2010).

[92] See "Effiziente und umweltfreundliche Rudersysteme" (2010).

[93] See Meyer (2009); cf. also DK Group (2013); Becker Marine Systems (2013).

[94] See Miola et al. (2010), p. 58f.

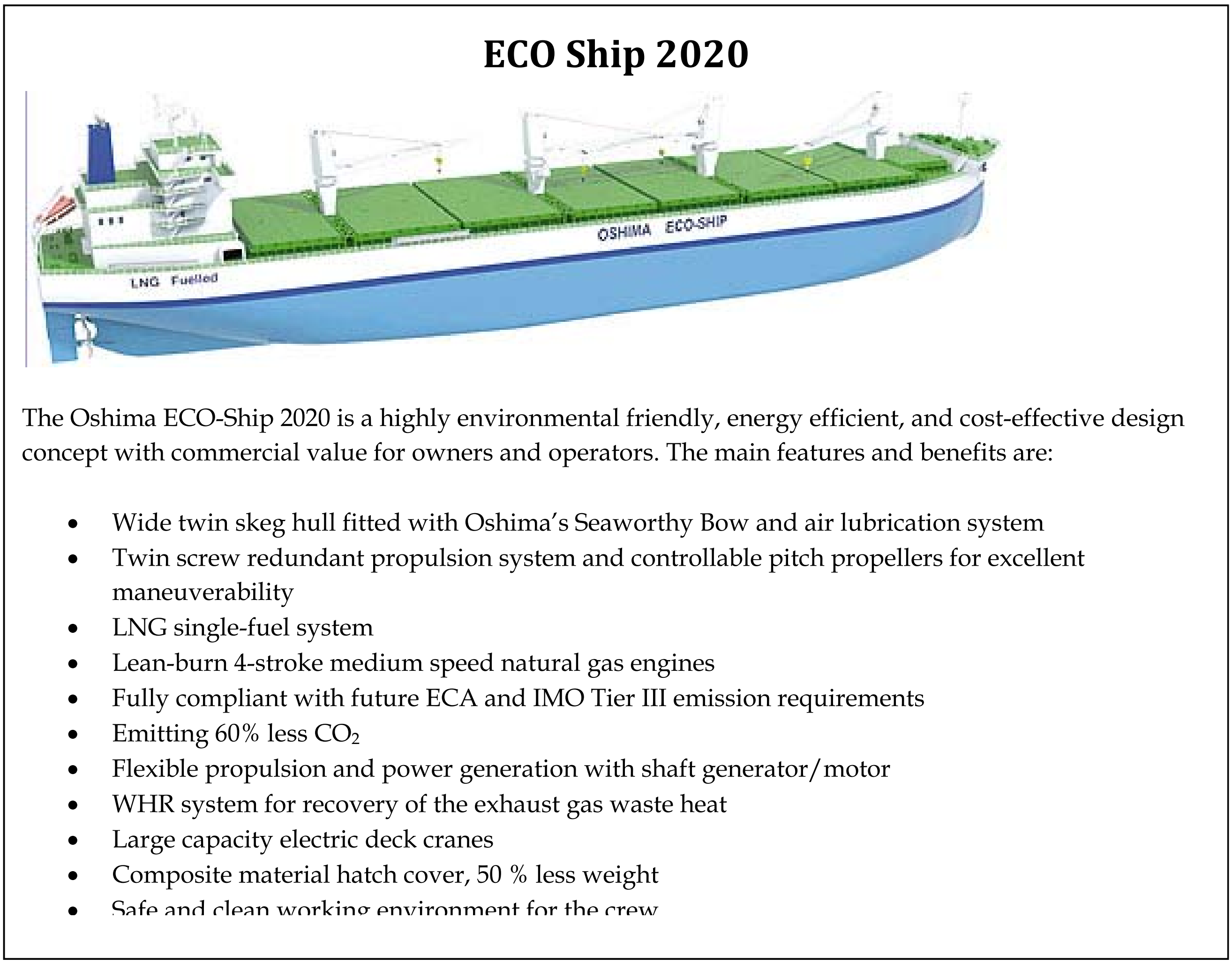
5.4. Indices

Some classification associations have developed certain indices such as the Green Rating Composite Index in order to create a possibility of comparing the eco-efficiency of ships. It is calculated from a constructional and an operational perspective and is based on a number of five criteria: Consumption, CO_2, NO_x and SO_x emissions, and attended time without dumping bilge water. A target index is calculated allowing theoretical considerations and comparison with an actual index on operational trials. Thereby, economic viability and amortization of green technologies are intended to become more comprehensible.

Other approaches as the Energy Efficiency Design Index (EEDI) were calculated by the ships dimensions, its displacement, and the hydrodynamic characteristics of the hulls. It is an IMO attempt to avoid the conflict with developing and emerging countries and is at the same time an Index pointing out the potential transport efficiency. Considered as an enhancement of MARPOL Annex VI all newly build ships bigger than 400 DWT must show a certain verification from January 2013 on out. This Index is required to undercut a given reference ("required EEDI").

The limit will be lowered by about ten percent in 4 steps in a 5 years cycle. For existing ships a comparable system is planned with the Ship Energy Efficiency Management Plan (SEEMP).[95]

Figure 13: ECO Ship 2020 (Source: DNV, 2011)



ECO Ship 2020

The Oshima ECO-Ship 2020 is a highly environmental friendly, energy efficient, and cost-effective design concept with commercial value for owners and operators. The main features and benefits are:

- Wide twin skeg hull fitted with Oshima's Seaworthy Bow and air lubrication system
- Twin screw redundant propulsion system and controllable pitch propellers for excellent maneuverability
- LNG single-fuel system
- Lean-burn 4-stroke medium speed natural gas engines
- Fully compliant with future ECA and IMO Tier III emission requirements
- Emitting 60% less CO_2
- Flexible propulsion and power generation with shaft generator/motor
- WHR system for recovery of the exhaust gas waste heat
- Large capacity electric deck cranes
- Composite material hatch cover, 50 % less weight
- Safe and clean working environment for the crew

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[95] See Mund & Köpke (2011).

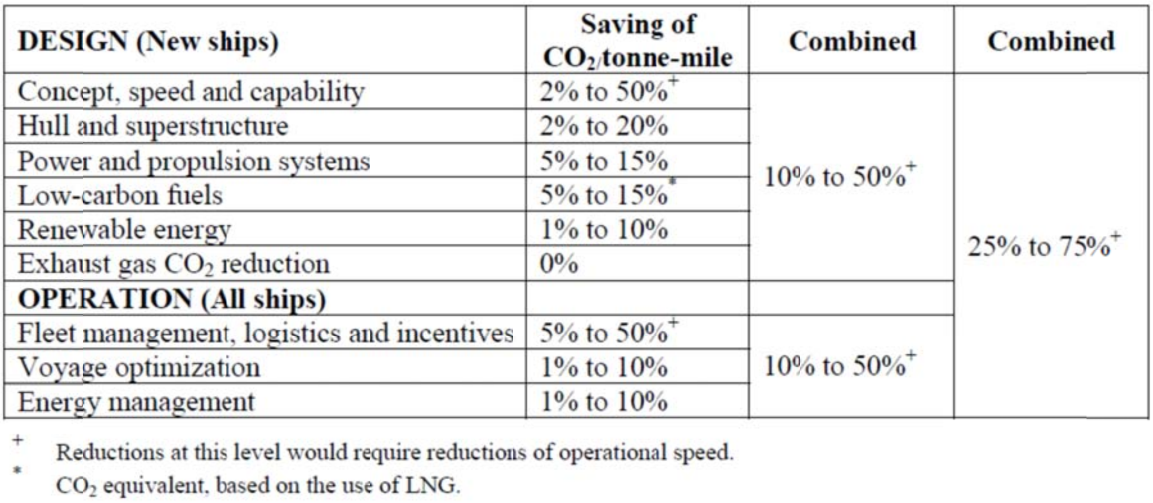
6. Conclusive Remarks

The report at hand illustrates that shipping makes considerable contributions to the ecological footprint of the transport sector. The transport of goods in vessels is the backbone of the international trade in the accelerating process of globalisation. Maritime shipping is expected to grow substantially in future. In a business as usual scenario this would also mean that the ecological footprint of shipping is increasing heavily.

Various approaches for improvements as reducing the emissions from burning of bunker oils in ships do exist. Some of the measures are, in principle, known for other modes in the transport sector. They are directly related to the process of energy conversion such as further increases in the efficiency of conventional engines but also the usage of alternatives to oil based propulsion, whereas, LNG seems to be the most promising approach. Other measures are specific for the characteristics of ships such as modifications in hull construction, employment of auxiliary systems in harbours, approaches such as skysails, slow steaming or weather routing.

The broad range of options illustrates that, from a technical point of view, the eco-efficiency of the shipping sector could be increased significantly. For example, the IMO Report gives an assessment of potential reductions of CO_2 emissions by using known technologies and practise (see Figure 14), and Figure 15illustrates the long-term reductions in emissions in the revised MARPOL Annex IV.

Figure 14: Assessment of potential reductions of CO_2 emissions by using known technologies and practices, (Source: IMO 2009, p.11).

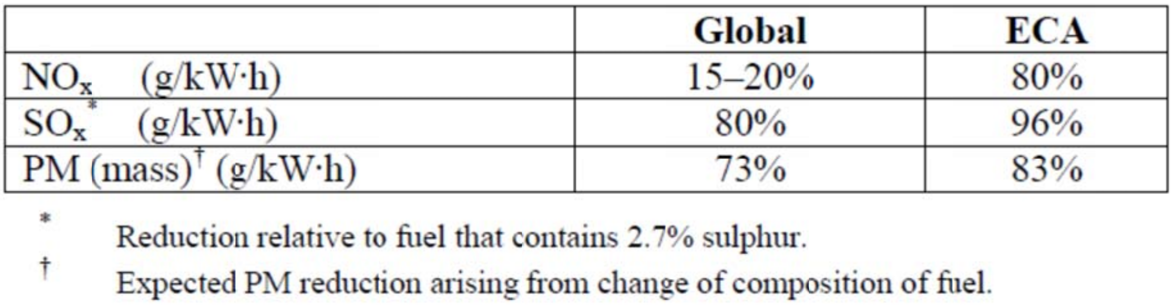


DESIGN (New ships)	**Saving of CO_2/tonne-mile**	**Combined**	**Combined**
Concept, speed and capability	2% to 50%+	10% to 50%+	25% to 75%+
Hull and superstructure	2% to 20%		
Power and propulsion systems	5% to 15%		
Low-carbon fuels	5% to 15%*		
Renewable energy	1% to 10%		
Exhaust gas CO_2 reduction	0%		
OPERATION (All ships)			
Fleet management, logistics and incentives	5% to 50%+	10% to 50%+	
Voyage optimization	1% to 10%		
Energy management	1% to 10%		

\+ Reductions at this level would require reductions of operational speed.

* CO_2 equivalent, based on the use of LNG.

Figure 15: long-term reductions in emissions in the revised MARPOL Annex IV (Source: IMO 2009, p.12).



	Global	**ECA**
NO_x (g/kW·h)	15–20%	80%
SO_x* (g/kW·h)	80%	96%
PM (mass)† (g/kW·h)	73%	83%

* Reduction relative to fuel that contains 2.7% sulphur.

† Expected PM reduction arising from change of composition of fuel.

So, strong improvements seem to be achievable, barriers are mainly related to economic constraints as well as to logistics (for example availability of LNG). Some combinations of measures are assessed in optimistic ways.

For example, McCollum et al. state that the use of LNG coupled with alternative energy sources such as wind power (sails) can reduce CO_2 emissions by up to 40 percent from current levels by 2050.[96] The authors consider other alternative fuel and power sources such as biofuels, solar photovoltaic cells, and fuel cells to be more uncertain longer-term options. The expressed scepticism regarding biofuels is shared by other authors.[97] It is quite likely that the biomass available for energy and transport will not be used in the maritime sector. Furthermore, some Authors argued that carbon pricing should be discussed as an additional instrument in the cost-benefit consideration - like fuel prices - to support eco-efficient modifications.[98]

The expected growth rates illustrate that, in particular when it comes to combating climate change, immediate actions are urgently needed. This includes retrofitting of the existing ships since what is characteristic for the shipping sector is the strong inertia in this field. Ships are used over decades; new developments implemented today might still be in use in the year 2050 and beyond. Therefore, and in contrast to the car sector which is a familiar field for most people, decisions taken today have a direct influence on the eco-efficiency of the maritime sector in 2050 and even beyond. These facts together with the expected growth rates underpin that there is a strong need for action in a sector which is of utmost importance for the daily life of European citizens but, at the same time, not that easily "visible" as other transport sectors such as the ones involving cars, trains or airplanes which are used frequently by citizens.

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[96] See McCollum, Gould, & Greene (2009), p.21.
Note: The Authors points out that the general focus of the paper are $C0_2$-emissions and other important non $C0_2$- emissions are excluded. Cf. p.11.

[97] See IMO (2009).

[98] See "McCollum, Gould, & Greene (2009), p. 18; Faber et al. (2012).

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List of figures

List of abbreviations and units

ACS	Air Cavity System
CEC	Commission of the European Communities (or: European Commission)
CHP	Combined heat and power station
CO_2	Carbon dioxide
DF	Dual-fuel
DME	Dimethyl ether
ECA	Emission Control Area
EEA	European Economic Area
EEDI	Energy Efficiency Design Index
EGR	Exhaust gas recirculation
ETAG	European Technology Assessment Group
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse gas
H_2	Hydrogen
HAM	Humid air motor
HFO	Heavy fuel oil
ICCT	International Council for Clean Transportation
IGF-Code	International Code of Safety for Gas-Fuelled Engine Installations
IMO	International Maritime Organization
ISO	International Organization for Standardization
IWT	Inland water transport
LNG	Liquefied natural gas
LSF	Low sulphur fuel
MARPOL	International Convention for the Prevention of Marine Pollution from Ships
MCR	Maximum continuous rate
MDO	Marine diesel oil
MEP	Member of the European Parliament
MEPC	Marine Environmental Protection Committee
MGO	Marine gas oil
MW	Megawatt
NO_x	Nitrous oxide
OECD	Organisation for Economic Co-operation and Development
PM	Particulate matter

rpm	Revolutions per minute
SCR	Selective catalytic converters
SECA	Sulphur Emission Control Areas
SOFC	Solid oxide fuel cells
SO_x	Sulphur oxide
SO_2	Sulphur dioxide
SNCR	Selective non-catalytic reduction
STOA	Science and Technology Options Assessment
UNFCC	United Nations Framework Convention on Climate Change
US	United States (United States of America)
WHR	Waste heat recovery
WTO	World Trade Organization
VOC	Volatile organic compounds

This document is the 'Interim report on Overview of potentials for an increased eco-efficiency in maritime shipping

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